The Forestry Corp

Watershed Assessment Model

GIS Application User Guide

August 1997

TABLE OF CONTENTS

1.0 OVERVIEW 3

1.1 Introduction 3

1.2 Data Requirements 6

2.0 APPLICATION BACKGROUND 7

2.1 Introduction 7

2.2 Data Issues 7
2.2.1 Digital Elevation Data 7
2.2.2 Corrected Streams Network 8
2.2.3 Plot Locations 8
2.2.4 Raster Output 8
2.2.5 WRNSFMF Input Data 9

2.3 Processing Issues 9
2.3.1 System Intensive Functions 9
2.3.2 Grid cell size 9
2.3.3 Project Area Selection 9
2.3.4 Processing New Points For an Existing Project 10
2.3.5 Order Route System Generation 10

3.0 GETTING STARTED 11

3.1 Overview 11

3.2 Message Windows 11

3.3 Help! 12

4.0 PROCESS FLOW 13

4.1 Overview 13

4.2 WAM Processing 13
4.2.1 Project Management 14
4.2.2 Generating an elevation grid 15
4.2.3 Generating a Corrected Stream Network 15
4.2.4 Generating Stream Order Route Systems 15
4.2.5 Attribute Calculation 16
4.2.6 Feature Density 16

4.3 WAM Output Data Descriptions 23

4.4 WRNSFMF Process Flow 26
4.4.1 Generate a Drainage Basin 27
4.4.2 Generate WRNSFMF Data File 28

5.0 FORMS 29

5.1 Overview 29

5.2 Generate Watershed Attributes 29

5.3 Generate WRNSFMF data file 33

5.4 Interface Menus 35

6.0 GLOSSARY 51

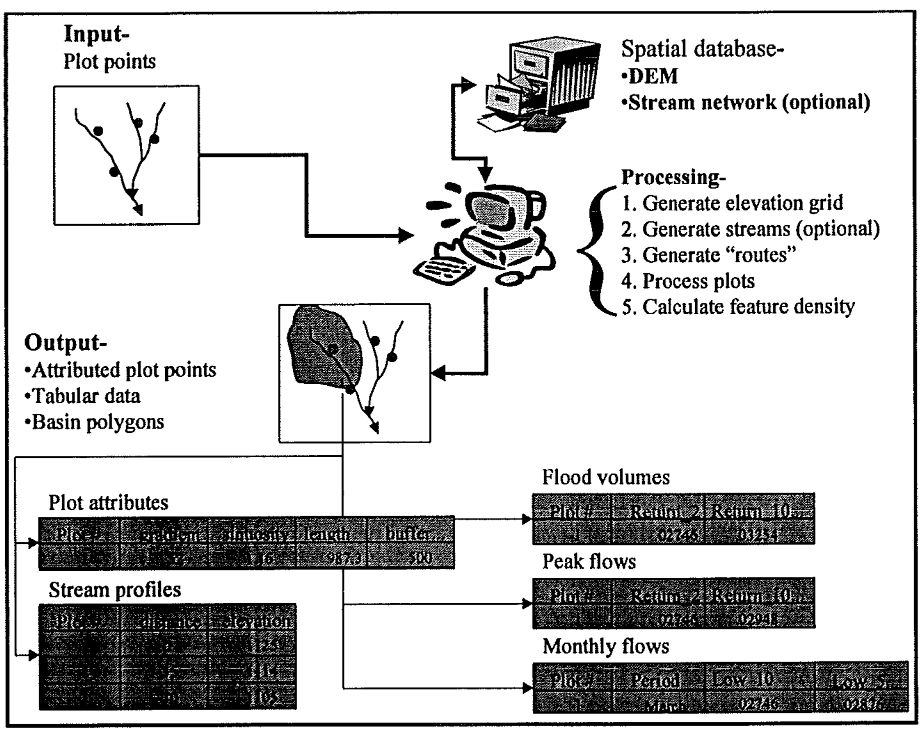
APPENDIX A – OUTPUT TABLE STRUCTURES 59

1.0 Overview

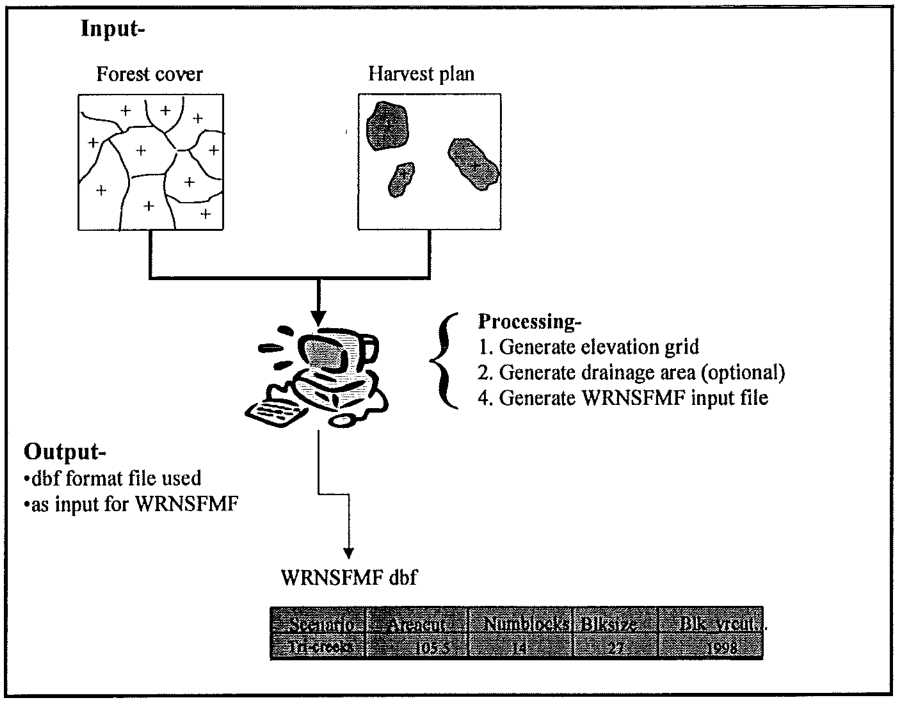
1.1 Introduction

The Watershed Assessment Model (WAM) is a GIS application which generates watershed and stream characteristics from existing digital point, DEM (digital elevation model), and stream network information. It is also capable of generating datasets in a format compatible with the WRNSFMF application for evaluating annual water yield changes.

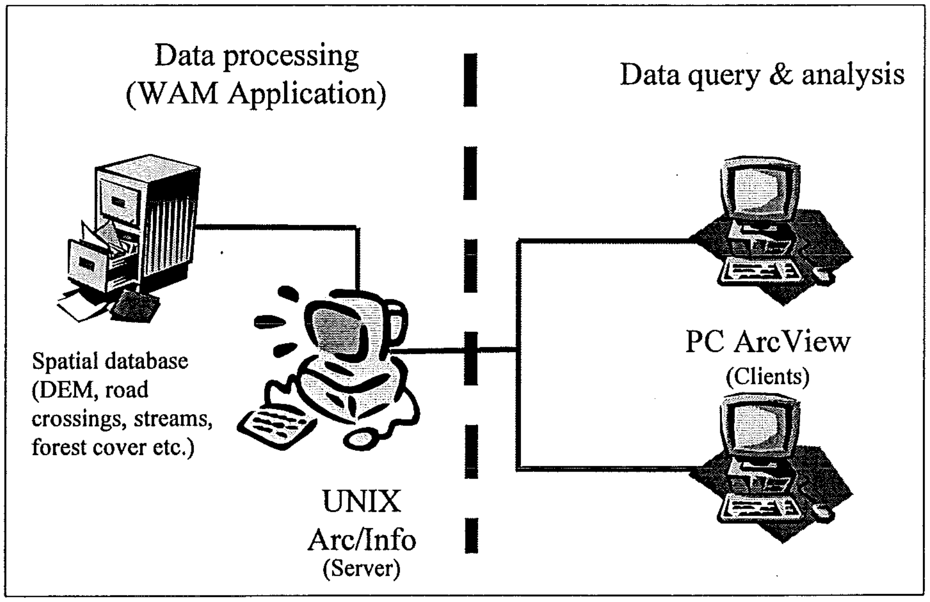
Stream and watershed characteristic calculation overview –



WRNSFMF dataset creation overview



WAM is structured in a client-server framework meaning that the GIS application runs in ArcInfo on a UNIX processing server and is strictly written for data processing. The resultant data is viewed and queried using ESRI's desktop GIS software, ArcView.



The processing aspect of the application is targeted at persons familiar with running custom applications on the UNIX platform, and with knowledge of the GIS file structures (coverages, tables etc.). More importantly, end users of the output data must have a good understanding of the source of the input datasets and the applicability of the results in watershed, streams, and forest resource management. This document addresses the issues relating to input and output data and gives detailed descriptions on how to use the application. In addition to this document the user can reference the on-line help for assistance on executing each menu. For detailed information on application installation, system requirements and altering the application see the *WAM System Guide*. For detailed information on the approach and methods involved in completing the WAM project, see the *WAM Final Report.*

1.2 Data Requirements

WAM processing involves the calculation of stream and watershed attributes for points on a stream. The points must be stored as an ArcInfo coverage. The points do not necessarily have to represent actual points on the ground, they can also be hypothetical points which may, for example, represent planned road crossing locations. A corrected streams network is a requirement to run the application, but there are also tools in place to generate this dataset. See the section 2.2.2 for more information on the required streams network. DEM data is also a required dataset, but it's availability and structure are transparent to the user therefore there is little related information in the User Guide. Please refer to the WAM System Guide for information on DEM requirements.

For the creation of the WRNSFMF dataset, the input formats are considerably more rigid. The following Arc/Info polygon coverages are required for generating a WRNSFMF dataset;

- Forest cover
- Harvest plan

Each of these coverages requires specific item names describing the spatial features represented in them. Section 4.3.2 describes the required field names.

2.0 Application Background

2.1 Introduction

The WAM application is unique and complex in terms of the approach taken to extract watershed information from a spatial database. This combination of uniqueness and complexity with incomplete input datasets introduces several data and processing issues that the user of the application and more importantly the user of the output data must be aware of. These issues are discussed in this section.

2.2 Data Issues

2.2.1 Digital Elevation Data

All calculations relating to elevation performed in the application are entirely dependent on the resolution and accuracy of the DEM data. DEM data in Alberta can be purchased at several different fixed grid resolutions (25, 50 or 100 meter spacing). The grid of points is derived from a combination of measured ground points and interpreted ground points. The two data sources are combined to mathematically interpolate a surface model at the requested resolution. Thus the user must be aware that the points in the DEM rarely represent the exact location of measured points, and the number of measured points is usually a small percentage of the actual number of points in the DEM grid. Also, DEM data can be acquired from a source different than that of interpreted streams data and therefore may not necessarily be coincident. This will have an impact on stream profile, gradient and elevation analysis when the stream location falls higher on the 'bank' of the stream, instead of in the actual flow path depression. This issue will have to be addressed if a corrected streams network is developed which is not matched to the DEM.

On the other hand though, the available DEM data is the most current province-wide data available and is no less accurate than contour data collected at a similar scale.

2.2.2 Corrected Streams Network

The WAM application requires a corrected streams network for most stream and fisheries related analysis. As the majority of users do not have these data available to them, there are functions in the application to create such a network solely from DEM data using ArcInfo. Therefore the generated network is entirely dependant on the accuracy of the DEM. During testing it was found that generated streams differed in varying degrees from interpreted streams in density and relative location. The resulting streams network is affected by three factors; original DEM data resolution, terrain variability, and grid cell size. Grid cell size will be discussed in section 2.3.2.

As discussed in section 2.2.1, DEM data is available in several different resolutions. Stream networks generated using for example, 100 meter resolution data will be less dense as any streams with a width less than the cell size may not being recognized.

During the testing of the WAM application varying success was achieved in streams generation based on terrain variability in two different areas in Alberta. Areas with considerable variability (Tri-Creeks), produced streams very similar to those of the 1:20000 interpreted base data, while in very flat areas (Red Earth Creek) the resulting streams were incorrect. These results were, although not to such an extent, predictable as the data (50m and 25m resolution) does not detect small changes in elevation to the extent required for stream flow generation in very flat terrain. Therefore it is important for the user to recognize the following:

- Incorrect stream arcs will be generated as part of this process, particularly in flatter terrain. Once analysis has been completed, the generated streams network should be examined visually to determine if any other results have been affected by erroneous arcs.
- Streams generation is an interim fix, to be used until a corrected streams network for the analysis area has been developed.

2.2.3 Plot Locations

Plot locations are the points at which stream and watershed analysis such as gradient and basin area will take place. The first step the application takes when calculating plot attributes is to find a point on the stream closest to the original plot location at which it will perform the analysis. This process is referred to as snapping. A search tolerance is set to tell the system how large of a circular buffer should be searched for the closest stream.

The first issue arises if a stream cannot be found inside the buffer. For such instances the field added to the plot attribute table called *snapped* which will be *.FALSE.* in the event a stream could not be located inside the buffer.

The second more significant issue is when plots do not snap to the intended stream. This problem will be immediately identifiable when the user views the drainage basin polygons. Erroneous plot locations will generate basins which are much smaller or much larger than expected. Fixing this problem involves copying the plot to a location closer to the intended stream or moving the original plot. Making a copy may be more desirable if the plot locations are known to be spatially accurate. These editing functions will have to be performed at the command line or using an editing interface such as ArcTools as there are no tools in the application for spatial editing.

2.2.4 Raster Output

As most watershed processing is performed using the raster spatial model (GRID), all resulting datasets have raster characteristics (see the glossary for a definition of raster vs. vector models). Specifically, arc and polygon data are defined by lines which appear blocky as they are generated directly from the outlines of cells defining, for example, a drainage basin. The user must therefore be aware how, in general, the blockiness affects results. This can be accomplished by visually comparing results using manual methods to those generated by the application. As blockiness will vary directly with cell size, the user can apply the findings of the visual test to any datasets which were created using the same grid cell size.

2.2.5 WRNSFMF Input Data

The spatial and attribute data formats required for the generation of a WRNSFMF data file are specified in section 4.3.2. Because the datasets coming into the application are somewhat complex (forest cover, harvest plan), the application is very rigid in terms of acceptable data formats. In other words, if the incoming data is not in exactly the correct format, the WRNSFMF tool will fail.

2.3 Processing Issues

2.3.1 System Intensive Functions

Most of the processing steps in the WAM application are very computer intensive. This is due to the size of the datasets, the complexity of the datasets and the complexity of the processing. Steps have been made since initial development to make the application faster but the processing time remains an issue. The table below illustrates examples of expected processing times for the particularly lengthy processes under the following conditions:

- Dataset covering six 1:20000 mapsheets (approx. 1200 km^2)
- Generating a 25 meter elevation grid
- Processing approximately 60 plots
- A Sun SPARC 10 50 MHz. processor with 48 Mb RAM

Task	Approximate processing time*
Generate elevation grid	5 hrs
Generate stream order routes	36 hrs
Calculate plot attributes	24 hrs

* These times are only estimates and do not take into consideration other drains on the computer system while the WAM application is running.

2.3.2 Grid cell size

Grid cell size is considered an issue as there are means by which the user can change cell size when creating the elevation grid. By allowing the user to increase cell size, significantly larger dataset could be analyzed. But in the same way that DEM resolution affects generated streams so does grid cell size. Generating an elevation grid with a cell size which is too large will cause all resulting processes to loose detail. If the user chooses to change grid cell size, they should check the resulting output to determine if they are acceptable.

2.3.3 Project Area Selection

Project area selection is the first step in processing data in the WAM application. Project areas must be selected due to the shortcomings of the available hardware and the inability of the software to process very large datasets. The issue arising from the project area approach is how they should be defined. There are mechanisms in place to define the area by selecting an existing polygon coverage or by on-screen digitizing. Once an area has been selected, the application finds which watersheds this area overlaps, and extracts the DEM for that area. At this point the user must select an area which encompasses the entire basin area of interest otherwise the resulting output may be incomplete.

Basin area is defined as the area flowing into the next downstream confluence from the plot where the stream order increases by one, and stream source is defined as that point to the longest contributing stream (see glossary). Both of these results are impacted if the edge of the elevation grid is reached before the next downstream confluence is located. This can be detected by viewing the output basin polygons and looking for polygons boundaries which are coincident with the boundary of the elevation grid. If such basins are detected, the results for these plots should be discarded.

2.3.4 Processing New Points For an Existing Project

The WAM application processes data on a project basis which is defined by a geographic area. As data preparation (generating the elevation grid and building route systems) requires a considerable amount of time, the most efficient method of processing may be to store project data for future use with updated plot location information. If this is the case, problems arise in the naming conventions used to store the output data as datasets with the default names may already exist in the project workspace. There are two ways in which to solve this problem.

1. Rename all the existing resultant data. The user should be aware that the system will write only the most recent resultant data to the project status table, and the original name and location will be overwritten with the new run. It is recommended that the user not change the prefix for the output Info tables when running the "calculate attributes" process. When ArcInfo exports coverages it will bundle all Info tables with a common coverage name prefix into the output export file.

   For example if the user were to export the *wam_plots* point coverage, all Info files such as the *wam_plots.monthflow* and *wam_plots.sourcepro* will be written to the export file. This allows for simple bundling of coverages and all information relating to that coverage.

2. Create a new project and copy the elevation grid and streams network coverage to this new workspace. The new points can then be run without the problem of having more than one resultant dataset in the project workspace.

2.3.5 Order Route System Generation

Route system structures representing stream order must be built on the corrected or generated streams network. This structure is the only way in which the application can measure up and downstream from a given point. This process is an issue because of the significant amount of time it requires to complete.

3.0 Getting Started

3.1 Overview

The WAM application is written to run on a UNIX workstation with Arc/Info software. The Arc/Info Tin and GRID add-on modules are also required. Data mapping and querying should be performed using ArcView software on a PC via a TCP/IP network connection or also on the UNIX workstation.

The application is launched from a command tool window as follows:

unix_prompt:> wam

This command starts Arc/Info and launches the GUI (graphical user interface) in the Grid module.

The remainder of this section describes some of the up-front characteristics of using the application and the resources available for getting help.

3.2 Message Windows

Throughout the application the user is kept informed of process problems and analysis progress through the use of message windows.

Processing is suspended and warning messages are displayed if the user attempts to create data which already exists, or attempts to select input data for a particular process with incorrect structure.

Examples of these message menus are illustrated in section 5.4.

3.3 Help!

The most detailed resource for help on running the application is this document. In addition, there is limited on-line help for the application accessed by pressing the *help* or *?* button located on each menu including the main application pull-down menu. The on-line help will describe how to use each option in the associated menu, and in some cases will provide notes on data requirements and potential problems. The user should also have available to them the Application System Guide. This document gives a detailed description of how the application is structured and it's lower level dependencies. Although it is written for the application administrator, there is information contained in it which may be very useful for system troubleshooting.

