Performing Hydrologic Simulation using *r.water.fea*

Program Tutorial

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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

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** ver. 3.0. The data used with the tutorial is part of the sample data set supplied with GRASS.

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 following terms in GRASS:

- raster data format,
- map layers,
- the current mapset and location,
- regions,
- **r.watershed**, and
- masks.

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 requires some preprocessing of the DEM. If a cell with zero slope is encountered, the model assumes a 5% slope at the cell.

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.fe**a 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:

Prompt>**my_comand** ***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*** when you start GRASS. 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=596565 e=599535 res=30***

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 format=percent***

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.

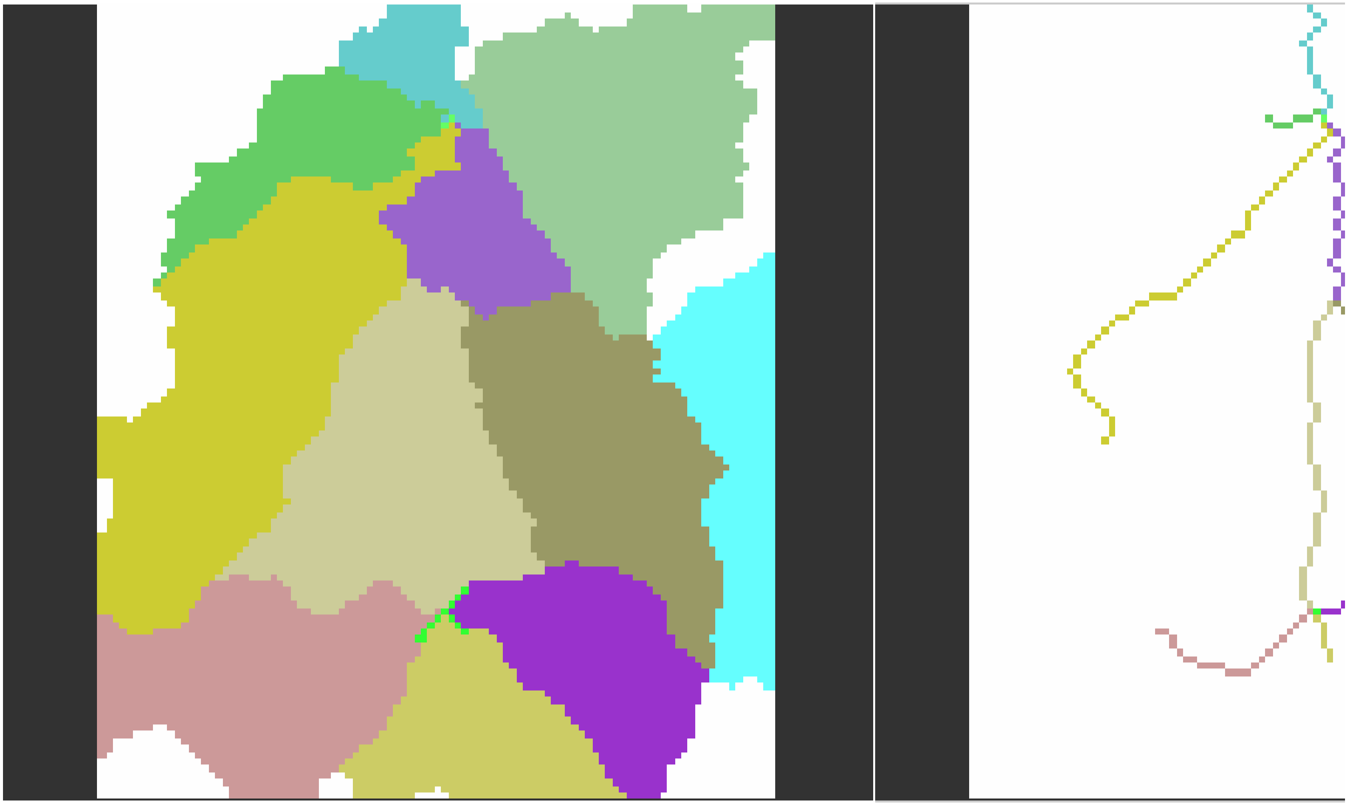

Figure 1. Basin map "bas" and stream map "str".

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 the project file name
Enter 'list' for a list of existing **r.water.fea** files
Hit RETURN to cancel request

>***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 appear as you proceed through this sample run.

These symbols have the following meanings:

> * 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 pressingyou will see the following:

