1 INTRODUCTION

Background

This document details the capabilities of **r.water.fea**, a program that provides the user with an event-based storm rainfall runoff simulation capability. The finite element numerical technique is used to assemble equations in space and the finite difference technique is used to compute time-dependent hydrographs. Results of **r.watershed** can be used in this analysis.

Objective

The objective of this work is to transfer knowledge of Geographic Resources Analysis Support System (GRASS) version 4.2 raster map analysis function to the field. This document guides the user through the process of using **r.water.fea** to simulate hydrographs resulting from a storm event.

Approach

This tutorial presents a step-by-step approach to the GRASS **r.water.fea** program.

Scope

This document discusses the 4.2-release version of GRASS **r.water.fea** program, completed in the summer of 1993. Some elements will be out-of-date and inaccurate for post-4.2 software releases.

Mode of Technology Transfer

The information in this report aids the technical transfer of USACERL's GRASS image processing and geographic information system. GRASS is being transferred to the field through the following mechanisms: training programs, hands-on experience, a user support center, newsletters, extensive documentation, institutional structures at the Army and interagency levels, communication networks, and other forums.

User feedback about GRASS program capabilities, documentation, and other technology transfer mechanisms is important to the development of the system. Users are encouraged to communicate such feedback to the GRASS development staff at USACERL, via existing electronic communication networks and via the GRASS Information Center at USACERL, P.O. Box 9005, Champaign, IL 61820-9005; phone 217-373-7220; fax 217-373-7222; or e-mail grassbug@zorro.cecer.army.mil.

2 ORIENTATION

This tutorial describes the use and syntax of the GRASS software tool **r.water.fea**. The tool uses the finite element numerical technique to model kinematic overland and channel flow in a watershed. **r.water.fea** is a distributed and deterministic hydrologic model. It allows the user to analyze a given watershed and produces individual basin hydrographs, stream junction hydrographs, and individual basin flow depth animation maps.

To utilize this tutorial, the reader should be familiar with the meanings of raster data format, map layers, the current mapset and location, regions, **r.watershed**, and masks in GRASS. These and other basic GRASS concepts are reviewed in the GRASS on-line help facility (accessible through **g.help**), in the *GRASS 4.1 Programmer's Manual* (Shapiro et al., 1993), and in other documents available through the GRASS Information Center at USACERL.

It is assumed that the user is also familiar with technical terms in surface water hydrology, such as overland flow, channel flow, infiltration, surface runoff, time of concentration, basins, watersheds, soil saturated hydraulic conductivity, soil capillary suction at the wetting front, soil porosity, degree of saturation, Manning's roughness coefficient, and Courant condition. These terms have been defined in many hydrologic textbooks.

Land managers are given the job of protecting, maintaining, and developing land areas and often need to determine the volume of surface runoff, volume rate of flow of surface runoff, and flow depth due to a particular rainfall event. The power of a geographic information system can be utilized to analyze watersheds and perform these tasks.

r.water.fea uses GRASS commands and the GRASS programming language along with 'C'. Most of the input required by **r.water.fea** can be easily generated with the **r.watershed** command.

Limitations
r.water.fea has the following limitations:

- Interstorm modeling, interflow, or baseflow are not considered.
- Backwater effects are not considered.
- The kinematic wave analogy is appropriate where the land surface slope and the channel slope are large. This may not be true in flat, marshy terrain and in slow, meandering river channels.
- The drainage map should route the water and not form pits, lakes, or ponds. This does not imply that the DEM by itself should not have any pits.

3. PROGRAM STRUCTURE

In the **r.water.fea** program the user can access previously analyzed information or make changes to previously analyzed areas. Analysis information is stored in the *<project_name>* directory under *$LOCATION* in the current mapset only. However, the user can select the input information from any other mapset in the current location.

If the user has already worked on a particular analysis area, identified by the *<project_name>* the project status is displayed on the current graphics monitor and the text terminal. The user can continue any previous work by referring to it by the *<project_name>*.

Getting Out
You can exit **r.water.fea** by selecting choice 8 in the menu. Hitting <CTRL-C> or <CTRL-D> during execution of the program may destroy project-related files.

