WATFLOOD™ / WATROUTE

Hydrological Model
Routing
&
Flow Forecasting System

SINCE 1972

Developed for

Surveys and Information Branch
Ecosystem Science and Evaluation Directorate
ENVIRONMENT CANADA

by

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IMPORTANT NOTE:

WATFLOOD programs now read onlyGreenKenue format files. Old file formats are no longer supported. A program called trns.exe can convert old formats to theGreenKenue formats. See Chapter 14

DISCLAIMER

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WATFLOOD - with Grouped Response Units

WATFLOOD is an integrated set of computer programs to forecast flood flows or do simulations for watersheds having response times ranging from one hour to several weeks. Continuous long term simulation can be carried out by chaining events. The emphasis of the WATFLOOD system is on making optimal use of remotely sensed data, radar-rainfall data, LANDSAT or SPOT land use and/or land cover data can thus be directly incorporated in the hydrologic modeling.

WATFLOOD is **the first** hydrological model to preserve the distributed nature of a watershed's hydrologic and meteorological variability without sacrificing computational efficiency. This has been accomplished through the use of **Grouped Response Units**, in which process parameters are tied to land cover and land cover mixes can vary from basin element to basin element. This approach is becoming more popular each year. The basic premise of the GRU method is that vegetation and/or land use is the predominant hydrological indicator of hydrological response.

The system is completely modular but has a consistent data structure throughout. It has been under continuous development since 1972. Several Master and Ph.D. research programs have provided the rationale incorporated in the software but programs have all been written or adapted by the author.

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NOTICE

The programs described herein belong to N. Kouwen and the University of Waterloo.

The programs are distributed free of charge at http://www.watflood.ca

Updates may be posted without notice at http://www.watflood.ca

This software and manual are not intended for the hydrologically naïve.

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These contributions are gratefully acknowledged.

N. Kouwen.
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1 WATFLOOD USER's MANUAL

1.1 Introduction

The model SPL9 is a combination of a physically-based routing model and a conceptual hydrological simulation model of a watershed. As with most hydrological models, it represents only a small part of the overall physical processes occurring in nature. The model is aimed at flood forecasting and long-term hydrologic simulation using distributed precipitation data from radar or numerical weather models. The processes modeled include interception, infiltration, evaporation, snow accumulation and ablation, interflow, recharge, baseflow, and overland and channel routing (Kouwen et al., 1993).

The model is programmed in FORTRAN 95 with dynamic memory allocation to make it suitable for use on any modern computing platform. Typically, the program takes approximately 6 minutes to run for a 1,000,000 km^2 watershed with a 15 km grid (4000 grid points), 1-year simulation, and hourly time steps on a 3.2 Ghz Pentium 4™.

The following sections describe the model and the input requirements. In addition to SPL9, there are a number of support programs to provide for data preparation and output presentation. The programs RADMET and RAGMET may be used to convert radar and rain gauge data to the square grid SPL9 input format; BSN may be used to assemble and create a 'basin file' for SPL9; and PLOTHYD is a program to plot hydrographs on a color monitor. The WATFLOOD menu program can be used to manage the data and organize the use of the model.

The model features the Hooke and Jeeves (1961) automatic pattern search optimization algorithm taken from Monro (1971). The program can be run to automatically determine which combination of parameters best fit measured conditions. The hydrological parameters for optimization are soil permeability, soil retention, a recharge factor, an interflow coefficient, overland flow roughness, melt factor, base temperature and a sublimation factor. For cjannel and lake routing the following parameters can be optimized: channel roughness, a lower zone coefficient and exponent, wetland conductivity and porosity and an instream lake damping coefficient.

1.2 Approach

A simple example will serve to show why weighted averages for the parameters that define the runoff characteristics of a watershed should not be considered. Take a one hectare city block and divide it into two parts, $2/3^{rds}$ of the area is grassed and the remaining $1/3^{rd}$ is impervious. If the US Soil Conservation Service (SCS) method is used to determine runoff, and the soil curve number for the grass is taken as 50, the weighted SCS number will be 67 and runoff will not commence until approximately 25 mm of rain have fallen (USDA, 1968). However, the impervious area will contribute runoff almost as soon as the precipitation starts. Using the same scenario, if the rational method is applied to the same area, a peak flow calculated using only the impervious area will be larger than using the whole area.

These inconsistencies have been known for a long time and led to the development of hydrological models, which did not require the averaging of the watershed parameters. The first of these, where runoff was computed separately, was using the Road Research Laboratory Method (Terstriep and Stall, 1996) followed by many others. The general trend has been to model areas of uniform hydrologic response such as the method developed by Leavesly and Stannard (1995) who introduced the Hydrologic Response Unit (HRU) method. During the last 15-20 years, “pixel models” have been developed where the hydrology is modelled at the scale of the pixel of LANDSAT or SPOT imagery or the resolution of the digital terrain data as for the TOPMODEL (Beven et al., 1995) or the MIKE SHE model (Refsgaard and Storm, 1995). However, the problem is where to make the cutoff for the smallest area that can be modelled. Often the determining factors are the image resolution and/or the computer resources available. This seems a rather arbitrary criterion, which is not based on hydrological considerations.

The WATFLOOD method is based first on a definition of the resolution of the meteorological data available and second, on the level of detail required in the output, for instance, the size of the smallest watershed for which information is sought. Once these general parameters are established, a model grid is chosen to reflect these points. On very large watersheds on the sub-continental scale, where the meteorological data may be provided by a numerical weather model with a resolution of 25 km, a 25 km grid size will be appropriate. On the other hand, for a small 100 km^2 watershed, where the precipitation may be provided by radar at a 1 km resolution, a 1 km grid would be more appropriate.

Any land cover image will reveal differences between neighbouring pixels. Unless a model grid size is chosen that is equal to the land cover pixel size, either the hydrologic parameters will have to be averaged or different hydrological units will have to be grouped. The WATFLOOD system is based on the latter. Using remotely sensed land cover data, pixels are classified to a number of land cover classes and the ratio of each land cover in each computation grid is determined. The runoff response from each hydrologically significant sub-group in each grid is calculated and routed downstream. With this method, there is no requirement for grids or sub-basins to be hydrologically homogeneous. So, the grid size can be chosen to conveniently match the resolution of the meteorological data or reflect the detail required in the model output.

Figure 1.1 shows the above concept. In this example, a land cover image is classified into 4 hydrologically significant groups A, B, C and D. There are 25 pixels with 8 in group A, 11 in group B, 2 in group C, and the remaining 4 in group D (i.e., 32% in group A, 44% in group B, 8% in group C and 16% in group D). WATFLOOD combines all pixels in one group for computational purposes. The pixels of one group do not have to be contiguous and their location in the grid is not considered significant with respect to routing. The runoff from a grouped set of pixels is routed by a two step procedure, first overland flow to the channel system and second, channel flow to the next grid.

For the grid in Fig. 1.1, there are four hourly runoff computations and four overland flow routing segments. The flows are then combined for the grid. It is as if there are four sub-watersheds in this grid in a pie-shaped configuration, with each segment contributing runoff according to its percent coverage. The four runoff amounts are added in each grid and routed downstream from grid to grid.

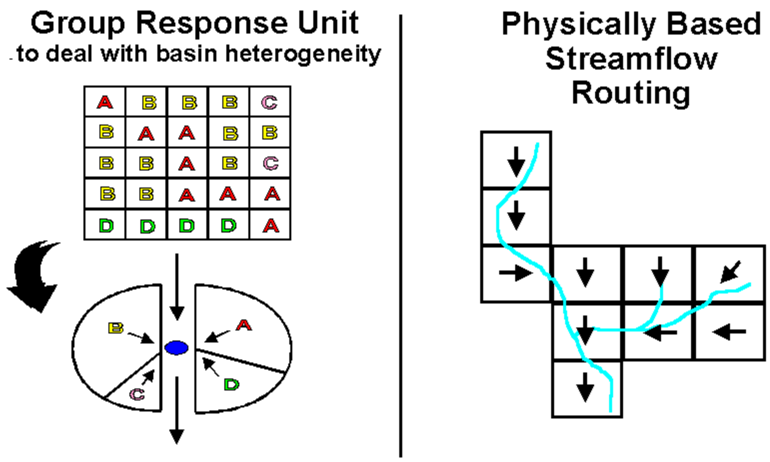


Figure 1.1 - Group response unit and runoff routing concept (Donald, 1992)

Figure 1.2 shows an array of grids where each grid may have a different makeup of land cover fractions. The essential property of this arrangement is that the parameters are associated with the land cover classes A, B, C and D. All grids in this method have the same hydrological parameters, even though the land cover makeup of each grid is not the same. The advantages of this scheme are: 1) the parameters can be used in other physiographically similar watersheds without recalibration, and 2) the parameters do not have to be recalibrated if land use in the watershed changes over time. For the latter, only the land cover map and the fractions in each grid need to be redefined.

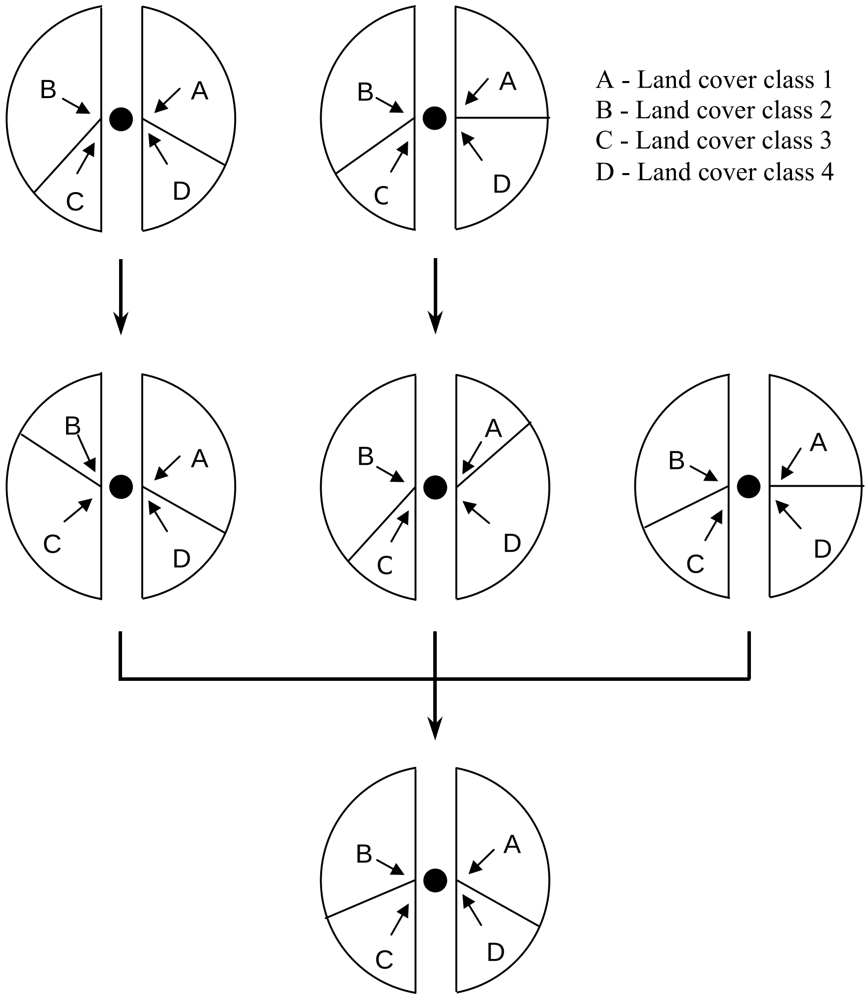


Figure 1.2 - Schematic of the GRU pixel grouping model and channel routing scheme

1.3 Getting Started

1.3.1 Overview

The WATFLOOD programs are mostly a set of FORTRAN programs for DOS, compiled in Visual Fortran Ver. 6.6.0. All computations can be run in DOS, as well as on various Unix platforms (SUN Solaris, SGI and Linux systems). All programs have been or will be converted to the Fortran 95 standard with dynamic memory allocation.

You will need at least 25 Mb of disk space on your hard disk to get started.

1.3.2 Installation - WINDOWS

Currently, because of the new file formats (described in this manual) the WINDOWS GUI version of WATFLOOD is not available. The programs can be executed using the WINXX interface but is is actually easier to use the WATFLOOD model on DOS.

1.3.3 Installation DOS:

1. Create a directory (folder), called SPL. It works best if it is in the root directory of any drive.

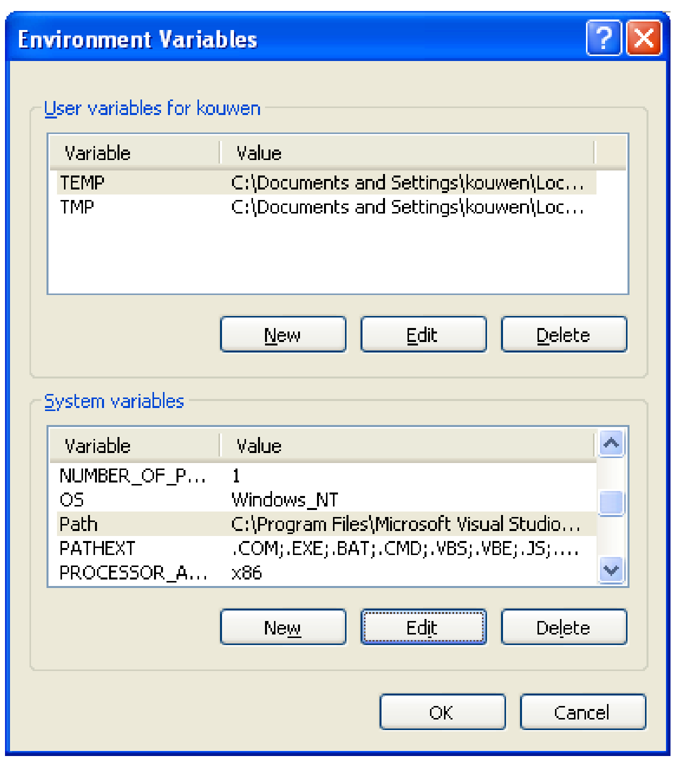
2. Download the ***watflood.zip*** *(all executables)*, ***spldata.zip*** *(gr10k example data set)* and ***manual**nn**.pdf*** files to the ***SPL*** directory. Recent updates of executables should also be copied to this directory.

3. Log to the ***spl*** directory and unzip ***watflood.zip*** to put all program (.exe) files in the ***SPL*** directory.

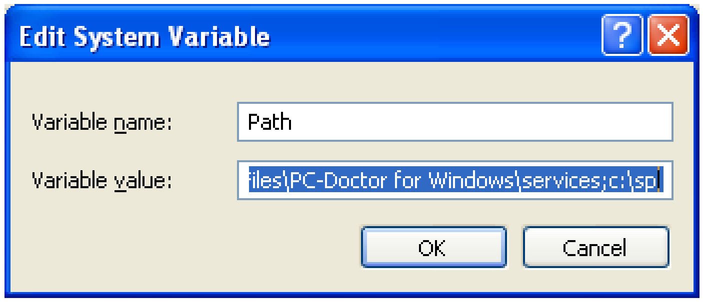
4. Unzip ***spldata.zip *.**** to give you the sample Grand River Data set that will run with the demo program. Preserve the directory structure: (–od option in PKUNZIP).

NOTE: When extracting files in Windows, usually a new folder is created and files do not end up with the same path. You may (will) need to move files to get them in the path as given in Section 1.3.4

5. **Set the path:** Right click on **Computer** and go to **Properties.** Click on **Advanced System Settings** and go to **Environment Variables** and select Path under System variables:



Click on **EDIT** and add ;c:\spl to the end of the Path line and click OK:



1.3.4 File Structure in WATFLOOD

The entire WATFLOOD system is installed under the **\SPL** directory. This directory should be in the root directory. The following file structure works well:

```
Drive:\SPL    -
      |---    GR10K                - some batch files
              |---    BASIN        - watershed files, parameter files
              |---    EVENT        - event files
              |---    DDS          - DDS working directory          << new!!
                      |---    DDS_bsnm    - DDS output              << new!!
                      |---    DDS_best    - best DDS input/output files << new!!
              |---    LKAGE        - leakage (ground water discharge) files
              |---    MOIST        - initial soil moisture files
              |---    RADAR        - radar ASCII files from RFA pictures
              |---    RADCL        - adjusted radar or rain gauge files
              |---    RADUC        - unadjusted radar files
              |---    RAING        - rain gauge data files
              |---    RCHRG        - recharge files
              |---    RESULTS      - model results DEFAULT          << new!!
              |---    RESRL        - reservoir release files
              |---    RUNOF        - surface runof & interflow files
              |---    SNOW1        - snow course and climate data
              |---    STRFW        - streamflow or river stage files
              |---    TEMPG        - point temperature files        << new!!
              |---    TEMPR        - gridded temperature files
      |---    SAUG
              |---    BASIN
              |---
              |---    etc.
```

The reason for the use of the dr:\spl\bsnm\results directory if to make the use of post processors easier. If the results are always in the same place, programs such asGreenKenue (KENUE) or GRAPHER™ can always find the required files. Some users prefer to use a RESULTS folder in the watershed directory (as shown in red above). For this, edit the outfiles.new (Section 10.4) file and insert the proper path and save the file as outfiles.txt in the working directory. When running multiple watersheds at once, this feature must be used.

1.3.5 Minimum File Requirements

In addition to files for specific events, the following files are ***required*** before the WATFLOOD (SPLX.exe or SPLD.exe) model can be executed:

```
:basinfilename                BASIN\gr10k_shd.r2c
:parfilename                  BASIN\GR10K.par
:pointdatalocations           BASIN\GR10K.pdl
:snowcoverdepletioncurve      BASIN\GR10K.sdc
```

```
:streamflowdatafile          strfw\19930101_str.tb0
:reservoirreleasefile        resrl\19930101_rel.tb0
:snowcoursefile              snow1\19930101_crs.pt2
:griddedinitsnowweq          snow1\19930101_swe.r2c
:griddedinitsoilmoisture     moist\19930101_gsm.r2c
:griddedrainfile             radcl\19930101_met.r2c
:griddedtemperaturefile      tempr\19930101_tem.r2c
```

Other files are needed for various preprocessors

In this example, gr10k is the *bsnm.*

With the exception of *bsnm*.map and *bsnm*_shd.r2c files, these files may be modified copies from the gr10k demonstration files.

Once all these files exist, EVENTS.EXE can be executed to initiate a new event.

For each event, the following files are required as a minimum:

Streamflow file	strfw\yyyymmdd_str.tb0
Reservoir release or rule file	resrl\yyyymmdd_rel.tb0
Gridded precipitation file	radcl\yyyymmdd_met.r2c

If evaporation is to be considered, a temperature file is required:

Gridded temperature file	tempr\yyyymmdd_tem.r2c

If snow accumulation is to be considered, the temperature file (above) and the snow course file to initialize the swe is required:

Gridded snow water equivalent file	snow1\yyyymmdd_swe.r2c

The names of the directories (folders) are suggested names. If everyone uses the same name structure and names, it is much easier for users to understand each others setup. (And 30 years of experience has shown it to be efficient).

For details on setting up a new watershed, please refer to Section 3.2

1.3.6 File Naming Convention

To help identify files and keep them organized, the file names should follow the following convention as shown in an event file for the Grand River:

```
Watershed files                 BASIN\gr10k.xxx
Watershed file - shd file only  BASIN\gr10k_shd.r2c

Point Temporal data files       xxxxx\19930101_xxx.tb0
```

```
Point values                    xxxxx\19930101_xxx.tp2
Gridded temporal files          xxxxx\19930101_xxx.r2c
```

Any file that refers to an event has the date YYYYMMDD while files that are fixed for a watershed have a name that identifies the watershed BSNM=GR10K in this case, where BSNM is used throughout this manual to refer to the watershed or basin name.

Unit number 98 is reserved for scratch files
Unit number 99 is reserved for the xxx_info.txt file where xxx is the executable's name such as snw, spl, moist, etc.

Note: The event file names YYYYMMDD are used only to identify files. Files can also be called YYYY_TEM.r2c etc. if the files are annual data sets or YYYYMM_TEM.r2c etc. for a specific month, or YYYYMMDD_TEM.r2c etc. if the event starts on a specific day.

***Note*:**
As of 2006, all data files will beGreenKenue compatible file formats and the names will reflect the type of file. For instance, tempr\19930101.tem will become tempr\19930101_tem.r2c GreenKenue will be able to load these files directly.

1.3.7 KENUE compatibility

With the exeption of a few files, all files in the WATFLOOD system will be theGreenKenue formats (pt2, tb0, r2c, etc.). Thus all files can be displayed inGreenKenue.GreenKenue creates the basinname.map file – which is arguable the most important file to get right in WATFLOOD.

Please note that in the file headers (meta data):

- For UTM coordinates the Zone **and** Ellipsoid are required.
- For LATLONG **only** the Ellipsoid is required, do not use the Zone line.
- For CARTESIAN coordinates, do not use Zone of Ellipsoid lines.

1.3.8 Event File

The event file contains a list of all the files that relate to a specific event. **All** WATFLOOD programs except BSN.EXE refer to this file to determine which files are active for a particular job such as distributing rainfall or calibrating radar.

The simulation length of an event is set by the number of hours of streamflow in the yyyymmdd_str.tb0 file. So if you want to run for 744 hours but have only 240 hours of data, enter missing data (-1.00) for the last 504 hours. Of course there will need to be precip and temperature etc. data for that period.

***New in 2008:* The event file is now free format and the entrees can be in any order for SPLX versions after 9.5.08 for the PC only. However, only backslashes \ can be used in the filenames, which makes the new parser unusable in UNIX for the time being.**

Length of events: if you are planning to run long time series, use annual events. For short runs you may use month long events. Monthly events or shorter are intended for operational use. If you are planning to do climate change runs, use annual events.

If you are planning say 40 year long runs, monthly events are awkward in use.

There is no limit on the number of chained events as of Dec. 26/08

***ALSO –* In Canada, start simulations Oct. 1 if possible (or even earlier in the North) to ensure the proper accumulation of snow for the winter unless you have snowcourse data to initialize the SWE.** It is perfectly ok to have a 3 month long event as the first event (recommended even).

The following file is an example of an event file used by all WATFLOOD programs except BSN.EXE. **The format of the event file is NO LONGER fixed**. The keywords are important and are allotted 30 characters. Data fields may be left blank in this file only. The order will not matter and only lines with data used for the particular job will need to be included. Section 1.5 also shows which files are **Mandatory** and which are **Optional** for each program.

Example of an EVENT file:

This example is for a 1 year long simulation. The user edits the file to add the event list at the bottom. The reason for reading the number of events to follow is so an event file can be set up to run a long time series (say 100 years) but has the option of running just the first few years (say as a calibration run) by just changing the number of events to follow but leaving the list intact.

Note: Older versions of SPL will NOT read this version of the event file. The current version of SPL will read older versions of the event file **as long as the keywords are exactly as below**.

Highlighted lines with no data may be left out of the list. The order of the entrees does not matter except that the section beginning with `:noeventstofollow` must be at the end of the event file – including the # symbol and then the list of events as shown below.

In this example, there are two special purpose lines of data:

```
:griddedevaporation            evapo\30000101_evp.r2c
:initlakelevel                 level\30000101_ill.pt2
```

which are needed for the Great Lakes model only. The event parser allows the inclusion of any files that are needed for special applications of WATFLOOD such as files for the isotope and water quality models. In the future, the output files will also be included in the event files so the outfiles.txt files will no longer be needed.

```
#
:filetype                     .evt
:fileversionno                9.8
:year                         3000
:month                        01
:day                          01
:hour                          0
#
:snwflg                       y
:sedflg                       n
:vapflg                       y
:smrflg                       n
:resinflg                     n
:tbcflg                       n
:resumflg                     n
:contflg                      n
:routeflg                     n
:crseflg                      n
:Kenueflg                     n
:picflg                       n
:wetflg                       n
:modelflg                     n
:shdflg                       n
:trcflg                       n
:frcflg                       n
:initflg                      n
:grdflg                       n
:ntrlflg                      n
:nudgeflg                     n
:resetflg                     n
#
:intsoilmoisture              0.25 0.25 0.25 0.25 0.25
:rainconvfactor                1.00
:eventprecipscalefactor        1.00
:precipscalefactor             0.00
:eventsnowscalefactor          0.00
:snowscalefactor               0.00
:eventtempscalefactor          0.00
:tempscalefactor               0.00
:tempscalefactor               0.00
#
:hoursraindata                  744
:hoursFlowData                  744
:deltat_report                    1
:spinupevents                     1
#
:basinfilename                basin\mack_shd.r2c
:parfilename                  basin\mack.par
:channelparfile               basin\mack_ch_par.r2c
:pointdatalocations           basin\mack.pdl
:snowcoverdepletioncurve      basin\mack.wqd
:waterqualitydatafile         basin\mack.sdc
#
:pointsoilmoisture            moist\30000101_psm.pt2
:pointprecip                  raing\30000101_rag.tb0
:pointtemps                   tempg\30000101_tag.tb0
:pointnetradiation
```

```
:pointhumidity               humid\30000101_hum.tb0
:pointwind
:pointlongwave
:pointshortwave
:pointatmpressure
:pointsnow                   snowg\30000101_snw.tb0
:pointdrain                  drain\30000101_drn.tb0
:pointdsnow                  dsnow\30000101_dsn.tb0
#
:streamflowdatafile          strfw\30000101_str.tb0
:reservoirreleasefile        resrl\30000101_rel.tb0
:reservoirinflowfile         resrl\30000101_rin.tb0
:snowcoursefile              snow1\30000101_crs.pt2
#
:radarfile                   raduc\30000101.rad
:rawradarfile                radar\30000101.scn
:clutterfile                 radar\30000101.clt
:griddedinitsnowweq          snow1\30000101_swe.r2c
:griddedinitsoilmoisture     moist\30000101_gsm.r2c
:griddedinitlzs
:griddedrainfile             radcl\30000101_met.r2c
:griddedsnowfile
:griddedtemperaturefile      tempr\30000101_tem.r2c
:griddednetradiation
:griddedhumidityfile         humid\30000101_hum.r2c
:griddedwind
:griddedlongwave
:griddedshortwave
:griddedatmpressure
:griddedsnow                 snowg\30000101_snw.r2c
:griddeddrain                drain\30000101_drn.r2c
:griddeddsnow                dsnow\30000101_dsn.r2c
:griddedrunoff               runof\30000101_rff.r2c
:griddedrecharge             rchrg\30000101_rch.r2c
:griddedleakage              lkage\30000101_lkg.r2c
:griddedevaporation          evapo\30000101_evp.r2c
:initlakelevel               level\30000101_ill.pt2
#
:noeventstofollow                11
#
event\30000201.evt
event\30000301.evt
event\30000401.evt
event\30000501.evt
event\30000601.evt
event\30000701.evt
event\30000801.evt
event\30000901.evt
event\30001001.evt
event\30001101.evt
event\30001201.evt
eof
```

1.3.9 Meaning of the flags in the event file

	Flag:	Result if 'y'
1	snwflg	snowmelt routines will be used
2	sedflg	sediment production and routing routines will be used
3	vapflg	Evaporation turned on (need temperature files)
4	smrflg	Precip. data will be smeared - e.g., precip. entered once every 24 hours will be 'smeared' over the whole day instead of taken as an hourly amount
5	resinflg	reservoir inflow data required and computed reservoir inflows will be compared. This flag is set in event.evt and used for all subsequent events.
6	tbcflg	The following files will be written in the working directory so a run can be continued with the same state variables: resume.txt flow_init.r2c soil_init.r2c **These files will not be written partway through a run even if the tbcflg='y'**)
7	resumflg	the resume.txt, flow_init.r2c & soil_init.r2c files will be used to initialize state variables - allows the program to resume a time series as if it was executed as a continous run NEW: for resumflg = 's', only the soil_init.r2c file will be read but the lzs and all flow variables will be initialized with streamflow.
8	contflg	continue the statistics from previous run via resume.txt file
9	routeflg	= 'y' For watroute write: \spl\bsnm\runof\yyyymmdd_rff.r2c \spl\bsnm\rchrg\yyyymmdd_rch.r2c \spl\bsnm\lkage\yyyymmdd_lkg.r2c \spl\bsnm\flow_init.r2c = 'q' write the tb0 files for flow 1D (no computed outflow from designated reaches)
10	crseflg	read snow course data to replace resume file data
11	kenueflg	Create \spl\bsnm\results\watflood.wfo file for GreenKenue
12	picflg	Create \spl\bsnm\results\pic.txt file for flow animation w/ MAPPER.exe
13	wetflg	Use coupled wetland-channel routing
14	modelflg	if ='i' run watroute with surface flow & interflow only if ='l' run watroute for surface and groundwater **l**eakage routing if ='r' run watroote for surface to channel and **r**echarge thru lz
15	shdflg	Replace the watershed file basin\bsnm.shd for next event
16	Trcflg	Use the tracer module
17	frcflg	Use fractionization module (under development)
18	initflg	Write flow_init.r2c file for WATROUTE (Initial flow for each grid) Write lzs_init.r2c file for WATROUTE (Initial lzs for each grid)

19	grdflg	If ='y' will write r2c files for flow, swe & evaporative loss gridflow.r2c, swe.r2c & evap.r2c respectively
20	ntrlflg	If ='y' and the rel file for the first event has coefficients for ALL lakes and reservoirs, any release data in the rel file will be ignored and flows routed according to the rule (coefficients)

21	nudgeflg	If ='a' all computed flows for all events this run will be replaced by observed flows at all flow stations. If='1' computed flows as designated in event no. 1 will be replaced by observed flows. (Designation is by setting value1 = 2 in the yyyymmdd_str.tb0 file for the **first** event) The default = 'n' if not specified in the event file. However, if Value1 = 2 in any yyyymmss_str.tb0 file for any station, the computed flow for that station and that event (only) will replaced by the observed flow. See Section 7.1.1 also.
22	resetflg	If = 'y' will reset the sums of precip, interception evaporation, evaporation and sublimation = 0.0 during the first week of October. This to allow the plotting of these with snow pillow and/or snowcourse data which is effectively a cumulative precip until the snow melts.

1.3.10 Multiple Events for Continuous Modelling (Chaining)

Up to 500 successive events can be sequentially linked to run a continuous simulation for up to 500 years. Runs Runs can be chained using a **resume.txt** file removing any limit on the length of a simulation. In the example, a continuous simulation of 12 months duration is required. The first event file would be event\19930101.evt and the successive events are as shown at the bottom of the event file after the line how many events are to follow the first event.. It is a good idea to leave the event\19930101.evt as the original event name and to call the extended event 1993.evt. That way, they can be differentiated.