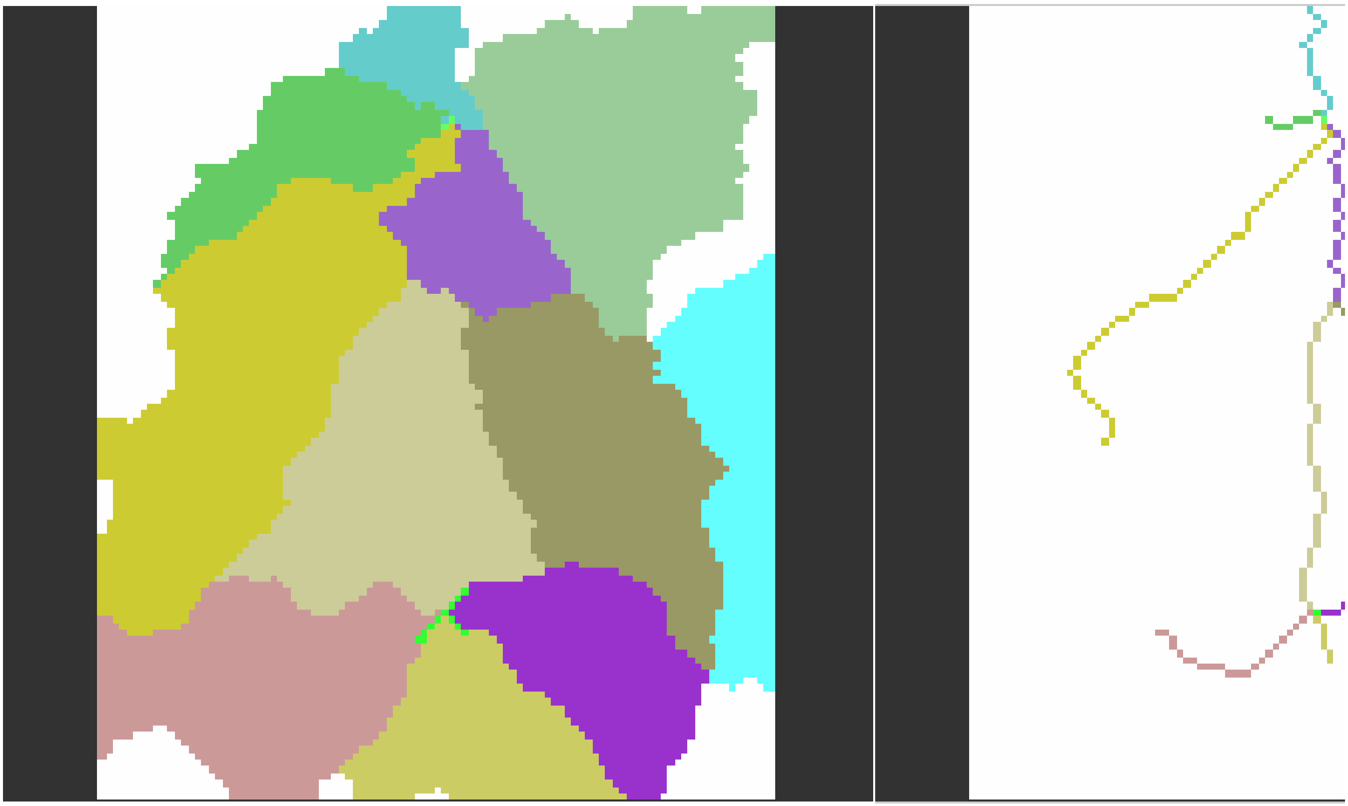

Figure 2. Basin map "bas" and stream map "str".

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.

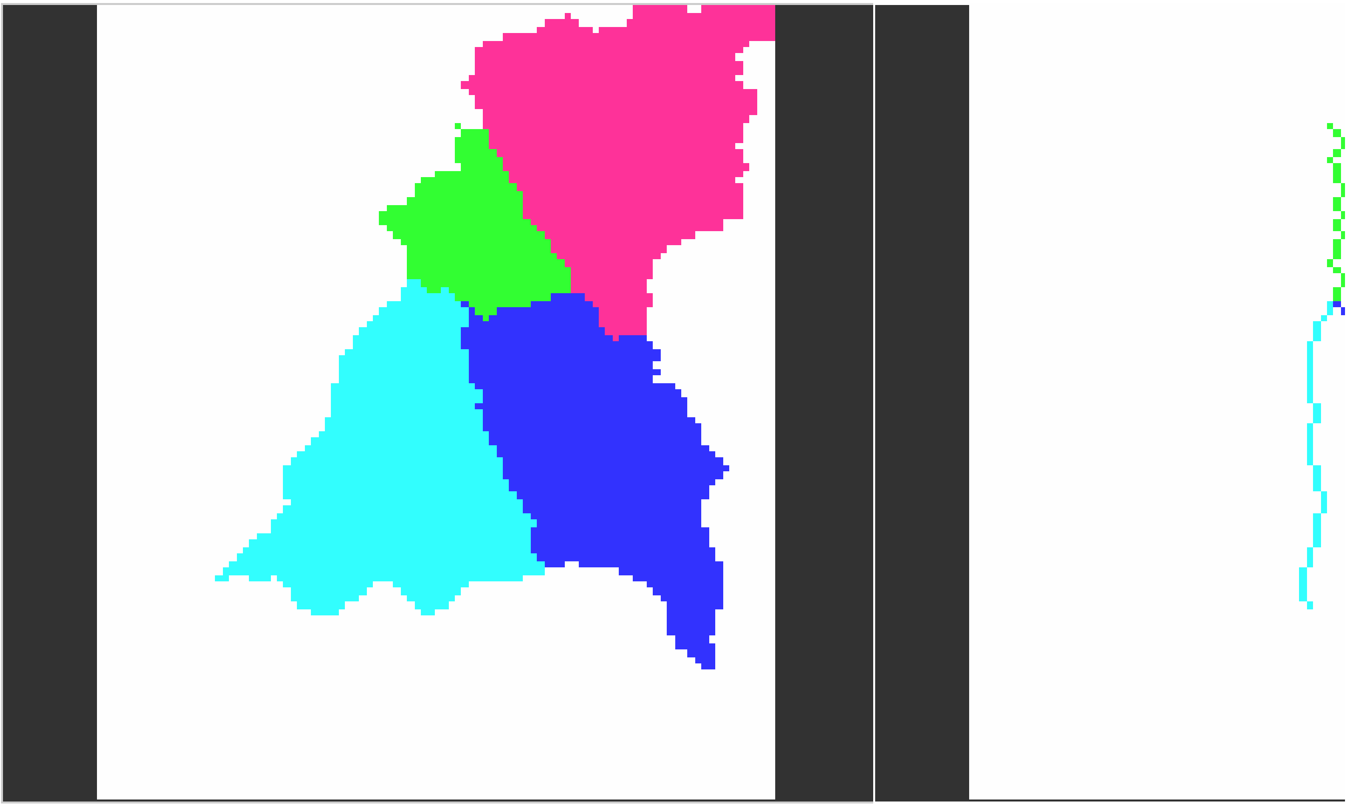

Figure 3. Selected basins and corresponding streams.