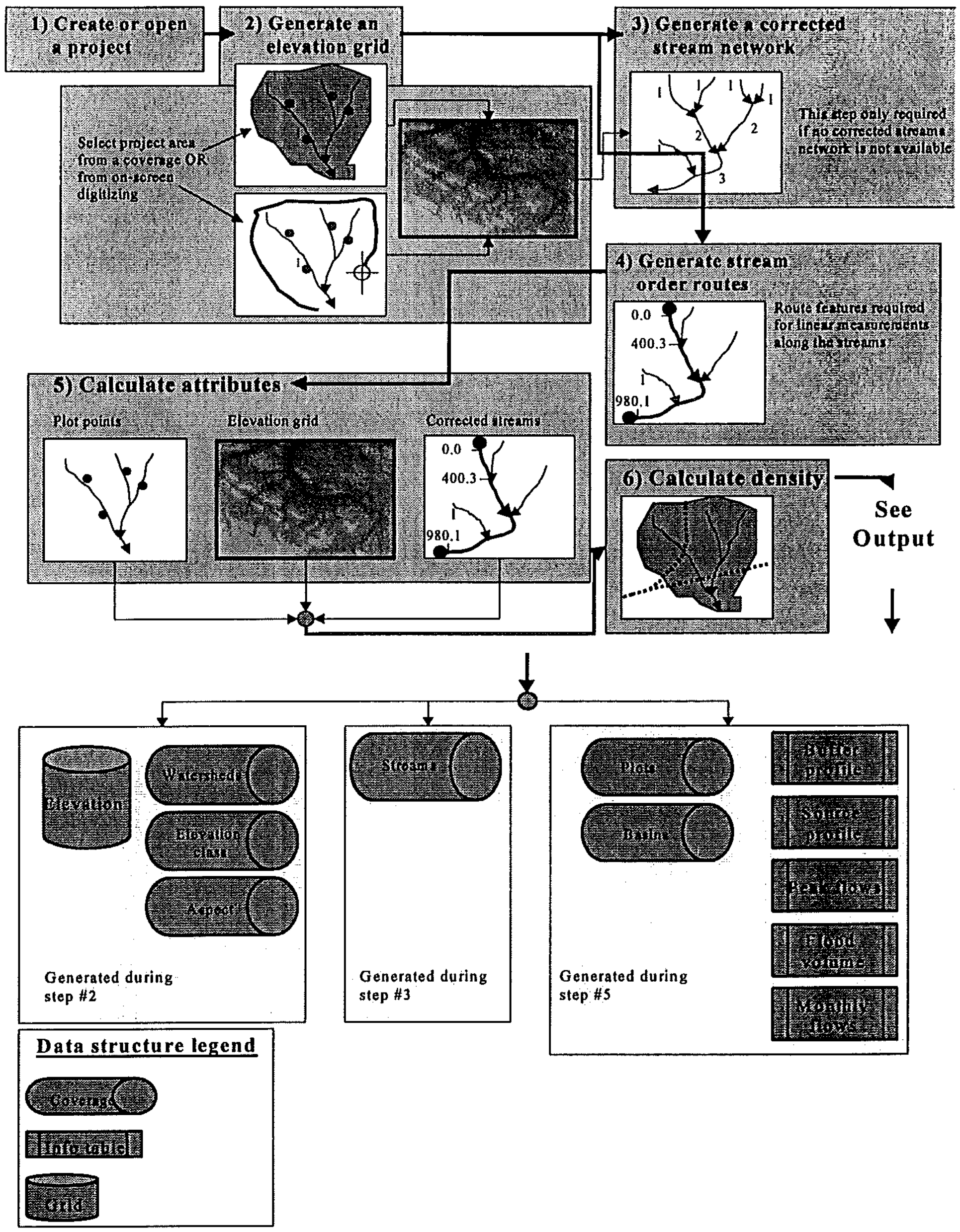
4.0 Process Flow

4.1 Overview

This section illustrates and describes in detail each step of the application process flow. This section is broken up into two parts, the first to describe the steps in generating watershed attribute data, the second to describe the steps in generating a WRNSFMF output dataset. These processes are separated as they can be run independent of one another. But, in order for the application to function correctly all processes must be completed and they must be completed in the correct order.

4.2 WAM Processing

The diagrams below illustrate the WAM processing steps and their output datasets. Each step in the processing corresponds to a textual description starting at section 4.2.1.



4.2.1 Project Management

Projects define processing for a geographic area of interest. Processing is organized in this manner for the following reasons:

1. Break management areas into pieces manageable in terms of system processing and storage.
2. Prevent confusion between resultant datasets.
3. Allow datasets requiring excessive processing time (elevation grid, generating order routes) to be used more than once.
4. Allow users to run datasets or scenarios without impacting a 'master' dataset.

Projects are defined either by an existing polygon coverage defining the project area, or by way of on-screen digitizing. Users are required to choose a location on disk for the output dataset, a name for the project and optionally a text description of the project. Each new dataset resides in a new workspace (directory) on the workstation as defined by the user.

A record for each project is maintained in a master database. Along with the project metadata the database tracks which datasets have been created by each project. The database is updated as each processes is successfully completed.

The option to delete records from the master project table DOES NOT delete any data from the system, only the record from the table. Data can be deleted using the data management tools.

4.2.2 Generating an elevation grid

The elevation grid is used to calculate basin areas, drainage areas, stream gradient, stream profiles and to generate the aspect, elevation class, and watershed coverages. Although additional calculations not dependant on elevation or aspect do occur, (e.g. sinuosity) they are performed at the same time as elevation dependant calculations and therefore all steps require the elevation grid as input. The single exception to this is the density calculation which was separated from other processes to accommodate multiple input sources (seismic, stream crossings) once the drainage basins had been completed.

Elevation data is stored in a grid structure to allow direct access for processing that can only be performed using Arc/Info GRID functions. Another reason to store elevation data in a grid format was to accommodate the utilization of the ANUDEM algorithm in Arc/Info's *Topogrid* command to generate the elevation grid. This command specifically generates a hydrologically correct elevation grid for watershed analysis. The application also uses several other native GRID functions to improve the resulting elevation grid by filling spurious sinks and peaks in the surface model.

The generation of the elevation grid requires an area of interest polygon either selected on-screen by the user or selected as a polygon coverage defining the project area. The application finds which watersheds the area of interest overlaps then buffers those watershed polygons to ensure complete coverage. See section 2.3.4 for more issues relating to project area selection. The application then extracts the required DEM data structures and builds the elevation grid.

4.2.3 Generating a Corrected Stream Network

If the user does not have a corrected stream network for the project area, one can be generated from the elevation grid. The resulting coverage will be composed of connected arcs flowing in a downhill direction and every arc will be attributed with a stream order based on the Strahler or Shreve methods.

The algorithms used to perform this task identify cells which have more than a specified number of cells flowing into them. This number of cells is referred to in the menu system as the *flow tolerance* and can be changed depending on the result desired. Selecting a higher number of cells will result in a less dense stream network, while a lower tolerance will result in a more dense network.

4.2.4 Generating Stream Order Route Systems

In order for the application to measure distances along streams, and more importantly measure distances along stream with a common order, it is necessary to build *route* systems on the streams network coverage. Route systems are an Arc/Info spatial model allowing a single linear feature represented by many arcs to be stored as a single feature. The application uses routes to store a segment of stream of identical order and to store the segment of stream from the plot location to the source of the stream.

This step in the data preparation process is currently very system intensive. See the section 2.3 for further discussion on route system building.

4.2.5 Attribute Calculation

With the exception of the feature density calculation, all other WAM calculations are performed in this step. This approach was taken to simplify the job of the user by requiring only one step instead of four or five. The down side of this approach is longer processing time depending on the number of sample points.

The following processes are completed during this step:

- Snap plots to point on closest stream
- Calculate length to source of stream
- Calculate sinuosity of plot buffer and to the stream source
- Calculate stream gradient on buffer
- Generate stream profile for buffer and to the stream source
- Generate drainage area and basin area polygon coverage
- Attach drainage and basin areas to plots
- Calculate flows at each plot location*

* It is very important that the user be aware of the source of all stream flow related data. These results are calculated from flow equations derived from monitoring stations in the Foothills Forest. See the *WAM Final Report* for details on the *Hydrologic Operational Manual* for applicability of results to other sites.

For a full description of output datasets see section 4.4.

4.2.6 Feature Density

The feature density function allows the user to retrieve any line or point theme, such as seismic, roads, culverts, or stream crossings and overlay it with the basin polygon coverage to calculate a density for that feature inside each basin. The system writes the density for the selected theme features within each basin back to the point attribute table in a user specified field name. For linear features it will generate a length value, and for point features it will generate a frequency value.

The user <u>**must**</u> select the basin coverage associated with the correct plot point coverage (i.e. there is a 1:1 relationship between points and basin polygons). If these datasets do not match, this process will fail.

4.3 WAM Output Data Descriptions

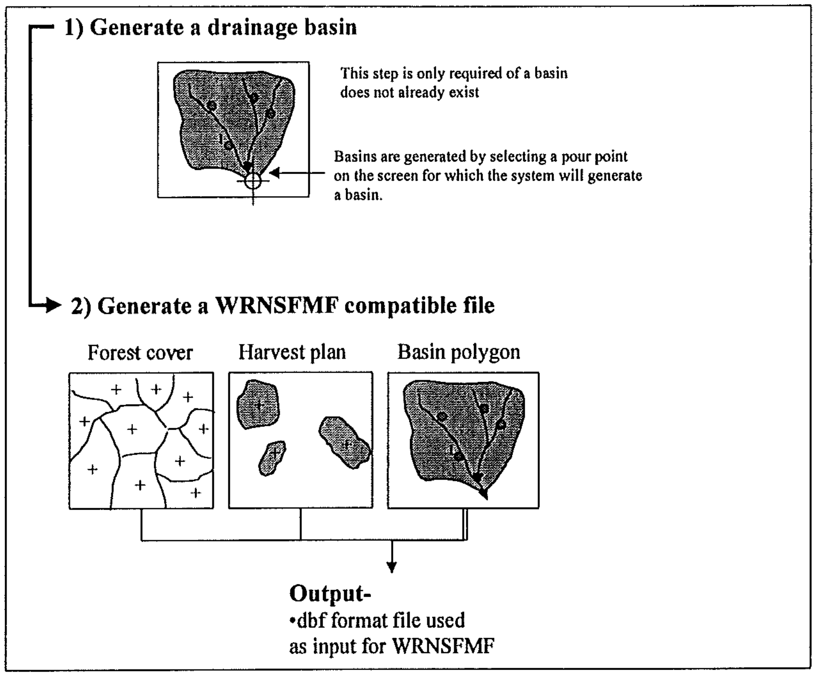
All processes performed in the WAM application generate new output datasets. Most of the new data such as the elevation grid, are straight forward, but other datasets, particularly that which is generated during the attribute calculation is more complex. The following table describes the default name of the resultant data and it's structure. All Info table structures and item definitions are also listed in the Appendix A.

Default name	Data type	Description
<wam_elevclass>	Polygon coverage	• Polygons representing 50 meter elevation classes
<wam_aspect>	Polygon coverage	• Polygons representing four cardinal aspect classes (N,S,E,W)
<wam_streamord>	Line coverage	• Corrected streams coverage generated from elevation grid

		• Route system "order" representing stream order
<wam_plots>	Point coverage	• Copy of input plot coverage with all attributes on the PAT • Additional field "wam_key" can be used to link to all additional Info tables and coverages
<wam_plots>.buffpro	Info table	• Stream profile table for plot buffer • Up to 100 sample points (ArcView limitation) for each input plot (wam_key) • Sample length (distance) is set for all streams based on longest stream divided into 100 sample points (max_length / 100)
<wam_plots>.sourcepro	Info table	• Stream profile table for plot to source of stream • Up to 100 sample points for each input plot (wam_key) • Sample length (distance) is set for all streams based on longest stream divided into 100 sample points (max_length / 100)
<wam_basins>	Polygon coverage	• Polygon coverage with region sub-classes representing drainage area and basin area • Region subclass "drain" (see glossary definitions) • Region subclass "basin" (see glossary definitions) • Each region subclass feature table (e.g. wam_basins.patdrain) will have a "wam_key" which acts as the key back the output plots coverage (wam_plots) and all other resultant datasets.
<wam_plots>.floodvol	Info table	• Flood volumes at each plot as calculated from Hydrologic Operational manual
<wam_plots>.peakflow	Info table	• Peak flows at each plot as calculated from Hydrologic Operational manual
<wam_plots>.monthflow	Info table	• Monthly flows at each plot as calculated from Hydrologic Operational manual

4.4 WRNSFMF Process Flow

The diagrams below illustrate the WRNSFMF dataset creation process flow and its output dataset.



4.4.1 Generate a Drainage Basin

One of the required input datasets for the WRNSFMF process is a single bounding drainage area polygon coverage encompassing the area of harvest for calculating water yield change. The basins coverage generated during the attribute calculation process is not acceptable for use with the WRNSFMF process **unless** it contains only a single polygon from processing with a single point.

This function allows the user to create the required basin by selecting a pour-point, then viewing reference themes in the background to ensure the generated coverage encompasses the required area.

4.4.2 Generate WRNSFMF Data File

This step requires that the user select the required input, forest cover, harvest plan , and basin area. The user must also select the output DBF format file which is to be created.

The following table defines the fields required for the input coverages.

Coverage	Field	Type
Forest cover	ht (representing stand height)	N (actual height)
	sp1 (representing primary species)	C (according to Weldwood domains)
Harvest plan	Yrcut (representing year of cut)	N (four digit year)

5.0 Forms

5.1 Overview

The forms that the user sees while the application runs are shown on the following pages. Each page contains comments on what functions are attached to the various buttons and fields. The title of each page corresponds to the menu name described in section 5.4.

5.2 Generate Watershed Attributes

Step	Task	See Menu Titled:	Action
1	Define a project	New Project	• Type in a project name, - no spaces between characters • Type in name for new workspace, - it can not already exist • Type in a project description - this is a free text field • Select a location for the new workspace to be created
2	Generate an elevation grid	Elevation Grid	• Select a polygons coverage covering the area for which to create an elevation grid OR • Select the area graphically • Type in names of output datasets if different from defaults • Check 'view results output' to view results, once complete, in a display window. • Change grid size if different from default
3	Build streams network	Stream Coverage	• Select elevation grid • Select output coverage name if different from default

Step	Task	See Menu Titled:	Action
			• Select pout point tolerance • Select stream ordering method
5.	Build stream order route systems	Stream Order Routes	• Select streams coverage
6.	Calculate plot attributes	Plot Attributes	• Select plot point coverage - The coverage CAN reside in another workspace • Select streams coverage - The coverage CANNOT reside in another workspace • Select elevation grid - The grid CANNOT reside in another workspace • Select stream search snap tolerance • Select plot buffer distance • Type in output dataset name if different from defaults
7.	Calculate feature density	Feature Density	• Select a coverage containing features feature for which to calculate density • Select density feature type • Type in new item to be placed on the plots coverage point attribute table if different from default. • Select input basin coverage • Select input plot coverage - The basin and plots coverage MUST be the results of the same 'calculate attributes' run in order that there is a 1:1 relationship of plots to basins!

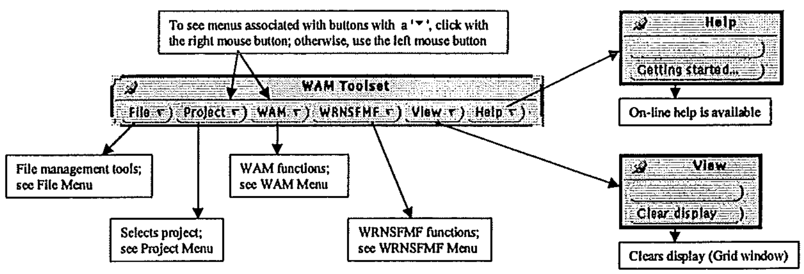
5.3 Generate WRNSFMF data file

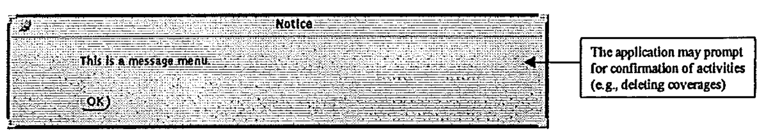
Step	Task	See Menu Titled:	Action
1	Generate a drainage area (if necessary)	WRNSFMF Drainage basin	• Select elevation grid • Type in output coverage name if different from the default • Graphically select a point on the screen for which to generate a drainage basin • If desired, draw reference themes in the background to ensure the area required has been covered.
2	Generate WRNSFMF data file	WRNSFMF	• Select basin coverage - The basin must be a polygon coverage with a single polygon representing the drainage area for the desired WRNSFMF run. The 'wam_basins' coverage generated by the WAM processes CANNOT be used for this

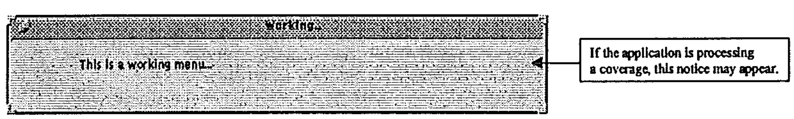
Step	Task	See Menu Titled:	Action
			task. • Select elevation grid • Select a harvest plan coverage • Select a forest cover coverage • Type in a scenario description • Type in the output dbf file name if different from default.

5.4 Interface Menus

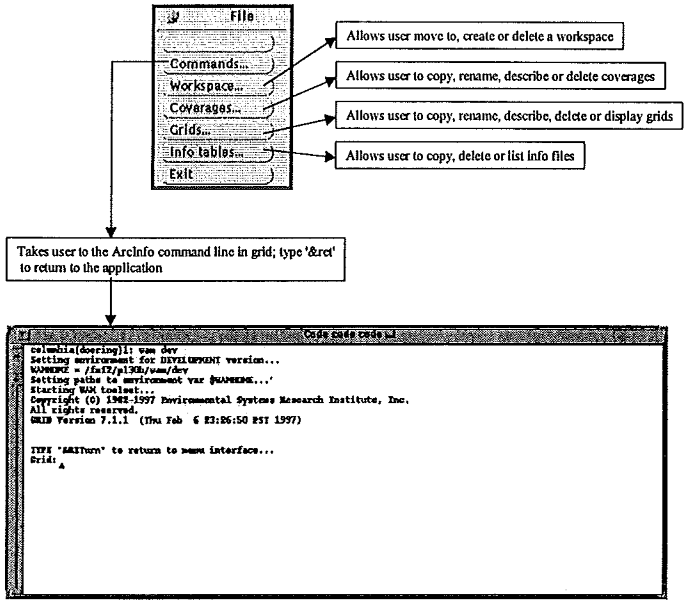
Main Menu



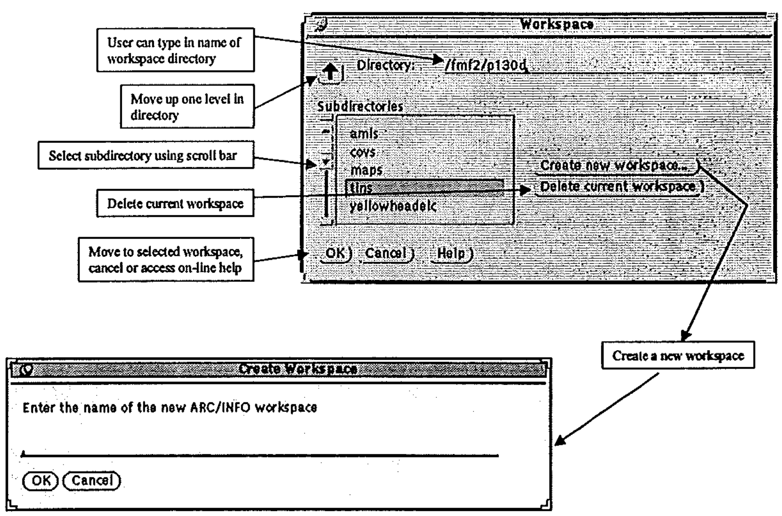




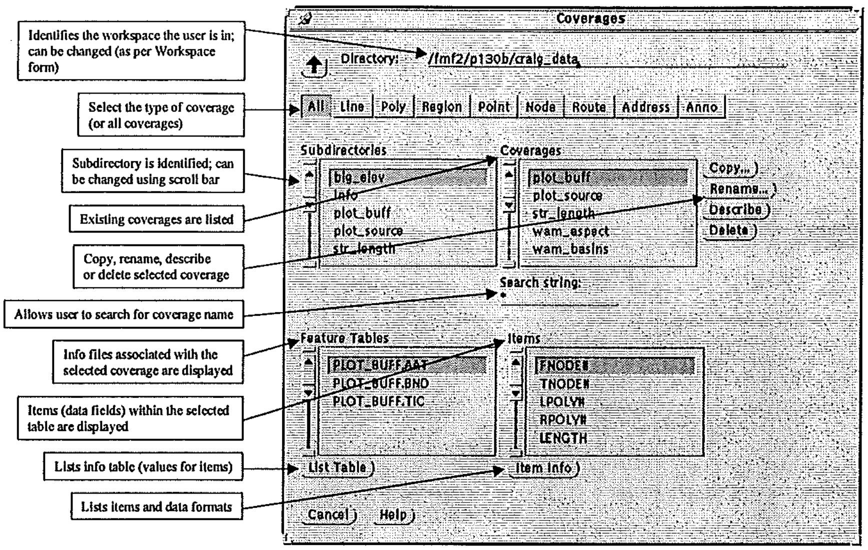
File Menu



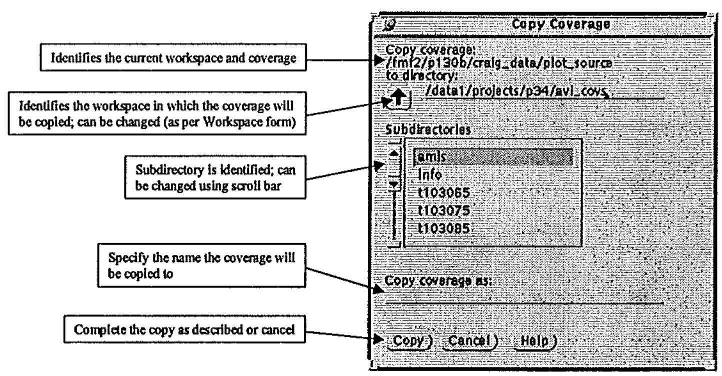
File Menu (cont'd)