Example of event file extended to add a sequence of events:

:noEventsToFollow	11									
#										
event\19930201.evt										
event\19930301.evt										
event\19930401.evt										
event\19930501.evt										
event\19930601.evt										
event\19930701.evt										
event\19930801.evt										
event\19930901.evt										
event\19931001.evt										
event\19931101.evt										
event\19931201.evt										
EOF										

If the event file is set up to run with 100 events to follow, a shorter run can be done by just changing the number of events to follow while leaving the list of events complete.

If everything went OK, you should be able to run **WATFLOOD,** using the demo files for the Grand River in Ontario, Canada, without a message that you are running a demonstration program. See **WATFLOOD TUTORIAL** starting in the next section.

1.3.11 Creating event files

The old event files have old event names that are not compatible with theGreenKenue formats. Instead of editing all the old evt files, just run MAKE_EVT.EXE in the working directory and a complete set of event files will be created. In the event files, there will be several file names created that are not needed for many applications. The event file is used by nearly all WATFLOOD programs such as RAGMET, TMP, SNW, MOIST, SPLX, etc. Each application has it's own need for certain files associated wich a given event. All required files for all programs are in the event file.

To create a set of new event files: while in the working directory, run MAKE_EVT.EXE and make the proper entries as in the example below:

```
E:\spl\glake>make_evt
 *******************************************************
 *                                                     *
 *                  WATFLOOD (TM)                      *
 *                                                     *
 *         Program make_evt   Apr. 20, 2006            *
 *                                                     *
 *           (c) N. Kouwen, 1972-2006                  *
 *                                                     *
 *******************************************************

 Please see file evt_info.txt for information re: this run
 event selection program
```

```
 warning: no damage yet, but if you enter the name
 of an existing event, all old files by that name
 and the series of events following
 will be over written. enter ^c or ^break to stop

 Enter the no of events to create:
35

 No. of months per event file (1 or 12)
1
 type in start of event - eg. yyyy mm dd hh
 please stick with this convention so radar files work
2000 10 01 00
 will you be running the snow melt routines? y/n

y
 enter the snow conversion factor
 e.g.  1.0 is snow wat. eq. in mm, 25. if in inches

1

 name of shd & par files: eg. gr10k, saug 8 char max

glake


 enter the initial soil moisture (0.0-0.33):

 enter -1 if you have antecedent precip. data at precip. gauges
 or enter average watershed value between .0 and .33

.25
 event\20001001.evt              created
 event\event.evt                 created
 event\20001101.evt              created
 event\20001201.evt              created
 event\20010101.evt              created
 event\20010201.evt              created
 event\20010301.evt              created
 event\20010401.evt              created
 event\20010501.evt              created
 event\20010601.evt              created
 event\20010701.evt              created
 event\20010801.evt              created
 event\20010901.evt              created
 event\20011001.evt              created
 event\20011101.evt              created
 event\20011201.evt              created
 event\20020101.evt              created
 event\20020201.evt              created
 event\20020301.evt              created
 event\20020401.evt              created
 event\20020501.evt              created
 event\20020601.evt              created
 event\20020701.evt              created
 event\20020801.evt              created
 event\20020901.evt              created
```

```
 event\20021001.evt             created
 event\20021101.evt             created
 event\20021201.evt             created
 event\20030101.evt             created
 event\20030201.evt             created
 event\20030301.evt             created
 event\20030401.evt             created
 event\20030501.evt             created
 event\20030601.evt             created
 event\20030701.evt             created
 event\20030801.evt             created
**Deallocation for AREA16A arrays failed**

E:\spl\glake>
```

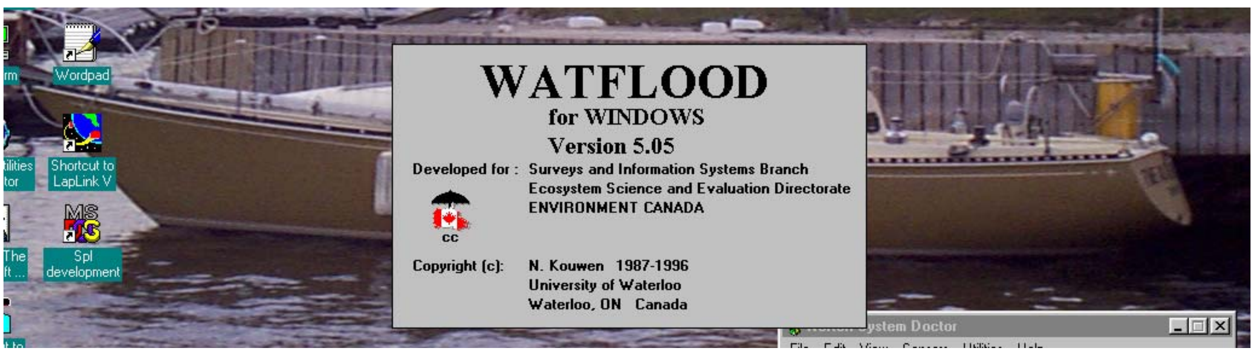
1.4 WATFLOOD TUTORIAL

WATFLOOD is now only available for DOS (or UNIX by special arrangement)

Section 1.3 is a quick introduction to running the program. This tutorial is somewhat more detailed

1.4.1 WATFLOOD for WINDOWS - SADLY, IT's GONE

Due to repeated incompatible changes in VisualBasic™ by Microsoft and upgrades to the WATFLOOD model, it has become impossible to maintain the WATFLOOD for WINDOWS program. Furthermore, it just slows things down. In addition, most new file formats have been made free format or space delimited. This removes the need for spreadsheet-type input pages to format the files. Only the event and parameter files have fixed formats. (Tabs are not allowed in any files as FORTRAN chokes up on them).



Some users manage to do all their WATFLOOD actions within the window environment. However, all programs are DOS based and only a few simple commands are needed to do all the work. This tutorial is now DOS based. One advantage of this is that this tutorial can then be easily used by UNIX users.

1.4.2 DOS (Disk Operating System)

DOS is the command level operating system. The WATFLOOD user needs only learn a few simple commands. The use of batch files is very helpful to speed up repetitive tasks. (more on this later.)

The WATFLOOD graphical interface had to be abandoned because of the continuous changes to MS Visual Basic. It promises not be supported in future versions of WINDOWS so it seemed like a loosing cause. Besides, DOS is faster!

1.4.3 Use Existing Event (e.g., Demonstration Program)

For this tutorial, it is assumed that the assumed that the demonstration dataset for the Grand River and the executables are set up on the C: drive with the file structure as shown in Section 1.3. For non-DOS users, a Directory is a Folder.

To make life easy, batch files can be set up in the c:\spl directory. Since this directory is in your path (if you have followed the instructions in Section 1.3), a batch file becomes a command. For example, create a ce.bat file in c:\splx with the following content:

```
copy event\%1 event\event.evt
```

Then log in to the working directory with the following commands:

```
C:↲      (↲ = enter)
Ce 1993.evt
```

This command will make the 1993.evt event file in the event\ directory the active event. Because the .bat file is in the path, the command will be found and executed. The event file has the names of all input files needed for a particular simulation.

1.4.4 Create New Event (under revision)

Allows the user to set up a new set of data files for a new event. In DOS, run the program EVENTS.EXE and answer the questions. A new set of files for precip., streamflow, etc. will be created. All values in these files will be -1 for missing data (-99 for missing temperature data) and the data will have to be entered through the menus or replaced by data from external sources (e.g. numerical weather model data and/or streamflow from archives). Please see Section ????? for an example.

1.4.5 Demonstration

The file structure is explained in Section 1.3 Getting Started.

Create the c:\spl and unzip the file SPLDADA.ZIP into the \spl folder
Current Watershed: C:\spl\gr10k (assuming that you are on the C: drive)
Event Name: 930103.evt

1.4.6 Editing Files

There are no templates for editing the WATFLOOD files but all input files can be viewed graphically inGreenKenue Green. All new file formats except the event file are free format –

space delimited. **So it is important not to leave spaces in names and descriptors and not leave blanks for missing data.** In a formatted file, a blank is read as zero but this is not the case in a space delimited file. The new formats are to a large extent self-explanatory. It should be possible to edit these files in a spreadsheet.

All WATFLOOD files are described in detail in Chapters 3 to 13.

1.4.7 Initiating Snow Accounting

The snow routine in SPL9 can be accessed by inserting a y in column 41 on line 1 of the event file. For snow, an expanded parameter file is required as described below.

Event file to include snow melt

```
#
:filetype                     .evt
:fileversionno                9.4
:year                         1993
:month                        01
:day                          01
:hour                         00
#
:snwflg                       y                        <required
:sedflg                       n
:vapflg                       y
:smrflg                       n
:resinflg                     n
:tbcflg                       n
:resumflg                     n
:contflg                      n
:routeflg                     n
:crseflg                      n
:Kenueflg                     n
:picflg                       n
:wetflg                       y
:modelflg                     n
:shdflg                       n
:trcflg                       n
:frcflg                       n
#
:intsoilmoisture              0.25 0.25 0.25 0.25 0.25
:rainconvfactor               1.00
:eventprecipscalefactor       1.00
:precipscalefactor            0.00
:eventsnowscalefactor         0.00
:snowscalefactor              0.00
:eventtempscalefactor         0.00
:tempscalefactor              0.00
#
:hoursraindata                744
:hoursflowdata                744
#
:basinfilename                basin\gr10k_shd.r2c
```

```
:parfilename                 basin\gr10k.par
:pointdatalocations          basin\gr10k.pdl
:snowcoverdepletioncurve     basin\gr10k.sdc          <required
:waterqualitydatafile        wqual\gr10k.wqd
#
:pointsoilmoisture           moist\19930101_psm.pt2
:pointprecip                 raing\19930101_rag.tb0
:pointtemps                  tempg\19930101_tag.tb0
:pointnetradiation
:pointhumidity
:pointwind
:pointlongwave
:pointshortwave
:pointatmpressure
#
:streamflowdatafile          strfw\19930101_str.tb0
:reservoirreleasefile        resrl\19930101_rel.tb0
:reservoirinflowfile
:snowcoursefile              snow1\19930101_crs.pt2
#
:radarfile                   raduc\19930101.rad
:rawradarfile                radar\19930101.scn
:clutterfile                 radar\19930101.clt
:griddedinitsnowweq          snow1\19930101_swe.r2c      <required
:griddedinitsoilmoisture     moist\19930101_gsm.r2c
:griddedinitlzs              lzstr\19930101_lzs.r2c
:griddedrainfile             radcl\19930101_met.r2c
:griddedsnowfile
:griddedtemperaturefile      tempr\19930101_tem.r2c      <required
:griddednetradiation
:griddedhumidity
:griddedwind
:griddedlongwave
:griddedshortwave
:griddedatmpressure
:griddedrunoff               runof\19930101_rff.r2c
:griddedrecharge             rchrg\19930101_rch.r2c
:griddedleakage              lkage\19930101_lkg.r2c
#
:noeventstofollow            11
#
event\19930201.evt
event\19930301.evt
event\19930401.evt
event\19930501.evt
event\19930601.evt
event\19930701.evt
event\19930801.evt
event\19930901.evt
event\19931001.evt
event\19931101.evt
event\19931201.evt
eof
```

The use of a "y" or "Y" for the **snwflg** invokes the melt routines. The default is "no snow melt". The lines marked **`<required`** show the additional files required to run the snow melt component. The first is the Snow cover Depletion Curve (sdc) which is a parameter file and therefore located in the \BASIN subdirectory. The next two files yymmdd.swe and yymmdd.tem are the gridded initial snow water equivalent (swe) and the temperature (tem) files. The yyyymmdd_tem.r2c file is normally in hourly time steps. If data is not available hourly, the hours with no data are treated as missing data and the last known temperature is used. The frame header has the time of the data. The program just looks for the next frame with data and fills in the missing hours with the temperature of the last know hour.

The _swe.r2c file is required only for the first event but can be used at the beginning of each subsequent event to update the swe on the watershed by setting the crseflg=y in the event file for that event. For instance, in the `event\19930401.evt` the crseflg can be set to ‘y’ and the swe would be updated for April 1, 1993. The computed value in the model would be discarded.

1.4.8 Scale Factors

Precipitation and temperature data can be adjusted up or down for individual events, all events or by type of precipitation. For precipitation, this is particularly important if some source of data is known to have a bias one way or the other. In the event file, the scaling factors can be set as follows:

Item: (variable name in code)		Purpose:
`:rainconvfactor` (conv)	`1.00`	This is to convert data units for say inches to mm or tenths of mm to mm for this event only.
`:eventprecipscalefactor` (scale)	`1.00`	Scale the precip, for current event only. if(scale.eq.0.0) scale=1.0
`:precipscalefactor` (readscale,scaleall)	`0.00`	Will scale all the precip in all the events in a run if precipscalefactor>0.0 Read in the first event of a run only. Overrides eventprecipscalefactor.
`:eventsnowscalefactor` (scalesnw)	`0.00`	Scale snow precip when temp<0°C in current event only if(scalesnw.eq.0.0) scalesnw=1.0
`:snowscalefactor` (readscalesnw,scaleallsnw)	`0.00`	Will scale all snow precip in all events when temp<0°C if snowscalefactor>0.0 Overrides eventsnowscalefactor.
`:eventtempscalefactor` (scaletem)	`0.00`	Will adjust temperatures in current event if set ≠ 0.0
`:tempscalefactor` (readscaletemp,scalealltem)	`0.00`	Will adjust temperatures in all events if set ≠ 0.0 in the first event. Overrides eventtempscalefactor.

1.5 WATFLOOD Programs - file requirements

WATFLOOD is a set of programs. Most are pre-processors and some are post processors. The table below summarizes the set.

Task	Program & Purpose	Input/output file(s)
Read CAPPI	RADMET.EXE Converts the radar data file to a SPL9 compatible format. This program has to be adapted for each radar source.	yyyymmdd.scn yyyymmdd.rad
Calibrate Radar	CALMET.EXE Fills in missing radar data with rain gauge data if available. It can also be used to adjust the radar data using Brandes method if the parameters are set to do so.	yyyymmdd.rad yyyymmdd_met.r2c
Distribute Rainfall	RAGMET.EXE This program will distribute gauge rainfall using a distance weighting technique. Can be used when no radar data is available at all or you want to ignore radar data.	Bsnm.pdl yyyymmdd.rag yyyymmdd_met.r2c
Distribute Snowcourse	SNW.EXE This entry will distribute snow course data with a distance weighting technique.	Bsnm_shd.r2c yyyymmdd_crs.pt2 yyyymmdd_swe.r2c
Distribute Initial Soil Moisture	SNW.EXE This entry will distribute initial soil moisture data with a distance weighting technique.	Bsnm_shd.r2c yyyymmdd_psm.pt2 yyyymmdd_gsm.r2c
Distribute Temperature	TMP.EXE Will convert point temperatures to gridded temperature fields.	Bsnm.pdl yyyymmdd.tag yyyymmdd_tem.r2c
Run SPLD (debug)	SPLD.EXE. Compiled for maximum error diagnostics in Visual Fortran 6.	See section 1.3.5 Files listed in outfiles.txt
Run SPLX (Speed)	SPLX.EXE. Same as above but compiled for speed and a minimum of error diagnostics.	See section 1.3.5 Files listed in outfiles.txt
Calculate Statistics	STATS.EXE Will calculate a number of statistics for the run	results\spl.csv results\stats.txt

All programs except stats.exe are executed while in the working directory (e.g. c:\spl\gr10k) The stats program is executed while in the c:\spl\bsnm directory.

The entrees are arranged in the order that they are normally executed. Not all programs need to be run for a complete sequence. For instance, to use radar data, the Read CAPPI, Calibrate Radar, and SPLX will have to be executed. Alternatively, Distribute Rainfall, Run SPLX will also be a complete sequence (assuming of course that all other files listed as minimum requirements exist – see Sect. 1.3.5. Distributing the Snowcourse data is an optional activity, depending on whether there is snow or not.

1.5.1 Read CAPPI (RADMET)

RADMET converts the radar data to a rainfall field for the default watershed and surrounding area. This is a custom program that is written to access radar data in the format provided by the radar facility. In the test programs, the radar data consists of a 2 km by 2 km grid containing rainfall data from the King City radar in southern Ontario. Since the formats of radar data vary depending on the source, this program will have to be adapted for each location. In the test program, this program (RADMET) extracts the radar data for the default watershed, converts the data to the proper grid size and writes a RAD file in the \SPL\BSNM\RADUC subdirectory.

1.5.2 Adjust (or Calibrate) Radar Data (CALMET)

CALMET will combine a radar rainfall file with rain gauge data using the Brandes radar rain gauge adjustment algorithm (Section 6.4.2). If there is missing radar data, rain gauge data will be distributed by itself. Should there be missing rain gauge data, radar is adjusted using the last available adjustment factors.

1.5.3 Distribute Rainfall Data (RAGMET)

RAGMET creates a file using the raing\yyymmdd_rag.tb0 file with point precipitation and distributes precipitation using a distance weighting method to each grid in the domain. The input files are basin\bsnm.pdl and raing\yyyymmdd_rag.tb0 and the output file is radcl\yyymmdd_met.r2c The event file is used to get these file names.

For details please see Chapter 6

Note: The extents of the met and tem files are determined by the values given in the bsnm.pdl file. The domain for the met & tem files can be larger than the domain of the shd file.

1.5.4 Distribute Snow Course Data (SNW)

Water equivalent snow cover amounts are distributed over the watershed using a distance weighting method identical to the rainfall distribution application. The program separates snow cover into land cover classes. The input files are basin\bsnm_shd.r2c and snow1\yyyymmdd_crs.pt2 and the output file is snow1\yyymmdd_swe.r2c. The event file is used to get these file names.

For details please see Section 5.1

Note: The size of the swe and gsm files is the same as the size of the domain in the shd file.

1.5.5 Distribute Soil Moisture Data (MOIST)

Initial soil moisture amounts amounts are distributed over the watershed using a distance weighting method identical to the rainfall distribution application. The program separates soil moisture by land cover classes. The input files are basin\bsnm_shd.r2c and moist\yyyymmdd_psm.pt2 and the output file is moist\yyyymmdd_gsm.r2c. The event file is used to get these file names.

For details please see Section 5.2

Note: The size of the swe and gsm files is the same as the size of the domain in the shd file.

1.5.6 Distribute Temperature Data (TMP)

Required only if the snowmelt or evaporation routines are invoked. TMP creates a file using the tempg\yyymmdd_tag.tb0 file with point temperatures and distributes temperature using a distance weighting method to each grid in the domain. The input files are basin\bsnm.pdl and tempr\yyyymmdd_tag.tb0 and the output file is tempr\yyyymmdd_tem.r2c. The event file is used to get these file names.

Note: The extents of the met and tem files are determined by the values given in the bsnm.pdl file. The domain for the met & tem files **can** be larger than the domain of the shd file.

For details please see Chapter 0

Note: There is no provision for the lapse rate in this program. However, a reference elevation and lapse rate can be specified in the .par file for splx.exe

1.5.7 Run SPL9 (SPL)

There are two versions of SPL9: SPLD and SPLX. They are the same except that SPLD is compiled to run in the DEBUG mode. It will provide error messages pointing to problems in the code. SPLD is slow in execution. SPLX is compiled for maximum execution speed but provides no debugging information. If a problems such as division by zero or exceeding array dimensions occur when running SPLX, run SPLD with the same data set, record the error message and send it to kouwen@uwaterloo.ca.

1.5.8 Single Event Mode

With this option, the model is run just once for all the rainfall data previously entered. The soil moisture is not optimized. The value used for the simulation is the one entered when the event was initiated. If the Antecedent Precipitation (AP) was entered for each rain gauge location, these values are converted to initial soil moisture by SPL. Otherwise, the values listed in the EVENT file are used.

1.5.9 Forecast Without Optimization Mode

This selection will result in a run by SPL where the soil moisture entered in the event file by a previous soil moisture optimization run will be used along with all entered rainfall data. This rainfall can include forecast rainfall. Forecast rainfall can be entered in the Enter Rainfall Menu in the same way that recorded rainfall is entered. This option can be used to try different future rainfall scenarios. Soil moistures are optimized only by executing the “Forecast With Optimization Mode”.

1.5.10 Forecast With Optimization Mode

This mode optimizes soil moisture during the initial rise of the hydrograph for the period when rainfall and streamflow are available. This choice will run the model in the forecast mode. SPL9 will run up to about 10 evaluations to match the initial soil moisture to the initial streamflow data. It will do this for the duration of the rainfall or limit the optimization period to the number of hours specified when the streamflow data is saved with the **F1** key or the period of rainfall, whichever is less. So if 24 hours of recorded rainfall and streamflow have been entered, this option will run the model a number of times to fit the calculated to the measured hydrographs. Once the optimization is complete, the model will run for the modeling period when the event was initiated, thus giving a forecast with the data that has been entered for the 24 hours.

It is assumed that in the operational mode we will have the rainfall and streamflow data for the same period, i.e. from the start of the event until the time the forecast is made.

This method of adjusting for all the errors is not desirable and is essentially a makeshift approach that will eventually be replaced by methods to adjust the precipitation fields. While it is a common practice to do this, it is not a good one.

1.5.11 Model Calibration Mode

This mode is intended for experienced users and for development purposes. In this mode, the user can completely destroy the model. However, with experience and proper care, this mode can fine tune the model for local watershed conditions. The parameters provided with the WATFLOOD software are those values found to work in Southern Ontario, Canada and elsewhere for a broad range of watershed conditions.

In the parameter optimization mode, up to 50 parameters can be optimized. The method is further described under "Model Parameters and Optimization" - Section 4.5.

1.5.12 Debug Mode

The Debug mode is primarily for model development and can be used to print the values of most state variables used in the program. The files are sent to the \results directory. Routing variables are sent to RTE.TXT, reservoir stuff to RES.TXT, optimization data to OPT.TXT, and runoff to RFF*n*.TXT. The *n* in RFF*n*.TXT refers to the number of the land cover class. Up to 9 landcovers classes can be displayed through the RFF*n*.TXT files although more classes can be used in the model. A more detailed explanation of the output file is given in Chapter 10.

When the program is run in the Debug mode, a debug level is specified in the basin\bsnm.par file. The level can be set from 0 to 5. The higher the level, the more stuff is printed. A value of 0 is the value for normal runs and is the fastest to execute. A value of 1 will produce the results\rff***n*.txt files (where n=1-9).** A value of 2 is used for program development only.

1.5.13 Forecast Mode Without RADAR Image Scaling

When the CALMET program is executed in this mode, rain gauges are used to fill in missing radar data but rain gauges are ignored when radar data is available. The entire RADAR filed is scaled according to the scaling factor stipulated in the active EVENT file.

1.5.14 Forecast Mode With RADAR Image Scaling

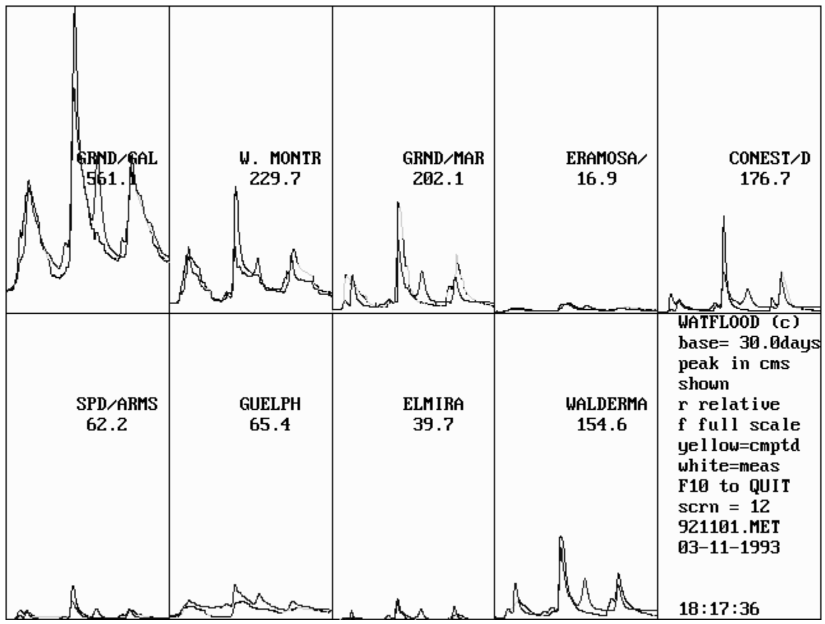
The RADAR rainfall values are scaled by an equal amount for the entire watershed by a factor that minimizes the root mean square error of the computed flows for the period that streamflow and radar data are available.

1.5.15 Plot Hydrographs (SPLPLT) (Really old stuff!)

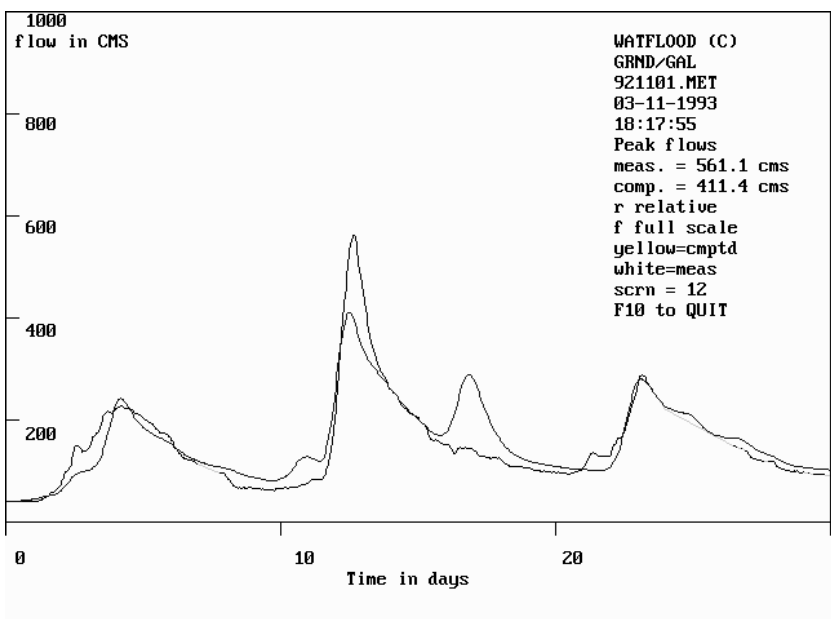
The best way to plot hydrographs is by opening the results\spl.csv file in MS EXCEL™ and plot pairs of columns 2-3, 4-5, etc. Grapher™ (http://www.goldensoftware.com/) is an awesome plotting package and templates can be created to show WATFLOOD output.GreenKenue Green was created to do the post processing for WATFLOOD. TheGreenKenue interface is explained in detail in Chapter 12.

Originally, before Excel™, Grapher™, andGreenKenue, simple plots could be made using SPLPLT.EXE. SPLPLT is a program in compiled QUICKBASIC™ to plot the measured hydrographs and simulation results on the same scale for each gauge site on the screen. This program could now be used as a "quick look" after running a simulation. SPLPLT plots the measured (white) and calculated (yellow) hydrographs. The scale of windows is the same and the peak flow in each window is printed. In the forecast mode, the dots are measured flows that might be available for historic events. In the real-time operational situation, these flows would not be available, as they will occur in the future. The R and F keys toggle the scales of the plots to relative and full scales respectively. Each hydrograph can be viewed in detail by entering En, where n is the number of each hydrograph in the window counted from the left.

An example of the plotted hydrographs is shown below. The horizontal line (if present) denotes the time when the forecast is made. The measured flows are available only up to this time. Measured flows beyond the forecast time are shown as dotted lines.
Example plot of computed hydrographs:



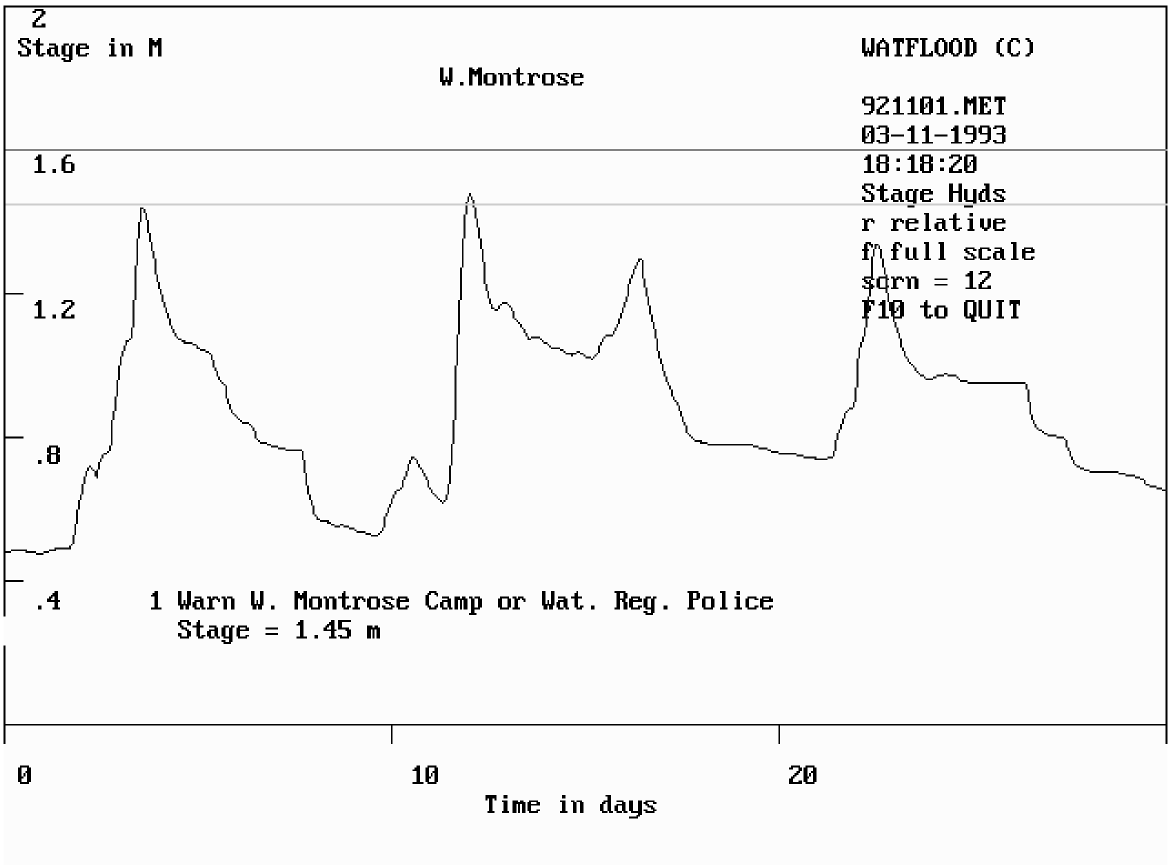
Example of expanded hydrograph plot:



1.5.16 Stage Hydrographs (STGPLT) (Provisional)

When appropriate information is provided through the BASIN\BSNM.STR file (now replaced by basin\bsnm.str, stage hydrographs can be plotted and damage elevations shown on the plot. The **F2** key toggles between flow hydrographs and stage hydrographs. The two are not necessarily at the same location. From DOS, enter the STGPLT command. An example plot follows.