One set of streams forms a discontinuous set in the map and also represents a basin that is not completely part of the current region. The program provides a feature to delete such basins. Thus, once all basins have been selected, the user is asked the following on the text terminal:

Your stream network should be continuous.
Do you wish to delete any basins ?
(y/n)***y***
You will see the following on the text terminal. You must now select the basins to be deleted.

Please select the basins that you wish to delete.

Buttons
Left: select basin
Right: quit
Click on the top right basin to delete it.
Basin <4> selected

On pressing the Right button on the mouse you will be shown the selected area as shown in Figure 4, on the graphics monitor.

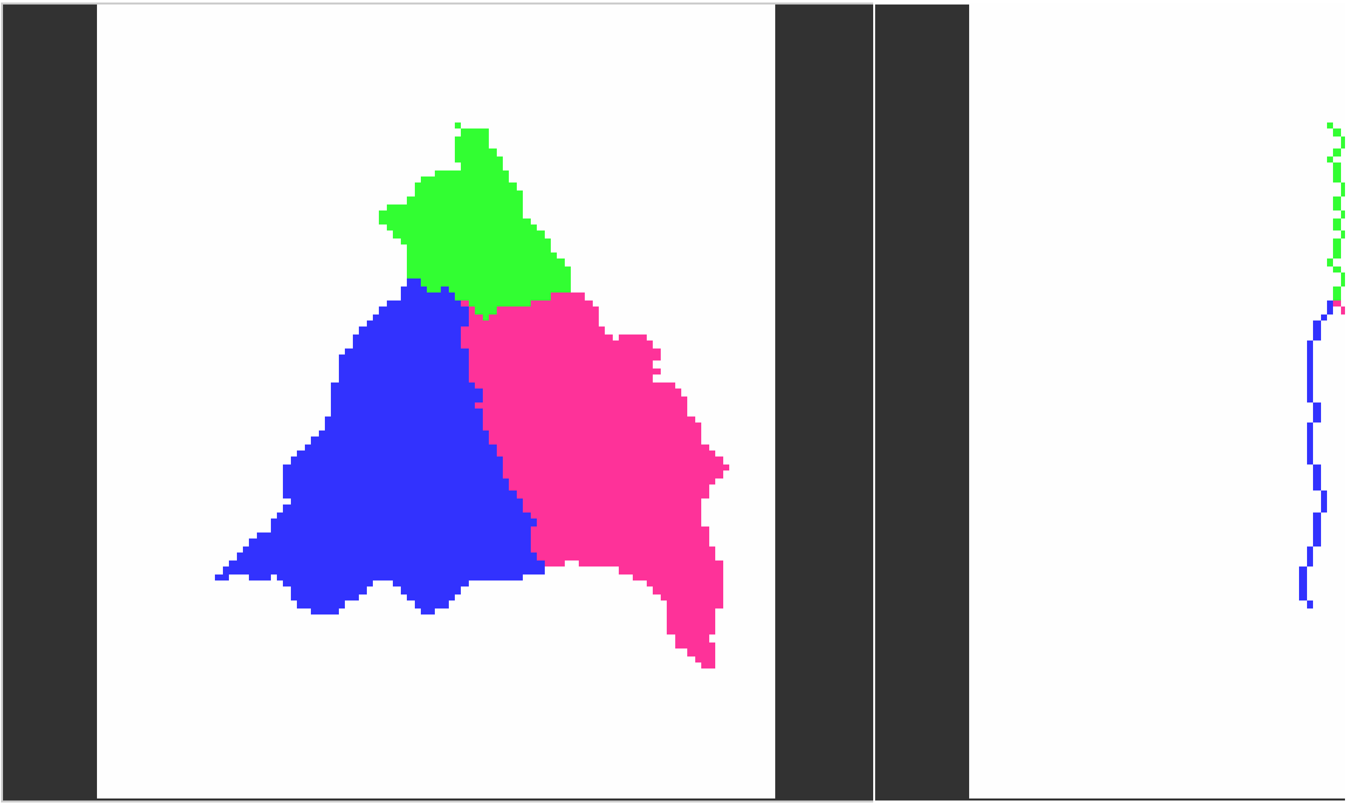

Figure 4. Edited set of basins and corresponding streams.

You will see the following on the text terminal:

These are the basins that you have selected.

These are the corresponding streams.

Your stream network should be continuous.
Do you wish to delete any basins ?
(y/n)***n*** At this point you should see icons at all stream junctions and at the outlet (not shown). The outlet of the selected watershed is always denoted by the "0" icon.

You will be presented again with the menu and the status of the user in running the program. From the menu one can see that the arrow "*->" has moved from 2 to 3. This implies that you should now select

- Choice: 3--to proceed in a sequential step. If you wish to select another analysis area, then you can go back to step 2. You cannot, however, jump to Choice: 4; on doing so the menu screen would be reprinted on the text terminal.

  You can decide to stop any time when the menu is prompted by selecting
- Choice: 8 from the menu. The third step in the menu generates the linked topology between different cells in the analysis area. For just the three basins selected in the analysis area this step should take minimal time.

Choose from the menu:

* 1. Process steps without breaks.
* 2. Select basins for simulation.

*-> 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 stopped after selecting basins.

Choice: 3

During the process of this step you will see the following on the text terminal:

Extracting data for Basin 1 .... 99%
Extracting data for Basin 2 .... 99%
Extracting data for Basin 3 .... 99%

Once all the data has been extracted you will again be presented with the menu and status. (The menu will not be shown hereafter.)

You stopped after extracting topographical data.