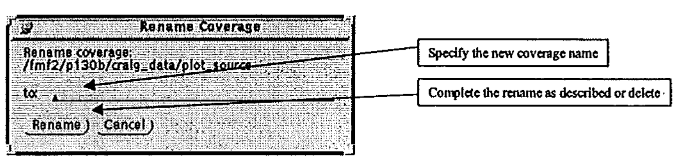


File Menu (cont'd)

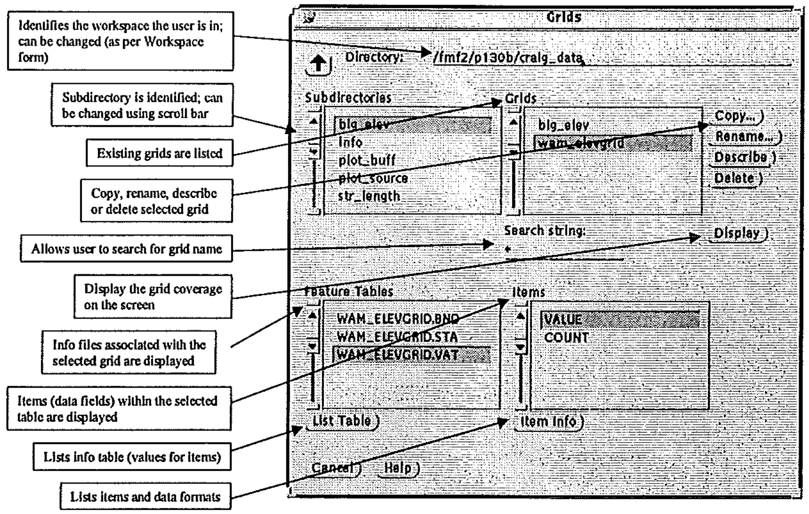


File Menu (cont'd)

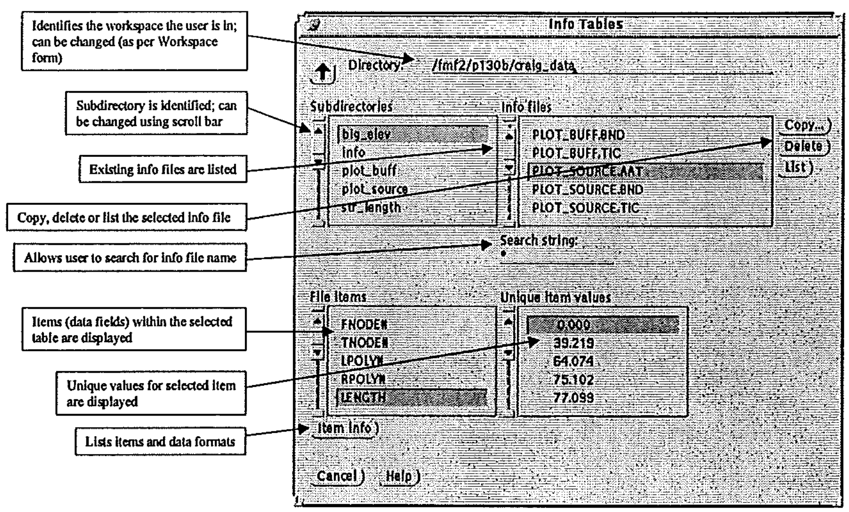




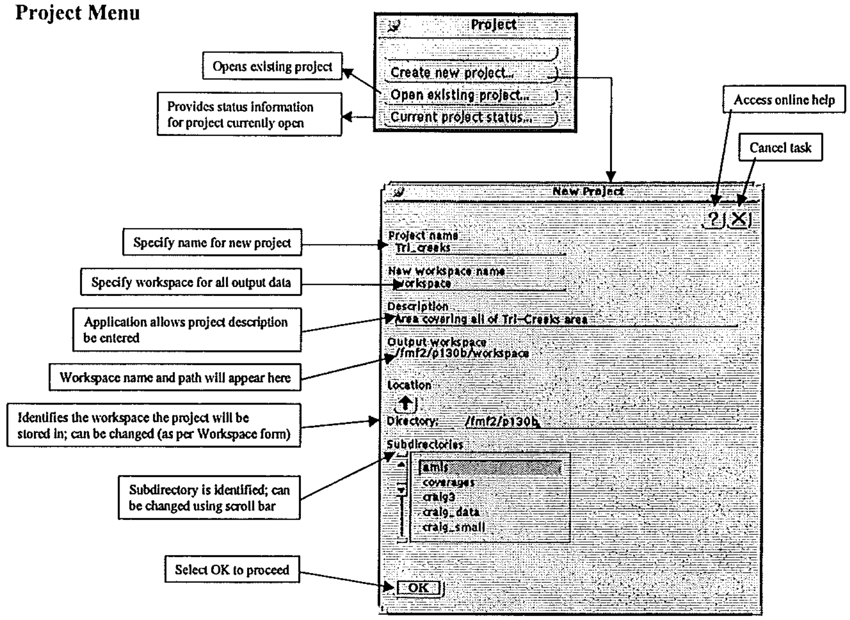
File Menu (cont'd)



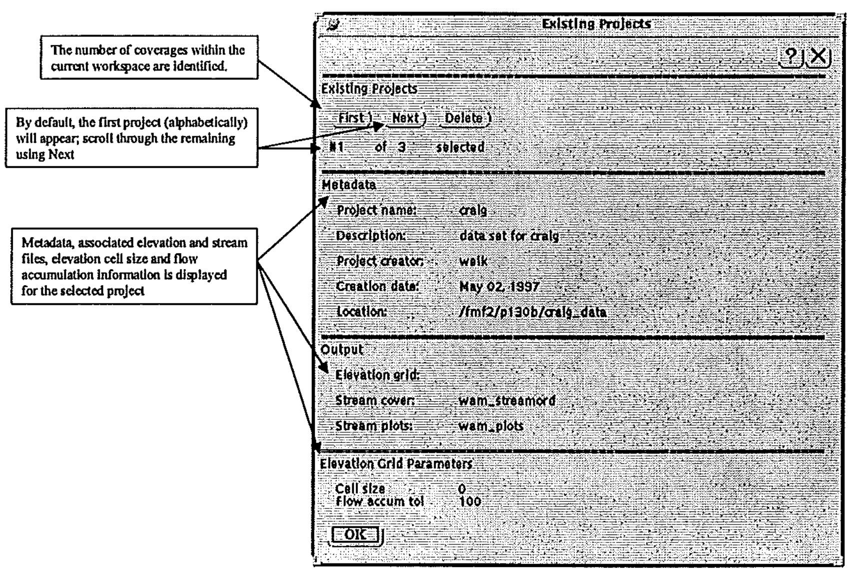
File Menu (cont'd)



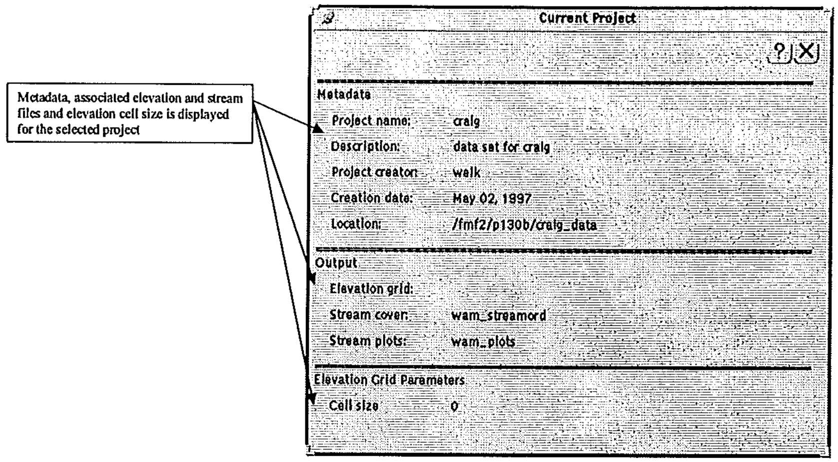
Project Menu



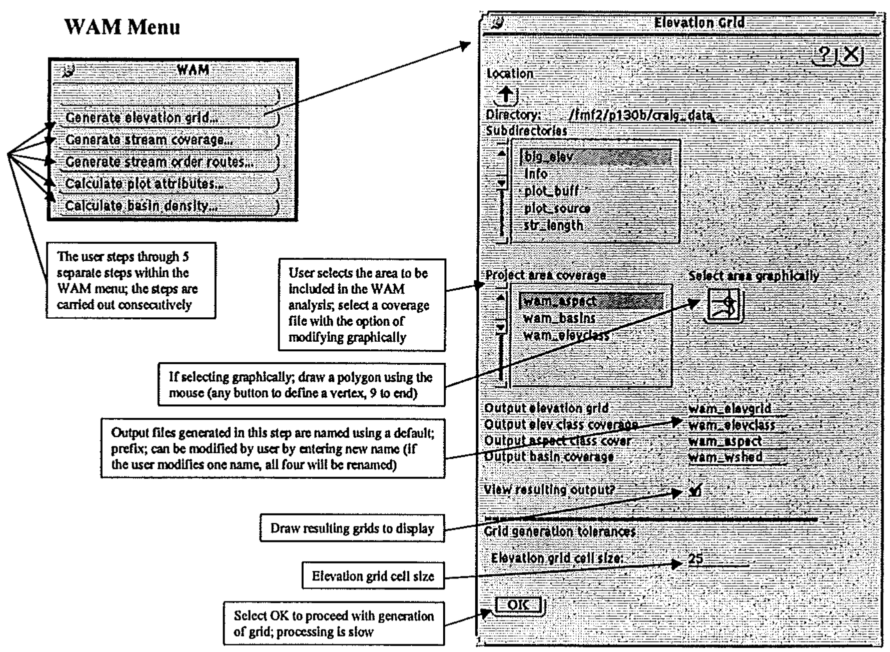
Project Menu (cont'd)



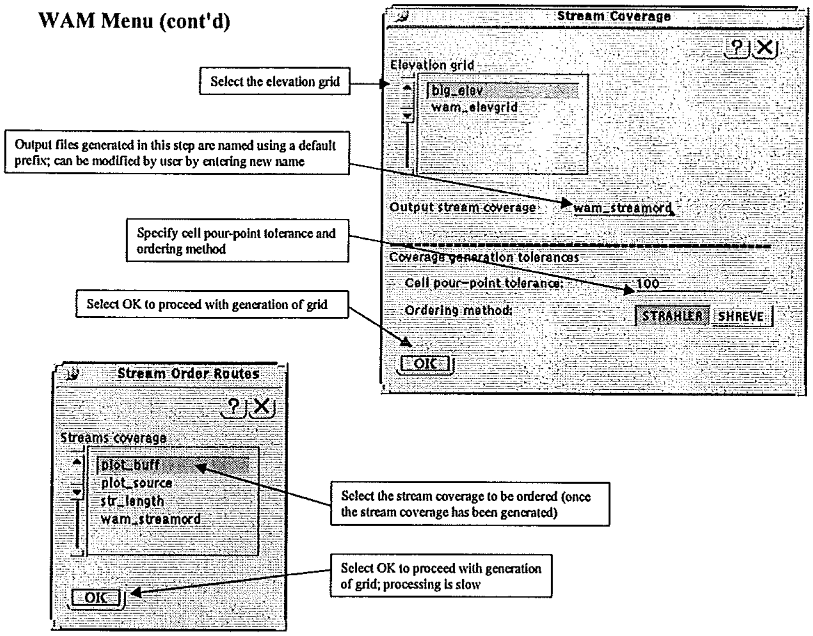
Project Menu (cont'd)



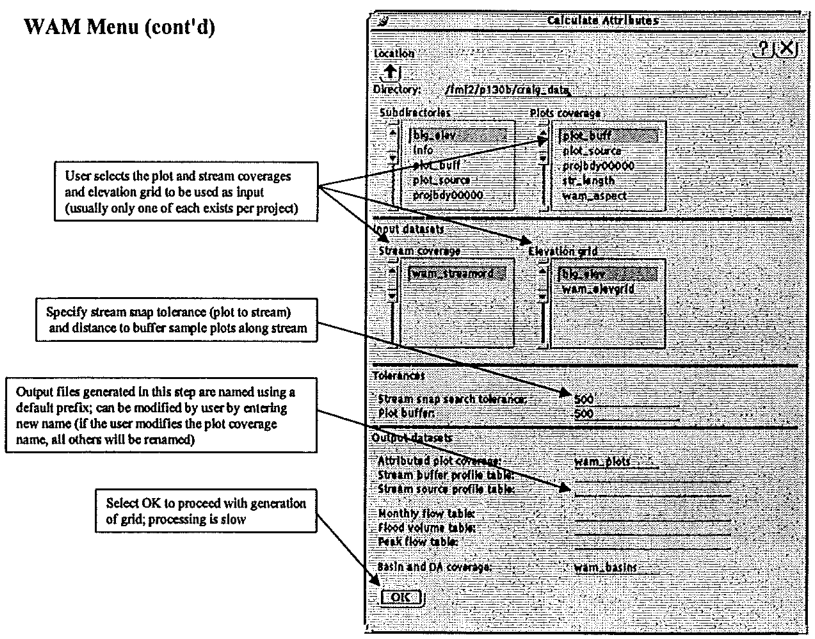
WAM Menu



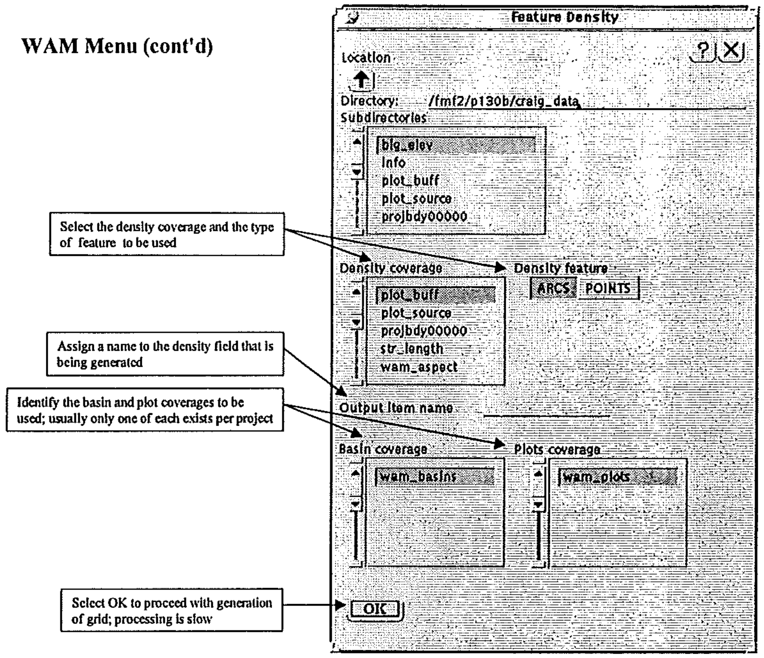
WAM Menu (cont'd)



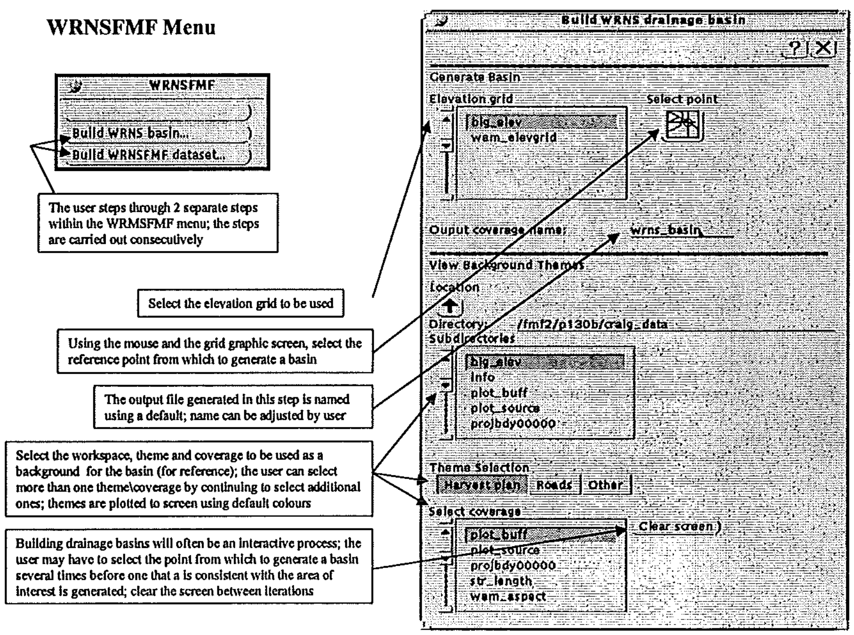
WAM Menu (cont'd)



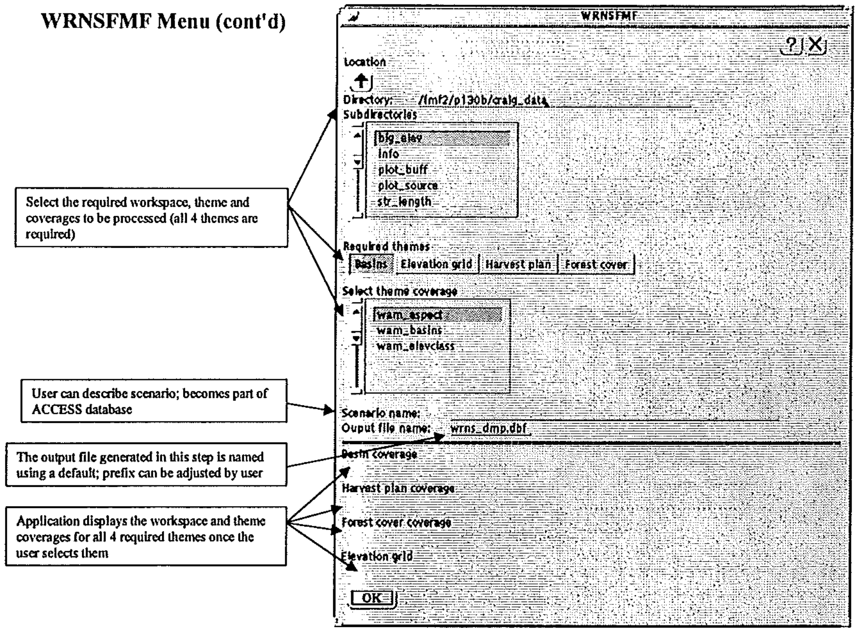
WAM Menu (cont'd)



WRNSFMF Menu



WRNSFMF Menu (cont'd)



6.0 Glossary

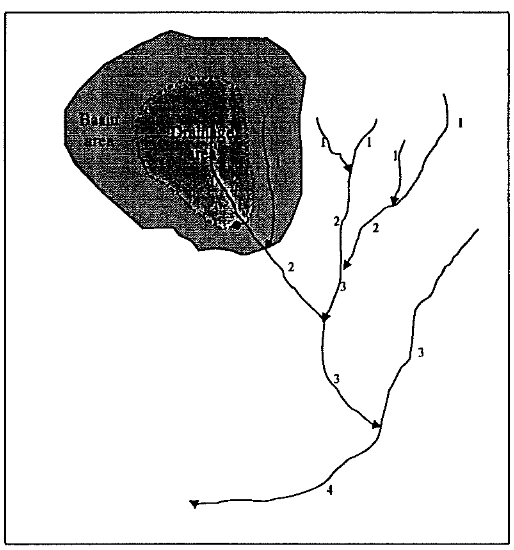
The glossary defines, and in some cases illustrates some of the terminology used in describing processes or data in the WAM application.