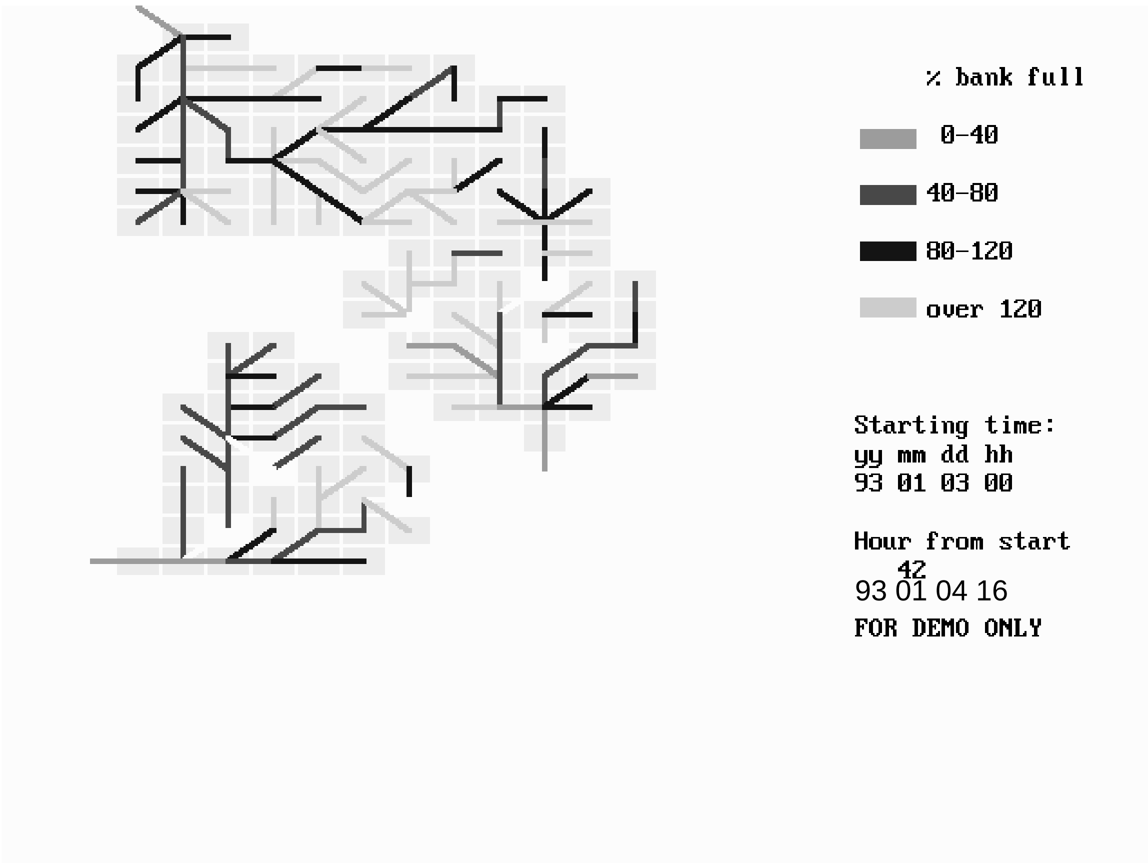
Example of an expanded stage hydrograph:



In the stage plot (above) the blue lines (if present) represent the levels for which warnings have been programmed in the \spl*bsnm*\basin*bsnm*.rag file (See gr10k demo files). Pressing the numeral 1 for the lowest line, 2 for the next line up and so on, will print the warning messages on the screen and change the affected blue line to a red line. In the above example for a site just below a dam, the peaks of the hydrograph just touch the first warning line as shown at the bottom of the figure. In this case, it appears that the dam was operated only to prevent flooding in the W. Montrose Camp.

1.5.17 Flow Animation (MAPPER) (old formats only)

The grids shown correspond to the computational elements in the watershed. The green represents streamflow from 0 to 75% bankfull, orange from 75% to 125% and red shows flows above 125% of bankfull. The bankfull flow is just an approximation because it is based on a geomorphologic relationship. (In the future, a table of bankfull discharge could be added to the basin file and the colour representation can be more realistic. The program automatically steps through a sequence of channel flows and shows the progression of the flood wave through the basin. This feature is under active development.)



1.6 Setting Up a New Event (Out of order)

The program EVENTS.EXE will create a template of a set of files. All data will be shown as missing data and can be replaced with actual data by the user. This program is very useful for creating the headers for each file. Currently under repair.

```
E:\spl\GR10K>

E:\spl\GR10K>events
event selection program

Warning: no damage yet, but if you enter the name of an existing event, all old files by that name
will be overwritten. Enter ^C or ^break to stop.

Type in start of event - e.g., yy mm dd hh
Please stick with this convention so radar files work:
92 10 13 00

            event name = 921013
Will you be running the snow melt routines? y/n
y

Enter the snow conversion factor:
e.g.,  1.0 is snow water equivalent in mm, 25.0 if in inches
1.0

Basin name - e.g. gr10k, saug, hmbr, thms, redd, etc.
gr10k

Conversion factor to convert rain files to mm
1.0

Enter the initial soil moisture:

Enter -1 if you have antecedent precip. data at rain gauges
or enter average watershed value between 0.0 and 0.33
0.25

If you enter a -1, the values at the gauges will be asked for
later, after other data has been entered.
-1

The duration of the event that can be simulated
depends on the time step of the recorded streamflow.
A total of 744 flows can be compared.
So, you can run one month.
```

If you want to run a longer period, chain the events.
No matter what, SPL9 runs at 1 hr intervals when
there is rain, which is always entered at hourly dt`s.

Enter the streamflow time increment in hours [kt]
1

Number of hours of streamflow (max = 8784)
120

Will input be flows ? y/n
y

Enter the climate data time increment in hrs.
12 hours should be the maximum to reflect
daily fluctuations.
6
(The program will now print some reference data.)
(If event exists, confirmation for erasing existing
files will be requested)

Enter initial soil moisture at each gauge.

No blanks please, -1 for missing data.
You have to enter at least 1 +ve value.

at CAMBRIDGE GA
0.3

at Elora ....etc.

More junk is printed out and the program ends.

Notes:
For the streamflow and temperature files, different time intervals can be used. For instance, daily recorded flows and a temperature every 12 hours can be used. When you are prompted for the number of hours of streamflow, it refers to the length of the event. So, if you are running for one month of 31 days, the number of hours of streamflow is 744. The time interval could be 1, 6, or 24. The length of the temperature file is the same (744 in this case) but the time interval can be different. Finally, the rainfall record can be of shorter length. This is to save disk space. Quite often we have a rainfall event that is a lot shorter than the length of the hydrograph. So, why bother to store all the zeros?

1.7 Debugging SPL

The first entry in the PAR file sets the debug level for SPL. As the value is raised from 0 to 5, more state variables in the model are printed in the various LST files in the results directory. There are separate LST files for various parts of the program. The RFF.LST is for the runoff subroutine, the RTE.LST is for the routing subroutine and the RES.LST refers to the reservoir release subroutine. Values of the state variables in each of the classes are printed. The feature exists to allow the user to check that the internal working of the model is in order. For instance, one can check that there is more infiltration in a forest than in a barren area. The continuity of the routing equations can be checked, as can all important processes. The output has headings that correspond to the variable names in the Hydrologic Model Section.

SPL has been compiled in two ways: one for maximum debugging SPLD.EXE and the other for maximum speed SPLX.EXE. If an error appears when running SPLX, not much useful information is printed out. (The operative word is "useful" here.) When this happens, run SPLD and the source of the error may become clear.

1.7.1 Common Problems

	Problem:	Remedy:
File errors	Visual FORTRAN does not seem to like tabs in the data files.	Replace tabs with blanks
	Sometimes old output files are write protected and the program cannot write to a file. The error message is obscure.	Delete old output files and try to run the program again. Sometimes the files are write protect and cannot be deleted. Only a reboot seems to work (Thanks Bill Gates). This error has not been seen for some time.
	Disk full errors. Usually obvious.	When running a long set of events, don't use debug modes. Reduce size of the watflood.wfo file forGreenKenue by specifying 24 hour time increments and/or fewer varables.
	Read errors	Check the spl.txt file to see how far the program was able to read the data. Use debug=1 in the .par file. Much of the input data is echoed in the spl.txt file.
Computing errors	When executing SPLX.EXE with the result of say division by zero or floating point overflow.	Run the debug program SPLD.EXE to determine the line of code where the error occurred. E-mail the details to kouwen@uwaterloo.ca and hope that the error can be located. Most often is is useful to send all the files in an event causing the problem.
	-ve storage errors	• slopes too steep for manning's n or

Manning's n too low for stepp slopes. Also, check overbank Manning's n – it could be too low.

- coefficients change in rel files if grid is in a lake or reservoir
- min time step in the par file too long

Example Crash: Run with SPLD.EXE and get:

```
forrtl: severe (59): list-directed I/O syntax error, unit -5, file Internal
-Directed Read
Image              PC        Routine              Line        Source
spld.exe           006490B9  Unknown               Unknown    Unknown
spld.exe           00648F17  Unknown               Unknown    Unknown
spld.exe           006480F4  Unknown               Unknown    Unknown
spld.exe           00648529  Unknown               Unknown    Unknown
spld.exe           00636783  Unknown               Unknown    Unknown
spld.exe           00635FFD  Unknown               Unknown    Unknown
spld.exe           004129C4  EF_MODULE_mp_PARS         870    EF_Module.f
spld.exe           00415A7D  EF_MODULE_mp_PARS        1424    EF_Module.f
spld.exe           00415CBC  EF_MODULE_mp_PARS        1471    EF_Module.f
spld.exe           00519B68  READ_FLOW_EF              107    read_flow_ef.f
spld.exe           0058B5D5  SUB                       197    sub.f
spld.exe           004BFA9C  OPTIONS                   186    options.f
spld.exe           0058A809  SPL9                     1122    spl9.f
spld.exe           00675449  Unknown               Unknown    Unknown
spld.exe           00665064  Unknown               Unknown    Unknown
kernel32.dll       7C817067  Unknown               Unknown    Unknown
```

In this case, the error was cause by an unrecognized projection when reading the yyyymmdd_str,tb0 file:

```
:Projection          LAMBERT_AZIMUTHAL
:Ellipsoid           NONE
:Zone                NONE
```

All you need is:

```
:Projection               CARTESIAN
```

\ instead of / in the event files

If you get output on the screen like this:

```
******************************************
 *                                        *
 *      ver=9.5.55  Feb. 11/09            *  gr10k_shd.r2c
 *      runtime    10:10:21               *  gr10k.par
 *      rundate  2009-02-20               *  basin
 *                                        *  basin
 *   debug level   1 ynynnnnnnnynnnnnnn   *  strfw
 *   channel type  0 123456789012345678   *  resrl
```

```
*                                       *   snow1
*             WATFLOOD(tm)              *   resrl
*                                       *   radcl
*    copyright (c) by n kouwen 1985-2008 *   tempr
*    university of waterloo,  canada     *
*                                       *
*****************************************

*****************************************
*    Writing a WATFLOOD.WFO file         *
*****************************************
Old format met files not accepted
Please create EF _met.r2c files & rerun
```

This happens when you probably have forward slashes / in the event files.

1.8 Output Files

Most output from SPL is written to the \RESULTS directory and overwrites previous output files. If you want to save any of these files (for instance the plot and list files), they have to be renamed and/or saved in another directory.

Each time you run SPLX.EXE an outfiles.new file is created that list the default SPLX output file set. You can edit this file to send the files anywhere you would like but you need to make sure the directories specified are created first.

Default file name	File use
results/spl.txt	Data echo mostly
results/opt.txt	Optimization tracking file
results/res.txt	Reservoir data echo and variable tracking
results/rff.txt	Useless file
results/rte.txt	River routing data echo and variable tracking
results/pic.txt	Mapper – flow animation (under repair)
results/snw.txt	Snow data echo and variable tracking
results/spl.plt	Observed and computed flows for SPLPLT.EXE
results/stg.plt	Observed and computed stage for STGPLT.EXE
results/spl.csv	Observed and computed flows for plotting programs (Grapher, Excel)
results/swe.r2c	Gridded SWE – set kenueflg = 'y'
results/snw.csv	Snow data echo and variable tracking
results/strout.1	Computed .str files – can be used to compare new vs. old runs
results/snwdebug.txt	Snow data echo and variable tracking
results/watflood.wfo	SPLX output forGreenKenue input
results/error.xyz	Gridded streamflow error for each sub-basin
results/error.r2s	Gridded streamflow error for each sub-basin
results/wetland.csv	Wetland data echo and variable tracking
results/sed.csv	Sediment data echo and variable tracking
results/qdwpr.txt	Reach inflows in DWOPER format
results/spl_dly.csv	Observed and computed daily streamflows (if hourly input is used)
results/ gridflow.r2c	Grid outflow inGreenKenue format – set kenueflg = 'y'
results/resin.txt	Reservoir inflows if known
results/evap.txt	Evaporation data echo and variable tracking
results/evt_means.csv	Mean observed and computed flow by event
results/peaks.txt	Event peaks – observed and computed
results/volumes.txt	Event volumes – observed and computed
results/spl_mly.csv	Observed and computed monthly streamflows (if shorted dt is used)
results/leakage.dat	Gridded recharge in hourly timestep. (for MODFLOW say)
results/lake_sd.txt	Lake information (levels etc.)
results/rff01.txt	State variables land cover class 1 – hourly time step (set iopt=1 in .par)
results/rff02.txt	State variables land cover class 2 – hourly time step (set iopt=1 in .par)
results/rff03.txt	State variables land cover class 3 – hourly time step (set iopt=1 in .par)
results/rff04.txt	State variables land cover class 4 – hourly time step (set iopt=1 in .par)
results/rff05.txt	State variables land cover class 5 – hourly time step (set iopt=1 in .par)
results/rff06.txt	State variables land cover class 6 – hourly time step (set iopt=1 in .par)
results/rff07.txt	State variables land cover class 7 – hourly time step (set iopt=1 in .par)
results/rff08.txt	State variables land cover class 8 – hourly time step (set iopt=1 in .par)
results/rff09.txt	State variables land cover class 9 – hourly time step (set iopt=1 in .par)
etc.	
results/tracer.csv	Various streamflow components depending on choice of tracer
results/tracerMB.csv	Tracer variable tracking
results/tracer_debug.csv	Tracer variable tracking
results/tracerWET.csv	Wetland tracer variable tracking
results/tracerWETMB.csv	Tracer variable tracking
results/evapsep.txt	
results/watbal1.csv	Water balance at program initiation
results/watbal2.csv	Water balance at program termination
spl_info.txt	Program warnings and errors
scratch5	
scratch6	

1.9 Do's and Don'ts

1.9.1 Do's

- To allow the creation of a precipitation adjustment file (PAF), the flow stations must be ordered in the downstream direction
- Do group (order) the stations by region **or** land cover dominance for easier calibration. (In Canada, use the order of the WSC station numbers).
- Do avoid sub-watersheds smaller or of the order of the area of one grid. Probably they are not useful although they can give good results. No more than one flow station can be located in one grid.
- Do check the modeled drainage area for each station against the published drainage area for that station. **Frac** can be adjusted for each grid to get matching areas.
- When adjusting flow paths, when you change a drainage direction for a grid, make sure the new receiving grid has a lower elevation.
- Do avoid sub-watersheds smaller or of the order of the area of one grid. Probably they are not useful although they can give good results. No more than one flow station can be located in one grid.
- Do check the modeled drainage area for each station against the published drainage area for that station. **Frac** can be adjusted for each grid to get matching areas.
- When adjusting flow paths, when you change a drainage direction for a grid, make sure the new receiving grid has a lower elevation.
- Use the 10 profiles for the 10 longest river reaches generated by the BSN.EXE program to spot flat reaches in the river when these are caused by flat spots in the DEM. Flat reaches cause lake-like routing conditions and result in really flat hydrograhs that do not represent reality. This can be avoided by entering a minimum slope when executing the BSN.EXE program. A minimum slope of 0.0001 works quite well.
- Do use yearly events for long simulations.
- If your data is daily precip use RAGMET.exe to disaggregate the daily amounts
- If your temperature is daily max and min, create a yyyymmdd_tag.tb0 file to reflect diurnal fluctuations. 4 or 6 hour time intervals are ok. If you lack programming skills, create 12 hour increments alternating the high and low temperatures.
- If your flow data is daily, do create yyyymmdd_str.tb0 files with 24 hour increments. SPLX.exe will automatically calculate daily means for comparisons.
- In Canada, it is preferable to use lat-long coordinates to enable use of theGreenKenue data base of the Canada Water Survey drainage layer. It is also better if you cross UTM zones.
- When using lat-long coordinates, to have roughly square grids, your E-W grid size must be approxiamately 1.5 times your N-S grid size. This varies with lattidue of course.
- For the map file, make sure you leave blank rows and columns outside the boundaries of the watershed outline. (KENUE will do this automatically but if you set you own origin, extent & delta's you need to ensure you do this also)

1.9.2 Don't's

- Do not make the grid size too small. It just wastes time & probably does not give better results.
- Do not expect an indiscriminate optimization of a whole bunch of parameters to give results that are any good.
- Do not resample a DEM to match the WATFLOOD grid size
- Do not resample a land cover map to match the WATFLOOD grid size
- Do not use polygons inGreenKenue to obtain the land cover percentages for WATFLOOD – use GEOTIF's. Convert polygons to a geotiff. (Poligons within polygons result in double counting of the land cover class)
- **Do not divide daily precipitation into 24 eaqual amounts**. Just enter the deltat in the header, enter the data at that time increment and let RAGMET disaggregate

1.10 Help (free for students – others: not so much)

You can get help by sending details of the problem to Nick Kouwen:
E-MAIL kouwen@ uwaterloo.ca
Please send the set of files that give you grief to kouwen@ uwaterloo.ca

2 HYDROLOGICAL MODEL

2.1 Introduction

The model SPL9 is a physically-based simulation model of the hydrologic budget of a watershed. As with such models, it represents only a small part of the overall physical processes occurring in nature. The model is aimed at flood forecasting and long term f simulation using distributed precipitation data from radar or numerical weather models. The processes modeled include interception, infiltration, evaporation, snow accumulation and ablation, interflow, recharge, baseflow, and overland and channel routing.

The model is programmed in FORTRAN 95 with dynamic memory allocation to make it suitable for use on any modern computing platform. Typically, the program takes approximately 6 minutes to run for a 1,000,000 km^2 watershed with a 15 km grid (4000 grid points), 1-year simulation, and hourly time steps on a 3.2 Ghz Pentium 4™.

The following sections describe the model and the input requirements in detail. In addition to SPL9, there are a number of support programs to provide for data preparation and output presentation. The programs RADMET and RAGMET may be used to convert rain gage data to the square grid SPL9 input format; BSN may be used to assemble and create a 'basin file' for SPL9.

The model features the Hooke and Jeeves (1961) automatic pattern search optimization algorithm taken from Monro (1971). The program can be run to automatically determine which combination of parameters best fit measured conditions. The parameters for optimization are soil permeability, overland flow roughness, channel roughness, depression storage, and an upper zone depletion factor. After optimization, a new parameter file called NEW.PAR is automatically put on disk.

2.2 Modeling Aspects

Before describing the watershed model in detail, it should be pointed out that with the equations describing the runoff-routing process, the values of many parameters need to be determined. While some may be assigned standard well-known values, others may be subject to great variations and uncertainty. Where possible, standard values are used, but those parameters which cannot be predicted are fitted using a pattern search optimization technique. In the following sections, those parameters which are optimized are shown.

The modeling process begins with the addition of rainfall to the watershed. The various processes shown in Fig. 2.1 are described below.

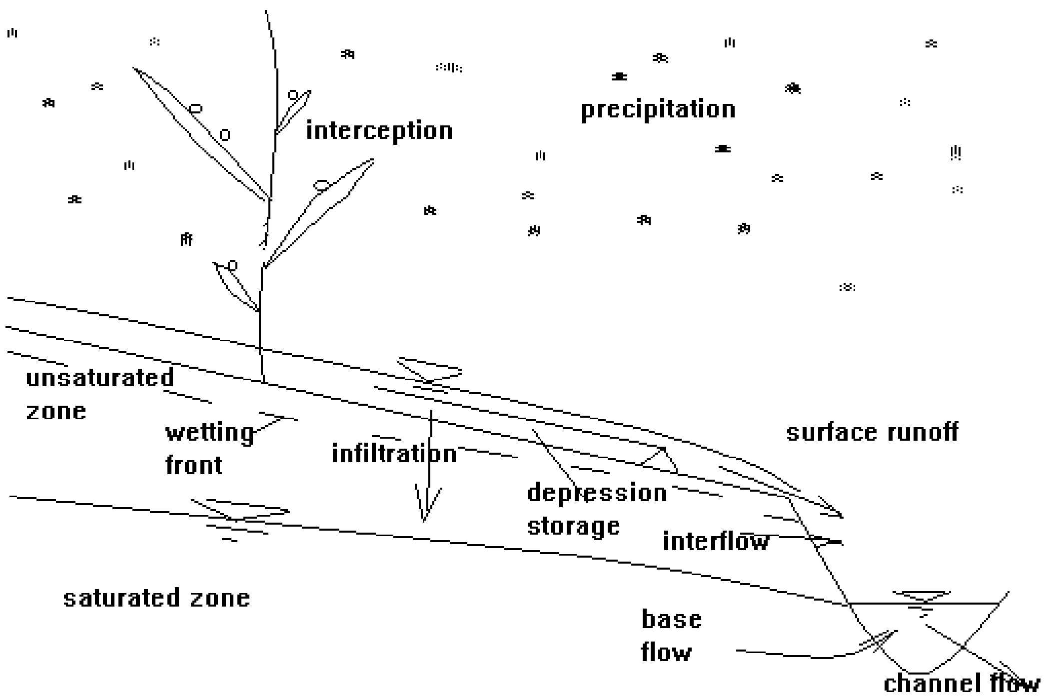


Figure 2.1 - Schematic of the runoff algorithm

2.2.1 Surface Storage

The ASCE Manual of Engineering Practice No. 37 for the design and construction of sanitary and storm sewers (ASCE, 1969) gives typical values of retention for various surface types. Table 2.1 is a listing of depression storage for various conditions and values are seen to vary greatly. Because of the uncertainty associated with depression storage, this is one of the parameters included for optimization, but it is ranked 5th out of 5 in priority.

As with interception, it is assumed that the limiting value of depression storage D_S is reached exponentially (Linsley et al., 1949):

$$D_S = S_d (1 - e^{-kP_e}) \qquad (2.1)$$

where D_S is the depression storage, P_e is the accumulated rainfall excess, S_d is the maximum value of depression storage and is reached exponentially depending on the cumulative rainfall and k is a constant.

Table 2.1 - Surface detention values.

Type of Surface	Detention (mm) (ASCE, 1969)	SPL9
Impervious urban areas	1.25	1.25
Pervious urban areas	3.0	2.0
Smooth cultivated land	1.3 - 3.0	2.0
Good pasture	5.0	3.0
Forest litter	8.0	10.0

2.2.2 Infiltration

Due to the importance of the infiltration process in runoff calculations, but also because infiltration capacity is such a highly variable quantity, this process requires a great deal of attention in any hydrologic model. Many formulae are used (see for instance Viessman et al., 1977) and the choice always is left open to criticism. However, in keeping with the underlying philosophy of keeping the model based on identifiable physical processes, the Philip formula (Philip, 1954) is chosen as representing the important physical aspects of infiltration process. It also readily incorporates the notion of surface detention. The Philip formula is identical to the Green-Ampt equation (Green & Ampt, 1911) except that it includes the head due to surface ponding as well as the capillary potential. The Green-Ampt approach assumes the ponding head is insignificant when compared to the potential head. Figure 2.2 is a schematic of the infiltration process. The Philip formula (Philip, 1954) expresses the rate of infiltration as:

$$\frac{dF}{dt} = K\left[1 + \frac{(m - m_o)(Pot + D1)}{F}\right] \tag{2.2}$$

where:

F	=	total depth of infiltrated water in mm.
t	=	time in hour
K	=	hydraulic conductivity in mm/hour **(optimized)**
m	=	the average moisture content of the soil to the depth of the wetting front
m_0	=	initial soil moisture content - based on API calculation or input
Pot	=	capillary potential at the wetting front in mm.
D1	=	depth of water on the soil surface

Equation 2.2 represents the physical process of infiltration in that the pressure gradient acting on the infiltrating water is used to determine the flow using Darcy's Law. Because of the uncertainty of its effective value over the basin, it is an optimized parameter. The values of K range from 2 mm/hr for forested areas to 0.3 mm/hr for bare or sparsely vegetated areas. These values are very low but this is because water tends to flow to low areas and infiltrate from ponds. The result is that when the value of K is expressed for the whole area, its effective value is greatly reduced because of large areas that do not contribute to infiltration except for short periods.

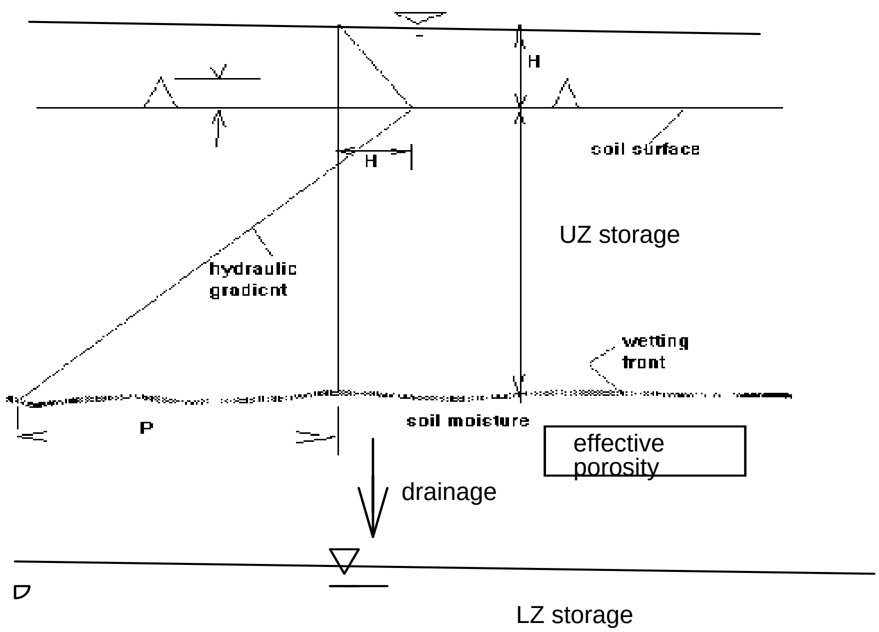


Figure 2.2 - Schematic of the infiltration process

Initially, the infiltration capacity is very high because of the shallow depth of the wetting front. This causes a very large pressure gradient inducing high infiltration. However, as the wetting front descends, the pressure gradient is quickly reduced, thus reducing the potential infiltration rate. Using the information in Philip (1954) relating permeability to capillary potential, the following relationship provides the capillary potential:

$$Pot = 250 \log (K) + 100 \qquad (2.3)$$

where:

Pot	=	the capillary potential in mm
K	=	hydraulic conductivity in mm/s.

The potential head calculated by Eq. 2.3 compares very well with values reported by Rawls and Brakensiek (1983). Water depth on the soil surface is continually modified to reflect the net precipitation input, infiltration, and overland flow discharge.

2.2.3 Initial Soil Moisture

SPL is a three layer model:

UZ	Upper zone storage (saturated)
IZ	Intermediate zone storage (unsaturated)
LZ	Lower zone storage (saturated)

The initial moisture m_o refers to the moisture content of the intermediate zone (IZ) and through the Philip formula, affects the infiltration rate of rain and melt water. The initial value of m_o is related to the antecedent precipitation index by:

$$m_o = API/100 \qquad (2.4)$$

with a maximum value equal to the porosity of the soil. The API in hour i is given by:

$$API_i = K\,(API_{i-1}) + P_i \qquad (2.5)$$

where K is a recession constant and in the model is represented by A5 and P_i is the precipitation in hour i in mm.

During the simulation, the API is modified on an hourly basis for each element according to:

$$m_o\,(t+\Delta t) = A5 * m_o\,(t) + P_i/100 \qquad (2.6)$$

where A5 is an optimized parameter (approximate value is 0.985 -0.998 on an hourly basis). When the temperature < 0 ^{O}C the soil moisture is not changed.

2.3 Potential Evapotranspiration

T. Neff.

Any one of three methods for estimating evapotranspiration can be used. Where radiation data are available, the Priestley-Taylor equation (Eq. 2.7) can be used to estimate the potential evapotranspiration (PET). The radiation data resides in a gridded format in the ET\DDMMYY.FLX files. Where only temperature data are available, the Hargreaves equation can be used to estimate the potential evapotranspiration (Eq. 2.9). Gridded hourly temperature data are required for the snow melt simulation. Where neither temperature nor radiation data are available, the original method of estimating evapotranspiration from published values can be used. It should be noted that these published values are considered to be the potential evapotranspiration rates (possibly measured by a class A evaporation pan), similar to those potential rates estimated by the Priestley-Taylor and Hargreaves equations.

2.3.1 Priestley - Taylor Equation

The Priestley-Taylor model (Priestley and Taylor, 1972) is a modification of Penman's more theoretical equation. Used in areas of low moisture stress, the two equations have produced estimates within ± 5% of each other (Shuttleworth and Calder, 1979). An empirical approximation of the Penman combination equation is made by the Priestley-Taylor to eliminate the need for input data other than radiation. The adequacy of the assumptions made in the Priestley-Taylor equation has been validated by a review of 30 water balance studies in which it was commonly found that, in vegetated areas with no water deficit or very small deficits, approximately 95% of the annual evaporative demand was supplied by radiation (Stagnitti et al., 1989).