Choice: 4The "*->" has now moved from 3 to 4. The fourth choice in the menu will allow you to select the hydraulic and simulation parameters. The values used herein are arbitrary but you should use the same values to replicate the results. On selecting the Choice: 4, you will see the following in Figure 5 on the monitor:

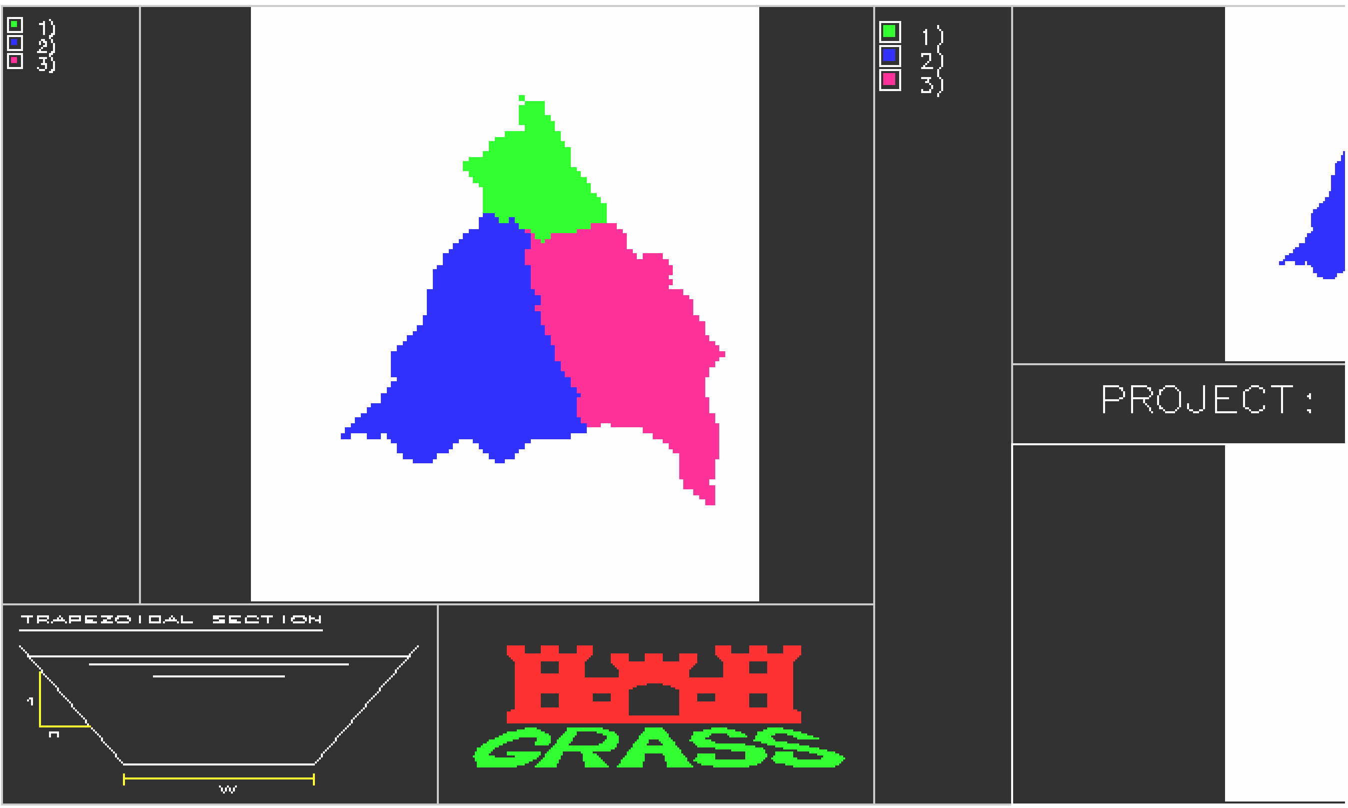

Figure 5. Basin and stream maps displayed with legend along with trapezoidal cross-section.

You will now be queried for various simulation and hydrologic parameters:

Enter the rainfall duration in minutes

DURATION: ***60***

Enter the maximum rainfall intensity(cm/hr) expected
MAX INTENSITY: ***5.0***

Please enter the maximum Manning's roughness value in your watershed
MAX. MANNINGS[0.01-0.9]: ***0.15***

COURANT TIME: 11.503015 seconds

For numerical stability use 5 seconds to 7seconds of the COURANT TIME

It is important to note that MAX. MANNINGS value you entered is used to calculate an estimate for the time step to prevent oscillations in the solution. You can easily present a lower value to obtain a different COURANT TIME. The time step that you select cannot be greater than the COURANT TIME or less than 1.

Enter time increment at which calculation should be made
TIME INCREMENT (seconds): ***10***

Enter the length of time for which you would like to monitor the hydrograph
MONITOR TIME (minutes): ***180***

Enter the name of the time file
Enter 'list' for a list of existing **r.water.fea*/my_project/timefiles*** files
Hit RETURN to cancel request
>***my_timefile***

Because the "Spatially constant and time variant" rainfall mode was selected in the configuration, you will be queried for the name of an ASCII text file containing information on the particular rainfall mode. All the files related to the particular rainfall scenario will be stored and accessed from the **r.water.fea*/project_name/timefiles*** directory. Since on the first run the file may not exist, you will be provided with an interface similar to the one shown below to create the file:

Rainfall data

[The time column must be filled in increasing order.]

Time [minutes] Intensity [cm/hr]

1 30 4.00
2 60 5.00
3
4
5
6
7
8
9
10
11
12
13
14
15

AFTER COMPLETING ALL ANSWERS, HIT [ESC] TO CONTINUE
(OR [Ctrl-C] TO CANCEL)

After filling the columns in an increasing order, you will be queried for the availability of certain parameter maps as described in the user's manual pages. If you can provide these maps then you need not provide the parameter values for every basin, else you will be queried for the values during basin simulations for each individual basin. The values queried are assumed to be constant for the entire basin being simulated.

Do you have maps of the following types?