4 SAMPLE SESSION

Included here is a sample **r.water.fea** session using the database *spearfish*. You should be able to completely replicate the interactive session with **r.water.fea** illustrated here. It is assumed that you can already get yourself into an interactive GRASS session. If you have difficulties with this, please refer to the GRASS on-line **g.help** program or other related documentation.

Commands that you are requested to enter are displayed in bold following the prompt indicator ">":

```
Prompt> my_command
```

Variable user responses are displayed in bold italics:

my_response

The sample session with **r.water.fea** can be reproduced on any normal text terminal and a color graphics monitor. To duplicate this session, you must request LOCATION *spearfish*. The mapset you choose is arbitrary, but must be a one-word name less than 14 characters long. Hit the escape (ESC) key when you are satisfied with your LOCATION and MAPSET.

You are now running the *spearfish* sample database provided with GRASS. Some initial commands are required to generate initial data for **r.water.fea**. The program can use the data layers generated by **r.watershed**. Enter the following to begin preparation of data:

```
GRASS 4.2 > g.mapsets PERMANENT
GRASS 4.2 > g.region n=4922615 s=4919135 w=599535 e=596565
GRASS 4.2 > r.watershed elevation=elevation.dem threshold=400 accumulation=acc
basin=bas stream=str drainage=dra
GRASS 4.2 > r.slope.aspect elevation=elevation.dem slope=slo
```

The basic data requirements for **r.water.fea** have now been generated. You should now have the following maps available.

```
Basin map name        : bas
Stream map name       : str
Accumulation map name: acc
Drainage map name     : dra
Slope map name        : slo
```

The basin map may require a random color table associated with it to distinguish the different basins. The same holds true for the stream map. This can be done by running the following:

```
GRASS 4.2 > r.colors -w bas color=random
GRASS 4.2 > cp $LOCATION/colr/bas $LOCATION/colr/str
```

The basin map "bas" and the corresponding stream map "str" should look similar to the maps shown in Figure 1.

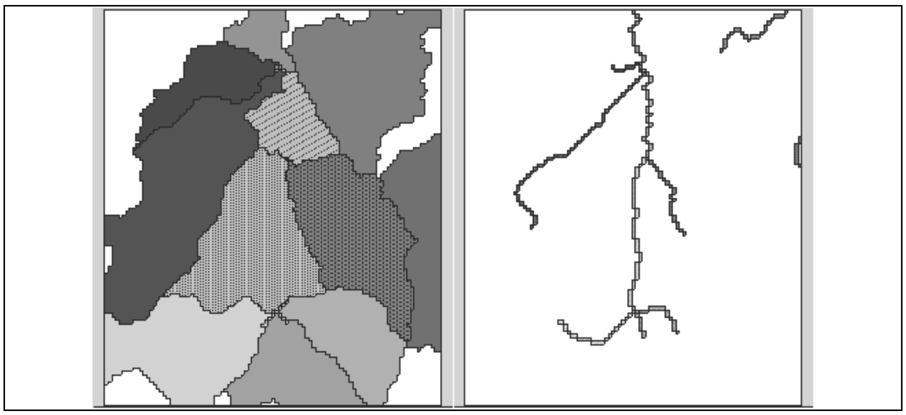

Figure 1. Basin map "bas" and stream map "str".

With all the settings made so far you are prepared to run the **r.water.fea** session by typing the following:

```
GRASS 4.2 > r.water.fea
```

The program will now prompt you for the name of the project. Enter the name of the directory to store the results and data to be created for the current run:

```
Enter project file name
Enter 'list' for a list of existing  r.water.fea files
Hit RETURN to cancel request
> my_project
<my_project>

Project name <my_project> does not exist,
Shall a new one be created?(y/n) [y] y
```

The program will now query you for the names of the data files:

```
Enter the name of the [BASIN] map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> bas

Enter the name of the [STREAM] map
Enter 'list' for a list of existing raster files
```

```
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> str

Enter the name of the [DRAINAGE] map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> dra

Enter the name of the [ACCUMULATION] map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> acc


Enter the name of the [SLOPE] map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> slo
```

Once all the data layers have been entered the program will query you for program configuration parameters that may be desired in running **r.water.fea**.

```
Rainfall mode:
        1. spatially uniform and constant in time
        2. spatially uniform but varying in time
Shall the rainfall mode be set to 2(y/n) [n] y
```

Answering "***y***" to the above question will require you to provide the name of an ASCII rainfall file later in the program.

```
Do you want to view basin level hydrographs (y/n) [n] y
```

Answering "***y***" to the above question will cause the display of basin level hydrographs. Basin level hydrographs means that a hydrograph will be drawn for each basin in the watershed.

```
Do you wish to view animation maps for individual basins(y/n) [n] y
```

Answering "***y***" instructs the program to prepare flow depth animation maps for each basin in the watershed. Please note that the animation maps are displayed only towards the end of the program.