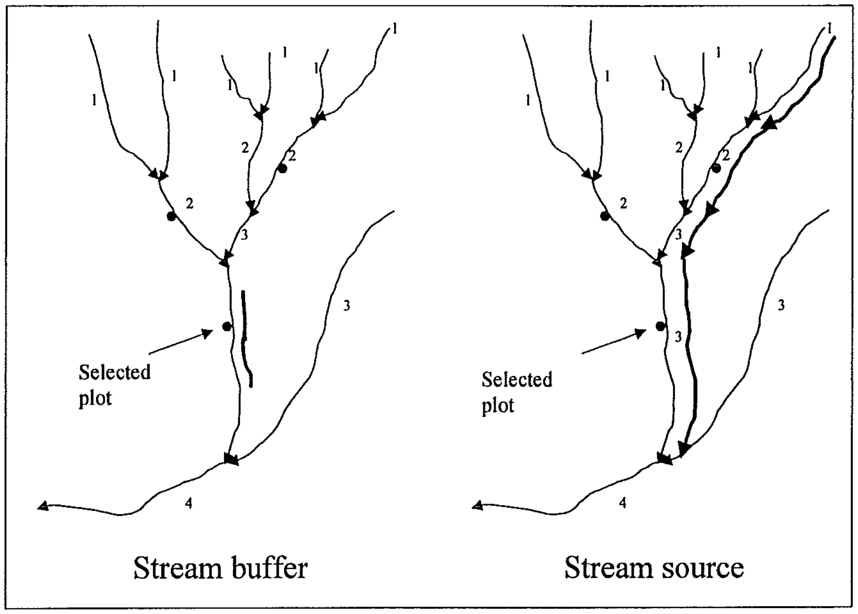
<u>Basin area -</u>

The height of land enclosing the point occurring at the next downstream change in order from a given plot location.

<u>Drainage area -</u>

The height of land enclosing a given plot location.





Stream buffer –

The lineal feature generated when travelling upstream and downstream from a given plot location the specified buffer distance. This lineal feature is then used to calculate sinuosity and gradient for the plot location as well as a profile table.

Stream source –

The lineal feature created by travelling to the next confluence point downstream from a given plot location, and then to the farthest reaching upstream tributary. The farthest reaching tributary is found by moving upstream to the next confluence where the stream order changes. The two or more streams flowing into the confluence are compared for length to the next change in stream order. The longest route to the next confluence is selected and the process is repeated until the end of the network is reached.

This lineal feature is then also used to calculate sinuosity, stream length and generate a stream profile table.

Routes –

Route features are a method of spatial data modeling used by the ArcInfo software to group continuous or non-continuous linear features. The WAM application uses continuous routes for storing multiple arcs belonging to the same stream order.

Events –

Event features are a method of spatial data modeling used by the ArcInfo software to store point or linear features which occur along a given route feature. The WAM application uses linear events to store where a plot location occurs on a given stream and then travels up and downstream the distance of the specified stream buffer. The application also uses events to store the path defining the stream source.

Sinuosity –

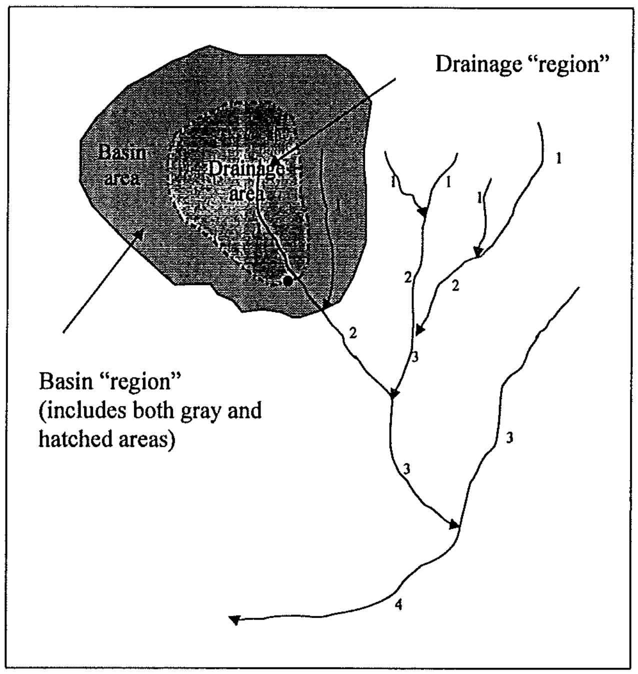
A measure of the number of turns or curves a stream takes. It is calculated in the application as being the actual distance traveled by the stream over the straight line distance. A straight line has a sinuosity of 1.

Gradient –

The measure of the slope of the stream from the upstream point to the downstream point. In the WAM application, the points used for the upstream and downstream measurements are at the ends of the stream buffer. It is calculated as the vertical change over horizontal change.

Regions –

Region features are a method of spatial data modeling used by ArcInfo to store continuous, non-continuous and overlapping polygons. The WAM application uses two continuous region sub-classes to store drainage areas and basin areas in the same coverage. This allows the user to view and query individual drainage and basin areas from the same coverage and to retrieve correct area values for each. Using conventional polygons features, each polygon could potentially have to exist on a separate coverage or the user would have to select all drainage polygons inside a given basin when querying for a basin information.



Flow accumulation tolerance –

The flow accumulation tolerance is used when generating the streams network from the elevation grid. The tolerance represents the number of accumulated grid cells which must flow into a single cell in order for a cell to become part of the stream network. The value for the tolerance is inversely proportional to the density of the output streams network .

Corrected streams network –

A corrected streams network is one which meets the following criteria;

- All streams are linked from source to mouth. This includes points where the stream passes through a water body such as a lake.

- All arcs are oriented in the same direction as the stream flow.
- All arcs have an attribute which represents stream order.

Also, it is desireable that the stream network coincide with the depressions in the DEM which represent the stream flow path. If this is not the case analysis requiring stream arcs to be draped over the DEM (gradient, profile, and elevation) could potentially be incorrect.

Raster vs. vector spatial models–

Raster and vector are the two methods used by Arc/Info to store spatial data. The raster spatial model stores geographic features by draping a grid of rows and columns over the geographic surface. It then categorizing each cell as to what it represents on the surface.

The vector model stores geographic features by defining their boundaries with points connected by lines.

Point attribute table (PAT)-

An Info database table which stores information about the spatial point coverage, and is created at the time topology is *built* for point features. In the application, most attributes associated with the points (gradient, sinuosity etc.) are stored on the PAT. Arc (arc attribute table) and polygon (polygon attribute table) features also have similar tables to store spatial feature related information. All of these types of tables are referred to as feature attribute tables.

Appendix A – Output Table Structures

This appendix gives a detailed descriptions of output Info tables.

WAM_PLOTS.PAT

Field Name	Description
AREA	Default ArcInfo item
PERIMETER	Default ArcInfo item
WAM_PLOTS#	Internal ArcInfo unique identifier
WAM_PLOTS-ID	ArcInfo identifier
FREQUENCY	Application residual
MAX-ELEV_ARC	Maximum elevation of arc created from buffer
MIN-ELEV_ARC	Minimum elevation of arc created from buffer
MEAN-ELEV_ARC	Mean elevation of arc created from buffer
STD-ELEV_ARC	Standard deviation elevation of arc created from buffer
XX00006#	Application residual
ORDER#	Application residual
ORDER-ID	Application residual
ORDER	Stream order of stream input plot was snapped to
ARCLENGTH	Application residual
MEASURELENGTH	Application residual
LOWMEASURE	Application residual
HIGHMEASURE	Application residual
FIRSTSECTION	Application residual
LASTSECTION	Application residual
NUMSECTIONS	Application residual
MEASURE	Application residual
BUFFER	Buffer distance up and downstream from the point
UPSTREAM	Distance downstream from the point upstream where the stream order decreases by one to the **upstream** extent of the buffer. A Value of 0 means the upstream extent of the buffer was less than the specified buffer. (e.g. 325 means the upstream extent is 325 meters from the point upstream where the stream order decreases by one.)

DOWNSTREAM	Distance downstream from the point upstream where the stream order decreases by one to the **downstream** extent of the buffer. Downstream - upstream = buffer length, otherwise the full extent of the buffer was not reached.
ELEV_PLOT	Elevation of plot once snapped to the stream
VALUE	Application residual
COUNT	Application residual
ELEV_ARC	Application residual
X_SNAP	X-coordinate of where point was snapped to the stream
Y_SNAP	Y-coordinate of where point was snapped to the stream
XXKEEP	Application residual
WAM_KEY	**Key used to link to all other output datasets including profile tables, stream flows, and basin polygons.**
SIN_BUFF	Sinuosity of plot buffer
LENGTH_BUFF	Length of buffer for all plots in run
STARTX_BUFF	X-coordinate of upstream start point for plot buffer
STARTY_BUFF	Y-coordinate of upstream start point for plot buffer
ENDX_BUFF	X-coordinate of upstream start point for plot buffer
ENDY_BUFF	Y-coordinate of upstream start point for plot buffer
SIN_SOURCE	Sinuosity of stream from source to "mouth"
LENGTH_SOURCE	Stream length from source to "mouth"
STARTX_SOURCE	X-coordinate of upstream start point for stream source
STARTY_SOURCE	Y-coordinate of upstream start point for stream source
ENDX_SOURCE	X-coordinate of upstream end point for stream source
ENDY_SOURCE	X-coordinate of upstream end point for stream source
X_ORIG	X-coordinate of input (and output) plot point
Y_ORIG	Y-coordinate of input (and output) plot point
SNAPPED	.TRUE. or .FALSE. as to if the plot was able to snap to a stream within the specified search tolerance
GRADIENT	Gradient of plot buffer
BASIN_AREA	Area in m^2 of basin area for plot
DRAIN_AREA	Area in m^2 of drainage area for plot
ROADS_LEN	In this case represents the length of road in the plot's basin area. This is only an example, this field name is defined by the user when the density is calculated.
CROSS_FRQ	In this case represents the number of road crossing points in the plot's basin area. As with the above item this field name is defined by the user when feature density is calculated

Profile tables

Field Name	Description
PX	X-coordinate of sample point
PY	Y-coordinate of sample point
SECTION-ID	ArcInfo identifier
SURFACE-ID	ArcInfo identifier
DISTANCE	Distance from start of profile arc
SPOT	Elevation
WAM_KEY	**Key used to link to all other output datasets.**
ELEV_PLOT	Elevation of actual plot. This can be used to find the elevation of the plot in relation to the profile when creating line graphs.

Flood volume flows

Field Name	Description
WAM_KEY	**Key used to link to all other output datasets.**
AREA	Drainage area in m^2 for elevation class described in next field
ELEV	Elevation class
RETURN_2	2 year return
RETURN_10	10 year return
RETURN_20	20 year return
RETURN_50	50 year return
RETURN_100	100 year return

Monthly flows

Field Name	Description
WAM_KEY	**Key used to link to all other output datasets.**
PERIOD	Month
LOW_10	10 year low flow
LOW_5	5 year low flow
MEAN	Mean flow
HIGH_5	5 year high flow
HIGH_10	10 year high flow

Peak flows

Field Name	Description
WAM_KEY	**Key used to link to all other output datasets.**
AREA	Drainage area in m^2
RETURN_2	2 year return
RETURN_10	10 year return
RETURN_20	20 year return
RETURN_50	50 year return
RETURN_100	100 year return

The Forestry Corp.

Watershed Assessment Model

GIS Application System Guide

August 1997

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 DEVELOPMENT ISSUES 2

2.1 Introduction 2

2.2 Project Area Selection 2

2.3 Generating Stream Routes 2

2.4 Arc Vertex Limit 3

2.5 ArcView Line Graph Limit 3

3.0 PROGRAMMING STRUCTURE 4

3.1 Introduction 4

3.2 Programming Model 4

3.3 In-Line Documentation 5

3.4 Temporary Files 6

3.5 Variables 6

4.0 INSTALLING AND RUNNING THE APPLICATION 7

4.1 Introduction 7

4.2 System Requirements 7

4.3 Application System Setup 7

4.4 Application Data 8

4.5 Launching the Application 9

4.6 General Flow 9

5.0 APPLICATION TABLES 10

5.1 Introduction 10

5.2 Application Defaults 10

5.3 Project Tracking 11

5.4 Stream Flow Calculations 12

APPENDIX A 13

Application Tables 13

1.0 Introduction

The Watershed Assessment Model (WAM) is an ArcInfo AML application used to generate watershed and stream characteristics from existing digital elevation, stream network, and plot location data. The application is intended to run in a client-server environment where all processing is performed using the WAM interface on an ArcInfo UNIX server, and the results are viewed and queried from ArcView on a networked PC.

The balance of this document will discuss some of the issues faced during the development of the application, the programming standards, how to install and launch the application, how to make changes in the application, and will illustrate program flow. The WAM System Guide is one of three documents delivered with the installation of WAM. The *WAM Final Report* describes the general approach and methods involved in completing the project from the initial concepts through to the completion of development. The *WAM User Guide* describes how to use the application, from launching the main menu to detailed descriptions of the resultant data. These documents can be referenced when information beyond the scope of this document is required.

The System Guide is written for the person(s) responsible for application administration. The responsibilities of the administrator include installation, system environment configuration, and performing any changes to the application which may be required. To perform these tasks, the administrator should be knowledgeable in both UNIX system administration and in ArcInfo, although the standard application startup and maintenance is not complex. The System Guide should be used in conjunction with the *WAM User Guide* to make the administrator aware of how to use the application, it's resultant data, and the potential impact of any changes made to the application.

2.0 Development Issues

2.1 Introduction

This section discusses unforeseen technical issues which arose during development of the application. Each issue is described generally, then an explanation as to how each was resolved and the impact, if any, to the original application framework.

2.2 Project Area Selection

Originally a single elevation dataset for the entire Foothills Model Forest area was to be built from which all WAM application analysis would be completed. Using the system in place at the time, the dataset was simply too large to process as insufficient virtual memory could be allocated for the ArcInfo *topogrid* command. This command is used to build hydrologically correct elevation grids from elevation point data. To solve this problem, functions were added to manage WAM analysis by project. The projects are defined by a geographic area for which an elevation grid is generated and all subsequent analysis is completed using the geographic extents of this dataset. The problem which can be encountered with this approach is that the user may select a project area which does not fully encompass the *drainage basin* (see User Guide glossary) for a selected point and will in turn calculate incorrect area values. The potentially incorrect basin area values are written to the output plots table, and are also used to calculate feature densities (density of a linear or point feature inside a basin area). To minimize the chance of an incomplete project area being defined, the selected areas are buffered and then overlaid with a Foothills Model Forest wide basin coverage to determine all overlapping basins. The extent of all selected basins is then used to define the extent of the project. This problem will likely only be completely solved once a dataset covering the entire management area can be created.

2.3 Generating Stream Routes

The application functionality includes the measurement of distances up and down stream from a point along a stream. To accomplish this the application applies ArcInfo's *dynamic segmentation* data structures to build *route* features from contiguous streams sharing the same order. Originally it was thought that the order *routes* could be generated using the single *arcroute* command and specifying the order item as the grouping attribute. But *arcroute* is unable to base *route* direction on the underlying arc direction meaning that using this command would result in some streams flowing uphill. The only method to build route systems and control the direction of individual routes is using the *makeroute* command in Arcedit and specifying an X and Y starting coordinate for the new route. Therefore an extra step was introduced (*build_routes*) to programmatically generate *routes* for individual stream order using the *makeroute* method. This workaround is very time consuming and processor intensive. The most likely fix for this problem is added functionality to the arcroute command to control route direction based on arc direction.

2.4 Arc Vertex Limit

During the *calc_attribs* process, stream lengths are calculated for those streams closest to input plot locations. Originally, the lengths were simply extracted from the AAT of the resultant coverage from the *eventarc* command. Currently there is an ArcInfo limitation which restricts a single arc to be comprised of a maximum 500 vertices. Once this limit is reached, the system automatically splits the arc. A fix for this problem sums the length of all arcs belonging to a single *route*. This process does not require significant additional processing time.

2.5 ArcView Line Graph Limit

During the *calc_attribs* process, stream profile tables are generated for buffer and source to mouth stream *routes*. Arcview can only generate line graphs for a maximum of 100 samples points. Although an option exists with the *surfacxsection* command to define a distance for sampling along the stream arcs, it was discovered that additional points were added in the tables and therefore could exceed the 100 point maximum. An additional process was added to ensure that there were no sample points closer than the specified sample distance. This process impacts processing time slightly, depending on the number of streams in the profile table. This problem can only be resolved by removing the limit of sample points for line graphs in Arcview or by a change to the *surfacexsection* functions which guarantees exact sample distances in the arc profiles.

3.0 Programming Structure

3.1 Introduction

The application administrator should be aware of the program structure of the application in the event they wish to perform changes to the AML code. These changes may be required for example, if the application is moved to another site, the input data structure changes, or to take advantage of updates to the ArcInfo GIS software. All application code is written in AML and is not encrypted allowing complete access and flexibility to the administrator should the need for changes arise. This section will discuss the programming and documentation standards used for development to assist the administrator in navigating through the application code.

3.2 Programming Model

The application programming structure is modeled after ArcInfo's Arctools. Each task or step in the application is performed using a tool designed specifically for this task. A tool is comprised of an AML, a menu and a help file, all with the same prefix name (eg. build_routes.aml, build_routes.menu, build_routes.hlp). All tools are launched, executed, and exited by running the AML and specifying a command line argument which executes a routine in the AML of the same name. All tools contain the standard routines described in the table below.

Standard Tool Routines

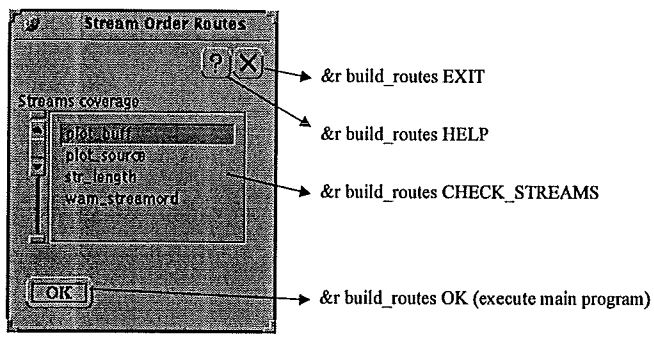
Routine	Function
INIT	launch tool menu (default)
USAGE	returns valid command line syntax
HELP	pops up a text window with menu help (if the help file exists)
EXIT	closes the menu, closes all sub-menus spawned by the tool, and deletes all tool variables
BAILOUT	called in the event of an AML error

Additional functions required by the tool such as validating widget input is run using the same syntax to execute the validation routine. Below is an example of the routines called from a menu. The following command would launch the *build_routes* menu.

```
Arc: &r build_routes init
```

Once the menu is present, all tasks associated with the widgets are called from the menu program using the standard syntax.

Example of menu program calls



The Arctools programming structure allows all tools to operate independently and are therefore more easily incorporated into existing applications. This advantage also allowed the easy integration of existing generic Arctools into the WAM application. All tools relating to data management were implemented in this way and can be identified in the AML header information.

3.3 In-Line Documentation

Header and in-line documentation also follow a similar standard to that used in Arctools. Standard header information is illustrated below.

```
/*-----------------------------------------------------------------------
/*            The Forestry Corp
/*-----------------------------------------------------------------------
/*   Program: AML_NAME.AML
/*   Purpose:
/*
/*-----------------------------------------------------------------------
/*     Usage: AML_NAME INIT {'position'} {'stripe'} {MODELESS | MODAL}
/*     Usage: AML_NAME <routine_name>
/*
/* Arguments: routine  - name of the routine to be called.
/*            position - (quoted string) opening menu position.
/*            stripe   - (quoted string)  menu stripe displayed.
/*            MODELESS | MODAL - keyword indicating modality of menu thread
/*
```

```
/*   Globals: (none external)
/*---------------------------------------------------------------------------
/*     Calls: AML_NAME.MENU
/*---------------------------------------------------------------------------
/*     Notes:
/*---------------------------------------------------------------------------
/*   History: Author - date - original code
/*===========================================================================
```

The history section of the header should be maintained to track any changes which are made to the AML after the initial installation. In addition, most general tasks in the code are described using in-line documentation

3.4 Temporary Files

Many of the processes in the application require the generation of temporary datasets in the form of grids, coverages, info tables, and system files. It is strongly recommended that the user not create files which start with 'XX' as this is the convention used in the application and by most ArcInfo processes to name temporary data. If all processes complete correctly there should be no residual temporary files. If for some reason a process has failed and temporary files do remain, they can be removed.