1. Manning's roughness coefficient
2. Saturated conductivity values (m/sec)
3. Capillary suction values (m)
4. Porosity values (%)

Please answer yes only if you have all the maps
(y/n) n

Finally you are queried for the channel characteristics to complete choice:4 of the menu:

Channel Characteristics

[Please enter channel characteristics assume trapezoid shown on monitor]

Basin number Side slops [n] Width [meters] Roughness [0.01-0.5]
1 **4______________ 14______________ 0.070**
2 **3______________ 12______________ 0.060**
3 **4______________ 15______________ 0.060**

3 of 3
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AFTER COMPLETING ALL ANSWERS, HIT [ESC] TO CONTINUE
(OR [Ctrl-C] TO CANCEL)

You are again presented with the menu and will see that "*->" has moved from 4 to 5. You are now ready to carry out individual basin simulations. You should now select Choice: 5 from the menu. The simulation results can be seen on the left frame of the monitor. Compare the hydrographs that you obtain with those shown in Figures 6, 7, 8. The legend basin map and stream map on the right frame allows you to visualize the basin corresponding to the hydrograph.

[ANALYZING BASIN 1 ....]
[Please enter basin overland flow parameters now.]

Mannings roughness coefficient(0.01 - 0.8):***0.12***

ASSEMBLING MATRICES ....100% done.
Please enter infiltration parameters:

Saturated conductivity [m/s](0 - 8e-06):***2.5e-06***

Capillary suction at wetting front [m](0 - 2):***0.18***

Porosity(0 - 0.9):***0.4***

Degree of saturation(0 - 1):***0.67***

Starting time step calculation 100%

[Hit RETURN to view hydrograph]

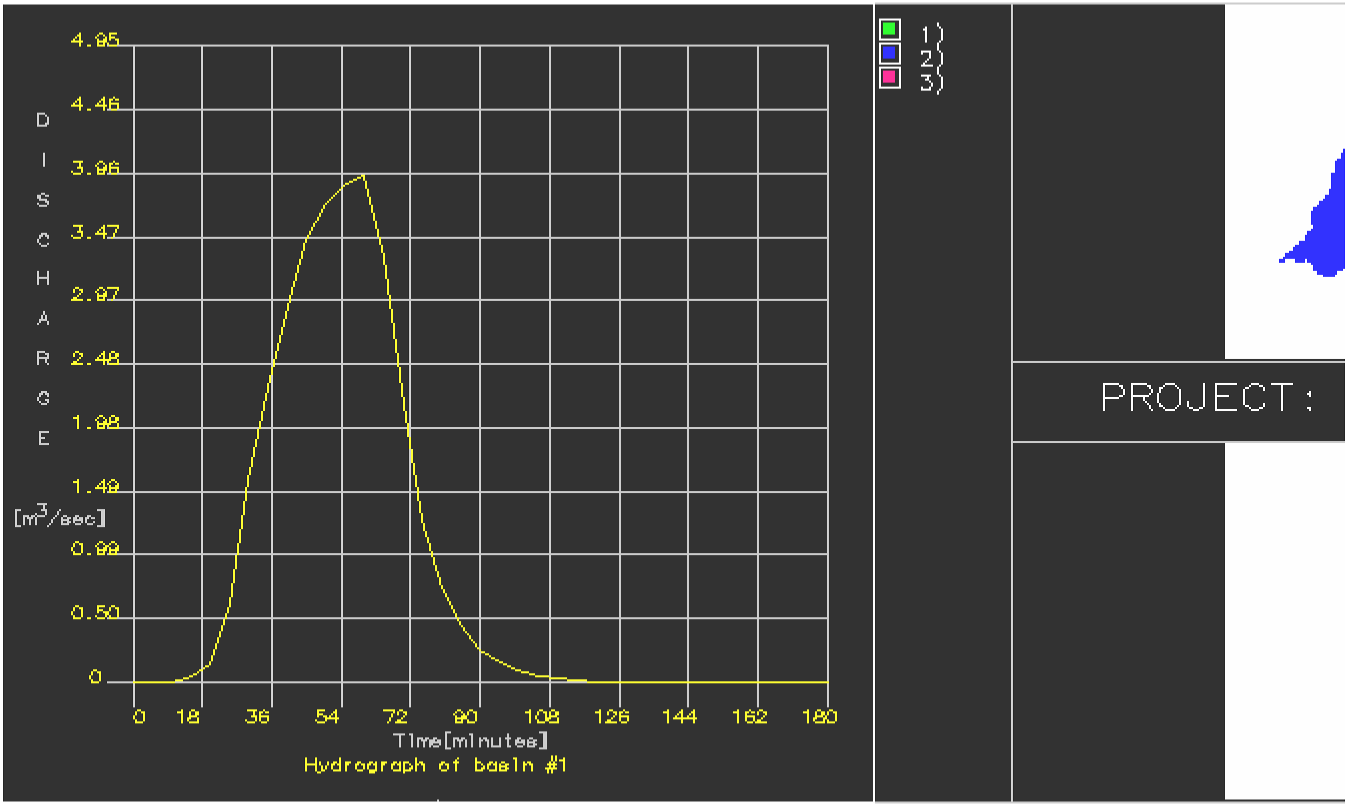

Figure 6. Hydrograph for basin 1.

[ANALYZING BASIN 2 ....]
[Please enter basin overland flow parameters now.]
Mannings roughness coefficient(0.01 - 0.8):***0.12***

ASSEMBLING MATRICES ....100% done.
Please enter infiltration parameters:

Saturated conductivity [m/s](0 - 8e-06):***0***

Capillary suction at wetting front [m](0 - 2):***0***

Porosity(0 - 0.9):***0***

Degree of saturation(0 - 1):***1***

Starting time step calculation 100%

[Hit RETURN to view hydrograph]