It is reasoned that under ideal conditions evapotranspiration would eventually attain a rate of equilibrium for an air mass moving across a vegetation layer with an abundant supply of water, the air mass would become saturated and the actual rate of evapotranspiration (AET) would be equal to the Penman rate of potential evapotranspiration. Under these conditions evapotranspiration is referred to as equilibrium potential evapotranspiration (PET_{eq}). The mass transfer term in the Penman combination equation approaches zero and the radiation terms dominate. Priestley and Taylor (1972) found that the AET from well watered vegetation was generally higher than the equilibrium potential rate and could be estimated by multiplying the PET_{eq} by a factor (α) equal to 1.26:

$$PET = \alpha \frac{s(T_a)}{s(T_a) + \gamma} \left(K_n + L_n \right) \cdot \frac{1}{\rho_w \lambda_v} \qquad (2.7)$$

where K_n is the short-wave radiation, L_n is the long-wave radiation, $s(T_a)$ is the slope of the saturation-vapour pressure versus temperature curve, γ is the psychrometric constant, ρ_w is the mass density of water, and λ_v is the latent heat of vaporization. Although the value of α may vary throughout the day (Munro, 1979), there is general agreement that a daily average value of 1.26 is applicable in humid climates (De Bruin and Keijman, 1979; Stewart and Rouse, 1976; Shuttleworth and Calder, 1979), and temperate hardwood swamps (Munro, 1979). Morton (1983) notes that the value of 1.26, estimated by Priestley and Taylor, was developed using data from both moist vegetated and water surfaces. Morton has recommended that the value be increased slightly to 1.32 for estimates from vegetated areas as a result of the increase in surface roughness (Morton, 1983; Brutsaert and Stricker, 1979). Generally, the coefficient α for an expansive saturated surface is usually greater than 1.0. This means that true equilibrium potential evapotranspiration rarely occurs; there is always some component of advection energy that increases the actual evapotranspiration. Higher values of α, ranging up to 1.74, have been recommended for estimating potential evapotranspiration in more arid regions (ASCE, 1990).

The α coefficient may also have a seasonal variation (De Bruin and Keijman, 1979), depending on the climate being modeled. The study by DeBruin and Keijman (1979) indicated a variation in α with minimum values occurring during the mid-summer when radiation inputs were at their peak, and maxima during the spring and autumn (winter values were not determined) when in relation to advective effects, radiation inputs were large. The equation has performed very well, not only for open water bodies, but also for vegetated regions. The satisfactory performance of the equation is probably because the incoming solar radiation has some influence on both the physiological and the meteorological controls of evapotranspiration. A value of 1.26 has been used for alpha throughout. Temporal variations in alpha as suggested by researchers are emulated by the conversion factors used in the calculation of AET from the PET which is described below.

Estimates of PET using the Priestley-Taylor equation have been adjusted as a function of the difference in albedo at the site where measurements of radiation have been made (albe), and the land classes with differing albedo (alb). In the adjustment, it is assumed that the ground heat flux (which should be included in the net all-wave radiation data if it is available) contributes 5% of the overall energy. The remaining 95% of the potential evapotranspiration estimate is scaled as a function of the difference in albedo:

$$PET = 0.05 \cdot PET + 0.95 \cdot PET \cdot \frac{1 - alb}{1 - albe} . \qquad (2.8)$$

2.3.2 Hargreaves Equation

The Hargreaves model is empirical in nature and with some recent modifications (Hargreaves and Samani, 1982) takes the form:

$$PET = 0.0075 \cdot R_a \cdot C_t \cdot \delta_t^{1/2} \cdot T_{avg.d} \qquad (2.9)$$

where PET is the potential evapotranspiration rate (mm d^{-1}), R_a is the total incoming extraterrestrial solar radiation in the same units as evaporation (mm for WATFLOOD), C_t is a temperature reduction coefficient which is a function of relative humidity (w_a), δ_t is the difference between the mean monthly maximum and mean monthly minimum temperatures (°F) {mxmn in the monthly_climate_normals.txt file), and $T_{avg.d}$ is the mean temperature (°F) in the time step. WATFLOOD uses a modified version of this equation to account for measuements of temperature in degrees Celcius. A relationship between the temperature reduction coefficient and the relative humidity has been regressed from measurements made at 18 locations in the United States to account for the reduction in PET with increased relative humidity:

$$\begin{aligned} C_t &= 0.035(100 - w_a)^{1/3} & w_a \geq 54\% \\ C_t &= 0.125 & w_a < 54\% \end{aligned} \qquad (2.10)$$

The following empirical simplifications permit the use of the formula with the sole input of temperature data, latitude (ϕ in degrees), and the Julian day (J) to estimate incoming solar energy (Duffie and Beckman, 1980):

$$R_a = 15.392 \cdot d_r \left(w_s \cdot \sin\phi \cdot \sin\delta + \cos\phi \cdot \cos\delta \cdot \sin w_s \right) \quad (2.11)$$

where d_r is the relative distance between the earth and the sun given by:

$$d_r = 1 + 0.033 \cdot \cos\left(\frac{2\pi \cdot J}{365} \right) \quad (2.12)$$

δ is the solar declination (radians) defined by:

$$\delta = 0.4093 \cdot \sin\left(\frac{2\pi \cdot J}{365} - 1.405 \right) \quad (2.13)$$

and w_s is the sunset hour angle (radians) given by:

$$w_s = \arccos\left(-\tan\phi \cdot \tan\delta \right) \quad (2.14)$$

With these modifications, the Hargreaves equation is more universally applicable, as it does not require the observed solar input.

A number of independent investigations have compared the estimates of evapotranspiration from different models. The Hargreaves equation consistently produces accurate estimates of potential evapotranspiration (as measured using energy balance techniques, the Penman combination equation, or lysimetric observations), and in some cases, much better than estimates made using other methods (Hargreaves and Samani, 1982; Mohan, 1991; Saeed, 1986). Mohan (1991) found the Hargreaves equation to have a high correlation with the Penman combination equation for estimates of average weekly evapotranspiration in humid regions.

The reason for the success with such an empirical model is because of the theory which it reflects. In a comparison with the Penman combination equation, the model considers the following: the incoming solar energy (R_a), the average amount of energy removed in the form of sensible heat from the amount available for evaporation (δ_t), an approximation of the ratio of $s(T_a)$ to the sum of $s(T_a)$ and γ by using the temperature (T), and a reduction in the driving gradient when the vapour pressure deficit is small (C_t).

2.4 Actual Evapotranspiration (by T. Neff.)

2.4.1 Soil Moisture Coefficient

Up to three coefficients have been applied to reduce the calculated PET to the AET. The first coefficient, the Upper Zone Storage Indicator (UZSI), estimates the evapotranspiration as a function of the soil moisture (UZS). Evapotranspiration is assumed to occur at the potential rate if the soil moisture is at a level of saturation (SAT) since the PET equations have been shown to provide accurate estimates under these conditions. The rate of evapotranspiration is reduced to a fraction of the potential evapotranspiration for values of soil moisture below the saturation down to zero at the permanent wilting point (PWP). The fraction is calculated by interpolating the soil moisture between the soil moisture capacity at saturation and the permanent wilting point at 1.0 and 0, respectively. That is:

$$\mathrm{UZSI} = \left[\frac{(\mathrm{UZS} - \mathrm{PWP})}{(\mathrm{SAT} - \mathrm{PWP})}\right]^{1/2} \qquad (2.15)$$

The root of the fraction is used to simulate the increased difficulty with which moisture is extracted by vegetation as the soil dries. WATFLOOD does not calculate the percent soil moisture; instead, the model calculates the moisture in the upper layer of soil as a depth of water, the Upper Zone Storage (UZS). During the calibration of the model, the value of the field capacity, called the retention factor (RETN), is optimized. Drainage from the upper zone storage is constrained to zero when the UZS is less than the RETN. Values of UZS below the RETN cannot be drained by the gravitational force, which is the driving force in the interflow and drainage to lower soil layers. Volumes of water in the Upper Zone Storage that are less than the RETN can only be drained by evapotranspiration. In this way, RETN is similar to the volume of water at which point the soil moisture is equivalent to the field capacity. Therefore, a theoretical depth (FULL) at which 100 percent of the soil pores is full of water can be calculated as the ratio of the RETN to the field capacity (FCAP).

$$\mathrm{FULL} = \frac{\mathrm{RETN}}{\mathrm{FCAP}} \qquad (2.16)$$

Theoretical depths of the PWP and SAT can be estimated by specifying the percent soil moisture at the permanent wilting point and at the saturation point (SPORE), and calculating the product of these values with FULL.

$$\mathrm{PWP} = \mathrm{FFCAP} \times \mathrm{FULL} \qquad (2.17)$$

$$\mathrm{SAT} = \mathrm{SPORE} \times \mathrm{FULL} \qquad (2.18)$$

2.4.2 Soil Temperature Coefficient

The second reduction coefficient (FPET2) applied to the PET to reduce it to the AET is based on the total number of the degree-days. The number of degree-days is accumulated beginning on January 1. Initially, the value of the degree-day will decrease to a negative number (approximately -500 for the Grand River in Ontario) and then rises when heat is added in the spring. Internal to the code, the accumulation of degree-days is reset on this minimun-value day of each year. The value of actual TTO is written out to the file \results\evap.txt for each hour for the "test" grid and for the largest % land cover class in that grid and should be used for establishing the value of Temp3. Temp3 should not be less than 0.0. For the Grand River, a value of 200 seems to work well. The higher this value, the slower will be the start of evaporation in the spring. It is best to experiment with the value of Temp3 until the spring hydrograph and the soil moisture values are reasonable. You can also use the rff*n*.txt file to plot cumulative precip and evaporation to see if the evaporated water amounts are what you would expect during the non-frozen months.

FPET2 is calculated as follows:

$$FPET2 = \frac{TTO - TTOMIN}{Temp3} \quad 0.02 < FPET2 < 1.0 \tag{2.19}$$

where TTO are the accumulated degree-days after January 1 of each year and TTOMIN is the lowest value reached during the winter.

The initial value of TTO can be set with the TTON parameter in the .par file.

2.4.3 Forest Vegetation CoefficientFTALL

The third coefficient used to reduce the PET is a function of the vegetation type. For tall vegetation, it has been shown that the evapotranspiration is significantly less than the potential rate (Price, 1987; Black et al., 1984; Giles et al., 1985; Spittlehouse and Black, 1981; McNaughton and Black, 1973). Typical values of AET from tall vegetation range from 60-90% of the PET. Stagnitti et al. (1989) used a coefficient of reduction of 0.60 for the Priestley-Taylor evapotranspiration to estimate the AET from tall vegetation. Past simulations have successfully used a reduction coefficient of 0.70 applied to the PET rate for the coniferous land classification. However, this parameter can be changed in the ET parameter file.

FTALL = 0.70 for Tall Vegetation

FTALL = 1.00 for Short Vegetation

2.4.4 Calculating AET from PET – land classes

The final reduction in transpiration is a function of the interception. Evaporation of intercepted water is assumed to occur preferentially to soil water transpiration. The sum of the atmospheric resistance and stomatal resistance to water evaporating from stomatal cavities is assumed to be greater than the atmospheric resistance to water evaporating from the surface of the vegetation. In each time step, the transpiration is reduced to zero during periods when interception evaporation (IET) is occurring. When the IET is less than the PET the reduction coefficients are applied to the difference to determine the rate of transpiration. Finally,

$$\begin{aligned}
&\text{AET} = \text{PET} && \text{if PET} < \text{IET}, \\
&\text{AET} = (\text{PET} - \text{IET}) \cdot \text{UZSI} \cdot \text{FPET2} \cdot \text{FTALL} \cdot \text{ETP} && \text{if PET} > \text{IET}, \\
&\text{AET} = \text{PET} \cdot \text{UZSI} \cdot \text{FPET2} \cdot \text{FTALL} \cdot \text{ETP} && \text{if IET} = 0, \text{ and} \\
&\text{AET} = \text{PET} && \text{for water (rivers / lakes)}
\end{aligned} \qquad (2.20)$$

This estimate of AET is the combination of the water transpired from vegetation and the water evaporated from bare soils and open water.

2.4.5 Calculating AET – water class (lakes)

Evaporation from a water body is calculated as

$$\text{AET} = \text{FPET} * \text{PET}$$

2.5 Interception (by T. Neff.)

The procedure used for tracking interception storage and IET follows the model developed by Linsley et al. (1949). This method calculates the total possible interception as the sum of the maximum canopy storage (h) and the amount of IET during the storm event (mm). Typical values of maximum canopy storage for deciduous forests range from 1.2-1.5mm/m^2 (Rowe, 1983). During the dormant season these storage values should be reduced accordingly to reflect the loss of leaf area. Logically, land classes with less dense vegetation will have lower values of h.

The amount of water in interception storage is reduced through IET which is estimated as a function of the PET in mm. During a precipitation event, the rate of interception evaporation is assumed to equal the rate of PET from a saturated surface because the interception surface is open to the atmosphere and is covered with water. Researchers have shown that, in fact, the evaporation rate of intercepted water can be well in excess of the potential rate (Stewart, 1977; Stewart and Thom, 1973). Therefore, after the cessation of precipitation, the IET rate is set to the product of the PET and a factor (FPET) which can range up to 4.0. Interception evaporation continues at this rate until the storage is reduced to zero, at which point IET is zero, or another precipitation event occurs and IET is reset to the potential rate. This increase (FPET) in the PET is substantiated by the fact that with precipitation there can be considerable wind-producing advective conditions which are not completely accounted for by the temperature and radiation-based equations. The FPET factor is not applied during the storm event because of the high humidity that usually exists concurrently with precipitation. These short-term increases in humidity are not considered when using longer-term averages of humidity for input data. Thus,

$$\mathrm{IET} = \mathrm{FPET} \cdot \mathrm{PET} \qquad (2.21)$$

where:

FPET = 1.0 during a precipitation event, and
FPET ≈ 3.0 after rainfall cessation

The fraction F of the total precipitation captured in interception storage (V), in mm, is calculated as a fraction of the sum (X2) of the maximum storage and the interception evaporation, in mm:

$$\mathrm{V} = \mathrm{F} \cdot \mathrm{X2} \qquad (2.22)$$

and

$$\mathrm{X2} = \mathrm{h} + \mathrm{IET} = \mathrm{h} + \mathrm{FPET} \cdot \mathrm{PET} \qquad (2.23)$$

The value of F depends on the total precipitation from the beginning of the storm. By defining the fraction as some function of the base of the natural logarithm to an exponent equal to the total precipitation since the beginning of the storm (P_i in mm), the rate of interception is established as decaying exponentially. That is to say, the rate of interception decreases as water is intercepted and is given by:

$$\text{fraction} = e^{-P_i / X2} \qquad (2.24)$$

and

$$\mathrm{V} = \mathrm{X2} \cdot e^{-P_i / X2} \qquad (2.25)$$

As a result of evaporating the intercepted water at the potential rate, the amount of water lost from interception storage can exceed the maximum value of the storage. While under certain conditions it might be possible for the volume of interception evaporation to exceed the interception storage (periods of moderate precipitation and highly advective conditions), this is not likely for the typical situation, particularly when h is relatively small compared to the PET. The IET has therefore been limited to the lesser of the h or the PET. This constraint affects the interception evaporation and interception storage for land classes with small values of h (e.g. the Fen class). Thus,

$$\mathrm{X2} = \mathrm{h} + \mathrm{FPET} \cdot \mathrm{PET} \qquad \text{if PET} \le \mathrm{h} \qquad (2.26)$$

or

$$\mathrm{X2} = \mathrm{h} + \mathrm{FPET} \cdot \mathrm{h} \qquad \text{if PET} > \mathrm{h} \qquad (2.27)$$

For each time step in each element and in each land class, the throughfall is calculated as the precipitation less the amount of precipitation captured in the interception storage:

$$\text{Throughfall} = \text{Precipitation} - (V_t - V_{t-1}) - \text{PET} \qquad (2.28)$$

where t indicates the time step. It is assumed that the intercepted water can only be removed from interception storage through evaporation. Lack of interception detention can be approximated by increasing the total throughfall (reducing h), although the timing of the throughfall would not be precise.

-

2.6 Interflow

Infiltrated water is initially what is commonly referred to as the Upper Zone Storage (UZS). Water within this layer percolates downward or is exfiltrated to nearby water courses, and is called interflow. Interflow is represented by a simple storage-discharge relation:

$$DUZ = REC * (UZS-RETN) *S_i \qquad (2.29)$$

where:

DUZ	=	is the depth of upper zone storage released as interflow in mm
REC	=	a dimensionless coefficient (optimized)
UZS	=	water accumulation in the upper zone region in mm
RETN	=	retention
S_i	=	internal slope (land surface slope)

REC is a coefficient, which cannot be predicted, and is therefore estimated through optimization. Values of REC are expressed as the depletion fraction per hour of the UZ storage that is drained off each hour ***when the internal slope (overland slope) is 1.0(i.e. a, 45^{o}slope).*** DUZ is calculated simultaneously with UZ to LZ drainage (see below). Reasonable values for REC are approximately 1 - 10. The best way to set an initial value for this parameter is to plot the value

Figure 2.6.1 Shows how the internal slope of a grid is related to the contour density within that grid. The greater the number of countours in a grid, the steeper the slope and the quicker the overland flow and interflow. Interflow is assumed to be Darcian flow so proportion to the gradient.

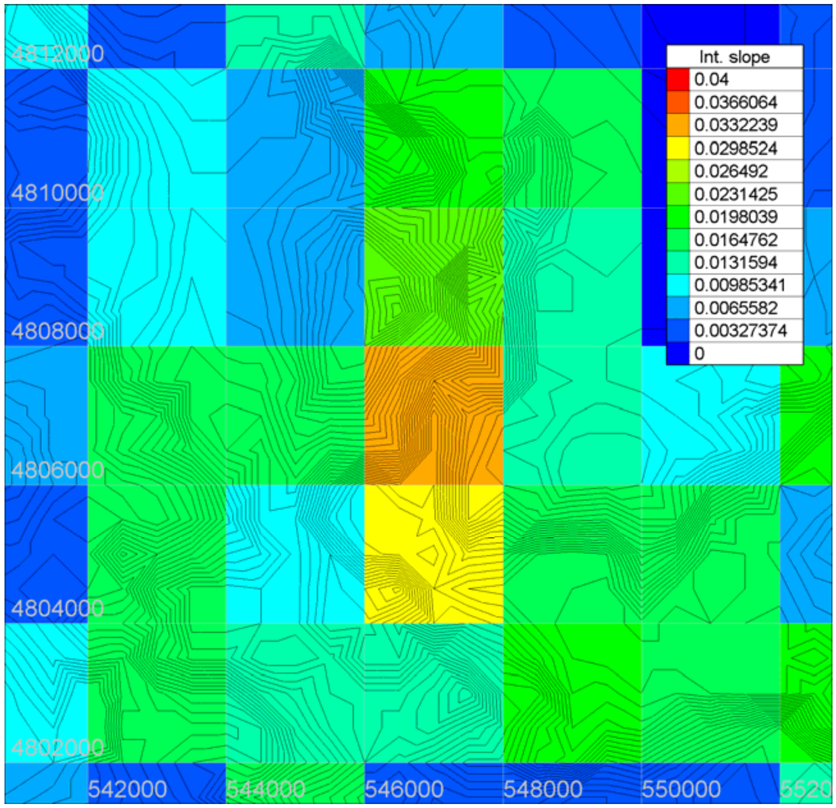


Figure 2.6.1 - Internal slope

2.7 UZ to LZ Drainage (or Ground Water Recharge)

Upper zone to lower zone drainage is a simple function as for interflow:

$$DRNG = AK2 * (UZS - RETN) \tag{2.30}$$

and is calculted simultaneously to the interflow. If the combined interflow and drainage depths exceed the available upper zone storage, the amounts are prorated according to the amouts calculated. AK2 is an intermideate zone (IZ) resistence parameter and RETN is the specific retention of the soil in the upper zone. Retained water can be evaporated but not drained. The state of the IZ is not considered to affect this process at this point, although it does affect the value of m_o and, as a result, affects the infiltration rate.

2.8 Overland flow

When the infiltration capacity is exceeded by the water supply, and the depression storage has been satisfied, water is discharged to the channel drainage system. The relationship employed is based on the Manning formula and takes the form:

$$Qr = (D1 - D_s)^{1.67} S_i^{0.5} A / R3 \qquad (2.31)$$

Where:

Qr = channel inflow in m^3/s
D1= surface storage in mm
D_s = depression storage capacity in mm (optimized)
A = the area of the basin element in m^2
R3 = combined roughness and channel length parameter (optimized)

The R3 parameter lacks physical meaning in that it includes roughness, drainage density effects, and the effects of the shape of elementary contributing areas (for instance, average overland flow path before the water reaches a stream). For a basic time step of one hour, values of R3 range from 1.0 for impervious surfaces in urban areas to approximately 100 for forested areas. These values serve only to show the relative effects of surface roughness and drainage density. Because of its nature, R3 obviously can only be evaluated through optimization.

In SPL9, Eqs. 2.1 to 2.27 are used separately for each land class in each computational element.

2.9 Base Flow

The initial base flow discharge is determined from a measured stream hydrograph at the basin outlet. The base flow contributed by each basin sub-element is found by prorating it to the total basin area. A ground water depletion function is used to gradually diminish the base flow. Ground water is replenished by drainage of the UZS (Eq. 2.30).

$$QLZ = LZF * LZS^{PWR} \qquad (2.32)$$

where:

LZF = lower zone function
PWR = exponent on the lower zone storage in the lower zone funnction.

There is only one LZS for each grid. All classes, except impervious surfaces, within an element contribute to the same LZS.

For flood forecasting, the model is not sensitive to this value because the events modeled are of relatively short duration and base flow is assumed not to change a great deal during the simulation. In addition, in the areas studied, base flow is insignificant compared to flood flows. However, for long-term simulation, this parameter takes on added significance and low flows especially are significantly affected by LZF and PWR. These values should be optimized with longer periods that have dry and wet periods. Not enough experience has been accumulated to indicate what the range of values might be. Initial calibrations indicate values of LZF = 10^{-6} to 10^{-4} and PWR = 1.5 - 2.5 but values may end up outside these ranges.

Dry weather flows are sensitive to the initial base flow. For this reason, it is important to start long term simulations during a dry spell, when river flows are base flow only, and not higher due to recent UZ drainage contributions.

2.10 Total Runoff

The total inflow to the river system is found by adding the surface runoff from both the pervious and the impervious areas, the interflow, and the base flow. These flows are all added to the channel flow from upsream grids and routed though the grid to the next downstream grid.

2.11 Routing Model

The routing of water through the channel system is accomplished using a storage routing technique. More sophisticated routing models are available but the application of such models does not appear to promise more accurate flood forecasts than the simple routing model. In fact, for large watersheds, differences between the routing methods may well be smaller than the noise in the data (Ponce, 1990). When the hydrologic errors are also considered, the use of more sophisticated and necessarily more computationally intensive methods are not warranted for flood forecasting on rivers where dynamic effects can be ignored. In addition, simple routing can be based on a minimal amount of river cross-section and profile data. The method involves a straightforward application of the continuity equation:

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{\Delta t} \qquad (2.33)$$

where

$I_{1,2}$	=	inflow to the reach consisting of overland flow, interflow, baseflow, and channel flow from all contributing upstream basin elements in m^3/s
$O_{1,2}$	=	outflow from the reach in m^3/s
$S_{1,2}$	=	storage in the reach in m^3
Δt	=	time step of the routing in seconds

The subscripts 1 and 2 indicate the quantities at the beginning and the end of the time step. The flow is related to the storage through the Manning formula as described in detail below..

The channel inflow is the sum of the discharge entering the channel at the upstream boundary (Q), and any lateral flow (qin) added or removed by hydrologic processes during the current time step:

$$I = Q + q_{in} \tag{2.34}$$

where I, Q, and qin are in cubic meters per second.

The lateral flow (qin) is the sum of interflow (qint), overland flow (q1), baseflow (qlz), precipitation falling on the stream (qstream), less evaporation (qloss):

$$q_{in} = q + q_{int} + q_1 + q_{lz} + q_{stream} - q_{loss} \tag{2.35}$$

The original cross section shape for WATFLOOD was triangular and the roughness coefficient R2 in the par file included the effects of varying width-depth ratios. However, most river cross sections are rectangular with flat bottoms and near vertical sides. To make the channel section more realistic and also to allow use of the familiar Manning's n instead of R2, the program was been modified (Rev. 9.2.11, September 2005). If the titles R1n and R2n are used instead of R1 and R2 on the par file, the program will expect Manning's n as the roughness parameter. **ALSO,** the width-depth ratio **widep** for the river channel in the par file **must** be specified for all channels as well as the channels through wetlands. The overbank cross section is assumed to be triangular with a constant width to depth ratio of 100:1. The left and right overbank areas are combined into one computational unit.

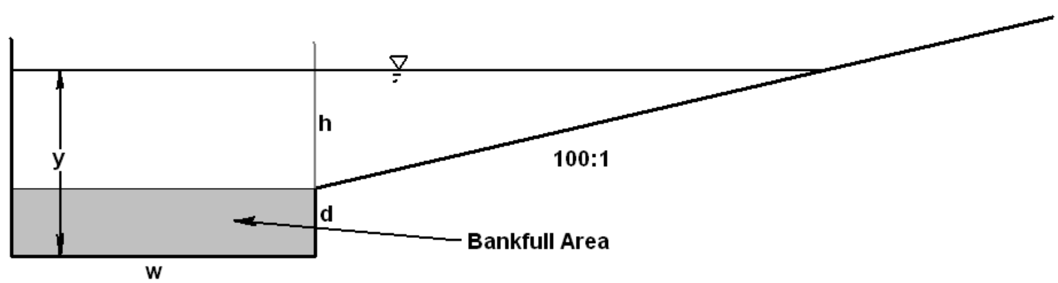


Figure 2.3 Representative river cross section

2.11.1 Main channel flow:

The following notation is used:

y = depth of flow = d+h
w = main channel width
A = Main channel cross sectional area of the flow
R = hydraulic radius main channel
Over = overbank area (not shaded)

Start with Manning's formula:

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \quad (2.36)$$

A= wy   Assume: R~y   so   R~A/w

$$Q = \frac{1}{n} \frac{1}{w^{0.667}} A^{1.667} S^{0.5} \quad (2.37)$$

This formula works for the main channel flow only.

2.11.2 Channel flow & overbank flow:

A triangular cross-section is assumed with a width-depth ratio of 100. The overbank area is the total cross sectional flow area – bankfull area:

$$\text{overbank area} = wh + 100h^2 \quad (2.38)$$

Solve for h using the quadratic equation:

$$h = \frac{-1 + \sqrt{1 + 4 * 100 * \text{overbankarea}}}{2 * 100} \quad (2.39)$$

$$Q = \frac{1}{n} \frac{1}{w^{0.667}} A^{1.667} S^{0.5} + \frac{0.17}{n_{ob}} (\text{over} - h * w)^{1.333} S^{0.5} \quad (2.40)$$

2.11.3 Lake effect on routing   <<new

In some locations there are hundreds of small lakes along creeks and rivers that greatly affect the timing of the hydrograph. For a small number of lakes, or just the larger ones, storage-discharge relationships can be set up in the **rel.tb0** files **(See Section 7.2.1).** To account for the effect of many small, the parameter Rlake can be used as a multiplier to Manning's n. It can be optimized.

2.11.4 Bankfull – Drainage area relationship

A requirement for running SPL9 is a relation to give the bankfull channel cross sectional area at any point in the basin. This is accomplished by measuring the channel width and depth at various points in the watershed, computing the bankfull cross sectional area and fitting a relation such that the channel cross-section area is given as a function of drainage area (Fig. 2.4). This relation is used to determine if the flow exceeds the channel's capacity at any point at any time.

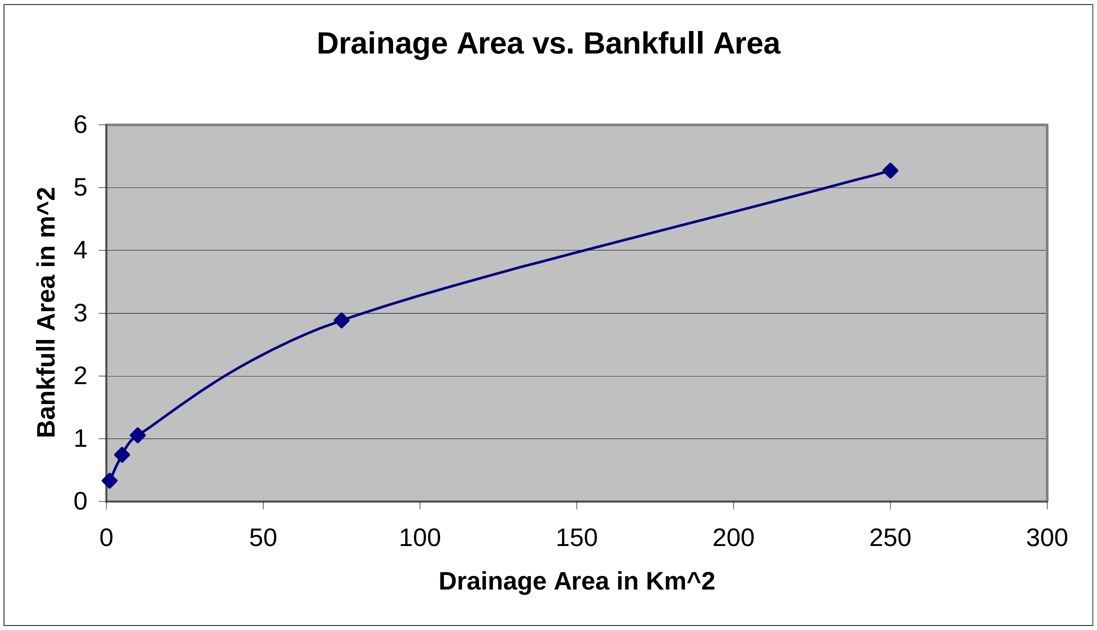


Figure 2.4 Example of bankfull area as a function of drainage area

Two equations can be used to calculate the bankfull cross sectional area. The original WATFLOOD equation is:

$$\text{Bankfull area} = \text{aa2} + \text{aa3} * (\text{drainage area})^{\text{aa4}} \qquad (2.41)$$

This expression is difficult to fit unless an optimization scheme is used. To allow a function to be derived using MS EXCEL™, the following function is used if aa4 is set to 0.0:

$$\text{Bankfull area} = 10.0^{(\text{aa2}*\log(\text{drainage area}))} + \text{aa3} \quad (\text{aa4} = 0.0) \qquad (2.42)$$

The aa2, aa3 and aa4 parameters can be specified for each river class in the .par file.