3.5 Variables

The standard global variable naming convention also adheres to the Arctools model. All global variable names have two components. The first part being the same name as that of the tool in which it was created, and the second describing what the variable represents. For example, *.build_basin$outcov* is set and referenced in the *build_basin* tool (AML or menu) and will represent the output coverage. All variables not required outside the program in which they were set is defined as a local variable. This convention allows easy identification and deletion of variables set by a particular process.

4.0 Installing And Running The Application

4.1 Introduction

This section will describe the system requirements for to running the WAM application, how to install the application code, how to set the system environment to run the application, how to launch the application, and finally the program flow.

4.2 System Requirements

The WAM application was developed in and requires ArcInfo (Rev 7.0.4) on the UNIX operating system . In addition to the core ArcInfo program the application requires the GRID raster modeling module and the TIN (Triangular Irregular Network) three dimensional surface analysis module. The application will run in any X graphic environment that is supported by ArcInfo. Menu and form placement on the display may not be consistent across different X environments, but this will not affect functionality. The actual application code requires approximately 800K of disk space and can reside anywhere on the system under a common parent directory. Running the application does require a significant amount of both memory and disk space as many of the processes are very CPU intensive and create large temporary and resultant datasets. For example, an 25m resolution elevation grid with 2.2 million cells requires about 3.6Mb but this may vary depending on theme variability.

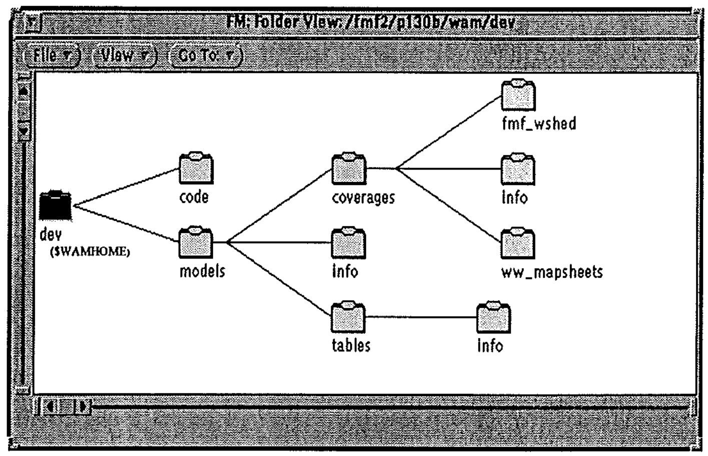
4.3 Application System Setup

WAM uses UNIX system environment variables to dynamically set the location of the application code, tables and data. In the user's .cshrc startup file, the *$WAMHOME* environment variable must be set to the directory which contains the subdirectories *code* and *models*. Examples are shown below, you must substitute the correct locations for your site.

setenv WAMHOME /opt/app/wam

Once the application is installed, the directory structure should be the same as that illustrated below.

Directory structure



The arc *topogrid* command used to generate the hydrologically correct elevation grid may require additional virtual memory allocation to complete successfully. To override default memory allocation limits it is recommended that the GRIDALLOCSIZE system environment variable be set to a value of at least 100, if it has not previously been set. This variable is set also in the .cshrc file using the same syntax as described for the WAMHOME variable.

setenv GRIDALLOCSIZE 100

4.4 Application Data

The application uses two ArcInfo coverages located in the *$WAMHOME/models/coverages* directory to determine the geographic extent of the DEM data required to build an elevation grid for a project. When the user selects a project area, either from an existing polygon coverage or from on-screen digitizing, the program first overlays that area with the *fmf_wshed* coverage to determine all overlapping watersheds. The extracted polygons are then buffered to try and minimize the possibility of a small portion of a watershed being eliminated due to the large scale digitizing from which the *fmf_wshed* coverage was created. This buffer result is then overlaid with the *ww_mapsheets* coverage to determine all overlapping 1:20000 mapsheets. Using the list of mapsheets the program then builds the elevation grid by extracting point data from the TINs which are available by 1:20000 mapsheet. The program was modeled this way as FMF's best DEM data existed in the TIN structure, by 1:20000 mapsheet. If the format for the DEM data changes there will have to be some custom programming performed in the *build_elevgrid* tool which allows the system to read other data formats.

At installation time the names of the two coverages mentioned above, and the location of the TIN datasets by mapsheet will have to be entered into the *wam_defaults* table. Below is a table listing the three variables in the table for which the values will have to be set at installation and if the coverage names are ever changed.

Variable	Description	Value
.build_elevgrid$masterwshed	master watershed coverage	$WAMHOME/models/coverages/fmf_wshed
.build_elevgrid$sheetbdys	name of coverage used for TIN selection	$WAMHOME/models/coverages/ww_mapsheets
.build_elevgrid$tinpath	path to all available tins	/fmf4/tins

4.5 Launching the Application

Once the *$WAMHOME* environment variable is set, the user can launch the application from within ArcInfo as described below.

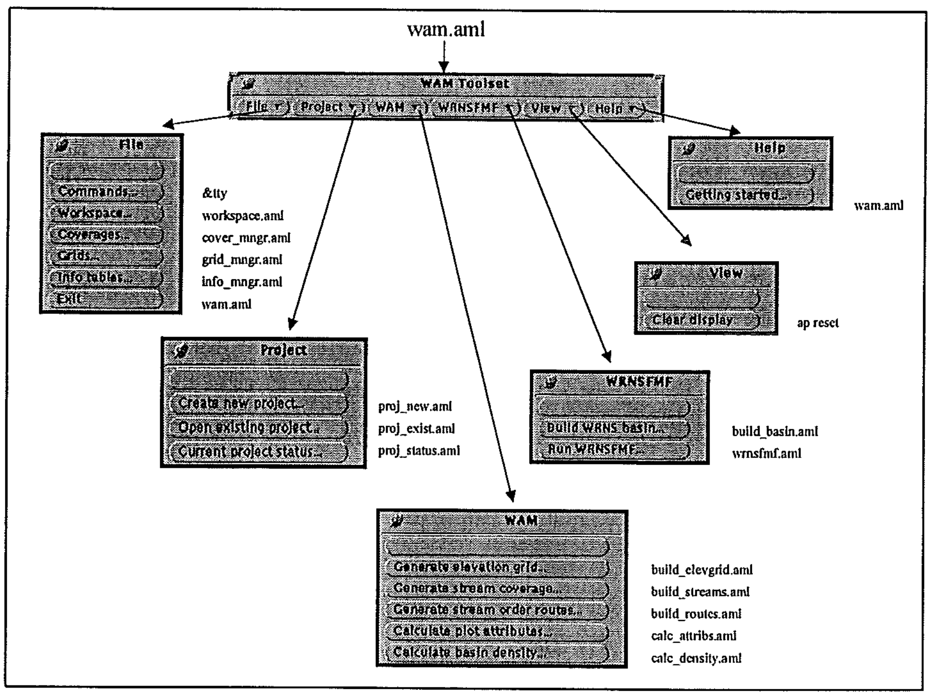
```
Arc: &r $WAMHOME/code/wam
```

The administrator may wish to set the above command in an alias which could be called either from the X window main dropdown menu or via a single command in a shell window. Either of these options will make it faster and simpler for the user to launch the application.

4.6 General Flow

The diagram below illustrates the commands executed by each of the main menu options. The launching program *wam.aml* is executed at the arc prompt as described in the previous section.

Main Menu Program Calls



5.0 Application Tables

5.1 Introduction

This section will instruct the system administrator on how to make *standard* changes to the application, and will discuss how the application tables are used.

5.2 Application Defaults

Standard changes are parameters which were identified during the development as having the potential to change in the event, for example, of the input DEM data resolution changing. To make changing these parameters simpler than altering program code, the parameter value and the variable used to hold the parameter value are stored as records in an INFO table. The *wam_defaults* table stores these parameters, where applicable. Some of the parameters are static, meaning that in order to change them the administrator must manually edit the table to change the value. Others are simply default values which initially populate menu widgets to simplify the interface. See Appendix A for a listing of the *wam_defaults* table and it's default values at installation. Below is a description of the variable name and what each represents. The *var_name* prefix will indicate the tool with which each is associated.

Wam defaults table

VAR_NAME	DESC
.build_basin$outcov	Default name of generated basin coverage.
.build_elevgrid$aspect_cov	Default name for output aspect coverage.
.build_elevgrid$cellsize	Default elevation grid cell size.
.build_elevgrid$elev_class	Default name for classified elevation coverage.
.build_elevgrid$elev_grid	Default output name for elevation grid.
.build_elevgrid$masterwshed	Name of coverage of watersheds for the FMF used in finding all watersheds overlapping the selected project area.
.build_elevgrid$sheetbdys	Name of coverage used to find all required TIN data structures to build an elevation grid for the project area.

.build_elevgrid$tinpath	Path to all available tins datasets.
.build_elevgrid$wshed_cov	Default name for output watershed coverage
.build_elevgrid$wshedbuff	Distance to buffer selected watersheds to ensure that they fully encompass the watersheds defined by the DEM.
.build_streams$flowtol	Default number of accumulated cells required to assign a cell as part of the flow path when generating streams from the elevation grid.
.build_streams$order_alg	Default stream ordering method.
.build_streams$stream_order	Default name of output stream coverage.
.calc_attribs$armtol	Search tolerance for 'arcrroutemeasure' command used to generate measures along routes from point features (the plots).
.calc_attribs$attrib_plots	Default name of output point coverage from the 'calc_attribs' process.
.calc_attribs$basincov	Default name of output basin and drainage area coverage.
.calc_attribs$buffer	Default buffer distance up and down stream from the plot location.
.calc_attribs$neartol	Default search tolerance to snap plots to streams using for the arc 'near command'.
.wrnsfmf$aspectitem	Aspect item on aspect PAT
.wrnsfmf$bufdist	Buffer distance around harvest blocks
.wrnsfmf$htitem	Height item name on fc PAT.
.wrnsfmf$outdbf	Default output dbf file.
.wrnsfmf$site	Site value.
.wrnsfmf$sp1item	First species item name on fc PAT.
.wrnsfmf$yrcutitem	Year of cut item on the harvest PAT.

The administrator should be aware of the consequences of changing any of the default parameters, specifically those which impact output results such as flow tolerance. These changes should first be discussed with end users to ensure that they are aware that any new datasets will be created using the altered parameters.

5.3 Project Tracking

As discussed in section 2.2 each WAM run that is performed on a project basis. This was done as a measure to solve the problems incurred by datasets which were simply too large for the ArcInfo software to process on available hardware. Prior to any analysis in the application the user must define a new project or select an existing one. This will automatically, in the event of a new project, create a new workspace, and then take the user to the appropriate workspace. The location path and name of the project workspace, any new datasets created by the application, and the parameters used to generate new datasets are written to an application INFO table called *Projects*. When defining a new project the menu allows the user to assign characteristics or metadata to the project which is also stored in the table.

5.4 Stream Flow Calculations

During the *calc_attribs* process, flood volumes, peak flows, and monthly flows are calculated at each plot location. The calculations are based on the generated basin areas and formulae developed for sites within the Foothills Model Forest which are published in the *Hydrologic Operational Manual.*

Below is a table which describes the application tables which are associated with the flow calculations. These tables should only be altered by persons knowledgeable in how the values are derived. The full tables and their original values are listed in Appendix A.

Table name	Description
peak_flow.vol	Peak flow hydrography volumes for three elevation zones. This is required for peak flow calculations.
monthflow_a1250.vol	Mean monthly unit flows for areas above 1250m. This is required for monthly flow calculations.
monthflow_b1250.vol	Mean monthly unit flows for areas below 1250m. This is required for monthly flow calculations.

Appendix A

Application Tables

To follow is a listing of all application tables. These tables are located in the $WAMHOME/models/tables directory.

wam_defaults – This table is used to set default values for menu widgets and for site-specific installation parameters.

VAR_NAME	DESC	VALUE
.calc_attribs$armtol	search tolerance for arcrroutemeasure	10
.calc_attribs$buffer	buffer distance from plot along stream	500
.calc_attribs$attrib_plots	name of output, attributed plot coverage	wam_plots
.calc_attribs$neartol	search tol to snap plots to streams using near	500
.calc_attribs$basincov	name of output basin and drainage area coverage	wam_basins
.build_elevgrid$cellsize	elevation grid cell size	25
.build_elevgrid$elev_grid	default output name for elevation grid	wam_elevgrid
.build_elevgrid$elev_class	default name for classified elevation grid	wam_elevclass
.build_streams$flowtol	cell tolerance for flowaccumulation command	100
.build_elevgrid$sheetbdys	name of coverage used for tin selection	$WAMHOME/models/coverages /ww_mapsheets

.build_elevgrid$masterwshed	master watershed coverage	$WAMHOME/models/coverages /fmf_wshed
.build_elevgrid$wshedbuff	buffer distance for selected master watershed poly	500
.build_elevgrid$tinpath	path to all available tins	/fmf4/tins
.build_streams$stream_order	name of output stream coverage	wam_streamord
.build_streams$order_alg	stream ordering method	STRAHLER
.build_elevgrid$aspect_cov	default name for output aspect coverage	wam_aspect
.build_elevgrid$wshed_cov	default name for output watershed coverage	wam_wshed
.wrnsfmf$bufdist	buffer distance around harvest blocks	100
.wrnsfmf$yrcutitem	year of cut item on the harvest PAT	yrcut
.wrnsfmf$aspectitem	aspect item on aspect PAT	aspclass
.wrnsfmf$site	default site value	fair
.wrnsfmf$sp1item	first species item name on fc PAT	sp1
.wrnsfmf$htitem	height item name on fc PAT	ht
.build_basin$outcov	default name of generated basin coverage	wrns_basin
.wrnsfmf$outdbf	default output dbf file	wrns_dmp.dbf

aspect.remap – Used to generate the output aspect class polygon coverage and to create aspect class polygons when generating the WRNSFMF output dataset.

VALUE	SYMBOL	ASPECT
1.0	0.0	F
2.0	96.0	N
3.0	98.0	EW
4.0	99.0	S
5.0	90.0	EW

floodvol.remap - This table is used to remap the area inside the drainage area for calculating the flood volumes.

VALUE	CLASS
1250.0	1250.0
1500.0	1500.0
4500.0	4500.0

monthflow_a1250.vol – Used in conjunction with drainage area to calculate monthly flows.

PERIOD	LOW_10	LOW_5	MEAN	HIGH_5	HIGH_10
march	0.0009	0.001	0.0015	0.0023	0.0029
april	0.0028	0.0034	0.0051	0.0079	0.0096
may	0.0031	0.0042	0.0076	0.014	0.019
june	0.0029	0.0038	0.0067	0.013	0.017
july	0.0019	0.0028	0.0062	0.014	0.022
august	0.0014	0.0021	0.0046	0.0098	0.014
september	0.0017	0.0023	0.0043	0.008	0.011
october	0.0015	0.0019	0.0032	0.0069	0.0093

monthflow_b1250.vol - Used in conjunction with drainage area to calculate monthly flows.

PERIOD	LOW_10	LOW_5	MEAN	HIGH_5	HIGH_10
march	0.0009	0.001	0.0015	0.0023	0.0029
april	0.0028	0.0034	0.0051	0.0079	0.0096
may	0.0031	0.0042	0.0076	0.014	0.019
june	0.0029	0.0038	0.0067	0.013	0.017
july	0.0019	0.0028	0.0062	0.014	0.022
august	0.0014	0.0021	0.0046	0.0098	0.014
september	0.0017	0.0023	0.0043	0.008	0.011
october	0.0015	0.0019	0.0032	0.0069	0.0093

monthflow.remap – This table is used to remap the area below and above 1250 meters inside the drainage area for calculating monthly flows.

VALUE	CLASS
1250.0	1250.0
4500.0	4500.0

peak_flow.vol - Used in conjunction with drainage area to calculate instantaneous peak flows.

RETURN_YRS	BELOW_1250	F1250_1500	F1500
2.0	25.0	45.0	50.0
10.0	65.0	75.0	90.0
20.0	80.0	90.0	110.0

50.0	95.0	110.0	135.0
100.0	110.0	125.0	160.0

elevgreen.lut – Used as a symbol look-up for drawing the elevation grid classified by 50 meter intervals. The shadeset must be *colornames* to display the correct shades. This table is not used directly by the application.

Value	Symbol
600.0	77.0
700.0	62.0
800.0	61.0
900.0	64.0
1000.0	65.0
1100.0	68.0
1200.0	69.0
1300.0	73.0
1400.0	110.0
1500.0	108.0
1600.0	105.0
1700.0	101.0
4500.0	95.0

class_50m.remap - Used as a symbol look-up for drawing the elevation grid classified by 50 meter intervals. The shadeset must be *colornames* to display the correct shades. This table is not used directly by the application. This table is not illustrated due to its size.

3.2.01

WAM
Watershed Assessment Model

Final Report (Phase 1)

by

Janice Traynor, R.P.F.

Prepared for:

Foothills Model Forest

and

MDFP Research Trust Fund

August 1997

Calgary, Alberta

Disclaimer

The project/study on which this report is based was funded by the Foothills Model Forest under the Partners in Sustainable Development of Forests initiative delivered by the Canadian Forest Service of Natural Resources Canada.

The views, statements and conclusions expressed and the recommendations made in this report are entirely those of the author and should not be construed as the statements or conclusions of, or as expressing the opinions of, Foothills Model Forest.

also,

The study on which this report is based was funded by the Manning Diversified Forest Products Research Trust Fund, which is a component of the Government of Alberta's Environmental Protection and Enhancement Fund. The views, statements and conclusions expressed and the recommendations made in this report are entirely those of the author(s) and should not be construed as the statements, conclusions, or opinions of members of the Manning Diversified Forest Products Research Trust Fund Committee, the Government of Alberta, or the Alberta Forest Research Advisory Council.

Foothills Model Forest Mission

"to develop and recommend an approach to sustainability and integrated resource management through research and technology developed by means of collaborative partnerships".

Relationship between Foothills Model Forest and Resource Management Agencies

The Foothills Model Forest represents a broad range of stakeholder groups with interest in Alberta's forests and how they are managed. However, Foothills Model Forest has no resource management authority or responsibility. The authority over, and responsibility for, the management of Alberta's public lands is vested in the Government of Alberta. The Government delegates certain rights and responsibilities to various resource industries and organizations which conduct their activities on public lands in Alberta. The Government of Alberta and other agencies and organizations will consider and respond to the recommendations of Foothills Model Forest from the perspective of their particular rights, responsibilities, obligations and stewardship commitments.

Abstract

The Foothills Model Forest Watershed Assessment Model (WAM), provides information on watersheds, their characteristics and resources. WAM presents an integrated approach using the results of computer models, GIS, and resource inventory data together with an interactive viewing interface. WAM output results provide basin, hydrology and resource inventory information generated by ArcInfo analyses and hydrology models for selected points or watersheds in the project area. Additional point information, such as inventory results from external databases can be linked to these results. This is the final project report and outlines WAM, the information generated by analyses, data issues and processing requirements. Details are given of the steps involved in preparing DEM data, using ArcInfo hydrologic analysis tools, calculating watershed characteristics and generating a stream network. Samples of the output datasets viewed through ArcView are shown and results compared to information generated manually from topographic maps.

The use of watershed information in planning and the value of topography information generated by GIS are outlined. The results of testing WAM on two diverse landscapes are presented and the strengths and limitations of the stream network generation functions discussed. Recommendations for additional testing and opportunities for users to provide input are given.

Executive Summary

The Foothills Model Forest Watershed Assessment Model (WAM), provides information on watersheds, their characteristics and resources. WAM presents an integrated approach using the results of computer models, GIS, and resource inventory data together with an interactive viewing interface. The purpose of the project was to develop a planning tool and provide resource information to managers to better evaluate land management alternatives for effects on hydrology, aquatic habitats and fish.

In January of 1994 Foothills Model Forest invited hydrologists, fish biologists and foresters familiar with the hydrologic and fish resources of the Foothills Model Forest to a workshop. In their proceedings of this workshop Rothwell and O'Neil (1994) outline a strategic plan which states that WAM should provide: landscape information for hydrologic and aquatic resource evaluation; information to describe regional and local hydrologic regimens and responses to forest harvesting in terms of annual yield and peak flow events; and information on key fish species and aquatic habitats.