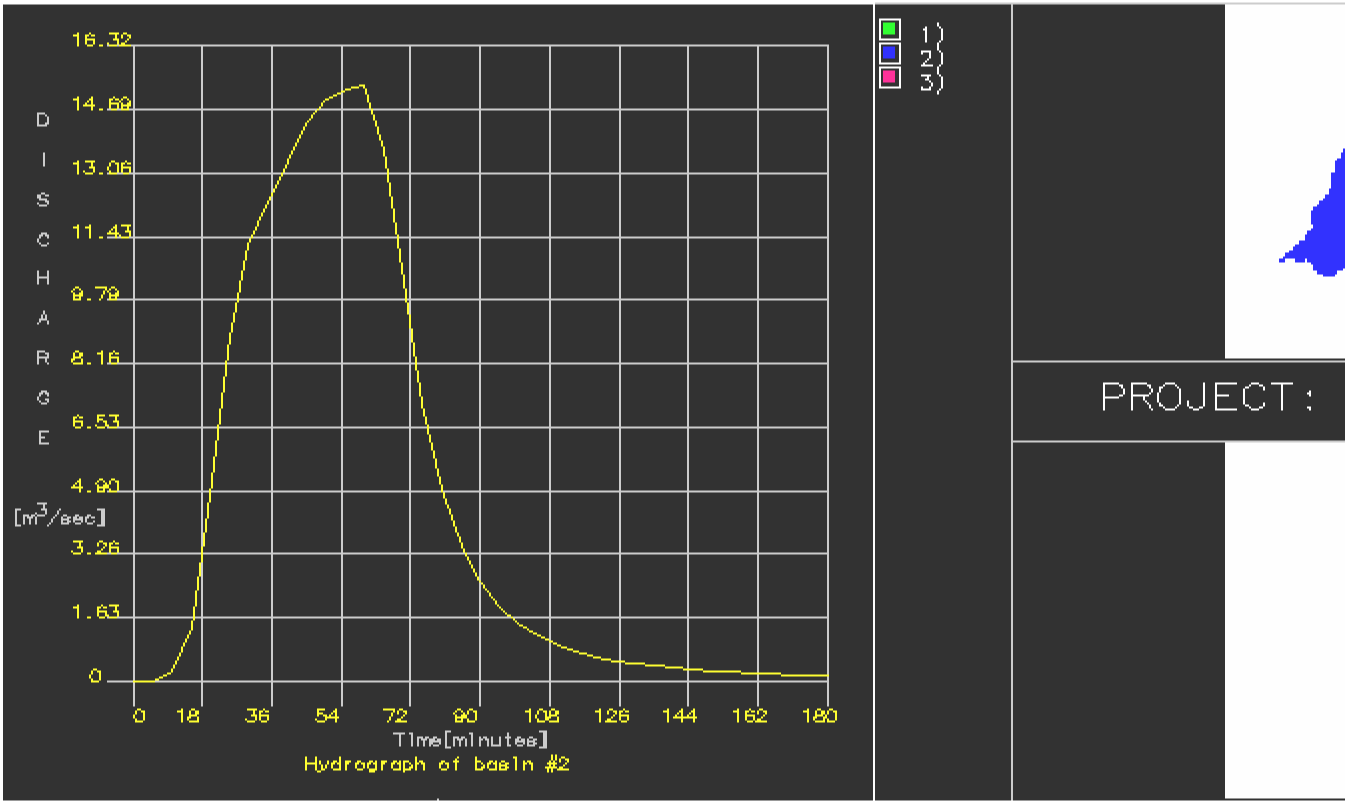

Figure 7. Hydrograph for basin 2.

[ANALYZING BASIN 3 ....]
[Please enter basin overland flow parameters now.]
Mannings roughness coefficient(0.01 - 0.8):***0.15***

ASSEMBLING MATRICES ....100% done.

Please enter infiltration parameters:

Saturated conductivity [m/s](0 - 8e-06):***3e-06***

Capillary suction at wetting front [m](0 - 2):***0.1***

Porosity(0 - 0.9):***0.35***

Degree of saturation(0 - 1):***0.76***

Starting time step calculation 100%

[Hit RETURN to view hydrograph]