You are now presented with a menu of selections to proceed with the analysis. The purpose of the menu is to provide a smooth flow between different steps and to give you an opportunity to make changes to the analysis if you wish to work on the same project at a later stage.

Please note that the line just above the "Choice:" prompt will tell you the program status. The symbols "*" , "X", and "*->" will become obvious as you proceed through this sample run. These symbols have the following meaning:

*   You can select this part from the menu.
*->   This is the step that you must select in order to proceed in a sequence.
X   You cannot select these parts of the menu (until previous steps have been executed).

Selecting Choice: 1 would be similar to going through steps 2 thru 5, 7 (without prompting you for the menu). We will start with step 2:

```
Choose from the menu:

          *   1. Process steps without breaks.

         *->  2. Select basins for simulation.

          X   3. Extract topographical data.

          X   4. Select hydraulic parameters and simulation time.

          X   5. Basin simulation.

          X   6. Simulate any particular basin.

          X   7. Channel routing of basin hydrographs.

          *   8. Stop.

You are starting from the beginning.

Choice: 2
```

After making the selection you will be presented with the following on the text terminal:

```
Please adjust location of your monitor.
[Hit RETURN to continue]
```

It is important to note at this point that you adjust the size of the graphics monitor such that the length of the monitor is approximately twice that of its height. After pressing <RETURN> you will see the following:

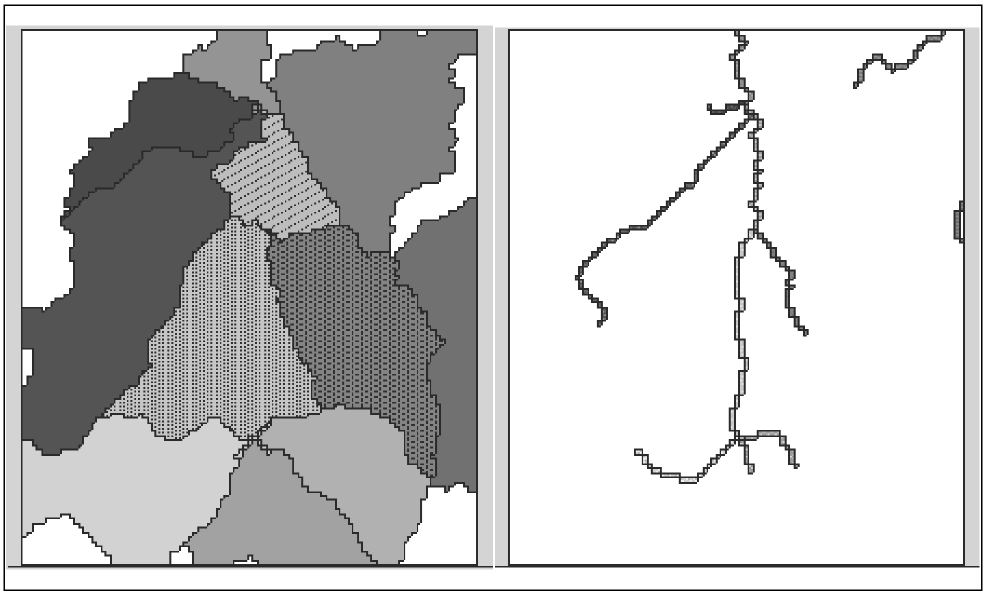

Figure 2. Basin map "bas" and stream map "str".

You are now ready to select the basins you wish to include in the analysis. This is done by pointing and clicking with the mouse. You will see the basin map cell values as you select the basins:

```
Drawing maps ....................

Buttons
 Left: select basin
 Right: quit
Basin <12> selected
Basin <10> selected
Basin <22> selected
Basin <24> selected
```

To replicate the results, select only the basins that produce the map as shown in Figure 3.