2.12 Wetland Routing (Bank Storage Model)

The design of the wetland routing routine is based on the work of McKillop (1997). The wetland routing routine has been provided in McKillop's Appendix B-1. Any water within the channel is routed using channel routing, and any water in wetland storage is routed using wetland routing. The interaction between the wetland and the channel is governed by the Dupuis-Forchheimer discharge formula as described by Bear (1979):

$$qo_{wet_{1,2}} = \frac{kcond}{2}(h^2_{wet_{1,2}} - h^2_{cha_{1,2}}) \qquad (2.43)$$

where: qowet is the lateral wetland outflow in cubic meters per second
kcond is the hydraulic conductivity in meters per second,
hwet is the height of water in the wetland in meters
hcha is the height of water in the channel in meters

The wetland outflow is positive if it is from the wetland into the channel, and turns negative if the channel feeds the wetland. In the model, qo_{wet} is the outflow per km of channel-wetland interface so Eq. 2.43 is multiplied by 2*gridlength. Figure 2.5 graphically illustrates the hydrologic interaction of the wetland and the channel:

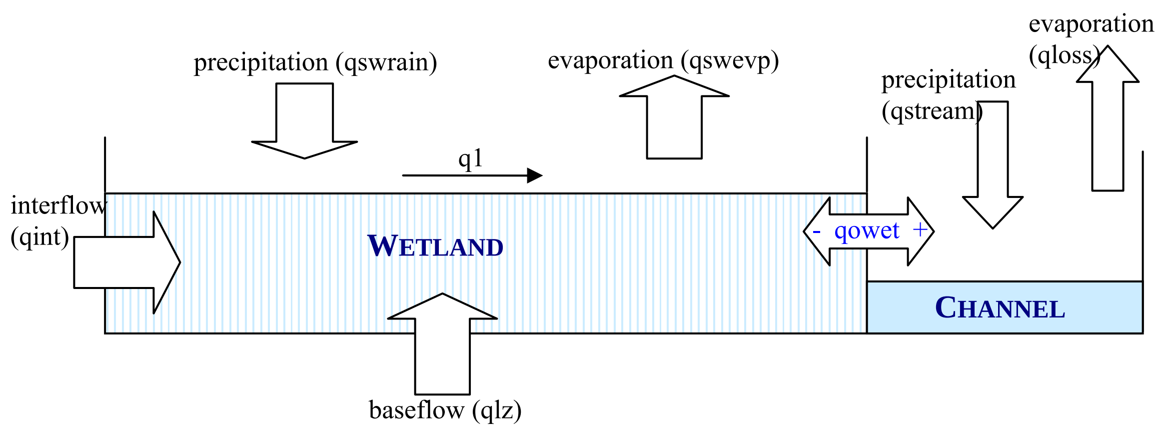


Figure 2.5: Hydrologic interaction between the wetland and the channel.

During wetland-storage routing, the lateral inflow (qin) contributing to total channel inflow (I) from equation 2.40 is reduced to the sum of streamflow (qstream) and wetland outflow (qowet), less the evaporation losses (qloss):

$$q_{in} = q_{in} + q_{stream} - q_{loss} + qo_{wet} \tag{2.45}$$

If water is moving from the channel into the wetland, qowet will be negative and will therefore reduce the total channel inflow (I). The lateral interflow (qint), overland flow (q1), and baseflow (qlz) instead contribute to the wetland inflow (qiwet), and not the channel inflow (qin):

$$qi_{wet} = q_{int} + q_1 + q_{lz} + q_{swrain} - q_{swevp} \tag{2.46}$$

where all flows are in cubic meters per second.

The flow contribution from precipitation (qswrain) is calculated in the wetland runoff routine and is added directly onto the wetland surface, and qswevp is the evaporation loss off of the wetland surface from the wetland evaporation routine.

The wetland outflows (qowet 1,2) contribute to the inflows I_1 and I_2 of equation 2.33. qowet can be +ve or –ve depending on the relative water levels in the channel and the wetland. Thus, the wetland routing routine uses the same storage continuity relationship as was used for channel routing. To use the wetland (or bank storage) model, three properties of the wetland are require to be entered in the parameter file: wetland width, wetland porosity (theta), the hydraulic resistance coefficient for the Dupuis-Forchheimer equation (kcond), and the channel width to depth ratio (widep). The wetland width is calculated by BSN.EXE by taking the fraction of the grid composed of wetlands ($frac_{wet}$) times the grid area divided by the reach length of the main channel in the grid. I.e., it is an average wetland width and is assumed the border the channel on both banks. Theta, widep and kcond are entered in the .par file.

To use the wetland or bank storage function, the wetland flag (wetflg) must be set to 'y' in the event file. Further, theta can be used as a switch to turn on or off the wetland function in a particular river class. When theta is set to a –ve value, the wetland routine is bypassed for that river class.

2.12.1 Wetlands - Fens and Bogs

If only one wetland class is present in the map file, it can be either coupled or uncoupled from the flow routing by the wetfld. However, in many actual situations, wetlands are divided into fens and bogs which are hydraulically coupled and uncoupled from the river passing through the grid. With bsn.exe, wetlands can be separated into bogs and fens. Usually a split of approximately 15-20% gives good results. Please see Section 3.3.13 for instructions in this regard.

2.13 Lake Routing

2.13.1 Reservoirs and Large Lakes

A lake can be modelled using a two step procedure. First mark each grid that is **all or part** of a lake with a reach number in the map file **except** if a streamflow station is located near the lake within the grid or if the grid is part of a gauged watershed. (The program will not produce a hydrograph if a station is in a lake grid and the watershed area will be incorrect if the grid is part of the lake). Number the lakes from 1 to the number of lakes. If a lake covers all or part of multiple adjoining grids, mark each grid **touched** by that lake with the same reach number. The land in a grid will still be treated as land for the purpose of calculating runoff but when a grid is marked as a lake, channel routing is replaced by the lake routing module. Reservoirs with controlled outlets should also be marked as lakes and should be placed ahead of the naturally controlled outlets. See Section 3.3.10 for an example of setting up the reach numbers in the bsnm.map file. Once the lakes have been located, the outlets should be located in the outlet grid and entered into the yyddmm.rel file as shown in Sect. 7.2.

Water is routed through the lakes using a user-specified function. Either a power function

$$\text{Outflow} = b1\ \text{Storage}^{b2} \qquad (2.47)$$

or a polynomial like

$$\text{Outflow} = b1*\text{storage} + b2*\text{storage}^2 + b3*\text{storage}^3 + b4*\text{storage}^4 + b5*\text{storage}^5 \quad (2.48)$$

must be used. If b3, b4 and b5 =0.0, a power function with coefficients b1 and b2 is assumed. If b3 or b4 or b5 ≠ 0.0, a polynomial is assumed. For the latter, b3 must have a value although b4 and/or b5 can be 0.0. However, it is very important that the coefficient of the highest order term is +ve. Also, the function must be monotonically increasing and must be forced through the origin. Each function should be plotted to ensure that the function reasonable represents the data of the storage-discharge curve. An example input file is shown in Section 7.2.

For controlled reservoirs, the releases must be entered in the resrl\yymmdd_rel.tbo file. The controlled reservoirs are indicated by b1 and b2 = 0.0 in the header of the yymmdd.rel file.

NOTES:

1. If all lakes have rule curves and there are no release data in the rel files, do not enter any data under the :EndHeader line
2. OR, if you do, be sure to put in the proper number of lines for that event. (no of hours/deltat)
3. If values are entered in the first event and –ve values are entered for b1-b5 for subsequent events, only the values given for the first event will be used. By entering values for a later event, new rules can be imposed at a later date.

2.13.2 Instream Lakes (numerous)

There are situations where there are many small lakes too numerous to program with storage-discharge rules. For these lakes, the channel in each grid will be widened to preserve the water surface area as determined from the land cover map. To include the hydrograph attenuation characteristics, Manning’s n is modified for that grid according to the formula:

R2n = r2n(n) * water_area(n) / channel_area(n) * a2 (2.48a)

for water_area(n) > channel_area(n) where a2 is a coefficient specified in the parameter file and channel_area is the default channel area based on the watershed’s geomorphology. 1.0 is a good starting value and can be adjusted up or down depending on the timing of hydrographs downstream from reached with many lakes. One or two small lakes do not have much of an effect.

2.14 Lake Evaporation

Lake evaporation can only occur for open water. There is no ice cover model in WATFLOOD but there is a work-around using the snow cover depletion curves (SDC). Snow is accumulated on water in the same fashion as on land. Since water is assumed to be ice covered if there is snow, the SDC curve can be used to specify how much of the water area is snow covered for a given amount of SWE, it in effect specifies how much of the water area is covered with ice. The data below indicates there are 2 points on the SDC curve for class no. 5. For zero depth of snow, the snow covered area is 0.0 while for 10 mm of SWE, the snow covered area is 100 % (1.000)

```
2    5  -600.000   water          ii=5
0.000      0.000                  sca(j),depth(j)
1.000     10.000
```

This means that when 10 mm of SWE has accumulated, the lake will be 100% frozen over and evaporation is halted. If the 10.000 is changed to 100.00, it will mean that the lake will not be 100% covered until 100 mm of SWE have fallen as snow. In this way, the rate of freeze up and open water can be controlled. The reverse happens during the thaw.

2.15 Snowmelt Model

J. Donald and L. Hamlin.

In WATFLOOD, snow-free and snow covered areas are modelled separately. Initially, for a deep snow pack, 100% of the area will be covered but as the snow melts, bare ground will appear. Following this, energy to melt snow is applied only to the snow covered area and as the snow covered area is reduced, surface storage and upper zone storage for the previously snow covered are is transferred to the snow free area.

2.15.1 Temperature Index Model

The temperature index algorithm used in the WATFLOOD/SPL9 is based on the National Weather Service River Flow Forecast system by Anderson (1973). The well-known algorithm is used in many operational models and is given by Eq. 2-35:

$$M = MF\,(T_a - T_{base}) \tag{2.35}$$

where M is the daily snowmelt depth (mm), MF is the melt factor, rate of melt per degree per unit time (mm $C^{-1}h^{-1}$), T_a is the air temperature (^{0}C), and T_{base} is the temperature at which the snow begins to melt (^{0}C).

The general heat balance is divided into two phases: melt and non-melt periods. For non-melt periods (i.e., snow pack is not ripe), there are two possibilities. The snow pack can either be heating or cooling, depending on the temperatures of the air and the snow pack. The snow cover heat deficit (represented as mm of water equivalent) provides a cumulative account of the heat required to warm the snow pack to the “ripe” phase. The change in heat deficit is based on the difference between the Antecedent Temperature Index (ATI) and the air temperature (T_a) as well as the addition of any precipitation (i.e., snow, S_f). The change in heat of the snow surface (ΔH_s), when the air temperature is less than or equal to 0 ^{o}C during a time step, is expressed as:

$$\Delta H_s = NMF(ATI_1 - T_{a2}) - \frac{S_f T_a}{160} \tag{2.36}$$

where ΔH_s is the change in heat deficit (mm of water equivalent), NMF is the negative melt factor – rate of change in heat deficit based on air temperature per unit time (mm.^{o}C/day), ATI is the antecedent temperature index, and S_f is the amount of snow fallen per unit time represented as snow water equivalent (SWE) in mm.

The first portion of Eq. 2-36 accounts for the difference between the snow pack surface temperature and the overlying air temperature converted to mm of water equivalent using the negative melt factor (NMF). In the NWSRFS model (Anderson, 1973), the value of the negative melt factor increased through the ablation period based on a sine curve function having a typical maximum value of 0.500 $mm.hr^{-1}.°C^{-1}$. In WATFLOOD, the negative melt factor does not vary through the ablation period and its value is set in the parameter file for each vegetation class. Donald (1992) found that values of 0.200 $mm.hr^{-1}.°C^{-1}$ produced reasonable results. The latter portion of Eq. 2-36 represents the change in heat resulting from the addition of new snow assuming that the temperature of the snow is equal to the air temperature (where T_a is less than or equal to 0 °C). If the air temperature is greater than 0 °C, the change in heat (ΔH_s) is assumed to equal zero and the heat deficit is reduced by the maximum probable melt as calculated in Eq. 2-35 (i.e., snow pack is warmed by the amount of maximum probable melt).

The Antecedent Temperature Index (ATI) in Eq. 2-36 is based on the transient heat flow equation for semi-infinite solids as reproduced in Eq. 2-37:

$$T(x, t) = T_o + \text{erf}\left\{\frac{x}{2\sqrt{\alpha t}}\right\}(T_i - T_o) \qquad (2.37)$$

where T(x, t) is the temperature at some depth "x" at time "t" (°C), T_o is the altered surface temperature (°C), T_i is the original surface temperature(°C), α is the thermal diffusivity (m^2/s) ($\alpha = \kappa/\rho.c$ which gives a value of $3.97 \cdot 10^{-07}$ for typical κ value listed below), κ is the thermal conductivity ($W \cdot m^{-2} \cdot °C^{-1}$) (common value for snow is 0.25 for a density of 300$kg \cdot m^{-3}$), and c is the specific heat of snow ($KJ \cdot kg^{-1} \cdot °C^{-1}$) (assume that it can be approximated by $c_{ice} = 2.1\ KJ \cdot kg^{-1} \cdot °C^{-1}$).

In WATFLOOD, the erf function is expressed by the lumped term "tipm", and can be altered in the parameter file for each land cover class. This is important because it supposedly accounts for the changes in temperature resulting from all the energy fluxes acting on the snow pack which vary substantially between different vegetation regimes. Theoretically, this parameter should also vary through the ablation period based on changes in snow pack density. However, in both Anderson's model (Anderson, 1973) and in WATFLOOD, it is held constant to simplify the computations. This simplification is used as snow pack densities can vary significantly both temporally and spatially, which results in difficulties in temporally updating operational models. Hence, an average value of the snow pack density is set (in the parameter file) for each vegetation class and is typically in the range of 0.10 to 0.35.

The Antecedent Temperature Index (ATI) is adjusted each time step using Eq. 2-38, which follows the same theory as Eq. 2-37. The only difference between the two equations is that the latter represents only the change in temperature of a solid resulting from a change in air temperature, whereas Eq. 2-38 supposedly represents all the energy fluxes acting on a snow pack.

$$ATI_2 = ATI_1 + tipm(T_a - ATI_1) \qquad (2.38)$$

where ATI_1 is the Antecedent Temperature Index at time "t-1" (°C) and ATI_2 is the Antecedent Temperature Index at time "t" (°C).

Anderson (1973) comments on typical values for "tipm" which can theoretically vary between 0 and 1 but commonly are between 0.1 (deep surface layer) and 0.5 (shallow surface layer). In his initial study using the NWSRFS model, Anderson found that a value of 0.5 produced reasonable results. In a later report by Anderson (1976) a value of 0.1 was used. Donald (1992) used value of 0.2 and managed to achieve good results for the Grand River basin in southern Ontario. In all studies to date using WATFLOOD, a value of 0.2 has been used primarily because of the lack of understanding of what the parameter actually represents.

There is an interrelationship between the tipm and NMF parameters as the value of tipm controls the magnitude of the Antecedent Temperature Index (ATI) (see Eq. 2-38). Anderson (1973) suggests fixing the value of tipm and using optimization techniques to determine the value for the negative melt factor (NMF). WATFLOOD doesn't allow for either parameter to be optimized but both are specified in the parameter file. Donald (1992) used values of 0.20 for both the NMF and the tipm parameters for all vegetation classes and this produced good results for the Grand River basin in southern Ontario.

The application of this algorithm in the SPL9 model varies from most other applications because an hourly time step is used to estimate the amount of snowmelt. Some authors have suggested that hourly time increments should not be used for temperature index models as the hour-to-hour fluctuations in melting conditions are controlled largely by the radiation component of the energy budget (Rango and Martinec, 1995). However, recent studies using the temperature index model included in SPL9 have shown that remarkably good results can be obtained (see Donald, 1992; Seglenieks, 1994; Hamlin, 1996). The transferability of these parameters in time and space can be problematic and sometimes leads to poor validation results. Another difference is that in WATFLOOD, the snow cover depletion curves are for each of the land cover classes rather than for sub-watersheds as in Anderson (1973).

2.15.2 Radiation-Temperature Index Algorithm

The radiation-temperature index model (Eq. 2-39), recently incorporated (but not avaialble to users) into the WATFLOOD model (Hamlin, 1996), is a combination of the temperature index and the surface radiation budget, as proposed by Martinec and de Quervain (1975), Ambach (1988), and Martinec (1989):

$$M = MF\,(T_a - T_{base}) + rn \cdot R \qquad (2.39)$$

where M is snowmelt depth (mm), MF is the melt factor, rate of melt per degree per unit time (mm. $^0C^{-1}.hr^{-1}$), T_a is the average air temperature over the time unit (^0C), T_{base} is the base temperature at which the snow will begin to melt (^0C), rn is the conversion factor for energy flux density to mm of snowmelt per hour (mm.h^{-1}.(W.m^{-2})$^{-1}$), and R is the net all-wave radiation acting on the snow pack (W.m^{-2}).

The first portion of the equation represents the turbulent energy components of the energy budget, namely the sensible and latent heat exchanges. The latter portion of Eq. 2-39 incorporates the surface radiation budget similar to that used in energy balance models. This landscape-based algorithm should provide a more stable parameterization than the temperature index algorithm since the radiative and turbulent energy components of the energy budget are separated creating a more physically-based model because it circumvents any lack of correlation found between net all-wave radiation and air temperature.

The same snow pack heat balance accounting system used in the temperature index model is also used for the radiation-temperature index model. No adjustments are made to the snow pack heat balance to incorporate a radiation component as this would significantly complicate the model and require considerably more detailed information about the spatial variations of terrain, aspect, vegetation cover and meteorologic conditions. The most significant being the variations in net long- and short wave radiation acting on the snowpack resulting from spatially varying vegetation cover densities.

3 WATERSHED DATA REQUIREMENTS

3.1 Georeference Requirements

All basin and rainfall data is based on coordinate system. The UTM or LAT-LONG coordinates are convenient for this purpose, but any grid can be used. The grid origin is at the bottom left hand corner of the map, with north at the top. This cannot be changed. In any case, it is the usual way we look at maps.

The grid for all the goereferenced data is originally entered in the MAP file either manually through the MAPUTIL program, fromGreenKenue or from the MAPMAKER program. The MAP file is then transformed into a _SHD.r2c file using the BSN.exe program. The output from BSN.exe is the "basin file", with all coordinates converted to a local grid. However, the UTM or lat-long coordinates listed in the SHD file are subsequently used by all programs that set up georeferenced data files for SPL9.

There must be at least one blank row and column surrounding the watershed boundary as shown in Figure 3.1. This is to accommodate a receiving grid at the watershed outlet. In addition, rain gauges that are located outside the watershed and are to be included for adjustment of the RADAR data have to be located on the grid. So the grid may be extended well outside the watershed to include the precipitation gauges but the penalty is larger RAD and MET files.

Initial steps:

1. Create a bsnm.map file manually or with the use of GreenKenue, MAPMAKER.exe or TOPAZ
2. Run BSN.exe to create bsnm_shd.r2c

3.2 Setting Up a New Watershed

The following is an overview of what is required to set up the files for a new watershed. The details of the data requirements and formats are found in Section 3.3

3.2.1 Mandatory Files (Summary)

BSNM is the designation for the basin name such as gr10k, colum,…….
The following files are requred in the drive: \spl\bsnm\basin directory:

File name	Purpose
Dr:/spl/bsnm/BASIN\bsnm.map	Contains all the watershed data in a gridded format. Created manually or by mapmaker. Data can be entered through Maputil - a Visual Basic Program.
Dr:/spl/bsnm/BASIN\bsnm_shd.r2c	Converted bsnm.map file to a watershed file as used by SPL. Some data is converted- e.g., elevations are converted to slopes.
Dr:/spl/bsnm/BASIN\bsnm_par.csv	Contains the parameters for SPL
Dr:/spl/bsnm/BASIN\bsnm.sdc	No longer needed. Values incorporated in the par file.
……\BASIN\monthly_climate_normals	
Dr:/spl/bsnm/basin/evap.dat	A table of climatic monthly evaporation. Can be used in lieu of calculating ET based on temperature and/or radiation data.
Dr:/spl/bsnm/BASIN\bsnm.pdl	Has the coordinates for the precipitation, snow course and temperature stations. Used to create new .rag, .snw and .tag files by the program events.exe (not yet implemented). Also has the coordinates for the streamflow gauging stations and reservoir and lake outlet locations. Used to set up new .str and .rel files for new events by events.exe (not yet implemented).
Dr:/spl/bsnm/BASIN\calmet.par	A parameter file for the program calmet.exe
Dr:/spl/bsnm/BASIN\weight.par	A parameter file for the programs calmet.exe and ragmet.exe

3.2.2 Steps to Set Up a New Watershed

1) Give the watershed a shortened name that identifies it - e.g. BSNM

(Replace BSNM with your own creation).

2) Create new folders (directories):

\SPL\BSNM	
\SPL\BSNM\BASIN	(required)
\SPL\BSNM\BSFLW	
\SPL\BSNM\EVAPO	
\SPL\BSNM\EVENT	(required)
\SPL\BSNM\LKAGE	
\SPL\BSNM\MOIST	(required)
\SPL\BSNM\RADAR	
\SPL\BSNM\RADCL	(required)
\SPL\BSNM\RADUC	
\SPL\BSNM\RAING	
\SPL\BSNM\TEMPG	
\SPL\BSNM\RCHRG	
\SPL\BSNM\RESRL	(required)
\SPL\BSNM\SNOW1	required)
\SPL\BSNM\STRFW	(required)
\SPL\BSNM\TEMPR	(required)

Shortcut: From the \SPL sub directory, use the command:
MAKEBSN BSNM
This will also copy some GR10K\BASIN\gr10k.XXX files that you can modify for the new basin.

3) The following files have to be created and placed in the \SPL\BSNM\BASIN subdirectory. Once these files are in place, every thing else is automatic.

For the following files, see the example data files.

BSNM.MAP - The data has to be taken from topographic maps and remotely sensed land cover data. The grid size should be such that the drainage pattern is reasonably well preserved. There is no specific requirement for the number of elements. Ten is fine if there are only two gauges and the drainage pattern and drainage areas are preserved. Also, the size of the meteorological stimuli must be considered. A 10 km by 10 km grid is sort of an upper limit if thunderstorms are involved. To date, from one to 7000 grids to represent a watershed have been used successfully with grid sizes ranging from 1 to 25 km.

To create the .MAP file, draw the watershed on the grid as in the example in Figure 3.1.

For a **manual** setup, make about 10 copies of the grid, one for each part of the data. There are several options to make the .map file automatically using TOPAZ, GREEN-KENUE and MAPMAKER. Intructions for making .map files are detailed in the

GREEN-KENUE manual. The instructions below provide a step-by-step set of instructions to create a .map file manually and provide the reasons for the use of the various data.
For a computer assisted setup (it isnot automatic!) please see Chapter 17. This Chapter presents a step-by-step set of instruction to set up a new watershed.

Once the .map file is complete, it is used as input to the BSN.exe program. BSN.exe will produce several files but the one to use is called NEW_SHD.R2C. This file has to be renamed to BSNM_SHD.R2C. This is the watershed file to be read by SPL.

3.2.3 Watershed Data

Two watershed files are used to organize all the watershed data required by WATFLOOD. The first retains the layout of the map and imagery from which the data is derived and has the file extention of .map. The second is a condensation of the data to a format that preserves all the information but reduces the memory requirements of the programs. Its file type is .SHD. In essence, elements outside the watershed being modelled do not use up space in the computer memory. This is accomplished by using vector arrays instead of matrix arrays within the executable. Figure 3.1below is an example of a watershed map (Grand River in Ontario, Canada).

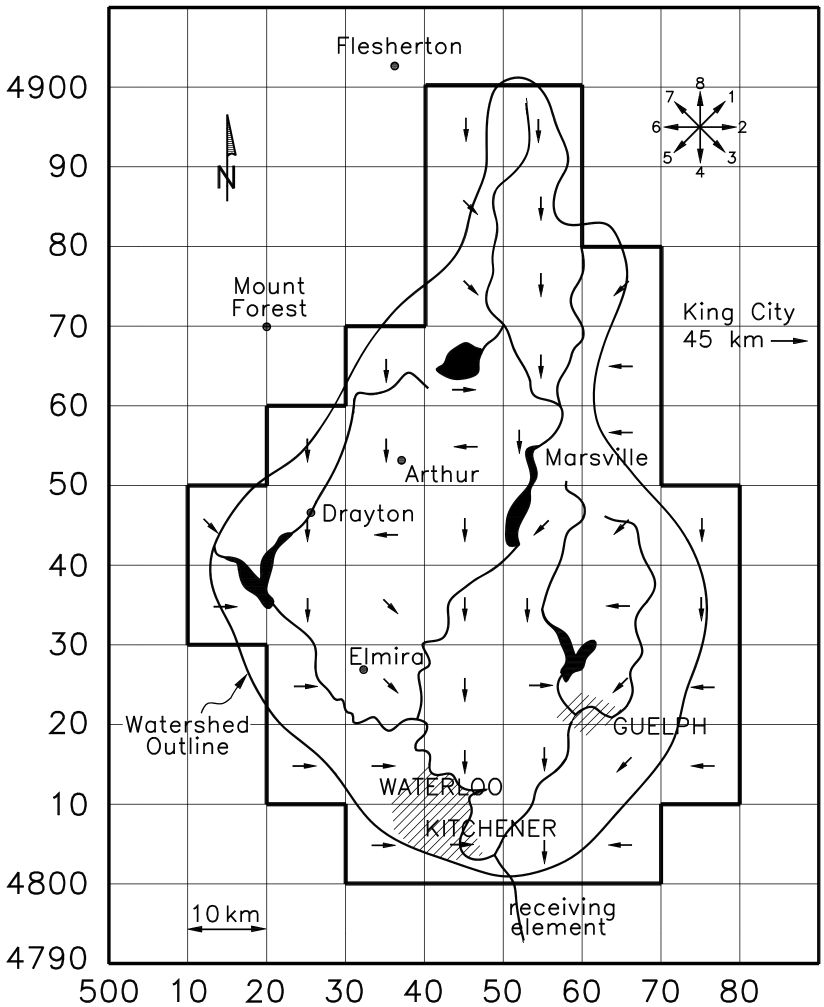


Figure 3.1 - Example watershed map showing UTM coordinates in km, basin outline, reservoirs, rain gauge stations, grid size and drainage directions. (NOTE: UTM coordinates must be entered in meters)

Notes:

1. The example data files are based on this figure.
2. There is a minimum of 1-grid buffer around the watershed. The receiving element may be, but does not have to be, within this border.
3. Each grid is referenced in its bottom - left corner.
4. So the grid is from 500000 - 590000 in the east-west direction and 4790000 to 4910000 the north-south direction.

3.3 Basin File

A WATFLOOD watershed map can be created automatically usingGreenKenue Green. This methodology is fully described in its manual. Capter 17 is a tutorial for a 2-day workshop showing the step-by-step process. Chapter 12 shows the use ofGreenKenue as a post processor. It also shows theGreenKenue map for the Grand River watershed shown in Fig. 3.1

The watershed map can also be created manually and this actually serves as a good training excersise leading to a better understanding of the model. Previously, a VB interface could be sued to enter and properly format the data for the next step of creating a condensed watershed file.

3.3.1 Entering Watershed Coordinates

Step 1. The first thing to do is make a drawing of the watershed as in Figure 3.1.

Step 2. Create a file called bsnm.map and enter the meta data as shown below.

Enter the watershed coordinates, being very careful to get the right grid coordinates. See notes 3 and 4 above. The menu below appears only when the NewWatershed menu item is selected. The number of land cover classes is also entered here (Maximum = 16, not 10).

The program MAPUTIL run in WINDOWS provides templates for entering the map data and performs some simple checks on the land use data. It ensures only that the data is formatted properly, not that it is correct. To set up a new watershed, the first thing is to create a basin file.

Once the grid dimensions are entered, the values will not reappear and can only be altered by editing the SPL\BSNM\BASIN\BSNM.MAP file. But once the grid corners have been entered, the remainder of the MAP data can be entered in properly dimensioned templates.
If an existing map file is being modified, the file can be opened from the Open File menu. In this example, the c:\spl\gr10k\basin\gr10k.map file is being opened.

This header data is stored in the .MAP file in the following self-explanitor formats.

Note:

- Only UTM, Cartesian and LATLONG are allowed
- For UTM, the Datum & Zone are **required**
- For Cartesian, Datum & Zone are ***not*** allowed
- For LATLONG, Datum is **required** and Zone is ***not*** allowed
- These have to be consistent for all files for a given watershed.

UTM format:

```
#
:CoordSys          UTM
:Datum             GRS80
:Zone              17
#
```

```
:xOrigin             500000.000
:yOrigin             4790000.000
#
:xCount              9
:yCount              12
:xDelta              10000.000
:yDelta              10000.000
#
:contourInterval     30.500
:imperviousArea      33
:classCount          5
:elevConversion      0.3048
#--------------------------------------------------------------------------
:endHeader
```

Cartesian format:

```
#
:CoordSys            Cartesian
#
:xOrigin             500000.000
:yOrigin             4790000.000
#
:xCount              9
:yCount              12
:xDelta              10000.000
:yDelta              10000.000
#
:contourInterval     30.500
:imperviousArea      33
:classCount          5
:elevConversion      0.3048
#--------------------------------------------------------------------------
:endHeader
```

LATLONG format:

```
#
:CoordSys            LATLONG
:Datum               GRS80
#
:xOrigin             -77.500000
:yOrigin             43.000000
#
:xCount              301
:yCount              201
:xDelta              0.025000
:yDelta              0.025000
#      changed contour interval
:contourInterval     1.00000               < changed contour interval
:imperviousArea      0
:classCount          6
```

```
:elevConversion     1.000000
#---------------------------------------------------------------------------
:comment   File created from 3 arc second DEM
:comment   river class 5 added for Spencerville  nk Nov. 15/03
#
:endHeader
```

Contour Interval	contour interval in meters – usually =1 when automatic procedures are employed, otherwise as on the map used.
Impervious Area	Used when land cover classification yields "urban area" but only a % of urban area is impervious. The value given is the % of urban area that is impervious. Remainder of the area is added to class 1 So class 1 should represent lawns if % Urban Area is > 0
Classcount	number of land cover classes in each grid (max=16) Classcount **<u>includes</u>** the impervious class. (In the code, NCLASS=NTYPE)
ElevConversion	S.I. Units= 1 0.305 for Imperial Units Default is 1.0 (if zero is entered)

Once all the data has been entered and stored in the BSNM.MAP file, the program BSN.EXE is run to convert the MAP file to a bsnm_SHD.r2c file.

3.3.3 Data Separators (Headings)

All data blocks in the bsnm.map files are separated by a blank line or a line that has a user defined header. Examples are shown below. These names are not used for any particular purpose.