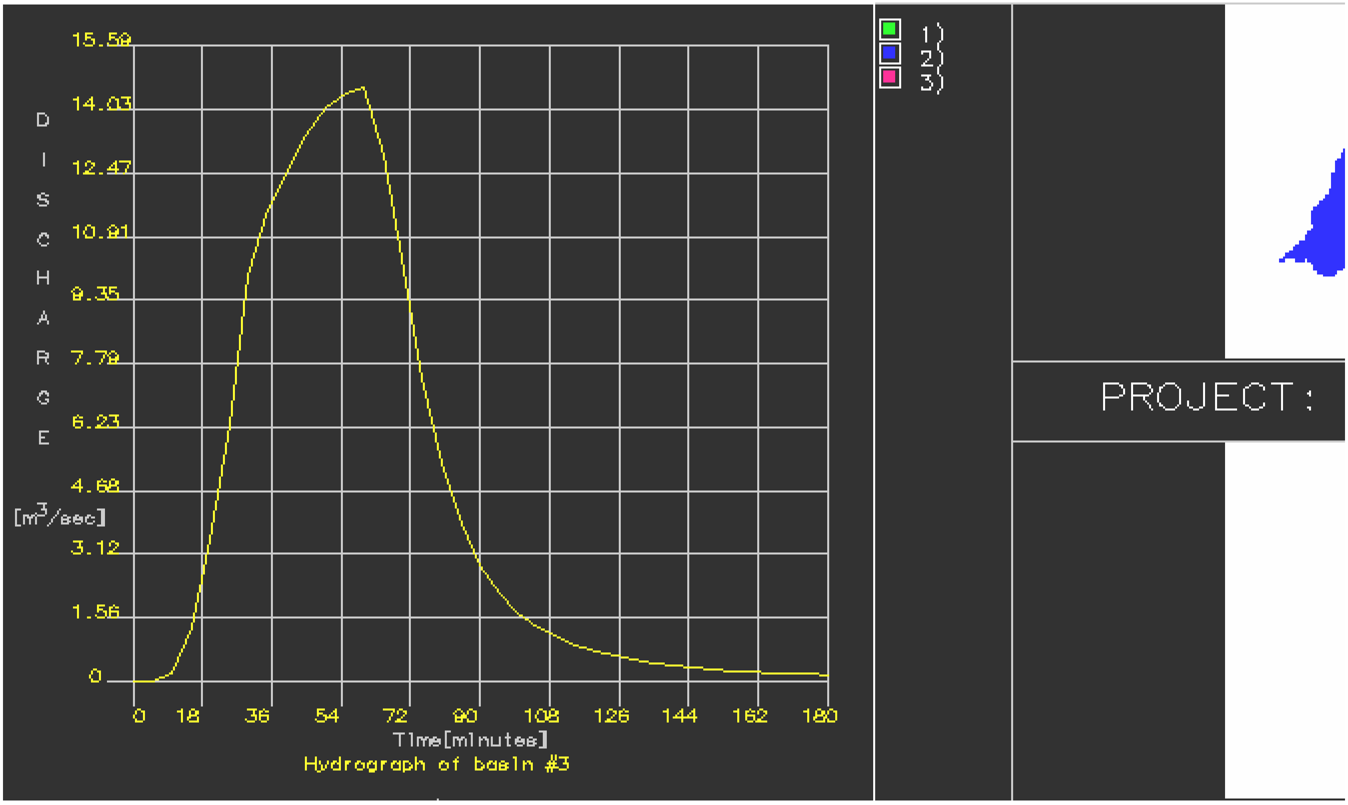

Figure 8. Hydrograph for basin 3.

All the basins have now been analyzed. To change the parameters for any particular basin, choose Choice:6 from the menu. It will prompt you for the basin number as follows:

Enter the basin number that you want to analyze
Basin number: 1
[ANALYZING BASIN 1 ....]
[Please enter basin overland flow parameters now.]
Mannings roughness coefficient(0.01 - 0.8):***0.1***

ASSEMBLING MATRICES ....100% done.
Please enter infiltration parameters:

Saturated conductivity [m/s](0 - 8e-06):***0***

Capillary suction at wetting front [m](0 - 2):***0***

Porosity(0 - 0.9):***0***

Degree of saturation(0 - 1):***1***

Starting time step calculation 100%

[Hit RETURN to view hydrograph]

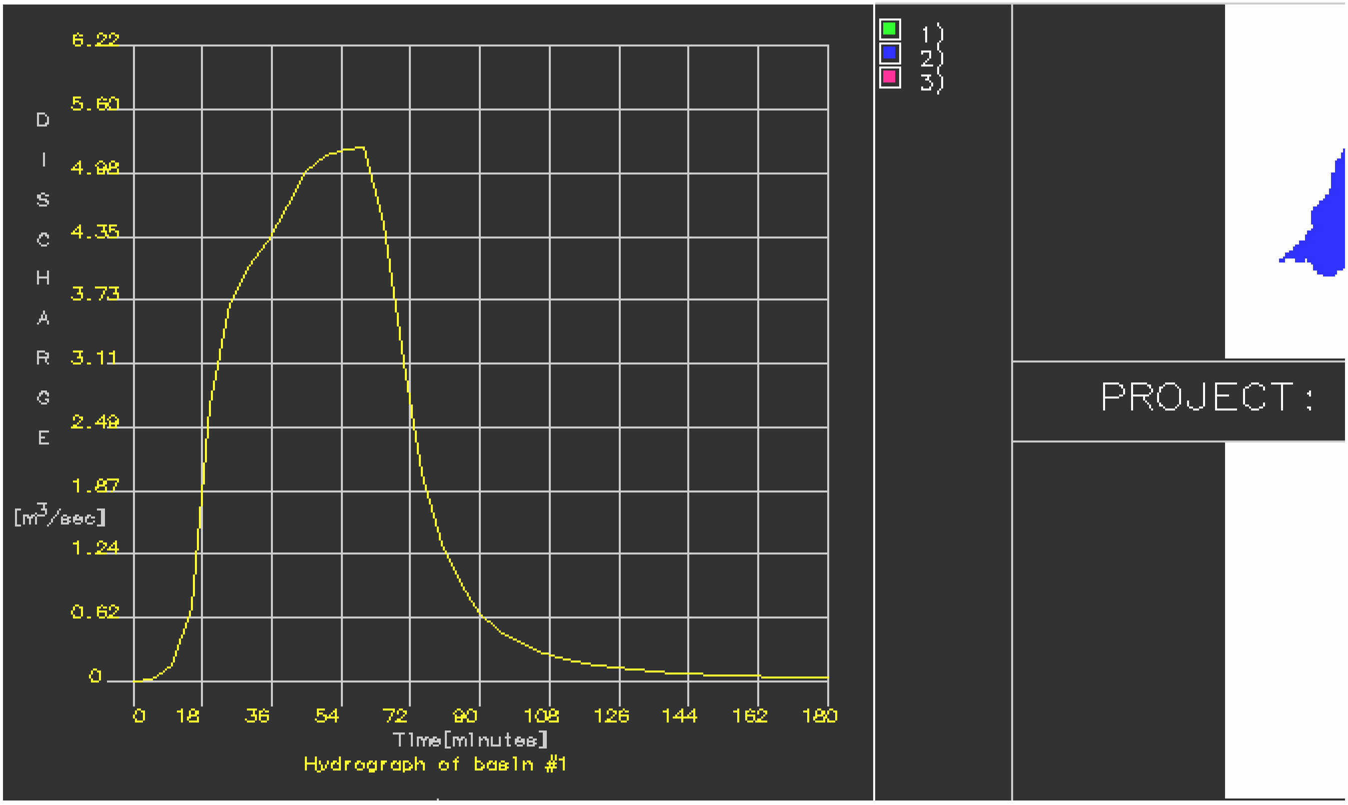

Figure 9. Hydrograph for basin 1 after changing parameters

.We changed all the parameter values to zero except the degree of saturation. This is similar to making the basin an impervious basin. Thus we actually observed the change in the basin hydrograph as though the same basin were impervious.