Physical properties such as slope, aspect, location and bedrock morphology combine with vegetation cover, climate and land use to make each watershed unique. GIS allows watershed characteristics to be calculated quickly and accurately however the results are dependent upon the quality of the spatial data. In the WAM application, a digital elevation model (DEM) presents a 3-D model of the surface of the watershed and is the starting point for hydrologic analysis. WAM uses hydrologic analysis tools within the GRID module of ArcInfo to predict watershed characteristics such as upstream drainage area, basin area, elevation, and also stream order, profile, gradient, length and sinuosity. WAM can also calculate the density for a variety of linear features such as stream, roads or seismic lines.

WAM incorporates the results from two separate FMF watershed projects to generate hydrologic information. The equations from the regional hydrologic study (Hydroconsult 1997) provide a simple means to estimate existing or baseline streamflow and the WRNSFMF model (R.H. Swanson & Associates 1997) simulates annual yield and peak flow changes and is useful in estimating cumulative effects on streamflow of sequential harvests through time.

The WAM process can be summarized in 7 steps:

1. **Select a project area.** This is the geographic area of interest and must include the entire basin, including headwaters surrounding any points of interest.
2. **Generate an elevation grid.** WAM utilizes ArcInfo hydrologic functions in the GRID module to generate a hydrologically correct elevation grid.
3. **Input or generate a corrected stream network.** A corrected streams network is a requirement of WAM. This is a network in which all arcs are connected, correspond to the direction of stream flow, have a unique identifier and an attribute of stream order. If a corrected streams network is unavailable WAM can build one from DEM data.
4. **Build a stream order route system.** A route allows multiple, connected arcs to be stored as a single linear feature. This is necessary to measure distances along streams.
5. **Calculate plot attributes.** Link the point to a location on the closest stream. Calculate stream lengths, sinuosity, stream gradient, stream profiles, generate drainage and basin boundaries, calculate areas and estimate streamflow.
6. **Calculate feature density**. A variety of point and line densities can be calculated for stream basins. Options include stream, seismic line or road densities and number of stream crossing or inventory sites (provided a point coverage of locations exists).
7. **Generate WRNSFMF dataset.** A database file is generated in a format that can be input directly to the WRNSFMF model to evaluate annual yield changes from forest harvesting.

Test results are presented for the Upper McLeod Watershed within the Foothills Model Forest and the Red Earth Creek Watershed in northern Alberta. WAM was able to create a stream network from DEM data and this closely resembled the interpreted streams network for the Upper McLeod watershed. The Red Earth Creek watershed is very flat and WAM could not generate a stream network in this terrain. The results of WAM were compared to calculated stream characteristics for the Tri-Creeks basin. In general the information provided by WAM closely resembled that calculated manually from topographic maps. Additional evaluation and testing of WAM output results for the Foothills Model Forest is recommended.

Generating watershed characteristics from the GIS is much more efficient that calculating them manually from an air photo or map however, these estimates are only as good as the data used to generate them. The user must consider the accuracy of the selected DEM and apply the results at an appropriate scale. Research demonstrates that analysis using a DEM can provide valid information on slope, drainage areas, drainage networks and other topological information.

Stream order is a mechanical classification. It is important to identify the characteristics of the data used to define the stream network and to understand the characteristics of a defined first-order stream if comparisons are to be made with stream order values from other sources.

WAM requires ArcInfo including TIN and GRID add-on modules on a Unix workstation and ArcView 3.0 on either the PC or workstation to run. The ideal configuration is a PC running ArcView linked to the Unix server running ArcInfo. The WAM analysis can also be run independently and the data exported to the user running ArcView on a stand-alone PC. WAM requires considerable system resources and is most efficiently run on an area less than 1000 km^2.

It is recommended that WAM analyses be completed on a large project area within the FMF. The results of these analyses should be provided to users interested in evaluating WAM. A mechanism to receive feedback and suggestions for improvements in WAM from these users should be implemented.

Acknowledgments

The success of the Watershed Program at Foothills Model Forest was due to the strong support of a wide range of sponsors and contributors. I would like to thank those attending the original FMF watershed workshop who developed a clear, concise strategic plan, which provided direction for the program and focus for development of a Watershed Assessment Model. Implementation of this plan was made easier by the strong support of staff of the FMF major sponsors, especially Alberta Environmental Protection. I would like specially to thank Carl Hunt, Natural Resources Service, Fish and Wildlife Division and John Taggart, Water Sciences Branch, Hydrology Section for their commitment to the concept and continued support from the original workshop, through the establishment of the FMF watershed program to the receipt of final deliverables. The development of WAM could not have proceeded without the expertise, advice and hard work of The Forestry Corp GIS staff, in particular Christian Weik, Carol Doering and Brian Maier.

WAM is the final product of the FMF Watershed Program (Phase 1) and incorporates the results of separate hydrology and fisheries projects. Those involved in these related projects provided expertise, comments and direction for WAM development. In particular, I thank Dr. Bob Swanson, consulting forest hydrologist, Craig Johnson, FMF fish ecologist and Gord Stenhouse, Weldwood wildlife biologist for their input. This program would not have been possible without funding from a wide variety of sponsors. Foothills Model Forest covered staff and administration costs throughout the program and core funding for most projects. The Natural Resources Canada, Canadian Forest Service provided funds for WAM development through the Decision Support System Initiative. Manning Diversified Forest Products Research Trust Fund also provided multi-year support for this project.

Disclaimer i

Abstract ii

Executive Summary iii

Acknowledgments v

1. Introduction 1

1.1 What is WAM? 1

1.2 History of FMF Watershed Program 1

1.3 Objectives 2

1.4 Related Projects 2

2. Methods 3

2.1 Overview 3

2.2 Concept development 3

2.3 Selecting components of WAM 3

2.3.1 Watershed characteristics 4

2.3.2 Hydrology estimates 5

2.3.3 Fish and aquatic habitat information 5

2.4 Testing of WAM 5

2.4.1 Develop streams layer from existing data 5

2.4.2 Spatial information 6

2.4.3 External databases 6

2.4.4 WAM runs 6

2.5 Workshops 7

2.6 Deliverables 7

3. Results 8

3.1 WAM GIS Application 8

3.1.1 Data requirements 8

3.1.2 Process 8

3.1.3 Output datasets 9

3.1.4 Viewing results 9

3.2 Examples 9

3.2.1 Use of these data 11

3.3 WAM Test runs 11

3.3.1 Upper McLeod Watershed 11

3.3.2 Red Earth Creek Watershed 12

4. Discussion 14

4.1 Watershed Information in Planning 14

4.2 Watershed characteristics from the GIS 14

4.2.1 DEM 14

4.2.2 Stream Order 15

4.3 Data Issues 15

4.4 Model and System requirements 15

4.4.1 Application development 15

4.4.2 Results testing 16

5. Recommendations 17

6. Project Summary 19

7. Literature Cited 20

1. Introduction

This report will document the development of WAM, the Foothills Model Forest (FMF) Watershed Assessment Model during Phase 1 of the model forest program (1994-1997). The reader will be shown a brief history of the project, the links to other projects in the FMF Watershed Program, watershed concepts addressed within WAM, the specific components of the WAM framework and results of WAM analyses. The report will also present the results of testing of WAM on two different watersheds located with the Upper Foothills and Northwest Boreal forest regions of Alberta. Discussions of the strengths and limitations of WAM and recommendations for further development of the WAM framework are included.

The User Manual and System Guides for WAM are published as separate, related documents (The Forestry Corp (TFC) 1997ab). The reader is directed to these documents for more detailed descriptions of WAM and computing and data requirements to run WAM.

1.1 What is WAM?

WAM provides information on watersheds, their characteristics and resources. WAM presents an integrated approach using the results of computer models, GIS, and resource inventory data together with an interactive viewing interface. Loucks (1995) defines a DSS as an interactive computer-based information provider which provides timely information to support decision makers. Under this simple definition WAM is a decision support system developed in the Watershed Program (Phase 1) of the Foothills Model Forest, Hinton Alberta. The WAM application runs on an Unix workstation running ArcInfo GIS software and results are viewed using ArcView 3.0 desk-top GIS software. The user selects a project area, which encloses the watershed(s) of interest for WAM analysis. WAM output results provide basin, hydrology and resource inventory information generated by ArcInfo analyses and hydrology models for selected points or watersheds in the project area. Additional information for these points, such as inventory results stored in a database format, can also be integrated. These results can then be viewed as maps, tables, graphs or point attributes on-screen or output to printer or file. The user can access the full capabilities of ArcView, including spatial analysis and queries to evaluate the results.

1.2 History of FMF Watershed Program

The Foothills Model Forest program began in 1992. The original proposal outlined initiatives to integrate forest management with watershed and aquatic ecosystem management. In particular the need to characterize aquatic ecosystems and their variability and to understand watershed responses to forest harvesting and the natural variability of streamflow were identified. Shortfalls in program funding meant that the start of the watershed program was deferred. While fiscal realities were understood staff and partners of Foothills Model Forest continued to lobby for a program which focused on the aquatic portion of the forest ecosystem.

In January of 1994 Foothills Model Forest invited hydrologists, fish biologists and foresters familiar with the hydrologic and fish resources of the Foothills Model Forest to a workshop. Participants were asked to investigate the feasibility of and develop a strategic plan for the development of a Watershed Assessment Model. In their proceedings of this workshop (Rothwell and O'Neil 1994) outlined a strategic plan for developing a watershed assessment model (WAM). The FMF Watershed Program was established in August of 1994 to implement this plan and continued until the end of Phase 1 of the model forest program, March, 1997. WAM is the final project in this program.

1.3 Objectives

The purpose of the "Development of Watershed Assessment Model (WAM)" project was to develop a planning tool and provide resource information to managers to better evaluate land management alternatives for effects on hydrology, aquatic habitats and fish. The original objectives, contained in the strategic plan (Rothwell and O'Neil 1994) can be summarized as:

1. Develop a spatial model, which provides information on watershed, hydrology, aquatic habitat and fish resources for use by resource managers.
2. Incorporate existing and developing resource information and models to better characterize these resources.
3. Construct an open, transparent application framework, which is modular in nature and incorporates local data specific to the region of interest.

The FMF work plan (December 1994) for this project listed the desired end result as:

> "A system capable of evaluating a harvest plan for the resulting cumulative effects of forest management activities on the quantity and quality of water yield from a given watershed or complex of watersheds, and in turn be able to evaluate the impact of the harvest plan on the quantity and quality of aquatic and fisheries habitat. By simulating the outcome of different land management alternatives in time and space, both negative and positive impacts of land disturbances can be identified and incorporated into management decisions. The primary goal of WAM is to assist managers in maintaining the integrity of aquatic ecosystems and associated hydrologic values, as a prerequisite for the support of viable, stable fish populations."

These comprehensive objectives guided the program and individual project development. At this stage in development WAM has met the objectives however all the outlined end results have not been achieved. WAM provides information on the quantity of water yield but assumes application of best management practices will address the issue of water quality. Information to describe aquatic habitat is generated by WAM however a means to measure the quantity and quality of fish habitat is not available. Achieving the end results will require testing and use of WAM in management decision-making. Some desired results, particularly evaluating quantity of aquatic and fisheries habitat is known to be difficult and may be impossible to measure. All results of WAM should be evaluated within a decision framework which reflects the specific goals, policies, management practices, local resource knowledge and expert opinion of the user and the organization they work for.

1.4 Related Projects

WAM is linked to other FMF watershed projects in a variety of ways. The equations from the Regional Hydrology Study (Hydroconsult 1997) are programmed directly into WAM to provide streamflow estimates. An output of the WAM analysis is a table of information (.dbf format) which can be used as the input dataset to the WRNSFMF model (R.H. Swanson & Associates 1997) to evaluate annual yield and peak flow effects of a forest harvest plan. The locations of fish and stream inventory sites are stored on the GIS and can be used as input points for WAM analyses. Additional site attributes calculated by WAM include stream gradient, stream order, basin areas, road density and distance from source. When viewing the output of WAM in ArcView, specific site information stored in external databases are joined with the results of WAM analyses to provide a comprehensive listing of available information for each point.

The flexibility of WAM allows a variety of external databases or spatial data to be incorporated. The previous examples all contain information specific to the Foothills Model Forest region. If WAM is to be used in other regions it is important that the broader applicability of these project results be assessed and local data used where possible.

2. Methods

2.1 Overview

The development of WAM was an evolving process. The WAM approach is unique, the knowledge base is growing and new tools, GIS capabilities and opportunities continue to arise. Thus there should be little surprise that the project encountered some dead-ends, roadblocks and a few curves. At this point the development of the WAM application is complete and ready for site installation and testing by users. The results of this application testing and comparison of results from WAM to those calculated manually or through other means should be used in evaluation of this project. WAM should continue to be viewed as a work-in-progress allowing it to benefit from and respond to user comments when, in the future it is used in an operational setting after installation on the FMF GIS system.

2.2 Concept development

The Strategic Plan for Development of a Watershed Assessment Model (WAM) (Rothwell and O'Neil 1994) provided direction for this project but not specific tasks. Literature reviews and discussions with resource professionals did not identify any previous research or tools which could be used as a prototype for development of WAM. The project benefited from a study of existing approaches to watershed analysis in use in the U.S. Pacific Northwest. The following documents (and telephone discussions with authors or users of these methods) were useful, especially in the early stages of WAM development:

- Standard Methodology for Conducting Watershed Analysis (Washington Forest Practices Board 1994)
- A Federal Agency Guide for Pilot Watershed Analysis (FEMAT 1994)
- Timber-Fish-Wildlife Ambient Monitoring Program Manual (D. Schuett-Hames *et al* 1994).

GIS was a necessary foundation for WAM not only to access and analyze spatial data but also to manage the large amounts and varied sources of data available for the landbase. ArcInfo and ArcView were in use at Foothills Model Forest and had inherent analysis, data management and data viewing capabilities, which were used in WAM. The components of WAM were chosen in response to the information requirements of the hydrologic models and the planning process.

In the past a number of significant watershed research programs have taken place within the Foothills Model Forest Region. Swanson and Hillman (1977) verified that water yield increased after forest harvesting. Results from Tri-Creeks experimental watershed program provided information on fish and hydrology in the region. In his summary of Tri-Creeks research results, Nip (1991) identified that point sources such as stream crossings and access roads crossing ephemeral draws and source areas were the main contributors of sediment entering stream channels. Rothwell (1978) provided watershed management guidelines for logging and road construction to minimize detrimental effects on water quality. These results helped establish priorities for development of individual components of WAM.

Most water quality concerns can be minimized through application of known, best management practices, especially for road and stream crossing construction. WAM provides information on topography to support planning decisions for road networks and stream crossing locations but does not include predictive equations for water quality. Equations to predict streamflow and the effects of forest harvesting on hydrology are important components of WAM.

2.3 Selecting components of WAM

The strategic plan (Rothwell and O'Neil 1994) states that WAM should provide:

- landscape information for hydrologic and aquatic resource evaluation,

- information to describe regional and local hydrologic regimens and responses to forest harvesting in terms of annual yield and peak flow events and
- information on key fish species and aquatic habitats.

Time and funding constraints dictate that, wherever possible existing information should be used. Hay and Knapp (1996) summarize the characteristics of the data required to investigate natural, potential, and human-induced impacts in a watershed as: (1) The data have both a spatial and temporal dimension; (2) there is a vast amount of data at multiple scales and formats; and (3) the data must be understood by a broad range of people with differing levels of scientific background. WAM is designed to address all three of these points. The following sections outline how and what types of information are generated within WAM.

2.3.1 Watershed characteristics

Watershed characterization identifies the physical properties that influence a watershed's hydrologic properties including water quality and the magnitude of streamflow. Physical properties such as slope, aspect, location and bedrock morphology combine with vegetation cover, climate and land use to make each watershed unique. Most of these data are available in a digital form however such datasets are usually large, complex and stored in a variety of formats. GIS is an ideal tool for watershed characterization. It allows one to measure watershed characteristics faster and more accurately (Civco *et al* 1995) however the accuracy is dependent on the spatial data's quality.

The digital elevation model (DEM) provides a three-dimensional representation of the basin. Each point has three coordinates. The X and Y coordinates identify the geographical or spatial location on the landscape and the Z coordinate provides elevation. In the WAM application, DEM data (points with elevations) are converted to an elevation grid (each cell has a single value for each coordinate). The spacing of these cells within the grid is specified by the user. The DEM models the surface of a watershed and is the starting point for hydrologic analysis.

There is a set of hydrologic analysis tools within the GRID module of ArcInfo. WAM uses these functions to predict many of the watershed characteristics. Using a digital elevation model as input the potential for surface flow is modeled and the following information calculated:

- the location of the watershed boundary (height of land) and the area enclosed in this polygon. In WAM two terms are used, **upstream drainage area** is the area that drains to a specific point located on a stream and **basin** is the area that drains to the location downstream of that specified point where the stream order changes.
- **elevation** of a point
- **stream order** for each section of the stream. A first order stream has no tributaries, a second order stream has two or more first order tributaries, a third order stream has two or more second order tributaries and so on. Stream order is an attribute of the corrected streams network.
- **stream profile** is calculated within a buffer (generally 500 m up and down stream) around the site and also from the stream source to the mouth. In WAM the mouth of the stream is the point downstream of the site where stream order increases. This table of values can be graphed in ArcView to view the profile.
- **stream gradient** within the buffer is calculated as a percentage, change in elevation (upstream to downstream) over length of the buffer.

ArcInfo routes based on stream order are used to identify the path to the source and mouth of the stream. From these routes, **stream length**, the distance from the site upstream to the source and downstream to the mouth is calculated. This distance is divided by the straight-line distance to calculate **sinuosity**. The upstream drainage area and area within specific elevation classes are used with equations from the regional hydrologic analysis (Hydroconsult 1997) to provide estimates of peak flow, flood volume and average monthly flows at the point. WAM also calculates the density for a variety of features depending on GIS data available. For line features such as stream, roads or seismic line the total length within the basin is calculated. For point features such as inventory sites or road-stream crossing sites (where locations are stored as points on GIS) the number of sites per area is calculated.

In a separate calculation WAM can prepare a database file which can be input directly into WRNSFMF (Swanson & Associates 1997) and used in an evaluation of annual and peak flow response to harvesting.

This calculation requires additional information on vegetation cover (species and height), forest harvest plans, and cut history. The reader should reference the WAM User Guide and System guides (TFC 1997ab) for more detailed information.

2.3.2 Hydrology estimates

WAM incorporates the results from two FMF watershed projects to generate hydrologic information on:

- **streamflow.** Hydroconsult (1997) prepared the Hydrologic Operational Manual from the results of a regional hydrology study completed in the Foothills Model Forest. This study performed a detailed hydrologic analysis on the data available from long-term streamflow monitoring undertaken by Water Survey of Canada. The resulting equations provide a simple means to estimate existing or baseline streamflow on any stream in the Foothills Model Forest. These equations are developed for streams in the area around Hinton. After evaluating local data they may be found to be useful for planning purposes in areas of the foothills north or south of FMF however when using WAM in other regions the results of a local regional hydrologic analyses should be used.

- **annual yield.** R.H. Swanson & Associates (1997) developed the WRNSFMF model and the WRNSFMF User's Manual to help evaluate the effect of forest harvesting on streamflow. The size, distribution, location, and vegetation of clearings in a watershed influences snow distribution (snow accumulation in clearings is greater than under a forest canopy) and consequently the amount of water available for runoff. WRNSFMF builds upon the WRENSS hydrologic procedure developed by the U.S. Environmental Protection Agency, adding the results of watershed research in Alberta and customizing the model for the FMF region. WRNSFMF simulates annual yield change using seasonal precipitation, forest harvest information and growth curves for basal area and height and is useful in estimating cumulative effects of sequential harvests through time.

The reader can reference these documents for more detailed information.

2.3.3 Fish and aquatic habitat information

FMF initiated a comprehensive literature review of habitat requirements for native sportfish species found in the region. R.L.& L. Environmental Services Ltd. (1996) completed An Information Review of Four Native Sportfish Species in West-Central Alberta. This report provides information on the habitat requirements of various life stages of the target species and potential effect of land use activities however the results did not identify specifics which could be programmed into WAM. Similar to the other components of WAM the knowledge base of fish and aquatic habitat information is continually expanding. The Fisheries staff at Foothills Model Forest is currently studying relationships between fish presence or abundance and habitat or watershed features.

WAM incorporates the results of recent and historical fish and stream inventories when questions relating to fish are evaluated. Site locations are stored as points in a spatial coverage and used to run WAM. Inventory results are stored in a relational database linked through a common site identity. When viewing results the external databases are linked to the point attribute results table from WAM analysis. This allows all site information to be available in a single table and viewed within ArcView. The attribute table can also be exported to supply watershed information to the inventory results database.