3.3.4 River Invert Elevation (ELV)

The elevations of the elements refer to the elevation of the main channel in the square at its midpoint between the element boundaries. The best way to get this elevation is to mark the locations where contours cross the rivers or streams. The midpoint elevations can then be interpolated. Note the border of blank elements surrounding the basin. Only one element is used as the receiving square (elv.= 850). More receiving elements are possible but they must all have the same elevation. This is automatic if the receiving elements are all in the same lake but if this is not the case, dummy receiving-elements must be used. That is, there will have to be at least two elements outside the watershed: one with the proper elevation and the second with an elevation common to all watershed outlets.

Care should be taken that successive downstream elements have lower stream bottom elevations. If this rule is violated, negative slopes result with dire consequences in SPL9. Also, the contributing areas to each streamflow gauge will be wrong. These points can be checked in the new_format.shd output file (no longer used by SPL). The slopes as listed in column # 5 should all be positive and the drainage area at the bottom grid should correspond to the Water Survey of Canada drainage area for the gauge. The BSN output file NEW_SHD.R2c (used by SPL) can be checked usingGreenKenue.

It is quite helpful, and really essential, to produce a square grid outline of the watershed (Fig. 3.1) to aid with the coding. There are:

```
Channel Elevation (ELV)
0 0 0 0 0 0 0 0 0
0 0 0 0 1700 1700 0 0 0
0 0 0 0 1625 1635 0 0 0
0 0 0 0 1575 1600 1600 0 0
0 0 0 1550 1575 1490 1590 0 0
0 0 1375 1475 1500 1415 1550 0 0
0 1350 1310 1400 1370 1330 1400 1275 0
0 1300 1200 1290 1200 1275 1300 1230 0
0 0 1140 1100 1040 1125 1025 1075 0
0 0 1225 1125 985 965 1100 1130 0
0 0 0 1200 915 875 1050 0 0
0 0 0 0 0 830 0 0 0
```

3.3.5 Grid Drainage Area (FRAC)

The drainage area of the basin cannot be closely matched if only rectangular border elements are used. There is a provision in SPL9 to accept partial elements. An example of the required data is shown below. The data is the percentage of each element FRAC within the basin. The 0's denote the blank rows. It is possible to adjust basin boundaries using these ratios. See for instance the values of ***35*** and ***165*** below.

A zero in the top left hand entry means the areas are % of a full grid area.

Drainage Area (FRAC) 0 0 0 0 0 0 0 0 0 0 0 0 0 10 60 0 0 0 0 0 0 0 20 100 0 0 0 0 0 0 0 72 100 68 0 0 0 0 0 72 72 120 72 0 0 0 0 68 100 100 91 50 0 0 0 40 100 93 120 50 101 60 0 0 10 90 118 **165 35** 31 110 0 0 0 95 65 165 45 146 65 0 0 0 40 98 100 100 80 12 0 0 0 0 19 85 85 22 0 0 *0 0 0 0 0 0 0 0 0*	In this case, the nominal grid size is 100 km^2, and the area in the top line are 10 and 60 km^2.

When a -1 is placed in the top left element, the area values for each grid are expected in km^2.
If the first two lines read as below, then:

Drainage Area (FRAC) **-1** 0 0 0 0 0 0 0 0 0 0 0 0 10 60 0 0 0 . .	In this case, the areas of the two grids shown are 10 and 60 km^2. (The same as above because the grid is 100 km^2.)

3.3.6 Drainage Directions (S)

Each grid drains into a lower grid. One of the eight possible directions is recorded for each grid. Figure 3.1 shows the coding for the possible directions. Priority lies with the largest channel in the square. When no channel is shown, or many creeks drain the element, use the predominant drainage direction. An grid cannot be split but FRAC can be used to apportion parts of a grid to neighbouring grids.

```
Drainage direction (S)
0 0 0 0 0 0 0 0 0
0 0 0 0 4 4 0 0 0
0 0 0 0 3 4 0 0 0
0 0 0 0 3 4 5 0 0
0 0 0 4 2 4 6 0 0
0 0 4 4 6 4 6 0 0
0 3 4 6 4 5 5 4 0
```

```
0  2  4  3  4  4  6  4  0
0  0  2  3  4  2  5  6  0
0  0  2  2  4  4  5  6  0
0  0  0  2  2  4  6  0  0
0  0  0  0  0  0  0  0  0
```

3.3.7 River Classification (IBN)

A classification of the element depending on river type and groundwater regime. For instance, rivers or streams can be classified according to their nature: upland versus lowland rivers, meandering versus straight. Up to sixteen classes can be used. Each class can be given different main channel and flood plain Manning's n parameter as R2n and R1n respectively. So river class 1 is assigned roughness R2n for the channel and R1n for the flood plain. Note: The LZF and PWR parameters are also assigned to each river class.

```
River Class (IBN)
0  0  0  0  0  0  0  0  0
0  0  0  0  1  1  0  0  0
0  0  0  0  1  1  1  0  0
0  0  0  0  1  1  1  0  0
0  0  2  2  1  1  1  0  0
0  2  2  2  2  5  5  0  0
0  2  2  2  5  5  3  4  0
0  5  5  2  5  3  3  4  0
0  0  5  5  5  3  3  4  0
0  0  5  5  5  5  5  5  0
0  0  0  5  5  5  5  0  0
0  0  0  0  0  0  0  0  0
```

3.3.8 Contour Density (IROUGH)

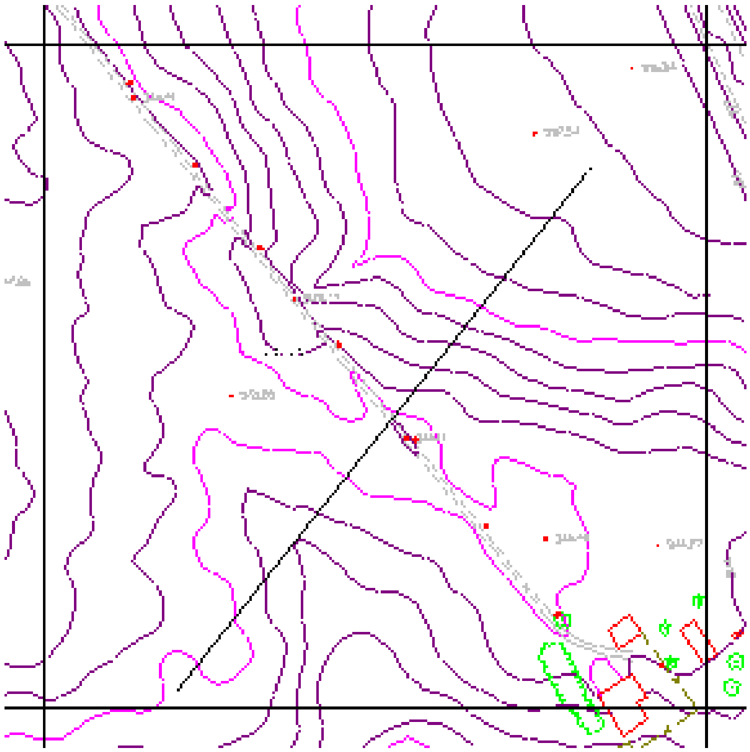
The surface slope of each element is calculated by:

$$\text{slope} = \frac{\#\text{of contours} \times \text{contour interval}}{\text{grid length}} \text{ X } 100 \qquad (3.1)$$

This is used in the runoff calculations. The input is the number of contours crossing a line equal in length to the grid length. Draw the line in such a way that the line lies within the grid but crosses the maximum number of contours (Fig. 3.2). The contours can go up or down continuously or can go up and then down or visa versa. They can go up and down many times. The program calculates an average land slope (not the channel slope) in each grid. If the same contour crosses the line more than once, count each crossing. Remember that slope is perpendicular to the contours.

When automatic methods are used to obtain the contour count based on a DEM, the contour interval is usually set to 1 m. The contour count will vary with grid size. If the grid size is 2 km for instance, and the average overland (internal) slope is 10%, the contour count will be 200.

(The previous limit of 99 has been removed as long as the free file format is used). For the example below, the countour density is 14.



There are 14 contours crossing the line in this example.

The line length = grid length.

Contour Density
IROUGH

0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	0	0	0
0	0	0	0	1	1	1	0	0
0	0	0	0	2	1	1	0	0
0	0	2	1	1	2	2	0	0
0	1	1	2	1	2	1	0	0
0	1	2	2	2	1	2	2	0
0	1	2	2	2	2	2	1	0
0	0	2	2	2	1	2	2	0
0	0	2	2	2	1	1	1	0
0	0	0	2	2	2	1	0	0
0	0	0	0	0	0	0	0	0

Fig. 5 Contour Density

The contour density is well correlated with a slope found by first calculating for each pixel in a DEM the steepest slope in all directions, and then averaging the slopes found for each pixel in a grid cell.

3.3.9 Channel Density (ICHNL)

Channel density is the number of channels traversing the element. This refers to main channels. If there are 2, 3, or up to 5 equally sized channels traversing the elements, that is the number coded. If a major stream passes through the square, the number is 1. The data is used only for routing streamflow and thus is not used in elements which have no upstream contributing area. But elements within the basin must have a value between 1 and 5.

Channel Density (ICHNL)

0	0	0	0	0	0	0	0	0
0	0	0	0	2	3	0	0	0
0	0	0	0	2	3	3	0	0
0	0	0	0	2	2	3	0	0

```
0 0 3 2 5 2 3 0 0
0 3 2 4 3 2 2 0 0
0 3 2 4 3 1 3 4 0
0 3 2 3 3 2 3 2 0
0 0 3 2 2 3 2 3 0
0 0 3 2 2 2 4 5 0
0 0 0 3 2 1 5 0 0
0 0 0 0 0 0 0 0 0
```

3.3.10 Routing Reach Number (IREACH)

In some situations, the user may wish to route flows outside the SPL program, for instance where back water or tidal effects have to be taken into account. For this purpose, a reach number can be inserted for those elements where channel inflows are desired as output in a separated file. The output will be in DWOPER format 8F10.3 in the \results\rte.lst file. A block of zeros is required where there is no external routing.

This block is also used to group elements into one or a number of reservoirs or lakes to allow an accounting of reservoir storage and/or reservoir level reporting. (See section on Lake routing).

```
Reach Number (IREACH)
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 1 0 0 0
0 0 0 0 0 1 0 0 0
0 0 2 0 0 0 0 0 0
0 0 0 0 0 3 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
```

Format: 999I2

In this example there are three reservoirs. The numbers 1 to 3 correspond to the reservoir locations in the resrl\yymmdd.rel file. In this example, the Belwood reservoir (No. 1) is located in two grids (not in reality) and the outlet is in the bottom grid.

3.3.11 Land Cover Classes (IAK)

The next groups of data indicate the percentage of each grid in each land use/soil classification group (IAK). In the example below, the land use/cover classes were obtained from LANDSAT false colour imagery.

The **last** class in the file is (now – since 2006) the Impervious Class. The percent impervious can be replaced by the percent urban area but then the % impervious area has to be specified in the map file header:

```
:imperviousArea     33
```

If it is specified as 33%, then 33% of the urban area is taken as impervious and the remainder, 67% is added to Class #1 which should normally be grass (urban areas are mostly impervious and lawns).

Any number of land cover classes can be specified (classcount). These are:

1	bare ground
2	forests
3	crops
4	.
.	.
.	.
classcount -3	glaciers
classcount -2	wetlands
classcount -1	**water**
classcount	**impervious**

The first classcount-4 can be reduced to a fewer number but the last ***four*** are always to be specified with the names and the order as shown above if present.

Important note:

- **Water & impervious are required classes**
- If present, the last four classes need to be in the order above
- If glaciers, wetlands, water and impervious are present you will need to have at least one other class.

When specifying **classcount** in the .MAP file, specify the **total number of classes** including the impervious class (new).

```
bare   class=1
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0
```

```
forest   class =2
34 27 25 23 18 28 22 19 29
26 24 25 27 22 31 19 20 23
27 26 24 26 24 21 20 19 11
15 20 20 27 20 21 23 25 19
24 20 18 16 23 16 14 19 30
16 9 15 8 9 11 15 25 27
9 14 11 10 14 20 27 24 29
9 6 6 9 11 18 20 23 17
3 4 6 8 13 13 14 29 25
14 10 16 13 12 13 16 28 34
9 12 10 7 11 10 26 27 25
9 4 4 11 13 21 17 19 15
all vegetation   class=3
57 64 64 68 72 65 74 70 43
66 67 67 66 74 64 76 63 62
68 67 70 71 71 75 73 72 75
80 67 70 63 62 75 73 66 68
71 71 76 77 42 72 74 58 46
80 86 80 85 84 79 74 56 53
87 81 84 85 79 62 58 56 60
90 89 84 85 79 73 68 63 63
93 92 89 86 78 73 61 52 63
79 86 78 63 62 76 61 55 51
79 83 81 77 59 49 55 51 62
87 92 91 79 75 63 73 67 64
wetland     class=n-1  (=4)
6 6 7 3 5 4 2 3 20
5 5 6 4 2 2 3 11 4
3 4 3 1 2 1 3 5 4
2 7 4 6 10 1 1 7 7
1 5 3 3 17 7 6 7 14
1 0 2 2 2 4 6 9 7
0 1 2 1 2 8 9 11 3
0 0 2 1 4 4 8 5 2
0 0 0 1 2 1 4 8 2
4 0 2 2 2 2 3 4 3
0 0 1 0 2 2 4 10 2
0 0 0 1 2 3 3 3 1
water    class=n      (=5)
1 0 1 2 3 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 11 0 0 0 0
0 0 0 0 0 0 0 0 1
0 0 0 0 0 4 0 0 0
0 0 3 0 0 0 0 0 0
0 0 0 0 0 0 3 0 0
0 0 0 0 1 0 0 2 0
0 0 0 0 1 2 0 0 0
0 0 0 0 0 1 0 0 2
Impervious Area       (=6)
0 0 1 1 1 1 0 6 6
1 2 0 0 1 1 0 4 8
0 1 0 0 1 1 1 2 8
0 2 1 2 5 1 1 0 4
```

```
0 1 1 1 2 3 3 11 7
1 2 1 1 2 2 2 6 8
1 0 1 0 1 4 3 6 5
0 2 3 1 3 1 2 5 15
1 1 2 3 2 9 14 7 6
1 1 1 18 19 6 15 8 9
9 1 4 13 25 34 11 8 7
2 2 2 5 7 9 3 7 14
EOF expected here, unless bankfull capacities provided.
```

Note 1:

- At this point the bankfull capacities in cms of the stream in each element can be entered. If no data is provided, a value is assumed for the purpose of doing the animation.
- This assumed value may be grossly in error.
- **This capability is currently an undocumented feature.**

3.3.12 Class Numbering - order of entering land cover classes

In 2006 when all files were changed toGreenKenue formats, a break was made with the old order of having the impervious class first. There were several reasons for this, including the need to have the impervious class treated the same as the other (pervious) classes to enable the isotope model.

The last 4 classes – if present – must be in this order:

glaciers
wetlands
water
impervious

The keywords must be as shown!!

3.3.13 Wetlands – Splitting Bogs and Fens

As mentioned in Section 2.12.1, wetlands can be either coupled or uncoupled from the flow routing by the wetfld. Usually a split of approximately 15-20% gives good results. Only one wetland class is specified in the map file.

To split the wetlands into two, enter the % of wetland you wish to couple to the channel, in the example below 20%:

```
Enter the split: % of wetland coupled to channel
 only if you have two identical sets of wetland
 land cover gridsas the 2 classes before the
 water class in the land use section of the map file
 Enter 0 if you have just 1 block of wetland cover
```

```
 Split =
20
```

With a split > 0, an additional wetland class will be added to the shd file (i.e. one more than the map file). They will both becalled ‘wetland’. The last one, before the ‘water’ class will be the coupled wetland class.

The last 5 classes – if present – must be in this order:

glaciers
wetlands
wetlands
water
impervious

Note (important):
The par and sdc files need to be edited to ensure that the number of classed are the same as in the **shd** file. The parameters for both wetlands can be the same.

3.3.14 Combining and Reordering Classes

Often land cover maps in GEOTIF format have too many classes. Often some, such as pasture, grass, savanna etc. can be combined. This can be accomplished with a class_combine.csv file or the class_combine.txt file. If both files are present in the **basin** directory, the **csv** file will be used.

The class_combine.csv file is more user-friendly than the class_combine.txt file

Example of the **class_combine.csv** file as edited in Excel:

class_combine_version	2	RED=US					attribute #
LANDCOVER	GEOBASE	Class_combine					
class_0	0	1	10	water			8
cloud	11	2	2	grass			9
Shadow	12	3	4	coniferous			10
water	20	4	11	water			11
non_vegetated_land	30	5	8	barren			12
snow_ice	31	6	9	glacier			13
rock_rubble	32	7	8	barren			14
exposed_barren	33	8	8	barren			15
developed	34	9	12	impervious			16
shrubland	50	10	7	shrub			17
shrub_tall	51	11	7	shrub			18
shrub_low	52	12	7	shrub			19
wetland	80	13	10	wetland			20
wetland-treed	81	14	10	wetland			21
wetland-shrub	82	15	10	wetland			22
wetland-herb	83	16	10	wetland			23
herb	100	17	10	wetland			24
grassland	110	18	2	grass			25
arg-cropland	121	19	1	crops	1	crops	26
agr-pasture	122	20	2	grass	2	grass	27
open_water	131	21	11	water	3	deci	28
prennial_snow_ice	132	22	9	glacier	4	coni	29
decidious_forest	141	23	3	deciduous	5	coni	30
Evergreen_forest	142	24	4	coniferous	6	mixed	31
mixed_forest	143	25	3	deciduous	7	shrub	32
developed_open_space	151	26	12	impervious	8	barren	33
developed_low_intensity	152	27	12	impervious	9	glacier	34
developed_medium_intensity	153	28	12	impervious	10	wetland	35
developed_high_intensity	154	29	12	impervious	11	water	36
herbaceous	171	30	7	shrub	12	impervious	37
barren_land	181	31	8	barren			38
crops	182	32	1	crops			39
wetlands_woody	190	33	10	wetland			40
hay_pasture	191	34	2	grass			41
wetlands_herbaceous	195	35	10	wetland			42
shrub-rock_rubble	202	36	8	barren			43
coni	210	37	4	coniferous			44
coni-dense	211	38	4	coniferous			45
coni-open	212	39	5	coniferous			46
coni-sparse	213	40	4	coniferous			47
broadleaf	220	41	3	deciduous			48
broadleaf-dense	221	42	3	deciduous			49
broadleaf-open	222	43	3	deciduous			50
broadlead-sparse	223	44	3	deciduous			51
mixedwood	230	45	6	mixed			52
mixedwood-dense	231	46	6	mixed			53
mixedwood-open	232	47	6	mixed			54
mixedwood-sparse	233	48	6	mixed			55

The third column is the class order as in the .map file and the 4th column has the order of the shd file. I.e. column 3 is mapped to column 4.

Example **class_combine.txt**:

```
 1    9     Urban and Built-Up Land
 2    1     Dryland Cropland and Pasture
 3    1     Irrigated Cropland and Pasture
 4    1     Cropland/Grassland Mosaic
 5    1     Cropland/Woodland Mosaic
 6    2     Grassland
 7    2     Shrubland
 8    2     Savanna
 9    3     Deciduous Broadleaf Forest
 10   4     Evergreen Needleleaf Forest
 11   5     Mixed Forest
 12   8     Water Bodies
 13   7     Wooded Wetland
 14   6     Barren or Sparsely Vegetated
 15   7     Wooded Tundra
 16   0     Mixed Tundra
```

The first colum is the class number in the map file generated byGreenKenue with the descriptions in the 3rd column.. The class in the map file is then entered into the class number in the 2nd column. For instance, classes 2, 3, 4 & 5 are combined into class 1 in the shd file. Class 1 in the map file becomes class 9 in the shd file and so on. This is handy if you already have a par file for a similar physiographic area and want to set up the land cover classes in the shd file to match these.

3.3.15 Non-Contributing Areas

For regions where areas have been identified as "non-contributing", the addition of the file **nca.r2s** to the working directory of BSN.exe (usually the basin\ sub-directory) will prompt BSN.exe to read a file of point data with values of 1 for points contributing to the river flows and 0 for points not contributing.

There are two ways of using the nca data and the methods can not be used simultaneously:

1. The area of each cell can be reduced by the amount of non-contributing area in that cell. For instance, if the cell area is 100 km^2 and the nca = 35%, the effective area of the cell will be 65 km^2. Each cell is treated o its own. The non-contributing area will then be completely ignored in the model.
2. Each of first two land cover classes can be split into separate land covers. For instance, if the first two land cover files in the shd file are crops and grass, these can be split into four classes crops, nca_crops, grass and nca_grass. In this case, the nca can be made to behave differently from the contributing area. For instance, the depression storage of the nca can be made much larger thus allowing runoff for very large precipitation events. Also, the contributing and non-contributing areas can have different recharge characteristics. In this way, the runoff from the non-contributing area can be vastly reduced and alse be required to surpass certain runoff thresholds.

NOTE: You need to make extra classes in the par file as needed.

The following is an example of the first few lines & columns the **nca.r2s** file:

```
########################################################################
:FileType r2s  ASCII  EnSim 1.0
# Canadian Hydraulics Centre/National Research Council (c) 1998-2010
# DataType                 2D Rect Scalar
#
:Application              GreenKenue
:Version                  3.1.55
:WrittenBy                NK
:CreationDate             Tue, Jun 07, 2011 08:37 AM
#
#-----------------------------------------------------------------------
#
:Projection LATLONG
:Ellipsoid WGS84
#
:xOrigin -104.617280
:yOrigin 49.776797
#
:xCount 9574
:yCount 3520
:xDelta         0.0009
:yDelta         0.0009
:Angle 0.000000
#
:EndHeader
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 . . .
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 . . .
.
.
```

For grids points in non-contributing areas the value will be 0. BSN.exe counts the number of 1 & 0 points in each WATFLOOD cell and calculated the fraction of a cell that is not contributing and multiplies that times the original cell area. The cell areas can be subsequently viewed by loading the bsnm_shd.r2c file into GreenKenue.

Steps for making the R2S File:

A)In GIS

1. Convert the shapefile to Raster, resoulution 100m=0.0009 degrees
2. Use “spatial analysis tools “ to reclass
   data (non-contributing) = 0 and
   nodata (contributing=1
3. Convert from Raster to ASCII format

B) In GreenKenue:

Load the ASCII file, assign the projection and ellipsoid (and zone if UTM) and save it as (filename).r2s file

The user will be prompted by BSN.exe at the appropriate stage of the program's execution –e.g.:

```
 .
 .
 nca.r2s file found
 non-contributing areas will be subtracted from frac for
 for each cell
 You can not subtract nca from frac if you want to split
 land cover classes into contributing & non-contributing

 Do you want to continue with this adjustment of frac?
 y or n:
n

 frac will NOT be adjusted for nca
 but the class areas may be depending on your answer

 opened input file:nca.r2s

 :Projection                  LATLONG
 :Ellipsoid                   WGS84
 #
 :xOrigin                       -115.2218
 :yOrigin                        48.81422
 :xCount                             13164
 :yCount                              6296
 :xDelta                        8.9999998E-04
 :yDelta                        8.9999998E-04
  reading the nca file
 Grid extents of non-contributing areas:
 xorigin_nca  -115.2218
 eastlimit  -103.3742
 yorigin_nca   48.81422
 northlimit   54.48063

  counting pixels
  calculating the nca on each cell
  writing the nca,xyz file
 nca.xyx written

  done computing non contributing areas
 Would you like to split any classes into
 contributing and non-contributing?
 You can only split the first `n` classes
 in the shd file (not the map file)
 e.g. if crops & grass are the first 2
 you can split these by answering 2
 If you want to split only the first one
 enter 1  -  for no split, enter 0
 2 is the maximum
 How many?
2
 You have elected to split           2  classes
 .
 .etc.
```

3.3.16 Basin File (bsnm_SHD.r2c) for UTM Coordinates

The watershed data as read by the model (SPLX.exe) is created by BSN.exe, which reads information obtained from maps (manually or usingGreenKenue, MAPMAKER or TOPAZ).

Example run with BSN.exe: (responses are highlighted)

Actual program output may vary.

```
C:\spl\gr10k\BASIN>bsn
 ******************************************************
 *                                                    *
 *                  WATFLOOD (TM)                     *
 *                                                    *
 *      Program BSN Version 10      Mar 13, 2008      *
 *                                                    *
 *            (c) N. Kouwen, 1972-2008                *
 *                                                    *
 ******************************************************

 Please see file bsn_info.txt for information re: this run

 VERY IMPORTANT CHANGE:

 In the bsnm.map file
 the impervious area is now the LAST class - not the first
 The no of classes is now the TOTAL number - including the
 impervious class

 Please change the .map file accordingly if you have not
 yet done so.  Sorry for the inconvenience  NK

Hit enter to continue - Ctrl C to abort


 error in bsn_responses.txt

 Previous responses have been found:
 Map file = gr10k.map
 Par file =
 Author =
 Wetland split =  0.0000000E+00
 Minimum slope =  0.0000000E+00

 Please re-enter the values
 Enter the basin (map) file name:
gr10k.map
 Enter the parameter (par) file name
 if you want a bsnm_par.r2c file for watroute
 other wise, hit return
gr10k.par                               <<OPTIONAL

 Enter your name or initials
nk
 gr10k.par
```

```
  Enter the grid you would like included
  in the simulation

  This should NOT be the receiving grid!!!!

  There can only be one (1) outlet with this option

  example:  6639   Hit Return to use whole dataset
```

<<OPTIONAL

```
GreenKenue compatible free format map file expected

:CoordSys           UTM

 :CoordSys           UTM
 :Datum              GRS80
 :Zone               17
 #
 :xOrigin               500000.0
 :yOrigin               4790000.
 :xCount                        9
 :yCount                       12
 :xDelta                10000.00
 :yDelta                10000.00
 :contourInterval       1.000000
 :imperviousArea               10
 :classCount                    6
 :elevConversion       0.3050000
 #--------------------
 :endHeader
  Computed nominal grid size=    10000.00
please check above numbers & hit enter to continue
(hit enter here if ok)

 Enter the split: % of wetland coupled to channel
 only if you have two identical sets of wetland
 land cover gridsas the 2 classes before the
 water class in the land use section of the map file
 Enter 0 if you have just 1 block of wetland cover

 Split =
0
 Number of classes now includes the impervious class
 Number of classes stipulated =            6

 Is this correct?  y or n
y
 before allocating area17
 area17 allocated

  Often DEM have flat spots filled and you end up with
  unwanted flat spots in your river profile
  It causes severe flattening of the hydrographs
  Enter the minimum allowable river slope
  that you have in your sustem - e.g. 0.0001
```

```
  Min accepted value = 0.0000001
  Max value accepted is 1.0 (45 degrees!)
```

.0001

```
 No of river classes found in the map file =           5
 This should match the number specified in the par file

Bare
forest
crops
wetland
water
impervious

  end of map file reached
 Note:    impervious area > 0 in the header
          89 % of the impervious class (urban)
 has been subtracted from class           6
 and added to class 1
 Class 1 should be a land cover compatible with
 the pervious areas in urban areas (eg. grass)

 ios=          -1

  No bankfull values found
  Default assumed

 frac_2d(    1    6)=     0.000 - please check
   Basin # not coded @ grid #    47 @      1     6 elv=253.150
# contours not coded @ grid #    47 @      1     6 elv=253.150
# channels not coded @ grid #    47 @      1     6 elv=253.150
       next grid = 0 @ grid #    47 @      1     6 elv=253.150
Possible cause: wrong drainage direction
Errors OK if last receiving grid !!!!!!!!!!!!!

Please see new_format.shd file for -ve slope location
 nrvr=          5
 ver     9.300000     parameter file version number
 in rdpar - problem opening BASIN\evap.dat file
          zero values are inserted for evap.dat

 parameter file read
 na,naa/          47          46
  frame=           1  written
  frame=           2  written
  frame=           3  written
  frame=           4  written
  frame=           5  written
  frame=           6  written
  frame=           7  written
  frame=           8  written
  frame=           9  written
  frame=          10  written
  frame=          11  written
  frame=          12  written
  frame=          13  written
  frame=          14  written
```

```
  frame=           15  written
  frame=           16  written
  frame=           17  written
  frame=           18  written
 new_shd.r2c written
  frame=            1  written
  frame=            2  written
  frame=            3  written
  frame=            4  written
  frame=            5  written
  frame=            6  written
  frame=            7  written
  frame=            8  written
  frame=            9  written
  frame=           10  written
  frame=           11  written

 new_ch_par.r2c written

 wfo_spec.new  written

 new.pdl  written

 finished writing profil01.dat
 finished writing river01.dat
 finished writing profil02.dat
 finished writing river02.dat
 finished writing profil03.dat
 finished writing river03.dat
 finished writing profil04.dat
 finished writing river04.dat
 finished writing profil05.dat
 finished writing river05.dat
 finished writing profil06.dat
 finished writing river06.dat
 finished writing profil07.dat
 finished writing river07.dat
 finished writing profil08.dat
 finished writing river08.dat
 finished writing profil09.dat
 finished writing river09.dat
 finished writing profil10.dat
 finished writing river10.dat

 No. of errors found in the map file =            0
 No. of errors found in the map file =            0
 No. of errors found in the map file =            0

 new_shd.r2c has been written
 Please rename new_shd.r2c or replace the bsnm_shd.r2c

 Normal ending

C:\spl\gr10k\BASIN>
```

This basin file for SPL9 must have the file type as _SHD.r2c to differentiate it from other files. The following example is the basin file for the Grand River watershed above Galt in Ontario. The file is described below for information only. **Note that north is down & south is up.**