We are now in the final step where the individual basin hydrographs are routed downstream through the channel network. Observe that the "*->" has moved from 6 to 7, indicating that you should now choose Choice: 7 from the menu.

The final step shows you the hydrographs at stream junctions previously identified by the icons.

If the animation configuration has been set, then twenty animation maps are displayed to the user, one for every other time step. The hydrograph at the stream junctions should look like Figure 10 and the animation maps are displayed one-by-one on the right-hand side frame:

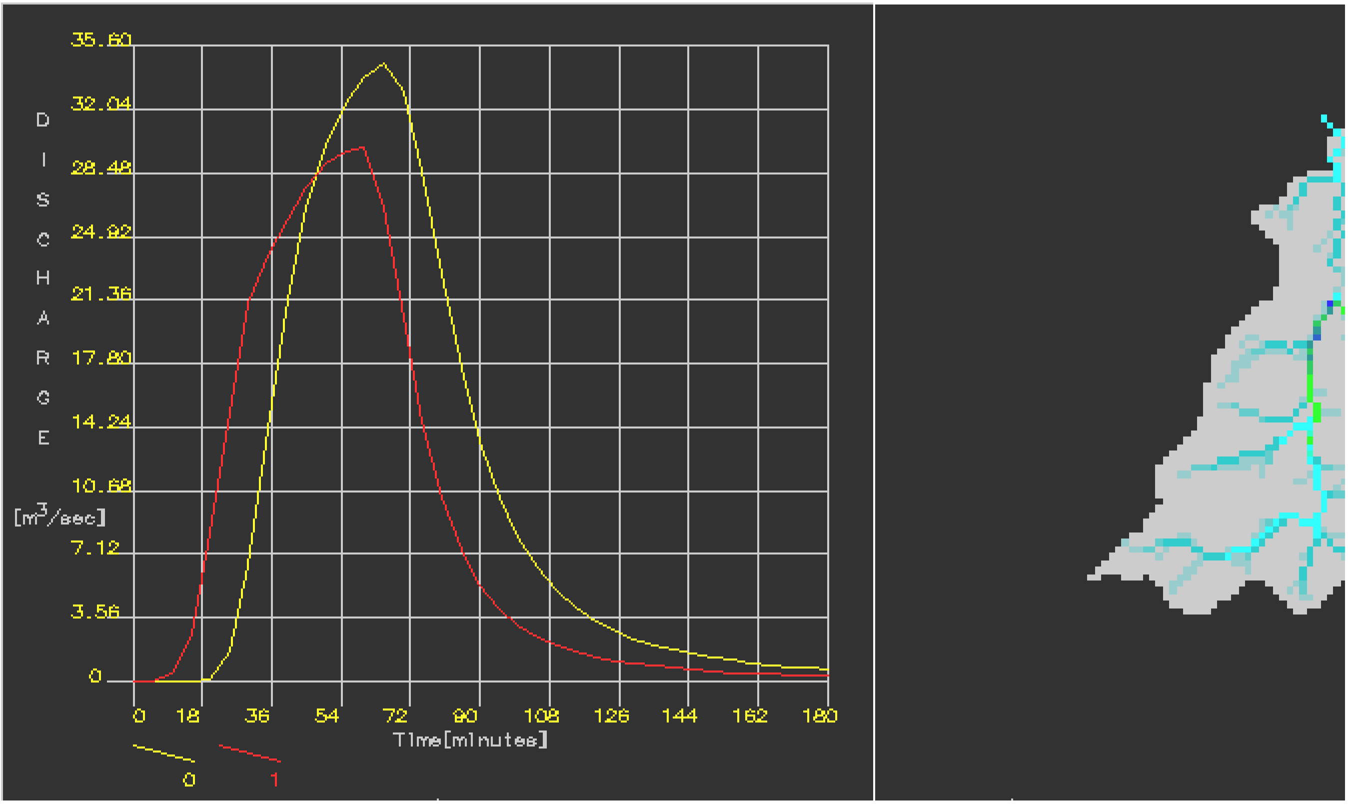

Figure 10. Hydrographs at stream junctions.

You should now see "Done" written above "Choice". At this point you can choose to go back or you can select Choice: 8 in the menu to stop this session.

5 RESULTS

The results of **r.water.fea** are stored for you to later transfer files to other analysis packages and to revisit the same project. They are in the ***$LOCATION/r.water.fea/*** directory. You have just finished working on the my_project project. You can view the list of files by typing:

GRASS 4.2 > **ls -l *$LOCATION/r.water.fea/my_project***
total 1251
-rw-r--r-- 1 login 66 Jul 20 15:26 basin_info
-rw-r--r-- 1 login 137 Jul 22 11:55 control
-rw-r--r-- 1 login 67728 Jul 20 15:43 coordinates
-rw-r--r-- 1 login 1313 Jul 21 09:45 disch.basin
-rw-r--r-- 1 login 1221 Jul 21 09:46 disch.junction
-rw-r--r-- 1 login 1041461 Jul 21 09:30 disch_file
-rw-r--r-- 1 login 53 Jul 20 15:26 input.basin
-rw-r--r-- 1 login 137235 Jul 20 15:43 input.file
-rw-r--r-- 1 login 0 Jul 22 12:35 timedata
drwxr-xr-x 2 login 512 Jul 22 12:35 timefiles

All the files of interest in this list are described in the user's manual program pages. Note that the disch_file occupies a large space which is only created if the animation configuration is set.

Removing Project Files

All the files related to the project in the sample session can be removed by using the following:

GRASS 4.2 > **rm -r** ***$LOCATION/r.water.fea/my_project***

This will remove only the files created by the program **r.water.fea**. The maps created by this program can be removed by using the GRASS **g.remove** program as shown below:

GRASS 4.2 > **g.remove** ***rast=fea.my_project.basin,fea.my_project.stream***

Similarly the flow depth animation maps can be removed by using the GRASS **g.remove** program.