2.4 Testing of WAM

2.4.1 Develop streams layer from existing data

A corrected streams network is a requirement of WAM. This is a network in which all arcs are connected, correspond to the direction of stream flow, have a unique identifier and an attribute of stream order. At this time few organizations have a corrected streams network. Midway through the project the decision to develop a corrected streams network for all of Foothills Model Forest was changed to developing a network for a smaller pilot study area in the Upper McLeod watershed. FMF staff and consultants identified four tasks to upgrade the GIS streams data.

1. Connect arcs from the provincial base layer and replace representations of double-line rivers and lakes with single lines to form a stream network.
2. Ensure the direction of all arcs corresponded to the direction of flow.
3. Identify named stream routes and assign a unique number to each of these streams. The single route for a named stream contains all the arcs from the source (the longest first order stream) to mouth (where the stream flows into another named stream). For unnamed streams, routes contain a set of arcs from the first order source stream to the mouth where the streams flow into a named streams. The stream name of Unnamed is assigned to each of these routes along with a unique number. This unique stream number allows unnamed streams to be differentiated.
4. Assign stream order attributes. Calculate stream order for each section of stream and input this information as an attribute of the streams network. This task was not completed manually due to time and funding limitations. Two GIS application tools that assign stream order to a corrected network were identified however the time to test these tools was not available.

Test runs of WAM components used the DEM to generate a corrected stream network. The User and System guides (TFC 1997ab) provide detailed descriptions of the steps involved in generating a stream network and elevation information.

2.4.2 Spatial information

WAM requires DEM data to run and much information is generated from this one data source. The additional information required for specific WAM components include vegetation cover, forest harvest history, and forest harvest plans. Road and seismic coverages can be used in density calculations. This information was available for the Foothills Model Forest from Weldwood of Canada, Hinton Division, a major sponsor of FMF. Fish and stream inventory and road-stream crossing inventory site locations were also available as a point coverage. Daishowa Marubeni International Ltd. provided data for Red Earth Creek.

2.4.3 External databases

WAM can utilize a wide variety of external databases. The user can best identify what external data to include relative to the questions being asked. Test runs included inventory results for the FMF Fish and Stream Inventory project results for 1995 and 1996, historical fisheries inventory results from Alberta Fish and Wildlife, and for demonstration purposes only, the results of a road-stream crossing inventory completed by Weldwood. The only requirement is that a common, unique identifier links the external database to a point or polygon location on a spatial coverage.

2.4.4 WAM runs

The Upper McLeod watershed was used as the development area for WAM. This watershed includes the Tri-Creeks Experimental watershed area and is located south of Hinton, Alberta. The headwaters form in the watershed divide on the border of Jasper National Park. This is a typical foothills stream system and the topography is quite variable. GIS data, hydrologic models and inventory results were available to test all components of WAM.

Near the end of development WAM was tested on a completely different watershed, Red Earth Creek in northern Alberta. This region has very little relief and the stream density is very low. Fewer data are available for this area. Daishowa Marubeni International (DMI) provided DEM, vegetation cover, uncorrected streams information, historical cut and harvest plan data. Streamflow calculations used equations from a regional hydrologic analysis completed on the Peace River by the Water Sciences Branch, Alberta Environmental Protection. Water yield calculations used WRNSDMI, a related model to WRNSFMF which is customized for the hydrologic conditions in the northern boreal forest.

2.5 Workshops

Two workshops to introduce WAM took place in April, 1997. The workshops were led by GIS staff of the Forestry Corp, the developers of WAM application and Janice Traynor, former Watershed Coordinator of the Foothills Model Forest who directed the project. The first workshop in Hinton presented WAM to an audience of resource professionals (fisheries, forestry, parks and wildlife) from across Alberta. The second, held in Manning presented WAM to an audience of forestry and water resources professionals working in northern Alberta.

2.6 Deliverables

Three documents are available as deliverables for this project. In addition to this report the User and System guides (TFC 1997ab) outline the specifics of model use, data needs and system requirements. The WAM GIS application is also available however this is not an application that can be packaged and distributed independent of technical support. Contact Foothills Model Forest for additional information on these deliverables.

3. Results

The major results associated with this project are the WAM GIS application and the output datasets generated by WAM. In this section an overview of the WAM application is presented. The reader is directed to the WAM User Guide and System guides for more detailed information. The results generated by WAM will depend upon the questions asked, the project area location, the data available and the analyses selected. As an introduction to the datasets produced by WAM some examples and potential uses are shown. Finally results of test runs on two types of landbases, the Tri-Creeks area near Hinton, and Red Earth Creek in northern Alberta are presented.

3.1 WAM GIS Application

The WAM application is unique in terms of the approach taken to extract watershed information from a spatial database and is consequently complex. The WAM application is written to run on the UNIX workstation with ArcInfo software. The ArcInfo TIN and GRID add-on modules are required. ArcView 3.0 is used as the user interface to view the results. The full capabilities of ArcView can be used to evaluate the results from WAM.

3.1.1 Data requirements

A digital elevation model (DEM) is the foundation for many of the WAM calculations. During WAM tests the Alberta Provincial DEM (50 metre resolution) was used. WAM also requires an input point coverage to initiate attribute and density calculations. These points may represent existing inventory site locations or indicate locations of interest such as a potential road/stream crossing locations. To create the WRNSFMF dataset forest cover, harvest plans and historical harvest information is required. These data must adhere to rigid input formats and structures as outlined in the User Guide.

3.1.2 Process

The WAM process can be summarized in 7 steps:

1. **Select a project area**. This is the geographic area of interest and must include the entire basin, including headwaters surrounding any points of interest. Each WAM run is called a project and assigned a unique name by the user.
2. **Generate an elevation grid**. WAM utilizes ArcInfo hydrologic functions in the GRID module to generate a hydrologically correct elevation grid. Default grid cell size is 25 metres. If a larger cell size is chosen (i.e. 100 metres) processing speed is increased however the resolution of the data is lower.
3. **Input or generate a corrected stream network**. If a corrected streams network is unavailable WAM can build one from DEM data. This generated stream network is dependent on the accuracy of the DEM and reflects the DEM data resolution, terrain variability and grid cell size. Stream order attributes are calculated for the network.
4. **Build a stream order route system**. A route allows multiple, connected arcs to be stored as a single linear feature. This is necessary to measure distances along streams. Routes are calculated for each section of stream based on stream order and from the point upstream to the source and downstream to the mouth of the stream.
5. **Calculate plot attributes**. Link the point to a location on the closest stream. Calculate stream lengths, sinuosity, stream gradient, stream profiles, generate drainage and basin boundaries, calculate areas and estimate streamflow.
6. **Calculate feature density**. A variety of point and line densities can be calculated for stream basins. Options include stream, seismic line, road or stream crossing densities.

7. **Generate WRNSFMF dataset.** A database file is generated in a format that can be input directly to the WRNSFMF model to evaluate annual yield changes from forest harvesting.

3.1.3 Output datasets

WAM generates 12 output datasets for each project. Polygon coverages are created for elevation (50 metre elevation classes), aspect (north, south, east or west), and basins (upstream drainage areas and basins). The corrected streams coverage is a line coverage coded by stream order. Info tables present stream profile results for the buffer and the stream and streamflow estimates for flood volumes, peak flows and monthly flows. WAM_PLOTS is a points coverage generated from the input point locations. Attached to each point are the calculated plot attributes and feature density results.

3.1.4 Viewing results

All output datasets from WAM can be viewed within an ArcView project. ArcView provides a visual representation of information and relationships in a comprehensive, fairly easily learned software package. Additional data can be linked to the output datasets by joining theme attribute tables to external databases containing inventory results.

Data can be presented in a variety of ways within ArcView: A view can map plot locations on streams; a table presents specific data on that plot location; a chart graphs relationships and scripts can automate common procedures. Views organize spatial data as theme layers, the building blocks of the project. A view is useful for looking at information by features, using the identify tool and a point and click interface. Data can also be viewed within tables. Theme tables present attributes of the spatial features. External databases (e.g. inventory data, model results) can be attached to these theme tables using a common plot number. Charts graph table information in a variety of formats. Layouts provide the template to produce reports and hard copies of the results. ArcView allows a wide range of viewing and reporting options for WAM. The reader can access all the capabilities of ArcView and customize this to best address their information needs and reporting requirements. It is likely that these will be different for each user or organization and for each question.

3.2 Examples

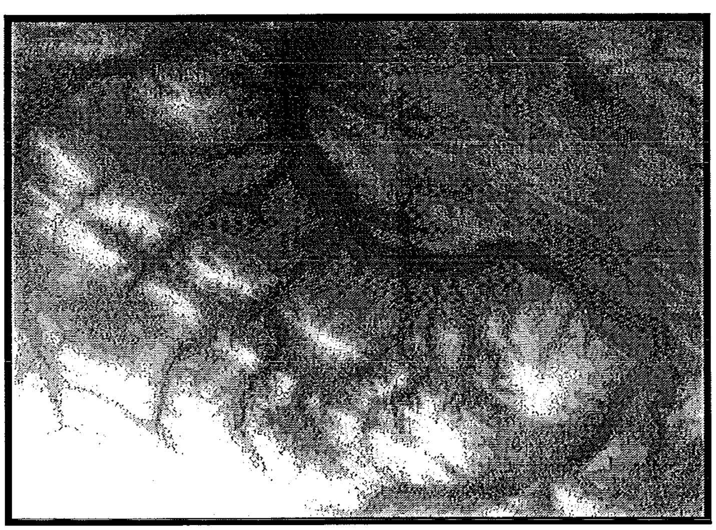


Figure 1.

This is a grey-shade representation of DEM data. Lower elevations are darker and the pattern of streams is evident.

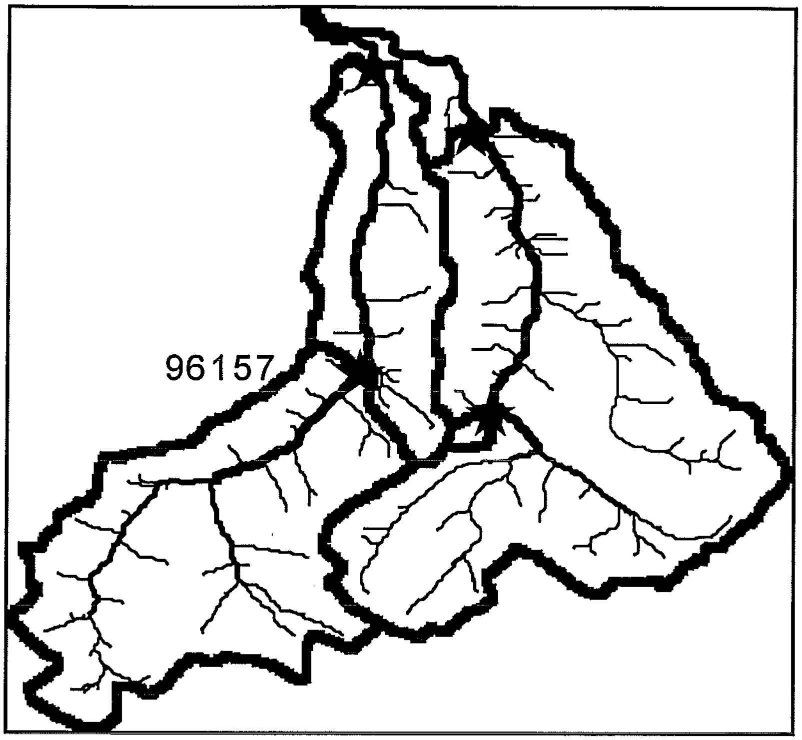


Figure 2.

A View of basins and stream network generated by WAM for part of the Tri-Creeks area.

Note the small basin in the center of the figure. This plot has been snapped to the incorrect stream and consequently plot attribute data is incorrect. This plot should be copied to a location closer to the main stream and the WAM analysis repeated for this plot.

Tables of information for the selected plot are shown below.

Plot Attributes Calculated by WAM	
FMF Fish Inventory Plot	**96157**
Stream Order	4
Elevation of Point (m)	1346
Stream Length from Source (m)	2284
Sinuousity of Stream Length	1.3
Length of buffer (m)	1000
Sinuousity within Buffer	1.1
Stream Gradient at Point	2.4
Basin Area (m2)	416653120
Upstream Drainage Area (m2)	10288125

Information from attached database	
FMF Fish Inventory #	96157
Stream Name	DEERLICK CREEK
Sample Date	Sept. 9, 1996
Mean Stream Depth	0.1
Mean Wetted Width	2.0
Number of Fish	150.0
Fish Species Codes	RNTR

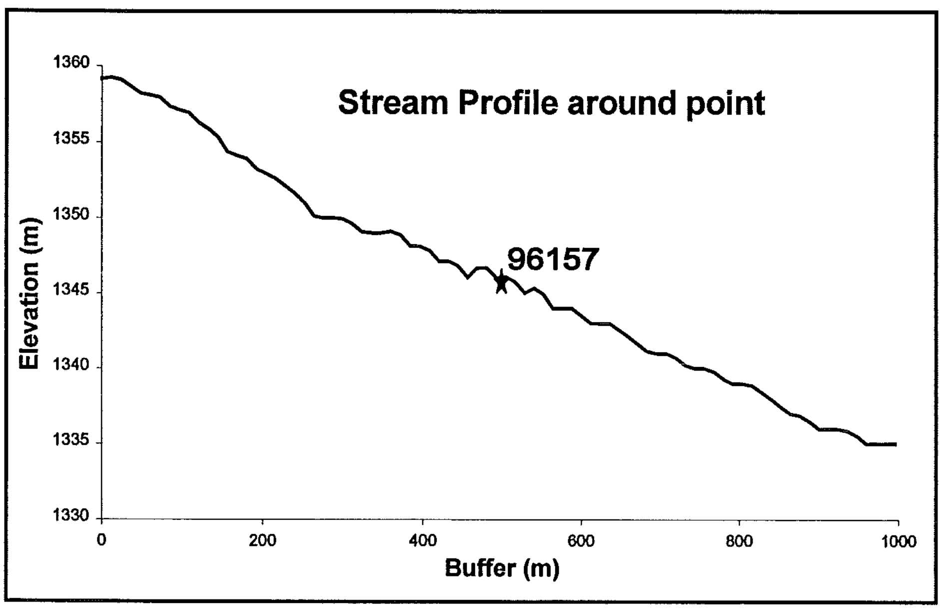


Figure 3.

Stream profile, site 96157.

Note that the profile seems to go slightly uphill at some points. This is an anomaly introduced during the conversion of a raster to a vector structure. See WAM User Guide (TFC 1997b) for additional information.

3.2.1 Use of these data

The use of information is linked to the question being asked, assumptions inherent in input data and characteristics of the region. It will reflect the perspective and expertise of the user. This information generated by WAM should be evaluated within a decision framework built upon scientific knowledge, research results, best management practices and expert opinion appropriate to the decisions to be made and the region and organization where WAM is being used..

A WAM run using an input point data coverage of fish and stream inventory sites could be used in a variety of ways. The point attributes calculated for each sample site includes some information such as stream order, elevation and stream length which in past studies has been calculated from 1:50,000 NTS topological maps. This information is generated much more efficiently through WAM. An investigation of relationships between fish presence or abundance and watershed features might use information on watershed characteristics generated by WAM. In ArcView streams could be coded according to the species which have been found there, for instance all streams with bull trout could be shown in red. Specific management practices may be identified for these streams.

An input points coverage could be generated which indicates potential locations for road-stream crossings. WAM datasets generated from these points will be useful in planning and evaluating these crossing locations. Streamflow estimates provide information on the peak streamflow and flood volumes at the site. Stream profile, gradient and sinuosity information provides some broad site characteristics for the preliminary steps in planning. Fisheries information may indicate the type of crossing (bridge or culvert) to install. Species present in the inventory will help to define the in-stream-operating window for construction. The density of existing roads and crossings is important information to help define cumulative effects of new development.

Completing a WAM run for a basin designated for harvest will provide resource information for a forest planner. Harvest plans can be evaluated for effects on annual yield and peak flows using WRNSFMF. Fish inventory results for the streams in the basin identify species present and historical inventory results can help to characterize populations. Seismic, road and crossing densities provide information on existing development and may help to quantify the impact of additional development.

3.3 WAM Test runs

3.3.1 Upper McLeod Watershed

Numerous test runs within the Upper McLeod watershed were completed during development. Project areas ranged from a small watershed 1 to 2 km^2 to a final run for a project area covering nearly 6 UTM mapsheets (13 ATS Townships) or 1200 km^2. The most recent dataset represents almost 60 inventory sites and covered over 1000 km^2. The results of testing are summarized in three sections, stream network generation, input data and output datasets.

Stream network generation

In the absence of a corrected stream layer a stream network was generated by the DEM and compared to the streams coverage based on 1:20000 interpreted base data. The stream network generated by WAM reflects the accuracy of the DEM, the grid cell size and flow accumulation tolerance selected. Different cell sizes and flow accumulation tolerances were tested. A 25 m grid cell size and flow accumulation tolerance of 100 were found to produce the network which best emulated the interpreted data (based on a visual evaluation). In general, these stream networks were very similar at a planning scale (1:15000). The generated streams network had a higher stream density than the interpreted data. This is a function of the value chosen for flow accumulation tolerance, which determines stream density. The generated network had more 1st order stream segments although interpreted 1st order stream segments were generally longer than the generated streams (again a function of flow accumulation tolerance). It is likely that on the ground many of these additional generated 1st order streams might be classed as ephemeral draws or intermittent streams and contain streamflow at some point during the year.

In our testing, the generated network was found to model the stream network in this area well and is appropriate to use to generate information to support basin level planning. Before using a generated stream network the user should compare this with other available streams data. Such comparisons should consider the accuracy of both the DEM data and the interpreted data, the resolution required for decision-making and the time and costs associated with generating the two types of stream networks. In the absence of a corrected streams network in this type of foothills terrain the generated streams network will be useful.

Input data

The Upper McLeod watershed is located in a region with many years of fish inventory and forest management. Spatial data are available for most of the landbase. A number of hydrologic research studies and long-term flow monitoring stations have been established in this region. The literature also contains information on this type of foothills stream, the fish resources and the aquatic habitat requirements. As part of the FMF Watershed program digital copies of much of this information were created. The only data unavailable for WAM was a corrected streams network. As mentioned previously the generated streams network worked well as a substitute.

Output data

A preliminary evaluation of the output datasets shows that point attribute results generally reflect expected values for this region. A comparison of WAM information for streams in Tri-Creeks (Eunice, Deerlick and Wampus creeks) with information calculated from 1:15000 topographical maps presented in Nip (1991) showed:

- Stream order at the mouth (confluence with the McLeod River) for generated streams were 4 and from the map were 3.
- Stream lengths for Eunice and Deerlick were within 10% of the map measurements. For Wampus Creek the generated stream measurement was 20% less. This difference is attributed to differences in first order source streams.
- Total basin area measurements differed by less than 3%.

Although the generated streams network is available care must be taken in its use due to the existence of spurious streams, generally small 1st order streams to which plots are incorrectly snapped to for analyses. In a test of 60 points over 10% of these were snapped to spurious 1st order streams. For these plots most calculated information is then incorrect. Fortunately these points are easily identified when the basins coverage is viewed.

Solutions to the problem of points snapping to incorrect streams include: generating a stream network which is less dense and consequently would have less spurious streams by adjusting flow accumulation tolerance; ensuring plots are associated with the appropriate stream when the points coverage is created (thereby ensuring calculations are performed on the proper stream); or rerunning the analyses with a coverage where points have been moved or copied closer to the proper stream. The availability of a permanent, corrected streams network would minimize this problem.

Basins for some points near the edge of the project area appear irregular. It is important the project area completely enclose the basins surrounding any points of interest. When the large area was selected, basins for a few points on the edge of the project area were delineated with a straight line on one side, indicating the project area did not cover the full basin. Results for these points will be discarded and WAM analysis repeated using an expanded project area.

3.3.2 Red Earth Creek Watershed

The Red Earth Creek is a very flat watershed in the northern boreal forest of Alberta. These data were provided for testing to evaluate WAM on a landbase completely different from the Upper McLeod watershed. Testing was completed on an area covering 4 UTM mapsheets, approximately 750 km^2. The results are presented in terms of the streams network, input data and output data.