WATFLOOD reads only this shd file. The older formats are no longer supported. However, bsn.exe does produce the old format as shown in sections 3.3.17 and 3.3.18 because it is easier to directly compare the attributes of 2 or more grids.

```
########################################
:FileType r2c  ASCII  EnSim 1.0
#
# DataType               2D Rect Cell
#
:Application             EnSimHydrologic
:Version                 2.1.23
:WrittenBy          nk
:CreationDate       2011-12-02  12:38
#
#---------------------------------------
:SourceFileName      gr10k.map
:NominalGridSize_AL    10000.000
:ContourInterval           1.000
:ImperviousArea            0.100
:ClassCount                    6
:NumRiverClasses               5
:ElevConversion            1.000
:TotalNumOfGrids              47
:numGridsInBasin              46
:DebugGridNo                  23
#
#
:Projection         UTM
:Zone               17
:Ellipsoid          GRS80
#
:xOrigin               500000.00000
:yOrigin              4790000.00000
#
:AttributeName 1 Rank
:AttributeName 2 Next
:AttributeName 3 DA
:AttributeName 4 Bankfull
:AttributeName 5 ChnlSlope
:AttributeName 6 Elev
:AttributeName 7 ChnlLength
:AttributeName 8 IAK
:AttributeName 9 IntSlope
:AttributeName 10 Chnl
:AttributeName 11 Reach
:AttributeName 12 GridArea
:AttributeName 13 Bare
:AttributeName 14 forest
:AttributeName 15 crops
:AttributeName 16 wetland
:AttributeName 17 water
:AttributeName 18 impervious
#
:xCount                        9
:yCount                       12
:xDelta                 10000.00000
:yDelta                 10000.00000
#
:EndHeader
    0    0    0    0    0   47    0    0    0
    0    0    0   30   45   46   40    0    0
    0    0   29   35   43   44   37   34    0
    0    0   33   38   41   36   42   39    0
    0   23   31   25   32   26   24   28    0
    0   20   22   16   19   21   17   27    0
    0    0   18   14   12   15   10    0    0
    0    0    0   11    8   13    7    0    0
    0    0    0    0    9    5    6    0    0
    0    0    0    0    4    3    0    0    0
    0    0    0    0    1    2    0    0    0
    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0
    0    0    0   45   46   47   46    0    0
    0    0   35   43   45   46   46   37    0
    0    0   38   43   43   42   44   42    0
    0   31   33   41   41   36   26   39    0
    0   31   31   22   32   32   26   28    0
    0    0   22   16   14   21   15    0    0
    0    0    0   14   13   15   13    0    0
    0    0    0    0   13   13   13    0    0
    0    0    0    0    5    5    0    0    0
    0    0    0    0    4    3    0    0    0
    0    0    0    0    0    0    0    0    0
```

.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00
.0000000E+00	.0000000E+00	.0000000E+00	.1900000E+02	.2628000E+04	.3520000E+04	.2200000E+02	.0000000E+00	.0000000E+00
.0000000E+00	.0000000E+00	.4000000E+02	.1380000E+03	.2524000E+04	.6930000E+03	.9199999E+02	.1200000E+02	.0000000E+00
.0000000E+00	.0000000E+00	.7680000E+03	.8330000E+03	.1453000E+04	.2120000E+03	.5930000E+03	.2350000E+03	.0000000E+00
.0000000E+00	.9999999E+01	.6730000E+03	.1180000E+03	.1170000E+04	.1670000E+03	.3100000E+02	.1700000E+03	.0000000E+00
.0000000E+00	.4000000E+02	.5330000E+03	.3650000E+03	.1200000E+03	.8850000E+03	.1010000E+03	.6000000E+02	.0000000E+00
.0000000E+00	.0000000E+00	.6800000E+02	.2720000E+03	.1000000E+03	.8350000E+03	.5000000E+02	.0000000E+00	.0000000E+00
.0000000E+00	.0000000E+00	.0000000E+00	.7200000E+02	.7200000E+02	.6940000E+03	.7200000E+02	.0000000E+00	.0000000E+00
.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.7200000E+02	.2900000E+03	.6800000E+02	.0000000E+00	.0000000E+00
.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.3000000E+02	.1600000E+03	.0000000E+00	.0000000E+00	.0000000E+00
.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.9999999E+01	.6000000E+02	.0000000E+00	.0000000E+00	.0000000E+00
.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00	.0000000E+00

0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.000
0.000	0.000	0.000	3.267	438.100	586.767	3.767	0.000	0.000
0.000	0.000	6.767	23.100	420.767	115.600	15.433	2.100	0.000
0.000	0.000	128.100	138.933	242.267	35.433	98.933	39.267	0.000
0.000	1.767	112.267	19.767	195.100	27.933	5.267	28.433	0.000
0.000	6.767	88.933	60.933	20.100	147.600	16.933	10.100	0.000
0.000	0.000	11.433	45.433	16.767	139.267	8.433	0.000	0.000
0.000	0.000	0.000	12.100	12.100	115.767	12.100	0.000	0.000
0.000	0.000	0.000	0.000	12.100	48.433	11.433	0.000	0.000
0.000	0.000	0.000	0.000	5.100	26.767	0.000	0.000	0.000
0.000	0.000	0.000	0.000	1.767	10.100	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0086925	0.0012200	0.0013725	0.0053375	0.0000000	0.0000000
0.0000000	0.0000000	0.0030500	0.0042700	0.0021350	0.0027450	0.0048526	0.0009150	0.0000000
0.0000000	0.0000000	0.0012200	0.0024802	0.0016775	0.0030500	0.0012940	0.0015250	0.0000000
0.0000000	0.0030500	0.0018300	0.0053917	0.0048800	0.0045750	0.0007625	0.0047275	0.0000000
0.0000000	0.0032350	0.0033550	0.0027450	0.0051850	0.0028037	0.0026959	0.0013725	0.0000000
0.0000000	0.0000000	0.0019825	0.0022875	0.0007625	0.0025925	0.0041175	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0022875	0.0025925	0.0022875	0.0030500	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0018332	0.0033550	0.0023724	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0005392	0.0010675	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0022875	0.0019825	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

0.0	0.0	0.0	0.0	0.0	253.2	0.0	0.0	0.0
0.0	0.0	0.0	366.0	279.1	266.9	320.2	0.0	0.0
0.0	0.0	373.6	343.1	300.4	294.3	335.5	344.6	0.0
0.0	0.0	347.7	335.5	317.2	343.1	312.6	327.9	0.0
0.0	396.5	366.0	393.5	366.0	388.9	396.5	375.1	0.0
0.0	411.8	399.6	427.0	417.9	405.7	427.0	388.9	0.0
0.0	0.0	419.4	449.9	457.5	431.6	472.8	0.0	0.0
0.0	0.0	0.0	472.8	480.4	454.5	485.0	0.0	0.0
0.0	0.0	0.0	0.0	480.4	488.0	488.0	0.0	0.0
0.0	0.0	0.0	0.0	495.6	498.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	518.5	518.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0.	0.	0.	0.	0.	10000.	0.	0.	0.
0.	0.	0.	10000.	10000.	10000.	10000.	0.	0.
0.	0.	10000.	10000.	10000.	10000.	14142.	10000.	0.
0.	0.	10000.	14142.	10000.	10000.	14142.	10000.	0.
0.	10000.	10000.	14142.	10000.	10000.	10000.	10000.	0.
0.	14142.	10000.	10000.	10000.	14142.	14142.	10000.	0.
0.	0.	10000.	10000.	10000.	10000.	10000.	0.	0.
0.	0.	0.	10000.	10000.	10000.	10000.	0.	0.
0.	0.	0.	0.	14142.	10000.	14142.	0.	0.
0.	0.	0.	0.	14142.	10000.	0.	0.	0.
0.	0.	0.	0.	10000.	10000.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.

0	0	0	0	0	0	0	0	0
0	0	0	5	5	5	5	0	0
0	0	5	5	5	5	5	5	0
0	0	5	5	5	3	3	4	0
0	5	5	2	5	3	3	4	0
0	2	2	2	5	5	3	4	0
0	0	2	2	2	5	5	0	0
0	0	0	2	1	1	1	0	0
0	0	0	0	1	1	1	0	0
0	0	0	0	1	1	0	0	0
0	0	0	0	1	1	0	0	0
0	0	0	0	0	0	0	0	0

0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0132000	0.0160000	0.0156000	0.0092000	0.0000000	0.0000000
0.0000000	0.0000000	0.0133000	0.0127000	0.0128000	0.0130000	0.0113000	0.0129000	0.0000000
0.0000000	0.0000000	0.0078000	0.0160000	0.0068000	0.0088000	0.0179000	0.0149000	0.0000000
0.0000000	0.0038000	0.0107000	0.0103000	0.0134000	0.0103000	0.0119000	0.0127000	0.0000000
0.0000000	0.0074000	0.0088000	0.0067000	0.0078000	0.0151000	0.0133000	0.0207000	0.0000000
0.0000000	0.0000000	0.0049000	0.0102000	0.0043000	0.0093000	0.0084000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0083000	0.0094000	0.0066000	0.0072000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0079000	0.0062000	0.0033000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0050000	0.0034000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0044000	0.0032000	0.0000000	0.0000000	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

0	0	0	0	0	0	0	0	0
0	0	0	3	2	1	5	0	0
0	0	3	2	2	2	4	5	0
0	0	3	2	2	3	2	3	0
0	3	2	3	3	2	3	2	0
0	3	2	4	3	1	3	4	0
0	0	2	4	3	2	2	0	0
0	0	0	2	5	2	3	0	0
0	0	0	0	2	2	3	0	0
0	0	0	0	2	3	0	0	0
0	0	0	0	2	3	0	0	0

```
  0   0   0   0   0   0   0   0   0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    3    0    0    0
   0    0    2    0    0    0    0    0    0
   0    0    0    0    0    1    0    0    0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0
.0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00
.0000000E+00 .0000000E+00 .0000000E+00 .1900000E+08 .8500000E+08 .8500000E+08 .2200000E+08 .0000000E+00 .0000000E+00
.0000000E+00 .0000000E+00 .4000000E+08 .9799999E+08 .1000000E+09 .1000000E+09 .7999999E+08 .1200000E+08 .0000000E+00
.0000000E+00 .0000000E+00 .9500000E+08 .6500000E+08 .1650000E+09 .4500000E+08 .1460000E+09 .6500000E+08 .0000000E+00
.0000000E+00 .9999999E+07 .9000000E+08 .1180000E+09 .1650000E+09 .3500000E+08 .3100000E+08 .1100000E+09 .0000000E+00
.0000000E+00 .4000000E+08 .1000000E+09 .9300000E+08 .1200000E+09 .5000000E+08 .1010000E+09 .6000000E+08 .0000000E+00
.0000000E+00 .0000000E+00 .6800000E+08 .1000000E+09 .1000000E+09 .9100000E+08 .5000000E+08 .0000000E+00 .0000000E+00
.0000000E+00 .0000000E+00 .0000000E+00 .7200000E+08 .7200000E+08 .1200000E+09 .7200000E+08 .0000000E+00 .0000000E+00
.0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .7200000E+08 .1000000E+09 .6800000E+08 .0000000E+00 .0000000E+00
.0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .2000000E+08 .1000000E+09 .0000000E+00 .0000000E+00 .0000000E+00
.0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .9999999E+07 .6000000E+08 .0000000E+00 .0000000E+00 .0000000E+00
.0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00 .0000000E+00
   0.000     0.000     0.000     0.000     0.000     0.084     0.000     0.000     0.000
   0.000     0.000     0.000     0.121     0.230     0.315     0.103     0.000     0.000
   0.000     0.000     0.009     0.169     0.178     0.056     0.142     0.074     0.000
   0.000     0.000     0.019     0.028     0.019     0.084     0.131     0.066     0.000
   0.000     0.019     0.028     0.009     0.028     0.009     0.018     0.047     0.000
   0.000     0.000     0.009     0.000     0.009     0.037     0.028     0.056     0.000
   0.000     0.000     0.009     0.009     0.019     0.019     0.019     0.000     0.000
   0.000     0.000     0.000     0.009     0.019     0.028     0.028     0.000     0.000
   0.000     0.000     0.000     0.000     0.046     0.009     0.009     0.000     0.000
   0.000     0.000     0.000     0.000     0.009     0.009     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.009     0.009     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.216     0.000     0.000     0.000
   0.000     0.000     0.000     0.072     0.112     0.103     0.271     0.000     0.000
   0.000     0.000     0.165     0.135     0.125     0.134     0.168     0.289     0.000
   0.000     0.000     0.062     0.082     0.137     0.135     0.146     0.302     0.000
   0.000     0.062     0.061     0.094     0.113     0.188     0.204     0.240     0.000
   0.000     0.146     0.112     0.104     0.146     0.204     0.278     0.247     0.000
   0.000     0.000     0.153     0.083     0.093     0.115     0.155     0.000     0.000
   0.000     0.000     0.000     0.165     0.242     0.163     0.144     0.000     0.000
   0.000     0.000     0.000     0.000     0.206     0.214     0.235     0.000     0.000
   0.000     0.000     0.000     0.000     0.245     0.214     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.222     0.316     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.649     0.000     0.000     0.000
   0.000     0.000     0.000     0.794     0.602     0.505     0.573     0.000     0.000
   0.000     0.000     0.804     0.656     0.646     0.784     0.642     0.567     0.000
   0.000     0.000     0.918     0.878     0.821     0.729     0.667     0.542     0.000
   0.000     0.918     0.857     0.885     0.814     0.760     0.694     0.656     0.000
   0.000     0.844     0.857     0.885     0.823     0.633     0.598     0.577     0.000
   0.000     0.000     0.816     0.885     0.866     0.823     0.763     0.000     0.000
   0.000     0.000     0.000     0.794     0.442     0.735     0.763     0.000     0.000
   0.000     0.000     0.000     0.000     0.639     0.765     0.745     0.000     0.000
   0.000     0.000     0.000     0.000     0.724     0.765     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.747     0.653     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.031     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.020     0.021     0.042     0.000     0.000
   0.000     0.000     0.021     0.021     0.021     0.021     0.032     0.041     0.000
   0.000     0.000     0.000     0.010     0.021     0.000     0.042     0.083     0.000
   0.000     0.000     0.000     0.010     0.041     0.042     0.082     0.052     0.000
   0.000     0.010     0.020     0.010     0.021     0.000     0.093     0.113     0.000
   0.000     0.000     0.020     0.021     0.021     0.042     0.062     0.000     0.000
   0.000     0.000     0.000     0.031     0.179     0.071     0.062     0.000     0.000
   0.000     0.000     0.000     0.000     0.103     0.010     0.010     0.000     0.000
   0.000     0.000     0.000     0.000     0.020     0.010     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.020     0.020     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.010     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.010     0.021     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.010     0.000     0.000     0.021     0.000
   0.000     0.000     0.000     0.000     0.000     0.042     0.000     0.000     0.000
   0.000     0.000     0.051     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.122     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.116     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.009     0.000     0.000     0.000
   0.000     0.000     0.000     0.013     0.026     0.035     0.011     0.000     0.000
   0.000     0.000     0.001     0.019     0.020     0.006     0.016     0.008     0.000
   0.000     0.000     0.002     0.003     0.002     0.009     0.015     0.007     0.000
   0.000     0.002     0.003     0.001     0.003     0.001     0.002     0.005     0.000
   0.000     0.000     0.001     0.000     0.001     0.004     0.003     0.006     0.000
   0.000     0.000     0.001     0.001     0.002     0.002     0.002     0.000     0.000
   0.000     0.000     0.000     0.001     0.002     0.003     0.003     0.000     0.000
   0.000     0.000     0.000     0.000     0.005     0.001     0.001     0.000     0.000
   0.000     0.000     0.000     0.000     0.001     0.001     0.000     0.000     0.000
```

```
    0.000     0.000     0.000     0.000     0.001     0.001     0.000     0.000     0.000
    0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```

3.3.17 Basin File (.SHD) for UTM Coordinates

For the time being, the previous format created by BSN.EXE filename= new_format.shd (as well as the new_shd.r2c) will be kept. It can be used for information only. It is useful to look at the data whenGreenKenue is not available to the user or to look at the data in column format.

The basin file for SPL9 should have the file type as _SHD to differentiate it from other files. The following example is part of the basin file for the Grand River watershed above Galt in Ontario. The entire file is created by the program called BSN, which reads information obtained from maps. This program is described later in Section . The file is described below for information only.

```
#
#
:Created     :      12:38:46  02-12-2011
:InputFileName       gr10k.map
#
:CoordSys           UTM
:datum1              GRS80
:Zone               17
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
:NominalGridSize_AL    10000.000
:ContourInterval           1.000
:ImperviousArea            0.100
:ClassCount                    5
:NumRiverClasses               5
:ElevConversion            1.000
#
:TotalNumOfGrids              47
:numGridsInBasin              46
:DebugGridNo                  23
#
:endHeader
```

Notes:
There is a border of 0's surrounding the basin to accommodate a receiving grid - *#47* in this example. Also, the border surrounding the watershed can accommodate rain gauges to adjust the RADAR data field. **The borders can be enlarged to accommodate more gauges.** This would only be needed if there is a need to calibrate radar data using precip gauges outside the minimum

domain. Precip gauges can be outside the domain and still be included in the distabce weighting scheme in the programs RAGMET.EXE and TEMP.EXE.

The receiving element ***47*** is outside the watershed. If there are more than 1 receiving elements, they must be the last rows in the .SHD file.

If there are multiple watershed outlets, the receiving cell elevation must be lower than any cell elevation within any of the watersheds. This is to ensure that all receiving cells are at the bottom of the BSNM.SHD file. These receiving cells must all have a cell size of 0.0 to ensure that no computations are carried out for that cell.

This section is the .shd file as read by SPL9:

```
  n, next, row, col,   da,    bankfull, cha_slope,  elv, ch_lenth,iak,int_slope,chnl,reach,frac,imperv classes 1 -          5
  1    4   11    5    10.000   1.76667 0.0022875  518.5 10000.    1   0.00440    2    0    0.10 0.00 0.01 0.22 0.75 0.02 0.00
  2    3   11    6       60.     10.10 0.0019825  518.5 10000.    1   0.00320    3    0    0.60 0.00 0.01 0.32 0.65 0.02 0.00
  3    5   10    6      160.     26.77 0.0010675  498.7 10000.    1   0.00340    3    0    1.00 0.00 0.01 0.21 0.77 0.01 0.00
  4    5   10    5       30.      5.10 0.0005392  495.6 14142.    1   0.00500    2    0    0.20 0.00 0.01 0.24 0.72 0.02 0.00
  5   13    9    6      290.     48.43 0.0033550  488.0 10000.    1   0.00620    2    0    1.00 0.00 0.01 0.21 0.77 0.01 0.00
  6   13    9    7       68.     11.43 0.0023724  488.0 14142.    1   0.00330    3    0    0.68 0.00 0.01 0.23 0.74 0.01 0.00
  7   13    8    7       72.     12.10 0.0030500  485.0 10000.    1   0.00720    3    0    0.72 0.00 0.03 0.14 0.76 0.06 0.00
  8   13    8    5       72.     12.10 0.0025925  480.4 10000.    1   0.00940    5    0    0.72 0.00 0.02 0.24 0.44 0.18 0.12
  9   13    9    5       72.     12.10 0.0018332  480.4 14142.    1   0.00790    2    0    0.72 0.01 0.05 0.21 0.64 0.10 0.00
 10   15    7    7       50.      8.43 0.0041175  472.8 10000.    5   0.00840    2    0    0.50 0.00 0.02 0.15 0.76 0.06 0.00
 11   14    8    4       72.     12.10 0.0022875  472.8 10000.    2   0.00830    2    0    0.72 0.00 0.01 0.16 0.79 0.03 0.00
 12   14    7    5      100.     16.77 0.0007625  457.5 10000.    2   0.00430    3    0    1.00 0.00 0.02 0.09 0.87 0.02 0.00
 13   15    8    6      694.    115.77 0.0022875  454.5 10000.    1   0.00660    2    0    1.20 0.00 0.03 0.16 0.73 0.07 0.00
 14   16    7    4      272.     45.43 0.0022875  449.9 10000.    2   0.01020    4    0    1.00 0.00 0.01 0.08 0.89 0.02 0.00
 15   21    7    6      835.    139.27 0.0025925  431.6 10000.    5   0.00930    2    0    0.91 0.00 0.02 0.11 0.82 0.04 0.00
 16   22    6    4      365.     60.93 0.0027450  427.0 10000.    2   0.00670    4    0    0.93 0.00 0.00 0.10 0.89 0.01 0.00
 17   26    6    7      101.     16.93 0.0026959  427.0 14142.    3   0.01330    3    0    1.01 0.00 0.03 0.28 0.60 0.09 0.00
 18   22    7    3       68.     11.43 0.0019825  419.4 10000.    2   0.00490    2    0    0.68 0.00 0.01 0.15 0.82 0.02 0.00
 19   32    6    5      120.     20.10 0.0051850  417.9 10000.    5   0.00780    3    0    1.20 0.00 0.01 0.15 0.82 0.02 0.00
 20   31    6    2       40.      6.77 0.0032350  411.8 14142.    2   0.00740    3    0    0.40 0.00 0.00 0.15 0.84 0.01 0.00
 21   32    6    6      885.    147.60 0.0028037  405.7 14142.    5   0.01510    1    1    0.50 0.00 0.04 0.20 0.63 0.00 0.12
 22   31    6    3      533.     88.93 0.0033550  399.6 10000.    2   0.00880    2    0    1.00 0.00 0.01 0.11 0.86 0.02 0.00
 23   31    5    2    10.000   1.76667 0.0030500  396.5 10000.    5   0.00380    3    0    0.10 0.00 0.02 0.06 0.92 0.00 0.00
 24   26    5    7       31.      5.27 0.0007625  396.5 10000.    3   0.01190    3    0    0.31 0.00 0.02 0.20 0.69 0.08 0.00
 25   41    5    4      118.     19.77 0.0053917  393.5 14142.    2   0.01030    3    0    1.18 0.00 0.01 0.09 0.89 0.01 0.00
 26   36    5    6      167.     27.93 0.0045750  388.9 10000.    3   0.01030    2    0    0.35 0.00 0.01 0.19 0.76 0.04 0.00
 27   28    6    8       60.     10.10 0.0013725  388.9 10000.    4   0.02070    4    0    0.60 0.01 0.06 0.25 0.58 0.11 0.00
 28   39    5    8      170.     28.43 0.0047275  375.1 10000.    4   0.01270    2    0    1.10 0.01 0.05 0.24 0.66 0.05 0.00
 29   35    3    3       40.      6.77 0.0030500  373.6 10000.    5   0.01330    3    0    0.40 0.00 0.01 0.16 0.80 0.02 0.00
 30   45    2    4       19.      3.27 0.0086925  366.0 10000.    5   0.01320    3    0    0.19 0.01 0.12 0.07 0.79 0.00 0.00
 31   33    5    3      673.    112.27 0.0018300  366.0 10000.    5   0.01070    2    2    0.90 0.00 0.03 0.06 0.86 0.00 0.05
 32   41    5    5     1170.    195.10 0.0048800  366.0 10000.    5   0.01340    3    0    1.65 0.00 0.03 0.11 0.81 0.04 0.00
 33   38    4    3      768.    128.10 0.0012200  347.7 10000.    5   0.00780    3    0    0.95 0.00 0.02 0.06 0.92 0.00 0.00
 34   37    3    8       12.      2.10 0.0009150  344.6 10000.    5   0.01290    5    0    0.12 0.01 0.07 0.29 0.57 0.04 0.02
 35   43    3    4      138.     23.10 0.0042700  343.1 10000.    5   0.01270    2    0    0.98 0.02 0.17 0.14 0.66 0.02 0.00
 36   42    4    6      212.     35.43 0.0030500  343.1 10000.    3   0.00880    3    3    0.45 0.01 0.08 0.14 0.73 0.00 0.04
 37   46    3    7       92.     15.43 0.0048526  335.5 14142.    5   0.01130    4    0    0.80 0.02 0.14 0.17 0.64 0.03 0.00
 38   43    4    4      833.    138.93 0.0024802  335.5 14142.    5   0.01600    2    0    0.65 0.00 0.03 0.08 0.88 0.01 0.00
 39   42    4    8      235.     39.27 0.0015250  327.9 10000.    4   0.01490    3    0    0.65 0.01 0.07 0.30 0.54 0.08 0.00
 40   46    2    7       22.      3.77 0.0053375  320.2 10000.    5   0.00920    5    0    0.22 0.01 0.10 0.27 0.57 0.04 0.00
 41   43    4    5     1453.    242.27 0.0016775  317.2 10000.    5   0.00680    2    0    1.65 0.00 0.02 0.14 0.82 0.02 0.00
 42   44    4    7      593.     98.93 0.0012940  312.6 14142.    3   0.01790    2    0    1.46 0.01 0.13 0.15 0.67 0.04 0.00
 43   45    3    5     2524.    420.77 0.0021350  300.4 10000.    5   0.01280    2    0    1.00 0.02 0.18 0.12 0.65 0.02 0.01
 44   46    3    6      693.    115.60 0.0027450  294.3 10000.    5   0.01300    2    0    1.00 0.01 0.06 0.13 0.78 0.02 0.00
 45   46    2    5     2628.    438.10 0.0012200  279.1 10000.    5   0.01600    2    0    0.85 0.03 0.23 0.11 0.60 0.02 0.01
 46   47    2    6     3520.    586.77 0.0013725  266.9 10000.    5   0.01560    1    0    0.85 0.04 0.32 0.10 0.51 0.02 0.02
 47    0    1    6     0.000   0.10000 0.0000000  253.2 10000.    0   0.00000    0    0    0.00 0.01 0.08 0.22 0.65 0.03 0.01
```

Where:

N =	Grid number - gives order of computation
NEXTI =	Receiving cell number (must be more than N)
YY =	Row number from bottom left corner of the grids
XX =	Column number from left side of the grids
DA =	Drainage area in km^2
CH CAP =	Bankfull cross-section area of river channel in m^2
SLOPE =	River slope in m/m

ELV =	River bed elevation at mid-cell point
IBN =	Basin number or river class number
INTSLOPE =	The internal slope in each grid (Land slope in m/m)
CHNL =	No. of channels draining through the cell
REACH =	Reach number for lake, reservoir and/or external routing
FRACT =	Ratio of cell size to nominal cell size
6,1,2….N =	Fractions in each land cover class. Imperviouis fraction first. Water last.

This example of the basin file is the required format for SPL9. The proper format is automatically created by the program BASIN. Note that the last six columns in each row should add up to 1.0 to preserve the proper drainage area of each element. Thus for element 46 (highlighted), 12% of the area is impervious, 23% is in land use/cover class 1 (barren), 10% is in class 2 (forest), 51% is in class 3 (low vegetation, crops), 2% is in class 4 (wetland), and 2% is in class 5 (water). SPL9 checks that this sum is 100% and will correct the values if necessary. Any corrections made are listed in the SPL.ERR file in the working directory for a watershed.

Important notes:

Note 1: An important thing to check is that the drainage areas at the streamflow stations are correct. The .SHD file can be examined to see that this is the case. The coordinates of the gauges have to be carefully placed to accomplish this. To do this, locate the gauges on the watershed template (a grid such as the one in Figure 3.1 in the previous section). Then use the following part to determine the element number that has the gauge:

Suppose that the gauge is at the outlet of element # 46. The computed drainage area at that location is found in the fourth column for element number 46 as 3520 km^2. This should match the Water Survey drainage area.

```
   .