Streams network generation

A corrected streams network was not available for this region. Unfortunate WAM was unable to generate a stream network in this area of low relief using grid cell sizes up to 100 meters. In a flat landscape stream channel elevations are very close to those of the surrounding land and more difficult to define. The DEM resolution and accuracy were not sufficient to detect such small changes across the landscape and delineate a streams network. The results were not unexpected as the generated streams procedure was known to work best in regions with higher relief. Mackey *et al* (1994) applied the ANUDEM process (also used in WAM) in low relief areas of northern Ontario and was unsuccessful at 100m grid spacing. In low relief areas Mackey *et al* generated a connected streams network for the region from interpreted provincial base data. This streams network was then used to enhance the drainage enforcement algorithm in ANUDEM and help to identify streams and their associated valleys. Using a grid cell spacing of over 200 metres and extensive editing they were successful in generating topographic information.

WAM programming does not presently allow for additional streams input data when using the ANUDEM functions. If WAM is to be used in low relief areas additional programming and testing are needed. (See WAM User Guide (TFC 1997b) for additional discussion).

Input data

There are fewer resource data available for forests in northern Alberta and little information is stored in a digital form. For Red Earth Creek DEM data, vegetation cover, harvest history and harvest plans were available to produce the WRNS output dataset. The WRNSDMI annual yield model, customized for use in northern Alberta was used instead of WRNSFMF. A broad scale regional hydrology analysis provided predictive streamflow equations applicable to this area although the data to develop the equations were sparse.

Output data

WAM successfully developed the output dataset for input to WRNSDMI and evaluation of annual yield changes with forest harvesting. WAM was unable to generate a streams network or subsequent hydrologic analyses so basin size was calculated manually. In this region drainage basins cover a large area and spread across multiple map sheets.

4. Discussion

4.1 Watershed Information in Planning

The first objective of this project is to develop a model to provide information on watershed, hydrology, aquatic habitat and fish resources for use by resource managers. These resource values are interdependent. For example, watershed characteristics can influence fish directly through natural or introduced barriers to fish passage and also indirectly through forest harvesting influences on streamflow and aquatic habitat and consequently fish. This is only one of many relationships between these resources. This interdependence suggests that these resources should not be viewed in isolation and that planning should consider a wide range of watershed values. WAM provides information on this broad range of resource values however WAM does not make decisions. The manager makes the decision in response to the questions being asked and reflecting their own expertise.

WAM is based on the concept of watershed analysis, defined by Montgomery (1995) thus:

"Watershed analysis provides a framework for delineating the spatial distribution and linkages between physical processes and biological communities in an appropriate physical context, the watershed ..... (It) provides information, knowledge and understanding necessary for scientific interpretation to support informed decision making, but it is not equivalent to making management decisions. Determining the activity appropriate for a watershed rests on weighing potential future conditions against planning objectives, legal mandates, and management constraints"

WAM provides the information. Depending on the questions asked the land manager can then use this information to directly answer the question or to support a decision-making process where more complex questions are answered using an ecosystem approach to land management, considering the wide range and interrelationships of these data. Klock (1985) states that effective watershed management planning can reduce or eliminate many of the effects of land use practices in the forest ecosystem and the resulting impacts on site productivity and downstream aquatic ecosystems. Incorporating additional information at the front end of the planning process can help avoid crisis management. Management decisions are likely to be more defensible if potential impacts are realistically addressed based on current knowledge early in the planning process (Montgomery *et al* 1995).

Topography may be linked directly or indirectly to virtually every major ecosystem function across a landbase. WAM was developed to help address fish and hydrology concerns but the information on topography is more broadly applicable. Mackey *et al* (1994) outline local topography influences on site factors and the use of this information in the forest management planning process.

4.2 Watershed characteristics from the GIS

4.2.1 DEM

There is no question that generating watershed characteristics from the GIS is much more efficient that calculating them manually from an air photo or map. These estimates are only as good as the data used to generate them. One must recognize the accuracy of the selected DEM and apply the results at an appropriate scale. Research does, however, show that analysis using a DEM can provide valid information on slope, drainage areas, drainage networks and other topological information. Tribe (1991) found that "these techniques are faster and provide more precise and reproducible measurements than traditional manual techniques applied to topographic maps". The U.S. Geological Survey conducted comparison tests on "primary drainage-basin characteristics" derived from the GIS and manual topographic map measurements. The results indicate no significant difference between the two measurements (Eash 1994). Other research suggests that slopes and aspects obtained from USGS DEMs have no significant error (Bolstad and Stow 1994 *in* Civco 1995). These studies emphasized that results are dependent upon the resolution of the DEM and that measurements improved as grid cell size decreased. Louck (1995) states that individuals learn from trial and error experimentation and from performing sensitivity analyses. Being able to do this relatively quickly and interactively increases this learning experience. In addition to ease of use and timesavings a benefit of GIS generated information is the use of a standard operating procedure that can be duplicated. The results can be replicated and, if the DEM is the same resolution, comparisons between areas are appropriate.

4.2.2 Stream Order

Stream order is a mechanical classification. The definition of first order streams reflects the smallest streams defined on the GIS or map used as the base for numbering. Where two first order streams meet a second order stream is formed. Likewise, where two second order streams converge is designated a third order stream. In headwater areas, first order stream segments normally change from perennial (one that flows continuously) to intermittent (a stream that is usually dry during part of each year) to ephemeral (which only flows in direct response to precipitation or snow melt) (Lee 1980). It is important that the users identify or specify characteristics or the source of those streams classified as first orders (i.e. where an intermittent streams becomes permanent). There is no overall standard "first-order stream attributes" however within a discipline standard conventions may exist. For example in Alberta fish biologists traditionally used 1:50,00 NTS maps as the standard. A first-order stream was the smallest stream shown on these maps and would represent a permanent stream as identified by a photo interpreter. WAM uses GIS data generated from a DEM or from provincial base data and differs from this 1:50,000 NTS standard. It is important to identify the characteristics of the data used to define the stream network and understand the characteristics of a defined first-order stream if comparisons are to be made with stream order values from other sources.

Another issue arises when a generated stream system is used. If the GIS identifies spurious streams and incorporates these into the streams network the stream order classification may change. The existence of a corrected streams layer from interpreted data will solve this potential problem. Until then the influence of spurious streams must be recognized.

4.3 Data Issues

All information generated within WAM should be "value-neutral". It has been stated that management of natural resources such as fish, water and forests is both an art and science. The issues are complex and our understanding is incomplete. Adaptive management, which combines scientific research and knowledge with on-going evaluation of forest practices allows management decisions to evolve as new information becomes available. In this changing environment an information-generating model will be more useful in the long-term if it does not interpret the data. This also allows the information to be used to answer a wider range of questions from a more diverse group of users. It is important to recognize the assumptions inherent in each of the data sources for WAM.

During application development the components of WAM were tested to ensure that the results of analyses were those expected from the sample datasets. Additional testing and evaluation should be done to compare results of the WAM analyses to results generated manually or by other means. The results of WAM are dependent upon the quality of the input data and quality control tests of the output should be done both visually and through comparison of values. For the manager using WAM this results testing will help to generate confidence in the results, to develop a decision framework to use these results and indicate options for refinement of WAM.

4.4 Model and System requirements

4.4.1 Application development

The WAM application is unique and complex. Only during development did those involved come to understand how difficult development of the application would be. Many of the hydrologic functions in ArcInfo are new and few have been applied in a forest environment. The available documentation described tools to complete the tasks required within WAM however technical detail in this documentation lacking. Assumptions were made by the developer regarding the technical capabilities of ArcInfo and only at the testing phase were these found to be incorrect. Thus in planning these hydrologic tools were seen to be a perfect fit for WAM and only after testing were their limitations identified. One example is stream routes. In testing it was recognized that there was no provision for routes to flow downstream, the same direction as the arcs. Rather the direction was determined from one corner of the map sheet with no regard to topography. This resulted in stream routes that flowed uphill and required considerable additional coding to correct. The solution devised allows WAM to perform the required calculations however these additional steps increase the computation time. Also each requirement for a unique solution required time to complete. Fortunately, using the full capabilities of GIS, a broad range of GIS expertise and some creative solutions WAM was completed. At present WAM is installed on the GIS at The Forestry Corp. Installation at the Foothills Model Forest will take place in the future when the GIS is installed in their new office.

WAM requires ArcInfo including TIN and GRID add-on modules on a Unix workstation and ArcView 3.0 on either the PC or workstation to run. The ideal configuration is a PC running ArcView networked to the Unix server running ArcInfo. In this configuration all the data can be stored on the server and with X-emulation the user can initiate the WAM analysis from their PC. The WAM analysis can also be run independently and the data exported to the user running ArcView on a stand-alone PC. In much of the testing of WAM data were transferred using email between the developers in two cities. This option would allow staff in field offices without a server to use the information from WAM in decision-making.

WAM requires considerable system resources and is most efficiently run on an area less than 1000 km^2. Once the elevation grid and route systems for the area are calculated these steps do not have to be repeated for subsequent runs on the same area. It may be efficient to complete these steps once for project areas that cover the whole management region during low user load times (i.e. nights or weekends) and store in a common workspace. These data can then be used in future to complete any WAM analysis without the same need for system resources.

4.4.2 Results Testing

The next step in the WAM project should be to compare the results generated by WAM with those calculated manually or through other means. Those looking to use WAM are best able to identify results from alternate sources for comparison. Two suggestions for results testing are a comparison of basin shape and size with Water Survey of Canada information and completing a corrected streams network for the Upper McLeod Watershed and comparing this to the generated streams network.

Comparing basins

FMF received a GIS coverage of the location of Water Survey of Canada (WSC) hydrometric stations and the drainage basin for each station within the FMF. It is believed that these basins boundaries were digitized from manually delineated boundaries on 1:50 000 NTS maps. The points representing location of hydrometric stations can be used as input to WAM. The resulting basins boundaries and areas from WAM can then be compared with the polygons on the WSC GIS coverage.

Comparing stream networks

During the development of WAM considerable time was spent working to develop a corrected streams network for the Upper McLeod Study Area however it was not completed. The remaining tasks are to assign stream order attributes to the network and generate stream routes. If these tasks were completed WAM analyses could be run using both the corrected streams network and the generated streams network for the entire Upper McLeod Watershed Study Area. The results testing can include both visual and statistical comparisons of the location and shape of stream networks and a comparison of the resulting WAM output datasets.

Comparing with manually methods

WAM calculations for stream attributes such as sinuosity, gradient and stream profile can be compared with manually generated values for the same point. Common techniques for generating these values use 1:50 000 NTS mapsheets and a map wheel. The inherent limitations of data used in both calculations must be recognized.

5. Recommendations

The following recommendations are summarized from discussions and feedback amoung those involved in the project, FMF staff and workshop participants. A common thread in the comments received is that evaluation is difficult because WAM is not yet complete. Those interested in the project want a chance to use WAM, to review the results of WAM for an area they are familiar with, and to then have an opportunity to provide useful criticism and influence the final product. The time required for developing WAM, lack of GIS facilities at FMF and concurrent changes in FMF staff and programs meant that the end date for the project was reached before WAM was fully tested and operational. It is hoped these recommendations will provide future direction for FMF as they evaluate opportunities for implementation of WAM.

Install WAM on FMF GIS and generate WAM datasets for full FMF area.

The current version of WAM is best characterized as a "beta" or testing version. It can benefit from the comments and feedback of users once WAM is installed on the FMF GIS and used in an operational context. It is important that staff of the Foothills Model Forest and sponsors receive the results of WAM analysis for the Foothills Model Forest, not just a small pilot area. If this cannot be completed on the FMF GIS system due to limitations in staffing, system capabilities or technical expertise, the analysis should be completed elsewhere and the data provided to FMF. This will ensure that the output datasets can be evaluated and results accepted or rejected by potential users.

Complete results testing

It is important that the user compare information generated by WAM to similar information generated manually from maps or through other means. The results of these comparisons will help instill confidence in the use of these outputs and also indicate the appropriate scale and situations to use this information. This results testing should reflect the ways WAM information is to be used. Section 4.4.2 suggests some results testing to be completed.

Implement a mechanism to receive feedback and suggestions for improvements in WAM.

An application feedback mechanism should be put in place by FMF. The GIS administrator could implement this. When people are using the application on a regular basis they should have an opportunity to suggest improvements. WAM represents a new, unique application and there is bound to be room for minor improvements in response to user feedback.

Initiate workshops or discussions with potential users

Potential users of WAM have not had an opportunity to test WAM nor to become confident in the validity of the results generated by WAM. Workshop or discussions between users and the developers of WAM would be useful. A comparison of watershed information for a broad area generated by standard methods (such as manual calculation of basin characteristics from NTS maps) to those generated by WAM would provide information to support these discussions. A technical report outlining the capabilities of WAM and the results of testing could be prepared for distribution.

Investigate the cost and delivery time for acquiring corrected streams data.

Although the Province of Alberta corrected streams data is to be completed in the next two years, there are agencies that are currently capable of building this network in a short period of time. A corrected streams coverage is needed if WAM is to be used in flat terrain as the results to date are not acceptable. A corrected streams network from interpreted data would also help to address the problems of spurious streams and points snapping to incorrect arcs. Stream order attributes should be assigned and routes generated for the partially completed streams network in the Upper McLeod Study Area.

Complete further testing of WAM on moderate and low relief basins.

The applicability of the stream generation functions in WAM to areas outside of FMF has not yet been demonstrated. The application should be tested on basins of moderate and low relief and the results of this testing used to update this part of the WAM application. A generated streams network is available for the entire FMF region.

Adjust WAM application to take full advantage of the corrected streams data.

When a corrected streams network is available, the effectiveness of functions within WAM should be tested and evaluated to ensure the output results using the interpreted network are correct. For example, when the application builds basins from a point directly on the new streams, if the stream does not correspond exactly with the depression in the DEM the resulting basins could be incorrect. The potential to improve the results of the ANUDEM functions by using a corrected streams network should also be explored.

Use information generated by WAM to help investigate the issue of fish and fish habitat in land-use planning.

This is a complex issue with many components to be evaluated. FMF is currently researching these questions. The information generated by WAM could be used to support this investigation.

Drop the reference to model in the WAM name.

The WAM application presents the results of models but does not model any system. There is confusion with use of the term Watershed Assessment Model that might be alleviated with a new title. This fact must be balanced with the existing name recognition for the term WAM. FMF may wish to identify a better title for this application or use the simple title WAM with additional description.

6. Project Summary

The development of the WAM application was completed during Phase 1 of the Foothills Model Forest program however the testing, evaluation, refinement and operational use of WAM remain to be completed. The following table and comments are provided to document the current status of WAM and provide direction to FMF staff and partners as they evaluate and plot the direction of this WAM project during Phase 2 of the FMF program.

Issue	Comments
Results testing incomplete	The results of WAM need to be compared to existing data and alternate methods for calculating watershed information. Users of WAM with different expertise and information requirements should evaluate results and compare these with the information currently being used. This testing will provide information to support the decision to use WAM in management decision-making
Confidence in the digital representation of watershed	As with any model the results are dependent upon the quality of input data. The DEM is a keystone of all WAM processing. The user must recognize the resolution of the selected DEM. They must also be aware of the resolution and inherent limitations of current information sources i.e. maps, manual measurements and field truthing.
Availability of a corrected streams layer	Streams are integral to WAM analyses. Unfortunately, existing Alberta digitized base data does not contain a corrected streams network. WAM can generate a streams network however this is dependent on DEM data resolution, terrain variability, and grid cell size.
Quality of stream channel measurements on generated stream networks	Values for sinuosity reflect the type of line representation of the stream. Generated streams result from raster processing and consequently have a "blocky" outline. Results testing is needed to compare sinuosity values for a generated network to that from a digitized network.
Processing time requirements	The time required to complete the full WAM analysis is considerable. Any increases in system capabilities will result in more efficient processing.

The WAM User Guide contains more detail and discussion on many of these issues.

7. Literature Cited

Bolstad, P.V. and T. Stowe. 1994 An evaluation of DEM accuracy: elevation, slope and aspect. Photogrammetric Engineering and Remote Sensing, 60(11). pp. 11327-1332 *cited in* Civco *et al* (1995).

Civco, D.L., A.R. Garcia and G.S. Warner. 1995. Key steps to effective watershed characterization. GIS World, November 1995. pp. 62-67.

Eash, D.A. 1994. A geographic information system procedure to quantify drainage-basin characteristics. Water Resources Bulletin. Vol. 30, No. 1. pp. 1-8.

Forest Ecosystem Ecosystem Management Assessment Team (FEMAT). 1994. A Federal Agency Guide for Pilot Watershed Analysis. Version 1.2. 186 pp.

Hay, L.E. and L.K. Knapp. 1996. Integrating a geographic information system, a scientific visualization system, and a precipitation model. Water Resources Bulletin. Vol.32, No.2. pp.357-369.

Hydroconsult EN3 Services Ltd. 1997. Hydrologic Operational Manual. Prepared for Foothills Model Forest, Hinton, AB. 10 pp. plus 19 figures.

Klock, G.O. 1985. Modeling the cumulative effects of forest practices on downstream aquatic ecosystems. Journal of Soil and Water Conservation. pp. 237-241.

Lee, R. 1980. Forest Hydrology. Columbia University Press, New York. 349 pp.

Loucks, D.P. 1995. Developing and implementing decision support systems: a critique and challenge. Water Resources Bulletin. Vol. 31, No. 4 pp. 571-582.

Mackey, B.G.; McKenney, D.W.; Widdifield, C.A.; Sims, R.A.; Lawrence, K.; Szcyrek, N. 1994. A new digital elevation model of Ontario. Nat. Resourc. Can., Canadian Forest Service – Ontario, Sault Ste. Marie, Ont. NODA/NFP Tech. Rep. TR—6. 26 p. + App.

Martz, L.W. and J. Garbrecht. 1993. Automated extraction of drainage network and watershed data from digital elevation models. Water Resources Bulletin. Vol. 29, No. 6. pp. 901-908.

Montgomery, D.R., G.E. Grant and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. Water Resources Bulletin. Vol.31, No.3. pp. 369-386.

Nip, A. M.-K. 1991. The Tri-Creeks Experimental Watershed - Changes in hydrology and water quality following forest harvesting and their impact on salmonid fishes in the Tri-Creeks Basin. Alberta Forestry, Lands and Wildlife, Forest Service. 66 pp.

R.L. & L. Environmental Services Ltd. 1996. An information review of four native sportfish species in west-central Alberta. Prepared for Foothills Model Forest and the Fisheries Management and Enhancement Program. R.L.& L. Report No. 489F: 88 pp. and 2 app.

Rothwell, R.L. 1978. Watershed Management Guidelines for Logging and Road Construction in Alberta. Northern Forest Research Centre, Edmonton, AB. Information Report NOR-X-208. 43 pp.

Rothwell, R. and J. O'Neil. 1994. Proceedings of a workshop to develop a strategic plan for a watershed assessment model (WAM), January 10-12, 1994. Forest Technology School, Hinton, AB. Prepared for Foothills Model Forest. 35 pp. + 3 App.

Schuett-Hames, D., A. Pleus, L. Bullchild and S. Hall. (eds.) 1994. Timber-Fish-Wildlife Ambient Monitoring Manual. Northwest Indian Fisheries Commission, Olympic, WA.

Swanson. R.H. & Associates. 1997. WRNSFMF User's Manual. Using and applying the USEPA WRENSS hydrologic procedures for snow dominated regions "Rocky Mountains" and "Continental Maritime" applicable to the Foothills Model Forest, Hinton, Alberta, Canada. Version 1.2. 34 pp.

Swanson, R.H. and G.R. Hillman. 1977. Predicted increased water yield after clear-cutting verified in west-central Alberta. Northern Forest Research Centre, Edmonton, AB. Information Report NOR-X-198. 40 pp.

The Forestry Corp. 1997a. Watershed Assessment Model GIS Application System Guide. Prepared for Foothills Model Forest, Hinton Alberta. September 1997.

The Forestry Corp 1997b. Watershed Assessment Model GIS Application User Guide. Prepared for Foothills Model Forest, Hinton Alberta. September 1997.

Tribe, A. 1991. Automated recognition of valley heads from digital elevation models. Earth Surface Processes and Landforms 16(1). pp. 33-49. *cited in.* Martz and Garbrecht (1993).

Washington Forest Practices Board. 1994. Standard Methodology for Conducting Watershed Analysis. Board Manual Version 2.1.