   .
 45   46    2    5     2628.     438.10 0.0040000  915.0 10000.    5    0.00610    2    0     0.85 0.08 0.17 0.11 0.60 0.02 0.01
 46   47    2    6     3520.     586.77 0.0045000  875.0 10000.    5    0.00610    1    0     0.85 0.12 0.23 0.10 0.51 0.02 0.02
 47    0    1    6     0.000    0.10000 0.0000000  830.0     0.    0    0.00000    0    0     0.00 0.03 0.06 0.22 0.65 0.03 0.01
```

Note 2: Sometimes –ve slopes are calculated if the elevations and the drainage directions are not properly entered. The bsn_info.txt will show the slopes in column 7. The problem can be easily shown and fixed inGreenKenue by loading the .map file with the elevations and the drainage directions shown and importing the .shd to show the slope as points with 2 divisions below and above a slope of 0.0 as shown below. The red points show the locations of the –ve slopes.

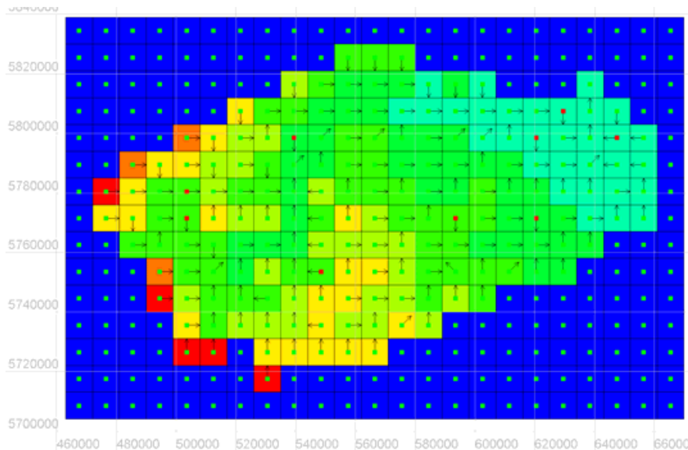


Figure 6 – Debugging the .map file withGreenKenue

3.3.18 Basin File for Geographical Coordinates (LATLONG)

When the BSN.EXE program reads a file for goegraphical coordinates, the header for the bsnm.shd file is as follows:

```
#
:Created     :      13:57:31  03-08-2004
:InputFileName      ont_new5.map
#
:CoordSys           LATLONG
:Datum              GRS80
#
:xOrigin             -75.8000031
:yOrigin              44.5999985
#
:xCount                       56
:yCount                       42
:xDelta                0.0250000
:yDelta                0.0250000
#
:NominalGridSize(AL)    2329.877
:ContourInterval           1.000
:ImperviousArea            0.000
:ClassCount                    6
:NoRiverClasses                5
:ElevConversion            1.000
:#
:Total#ofGrids              1025
:#GridsInBasin              1022
:Debug_grid_no               756
#
:endHeader
```

The explanation for the format is the same as for the bsnm.map file in Section 3.3

3.4 Setting up Sub-watersheds << new!!

When working with large watersheds, it can be advantageous to set up sub-watersheds as separate watershed files so they can be run independently. This is very useful for optimization as run times can be greatly reduced. For instance, if you wish to optimize on just one sub-watershed to concentrate on one dominant land or river class.

3.4.1 Creating a sub-watershed subbsnm_shd.r2c file << new!!

First a bsnm_shd.r2c file needs to be created. Then point data needs to be distributed as per usual, only the grid extents will be those of the sub-watershed. All point data for the total watershed can be used directly. Flow stations outside the sub-watersheds will just be ignored. The following steps are required:

1. Set up a new watershed folder complete with all the sub-folders as in Section 1.3.4
2. Copy *bsnm*\basin*bsnm*.map to the new subbsnm\basin\ folder
3. Delete the old bsn_responses.txt file. A new format file will be created
4. Run BSN.exe and enter the rank of the last sub-watershed grids you want to model – usually grids with a flow gauge. You need to enter only the rank of most downstream flow station if there are upstream flow stations. The rank of any grid can be determined by loading the bsnm_shd.r2c file in GreenKenue and overlaying the flow_station.xyz file.
5. Rename new.pdl subbsnm.pdl and *new*_shd.r2c *subbsnm*_shd.r2c
6. Edit the event files and replce *bsnm* by *subbsnm*
7. Run RAGMET.exe and TMP.exe to distribute precipitation and temperature data for all events. The domain size will match the new sub-basin extents as specified in the new pdl file. (RAGMET & TMP use the pdl file to set the domain limits)
8. Distribute initial soil moisture and swe for the first event with MOIST.exe and SNW.exe (MOIST & SNW use the shd file to set the domain limits)
9. Copy the subbsnm\basin\wfo_spec.new to subbsnm\wfo_spec.txt (and edit if needed)
10. Run SPLX.exe and edit the outfiles.new file for the next run or copy the outfiles.txt file from another watershed before executing SPLX.
11. Enjoy!

Note:
1. As of January, 2011 multiple sub-watersheds can be extracted from the original map file.
2. All point data files can be used without modification. Stations and/or reservoirs outside the reduced domain will simple be ignored.

Once BSN.exe is executed, a new format bsn_responsed.txt file will be available for subsequent runs. Example bsn_responses.txt file:

```
2                 version #
lwin18.map        map file name
                  blank for WATFLOOD/ file name for WATROUTE
nk                who dunnit
  3               3 subwatersheds to be modelled
 1366             rank of outlet #1
 1602             rank of outlet #
 1610             rank of outlet #
    20.0000       % wetland to be coupled with the channel
 0.0005           minimum slope to eliminate flat spots
```

3.4.2 Creating reduced met & tmp files << new!!

If point precipitatin and temperature data is available, with RAGMET.exe and TMP.exe gridded precipitation and temperature files will be created to match the reduced sub-watershed domain. However, some applications have met.r2c and tem.r2c files created externally, possibly for very large domains. Although these can be read directly as long as the watershed domain is covered and the grid coincides, it can slow execution, especially for repeated runs.

Reducing the domain of the met & tmp files can be easily accomplished by creating sub-directories in the radcl and tempr directories **radcl\new_grid** & **tempr\new_grid** and executing

SPLX.exe. The new files will be automatically created. Next, backup the original files and copy these new met & tem files to the radcl & tempr directories respectively. They are then ready for use.

3.5 Additional Required Files

3.5.1 BSNM.PDL File for UTM Coordinates

This file contains the streamflow station, reservoir and damage location coordinates. In the example below, there are 9 gauge locations, 3 reservoirs, 6 damage sites, and a number of messages at each damage sites. **The grid specifications are used for the precipitation and temperature distribution programs RAGMET & TMP**. The grid for the precipitation (and also temperature) field can be larger than the watershed grid. However, the grid size must be the same and the grids must coincide. This will allow grid-shifting of the precipitation to create “spaghetty plots”.

For LATLONG coordinates, the files are the same except the values are entered as degrees wuth the appropriate number of decimal places.

3.5.1.1 Example of a.pdl file created by BSN.EXE:

```
#
:FileType             bsnm.pdl
:CoordSys           UTM
:datum1              GRS80
:Zone               17
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
:NoPrecipStations     1
#
   545000.0       4850000.       centerville
#
:NoSnowCourses        1
#
   545000.0       4850000.       centerville
#
:NoTempStations       1
#
   545000.0       4850000.       centerville
#
:NoFlowStations       1
#
   545000.  4850000.  centerville 0.000E+00 0.000E+00 0.000E+00 0.000E+00  0
#
:NoReservoirs         1
#
   545000.  4850000.  centerville 0.000E+00 0.000E+00 0.000E+00 0.000E+00  0.000E+00
#
:NoDamageSites        1
#
```

You can change the above file with real numbers as in the example below:

3.5.1.2 Example of a user modified .pdl file:

```
#
:FileType             bsnm.pdl
:CoordSys           UTM
:Datum              GRS80
:Zone               17
#
:xOrigin            500000.000000
:yOrigin            4790000.000000
#
:xCount             9
:yCount             12
:xDelta             10000.000000
:yDelta             10000.000000
#
:NoPrecipStations            9
#
558000.   4820000.  GuelphColl
535000.   4814000.  Waterloo
553000.   4843000.  ShandDam
555000.   4860000.  GrandVall
562000.   4821000.  GuelphArb
520000.   4871000.  MtForest
548000.   4805000.  PrestonWP
501000.   4802000.  Startford
500000.   4811000.  W_W_Airpt
#
:NoSnowCourses               2
#
547000.   4832000.  EloraResSt
556000.   4799000.  ShadesMil
#
:NoTempStations              2
#
530000.   4900000.  Wormwood
530000.   4800000.  LoganFarm
#
:NoFlowStations              9
554000.   4801000.  Galt        0.829E+02 0.173E+01 0.660E+01 0.043E+00
545000.   4833000.  W.Montrose 0.000E+00 0.000E+00 0.000E+00 0.000E+00
556000.   4860000.  Marsville   0.482E+02 0.256E+01 0.354E+00 0.226E+00
570000.   4823000.  Eramosa     0.261E+02 0.176E+01 0.420E+00 0.250E+00
530000.   4849000.  Drayton     0.345E+02 0.241E+01 0.000E+00 0.626E+00
559000.   4833000.  ArmstrongM. 0.289E+02 0.200E+01 0.300E-01 0.330e+00
560000.   4820000.  Guelph       0.000E+00 0.000E+00 0.000E+00 0.000E+00
539000.   4830000.  Elmira       0.000E+00 0.000E+00 0.000E+00 0.000E+00
556000.   4860000.  Waldemar     0.000E+00 0.000E+00 0.000E+00 0.000E+00

#
:NoReservoirs                3
#
554000.   4843000.  Belwood          .00000    .00000    .00000    .00000
523000.   4836000.  Conestogo        .00000    .00000    .00000    .00000
559000.   4827000.  Guelph           .00000    .00000    .00000    .00000
#
:NoDamageSites               6
#
550000.   4800000.  Galt     6.112E-02 0.618E+00 0.000E+00 0.000E+00 0.000E+00
540000.  4810000. Bridgeport 5.411E-02 0.663E+00 0.000E+00 0.000E+00 0.000E+00
545000.  4833000. W.Montrose 9.479E-02 0.567E+00 0.000E+00 0.000E+00 0.000E+00
530000.   4820000. St.Jacobs 1.966E-01 0.473E+00 0.000E+00 0.000E+00 0.000E+00
520000.   4840000.  Drayton  6.473E-01 0.273E+00 0.000E+00 0.000E+00 0.000E+00
560000.   4820000.  Hanlon   3.301E-02 0.821E+00 0.000E+00 0.000E+00 0.000E+00
#
:DamageDetails
```

```
#
Galt                 4
Galt   573  3.3      On shoulder Hwy. 24
Galt   638  3.5      Over Hwy. 24
Galt   950  4.4      Over Bank at Riverside B.B. Serious flooding starts
Galt  1550  5.8      1974 Flood
Bridgeport           5
Brid   335 2.85      Warn Bingeman Park or Wat. Reg. Police
Brid   400 3.15      Bingeman Park = Flooded
Brid  1130  4.9      Issue advisory to Village
Brid  1370  5.5      Close Bridge St./ Sandbag end of street/ warn residents
Brid  1700  6.0      Evacuate residents
W.Montrose           4
W.Mo   106 1.45      Warn W. Montrose Camp or Wat. Reg. Police
W.Mo   125  1.6      West Montrose Camp Flooded
W.Mo   283  2.6      Flooding of roads and houses
W.Mo   675 3.45      1974 Flood
St.Jacobs            1
St.J   566  3.0      Channel Capacity
Drayton              1
Dray   255  2.9      Channel Capacity
Hanlon               1
Hanl   255  3.1      Channel Capacity (Approx)
:eof
```

3.6 Additional Optional Files (New 2012)

Optional Stage Hydrographs

The hydrographs can be entered as stage or flow hydrographs. For flow hydrographs, the fields after the station names are left blank. For stage hydrographs, the stage values are converted to flow using the following function:

$$\mathbf{flow = a_3 + a_1(stage - a_4)^{a_2}} \qquad (3.2)$$

In this equation, a_4 is the datum for the flow metering station. a_1, a_2 and a_3 are fitted parameters. The flow & stage measurement stations can be mixed. The first parameter a_1 is used as a flag. If it is 0.0, the hydrograph values are assumed to be flows. Otherwise they are used as stage and converted. All values in the results/spl.csv file are in flow units of m^3/s and can be used to check if the conversion is properly made from stage to flow.

3.6.1 Optional Storage-Discharge curves for lakes & reservoirs

Associated with the BASIN\bsnm.pdl file is the ability to program a lake storage-discharge curve for routing through natural lakes. The first two entrees b_1 and b_2 after the lake outlet (reservoir outlet) coordinates are used in the simple power function:

$$\mathbf{outflow = b_1 storage^{b_2}} \qquad (3.3)$$

Values for b_1 and b_2 of 10^{-11} and 1.75 respectively are reasonable first trial values. The initial storage of a lake is determined by a backward calculation from the initial flow at a downstream station.

The third, fourth & fifth entrees b3, b4, and b5 are used if the best fit is a polinomila. See Section 7.2 for more details and an example.

3.6.2 BSNM.PAR File

The makeup of the par file is described in detail in Chapter 4

Copy a parameter file from another watershed and modify as needed for the land and river classes.

3.6.3 CALMET.PAR File

This file is used only for radar calibration using the CALMET.EXE program.

Please refer to 6.4.3

3.7 Mean and Max grid elevations for lapse rate applications - New

In moutainous terrain the use of lapse rates for temperature and precipitation are required to account for the orographic effects on temperature and precipitation. While the WATFLOOD model cannot possibly mimic the atmospheric processes producing precipitation such as the carryover of higher precipitation on the leeward side of mountain crests for instance, the incorporation of lapse rates make it possible to still take in the elevation effects.

The midpoint elevation of the grid's main channel is already incorporated in the map file and is converted to channel slope for the shd file. However, this channel elevation may not be the most desirable to use for the calculation of the grid's temperature and precipitation amounts. For this purpose, if a file called **dem.r2s** is created by saving the dem in GreenKenue as an r2s file in the basin directory**, BSN.exe** will look for this file and if found, create two files called **elv_means.r2c and elv_max.r2c** *Be sure to assign a **Projection** and and **Ellipsoid** to the DEM in GreenKenue before saving it or you will have to edit the r2s file to add it.*

Once these files **elv_means.r2c & elv_max.r2c** are in the basin directory, RAGMET.exe will find **elv_max.r2c** and replace the channel elevations in the shd file with these highest grid elevations. TMP.exe will find **elv_means.r2c** and replace the channel elevations in the shd file with these average grid elevations. The temperature and precipitation adjustments using the lapse rates tlapse and rlapse respectively will be based on the mean and max grid elevations respectively

Based on modeling in the Alberta Rocky Mountains, use of the mean grid elevation works best for the temperature elevation adjustment. However, for the precipitation, the maximum (or highest) grid elevation appears to work best. Likely this is because the orographically induced airflow is most addected by the higher elevations.

See Sections 6-5 8-3 for the precipitation and temperature lapse rate discussions.

3.8 Watershed data summary

Once all these directories and files are created, you can run WATFLOOD. First you have to create an event file, enter and distribute some rainfall data, and run SPL.

Log to the \SPL\BSNM directory and run MAKE_EVT. Enter the appropriate data. Some times it takes a couple of tries to get started - you can not correct the data if it has been entered incorrectly. This will create two files in the EVENT directory: EVENT.EVT and YYMMDD.EVT. Please see sections 1.3.11.

The EVENT.EVT file is always the active file. Once you have more than one event entered, you can run any event by copying the YYMMDD.EVT file into the EVENT.EVT file. This makes the YYMMDD.EVT file the active event file. You can also make multiple event files with this program by entering the desired numbers.

Before attempting to run a new watershed, run the Grand River (GR10K) demonstration data set to ensure that everything is installed properly.

4 MODEL PARAMETERS AND OPTIMIZATION

4.1 Parameter File

The parameter file contains most of the parameters used in SPL9. There are others in the program, which are not likely to ever need changing. Any of these parameters can be handled by the optimization routine, but the selection depends on the programming in subroutine OPTIONS. The parameters to be optimized can be chosen from a list in part 2 of the parameter file. The possible choice list can only be changed by changing the source code.

A complete parameter file is shown in two parts below. The first part contains the parameters used for normal runs. The second part is used for optimization runs and is now free format – i.e. **blanks between entries**.

Notes:

1. The impervious class is now like any other – it needs all parameters.
2. The par file should be edited in Excel and saves as a CSV file
3. Recent changes are highlighted in yellow

WARNING:

When editing and saving a parameter file in Excel™ there can be unintended consequences. If you are getting weird results, like no runoff, upper zone storage or something like that, it is likely that Excel™ inserted some weird invisible characters in the file. To find these, compare results\parfile.csv to the par file that was read by the program. Blanks in the file saved by Excel™ seem to be troublesome and should be removed. Note that files saved from Excel™ look like this:

```
.
.
#,,,,,,,,,,,,,,,,
:RoutingParameters,,,,,,,,,,,,,,,
:RiverClasses,6,,,,,,,,,,,,,,
:RiverClassName,   default      ,rky_steep    ,rky_flat     ,fluvial      ,wetl_low     ,wetl_pry
,,,,,,,,,,
:flz,1.70E-04,7.00E-05,7.00E-05,2.10E-04,1.07E-03,2.91E-03,# lower zone oefficient,,,,,,,,,
:pwr,2.17,2.1,2.1,3.34,2.73,3.16,# lower zone exponent,,,,,,,,
:r1n,0.04,0.04,0.04,0.04,0.04,0.04, # overbank Manning`s n ,,,,,,,,,
:r2n,0.037,0.044,0.015,0.03,0.024,0.043, # channel Manning`s n ,,,,,,,,,
:mndr,1,1,1,1,1,1,# meander channel length multiplier,,,,,,,,,
:aa2,1.1,1.1,1.1,1.1,1.1,1.1,# channel area intercept = min channel xsect area,,,,,,,,,
:aa3,4.30E-02,4.30E-02,4.30E-02,4.30E-02,4.30E-02,4.30E-02,# channel area coefficient,,,,,,,,,
.
.etc
```

New: Important program revision:

The code reading the bsnm_par.csv file is now a parser which looks for key words. There are now sections of parameters – for instance:

:GlobalParameters

.
.

EndGlobalParameters

Etc.

These sections can be rearranged in order in their entirety. Within each sections, the entries can be rearranged in order but entries **cannot** be moved from one section to another.

The following programs read the par file:

SPLX64.exe & SPLd64.exe, RAGMET.exe, TMP.exe and DDS_WFLD_REV3.exe

All these programs work in unison and should be updated together.

Part 1 - for normal runs **New sections highlighted**

```
:FileType, WatfloodParameter,      10.10,# parameter file version number
:CreationDate ,2011-12-02  09:37:40
:GlobalParameters
:iopt,                   1,# debug level
:itype,                  0,# channel type - floodplain/no
:itrace,                 4,# Tracer choice
:a1,              -999.999,# ice cover weighting factor
:a2,                 1.000,# Manning`s correction for instream lake
:a3,                 0.050,# error penalty coefficient
:a4,                 0.030,# error penalty threshold
:a5,                 0.985,# API coefficien
:a6,               900.000,# Minimum routing time step in seconds
:a7,                 0.900,# weighting - old vs. new sca value
:a8,                 0.100,# min temperature time offset
:a9,                 0.333,# max heat deficit /swe ratio
:a10,                2.000,# exponent on uz discharce function
:a11,                0.010,# bare ground equiv. veg height for ev
:a12,                0.000,# min precip rate for smearing
:fmadjust,           0.000,# snowmelt ripening rate
:fmalow,             0.000,# min melt factor multiplier
:fmahigh,            0.000,# max melt factor multiplier
:gladjust,           0.000,# glacier melt factor multiplier
:rlapse,          0.000000,# precip lapse rate mm/m
:tlapse,          0.000000,# temperature lapse rate dC/m
:elvref,             0.000,# reference elevation
:rainsnowtemp,       0.000,# rain/snow temperature
:radiusinflce,     300.000,# radius of influence km
:smoothdist,        35.000,# smoothing diatance km
:flgevp2  ,          2.000,# 1=pan;2=Hargreaves;3=Priestley-Taylor
:albe  ,             0.110,# albedo????
:tempa2,            50.000,#
:tempa3,            50.000,#
:tton  ,             0.000,#
:lat   ,            50.000,# latitude
:chnl(1),            1.000,# manning`s n multiplier
:chnl(2),            0.900,# manning`s n multiplier
:chnl(3),            0.700,# manning`s n multiplier
:chnl(4),            0.700,# manning`s n multiplier
:chnl(5),            0.600,# manning`s n multiplier
:EndGlobalParameters
#
:RoutingParameters
:RiverClasses,           5
:RiverClassName,  upper_gr    ,conestoga   ,speed       ,eramosa     ,lower_gr    ,
:flz,               0.100E-05,   0.100E-05,   0.271E-04,   0.154E-04,   0.209E-05,# lower zone oefficient
:pwr,                3.20    ,    3.00    ,    2.00    ,    2.20    ,    2.60    ,# lower zone exponent
:r1n,               0.200E-01,   0.200E-01,   0.200E-01,   0.200E-01,   0.200E-01,# overbank Manning`s n
:r2n,               0.105E-01,   0.997E-01,   0.258E-01,   0.109E-01,   0.181E-01,# channel Manning`s n
:mndr,               1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,# meander channel length multiplier
:aa2,                1.10    ,    1.10    ,    1.10    ,    1.10    ,    1.10    ,# channel area intercept = min channel xsect area
:aa3,               0.430E-01,   0.430E-01,   0.430E-01,   0.430E-01,   0.430E-01,# channel area coefficient
:aa4,                1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,# channel area exponent
:theta,             0.700    ,   0.700    ,   0.700    ,   0.700    ,   0.700    ,# wetland or bank porosity
```

```
:widep,              10.0    ,    10.0    ,    10.0    ,    10.0    ,    10.0    ,# channel width to   depth ratio
:kcond,             0.800    ,   0.800    ,   0.800    ,   0.800    ,   0.500    ,# wetland/bank lateral conductivity
:pool,               0.00    ,    0.00    ,    0.00    ,    0.00    ,    0.00    ,# average area of zero flow pools
:rlake,              0.00    ,    0.00    ,    0.00    ,    0.00    ,    0.00    ,# in channel lake retardation coefficient
:EndRoutingParameters
#
:HydrologicalParameters
:LandCoverClasses,          6
:ClassName       ,bare_soil  ,forest     ,crops      ,wetland    ,water      ,impervious  ,# class name
:ds,                 1.00    ,    10.0    ,    2.00    ,  0.100E+10,    0.00    ,    1.00    ,# depression storage bare ground mm
:dsfs,               1.00    ,    10.0    ,    2.00    ,  0.100E+10,    0.00    ,    1.00    ,# depression storage snow covered area mm
:rec,                2.00    ,    2.00    ,    2.00    ,  0.900    ,  0.100    ,  0.900    ,# interflow coefficient
:ak,                 2.94    ,    12.0    ,    3.00    ,   400.    , -0.100    ,  0.100E-10,# infiltration coefficient bare ground
:akfs,              0.300E-01,    1.20    ,    3.00    ,   400.    , -0.100    ,  0.100E-10,# infiltration coefficient snow covered ground
:retn,               40.0    ,    70.0    ,    40.0    ,  0.400    ,  0.100    ,  0.100    ,# upper zone retention mm
:ak2,               0.200E-01,  0.100    ,  0.200E-01,  0.200E-01,  0.100E-02,  0.100E-10,# recharge coefficient bare ground
:ak2fs,             0.200E-01,  0.100    ,  0.200E-01,  0.200E-01,  0.100E-02,  0.100E-10,# recharge coefficient snow covered ground
:r3,                0.197    ,  0.848E-01,  0.197    ,  0.898E-01,  0.400E-01,    4.00    ,# overland flow roughness coefficient bare ground
:r3fs,              0.100    ,  0.100    ,  0.200    ,  0.100    ,  0.400E-01,    4.00    ,# overland flow roughness coefficient snow covered grnd
:r4,                 1.00    ,    10.0    ,    10.0    ,    10.0    ,    10.0    ,    10.0    ,# overland flow roughness coefficient impervious area
:fpet,               3.00    ,    2.00    ,    3.00    ,    3.00    ,    1.00    ,    1.00    ,# interception evaporation factor * pet
:ftall,              1.00    ,  0.700    ,  0.700    ,    1.00    ,    0.00    ,    1.00    ,# reduction in PET for tall vegetation
:flint,              1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,# interception flag  1=on  <1=off
:fcap,              0.150    ,  0.150    ,  0.150    ,  0.150    ,  0.150    ,  0.150    ,# not used - replaced by retn (retention)
:ffcap,             0.100    ,  0.100    ,  0.100    ,  0.100    ,  0.100    ,  0.100    ,# wilting point - mm of water in uzs
:spore,             0.330    ,  0.330    ,  0.330    ,  0.330    ,  0.330    ,  0.330    ,# soil porosity
:fratio,             1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,# int. capacity multiplier
:EndHydrologicalParameters
#
:SnowParameters
:fm,                   0.100,       0.080,       0.090,       0.080,       0.100,       0.150,# melt factor mm/dC/hour
:base,                -2.000,      -2.000,      -2.000,      -2.000,      -2.000,       2.500,# base temperature dC
:fmn,                  0.100,       0.100,       0.100,       0.100,       0.100,       0.100,# -ve melt factor
:uadj,                 0.000,       0.000,       0.000,       0.000,       0.000,       0.000,# not used
:tipm,                 0.100,       0.100,       0.100,       0.100,       0.100,       0.100,# coefficient for ati
:rho,                  0.333,       0.333,       0.333,       0.333,       0.333,       0.333,# snow density
:whcl,                 0.035,       0.035,       0.035,       0.035,       0.035,       0.035,# fraction of swe as water in ripe snow
:alb,                  0.180,       0.110,       0.110,       0.110,       0.110,       0.110,# albedo
:sublim_factor,        0.000,       0.000,       0.000,       0.000,       0.000,       0.000,# sublimation factor ratio
:idump,                    1,           2,           3,           4,           5,           6,# receiving class for snow redistribution
:snocap,            6000.000,    -600.000,    -600.000,    -600.000,    -600.000,    -600.000,# max swe before redistribution
:nsdc,                     2,           2,           2,           2,           2,           2,# no of points on scd curve - only 1 allowed
:sdcsca,               1.000,       1.000,       1.000,       1.000,       1.000,       1.000,# snow covered area - ratio=1.0
:sdcd,               200.000,     200.000,     150.000,     150.000,       1.000,     100.000,# swe for 100% snow covered area
:EndSnowParameters
#
:InterceptionCapacityTable
:IntCap_Jan,           0.110,       1.200,       0.650,       0.650,       0.110,       0.010,# interception capacity jan mm
:IntCap_Feb,           0.110,       1.200,       0.650,       0.650,       0.110,       0.010,# interception capacity feb mm
:IntCap_Mar,           0.110,       1.200,       0.650,       0.650,       0.110,       0.010,# interception capacity mar mm
:IntCap_Apr,           0.110,       1.200,       0.650,       0.650,       0.110,       0.010,# interception capacity apr mm
:IntCap_May,           0.600,       1.600,       1.060,       0.850,       0.110,       0.010,# interception capacity may mm
:IntCap_Jun,           0.600,       1.900,       1.560,       1.000,       0.110,       0.010,# interception capacity jun mm
:IntCap_Jul,           0.600,       1.900,       1.560,       1.000,       0.110,       0.010,# interception capacity jul mm
:IntCap_Aug,           0.600,       1.900,       1.560,       1.000,       0.110,       0.010,# interception capacity aug mm
:IntCap_Sep,           0.600,       1.900,       1.000,       1.000,       0.110,       0.010,# interception capacity sep mm
```

```
:IntCap_Oct,            0.350,       1.200,       0.650,       0.650,       0.110,       0.010,#       interception capacity oct mm
:IntCap_Nov,            0.110,       1.200,       0.650,       0.650,       0.110,       0.010,# interception capacity nov mm
:IntCap_Dec,            0.110,       1.200,       0.650,       0.650,       0.110,       0.010,# interception capacity dec mm
:EndInterceptionCapacityTable
#
:MonthlyEvapotranspirationTable
:Montly_ET_Jan,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration jan mm
:Montly_ET_Feb,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration feb mm
:Montly_ET_Mar,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration mar mm
:Montly_ET_Apr,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration apr mm
:Montly_ET_May,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration may mm
:Montly_ET_Jun,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration jun mm
:Montly_ET_Jul,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration jul mm
:Montly_ET_Aug,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration aug mm
:Montly_ET_Sep,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration sep mm
:Montly_ET_Oct,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration oct mm
:Montly_ET_Nov,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration nov mm
:Montly_ET_Dec,           0.0,         0.0,         0.0,         0.0,         0.0,         0.0,# monthly evapotranspiration dec mm
:EndMonthlyEvapotranspirationTable
#
:OptimizationSwitches
:numa,        0,# PS optimization 1=yes 0=no
:nper,        1,# opt 1=delta 0=absolute
:kc,          5,# no of times delta halved
:maxn,     2000,# max no of trials
:ddsflg,      0,# 0=single run  1=DDS
:errflg,      7,# 1=wMSE 2=SSE 3=wSSE 4=VOL
:EndOptimizationSwitches
#
:APILimits
:a5dlt,               -0.100E-02
:a5low,                0.980
:a5hgh,                0.999
:EndAPILimits
#
:HydrologicalParLimits
:ClassName       ,bare_soil   ,forest      ,crops       ,wetland     ,water       ,impervious  ,# class name
# infiltration coefficient bare ground
:akdlt,                -0.020,      -0.020,      -0.020,      -0.020,      -0.020,      -0.020,
:aklow,                 0.400,       0.040,       0.004,       0.040,       0.040,       0.040,
:akhgh,                50.000,      20.000,       0.050,       5.000,       5.000,       5.000,
# infiltration coefficient snow covered ground
:akfsdlt,              -0.020,      -0.020,      -0.020,      -0.020,      -0.020,      -0.020,
:akfslow,               0.004,       0.040,       0.004,       0.040,       0.040,       0.040,
:akfshgh,               0.500,      20.000,       0.050,       5.000,       5.000,       5.000,
# interflow coefficient
:recdlt,            -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:reclow,             0.500E-03,   0.500E-03,   0.500E-03,   0.500E-03,   0.500E-03,   0.500E-03,
:rechgh,             0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
# overland flow roughness coeff bare ground
:r3dlt,             -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:r3low,               1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,
:r3hgh,               25.0    ,    10.0    ,    25.0    ,    10.0    ,    10.0    ,    10.0    ,
# interception evaporation factor * pet
:fpetdlt,           -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:fpetlow,            0.500E-01,   0.500E-01,   0.500E-01,   0.500E-01,   0.500E-01,   0.500E-01,
```

```
:fpethgh,             3.00    ,    3.00    ,    3.00    ,    3.00    ,    3.00    ,    3.00    ,
# reduction in PET for tall vegetation
:ftalldlt,          -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:ftalllow,           0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
:ftallhgh,            1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,    1.00    ,
# multiplier for interception capacity
:fratiodlt,           -1.00    ,   -1.00    ,   -1.00    ,   -1.00    ,   -1.00    ,   -1.00    ,
:fratiolow,           0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
:fratiohgh,            10.0    ,    10.0    ,    10.0    ,    10.0    ,    10.0    ,    10.0    ,
# upper zone retention mm
:retndlt,           -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:retnlow,            0.100E-01,   0.100E-01,   0.100E-01,   0.100E-01,   0.100E-01,   0.100E-01,
:retnhgh,            0.300    ,   0.300    ,   0.300    ,   0.300    ,   0.300    ,   0.300    ,
# recharge coefficient bare ground
:ak2dlt,            -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:ak2low,             0.100E-03,   0.100E-03,   0.100E-03,   0.100E-03,   0.100E-03,   0.100E-03,
:ak2hgh,             0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
# recharge coefficient snow covered ground
:ak2fsdlt,            -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:ak2fslow,              0.00    ,    0.00    ,    0.00    ,    0.00    ,    0.00    ,    0.00    ,
:ak2fshgh,             0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
:EndHydrologicalParLimits
#
:GlobalSnowParLimits
# snowmelt ripening rate
:fmadjustdlt,          -1.00
:fmadjustlow,          0.100
:fmadjusthgh,           1.00
# min melt factor multiplier
:fmalowdlt,           -0.100
:fmalowlow,             0.00
:fmalowhgh,            0.750
# max melt factor multiplier
:fmahighdlt,          -0.100
:fmahighlow,           0.750
:fmahighhgh,            1.50
# glacier melt factor multiplier
:gladjustdlt,         -0.100
:gladjustlow,          0.500
:gladjusthgh,           1.50
:EndGlobalSnowParLimits
#
:SnowParLimits
:ClassName       ,bare_soil   ,forest      ,crops       ,wetland     ,water       ,impervious  ,# class name
# melt factor mm/dC/hour
:fmdlt,             -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,
:fmlow,              0.500E-01,   0.500E-01,   0.500E-01,   0.500E-01,   0.500E-01,   0.500E-01,
:fmhgh,              0.450    ,   0.500    ,   0.450    ,   0.550    ,   0.550    ,   0.550    ,
# base temperature dC
:basedlt,           -0.200E-02,  -0.200E-02,  -0.200E-02,  -0.200E-02,  -0.200E-02,  -0.200E-02,
:baselow,            -5.00    ,   -5.00    ,   -5.00    ,   -5.00    ,   -5.00    ,   -5.00    ,
:basehgh,             5.00    ,    5.00    ,    5.00    ,    5.00    ,    5.00    ,    5.00    ,
# sublimation factor OR ratio
:subdlt,            -0.100E-02,  -0.100E-02,  -0.100E-02,  -0.100E-02,  -0.100E-02,  -0.100E-02,
:sublow,            -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,
:subhgh,             0.500    ,   0.500    ,   0.500    ,   0.500    ,   0.500    ,   0.500    ,
```

```
:EndSnowParLimits
#
:RoutingParLimits
:RiverClassName,  upper_gr    ,conestoga   ,speed       ,eramosa     ,lower_gr    ,
# lower zone oefficient
:flzdlt,            -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:flzlow,             0.100E-06,   0.100E-06,   0.100E-06,   0.100E-06,   0.100E-06,
:flzhgh,             0.100E-03,   0.100E-03,   0.100E-03,   0.100E-03,   0.100E-03,
# lower zone exponent
:pwrdlt,            -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:pwrlow,             0.300    ,   0.300    ,   0.300    ,   0.300    ,   0.300    ,
:pwrhgh,              4.00    ,    4.00    ,    4.00    ,    4.00    ,    4.00    ,
# channel Manning`s n
:r2ndlt,             0.200E-01,   0.200E-01,   0.200E-01,   0.200E-01,   0.200E-01,
:r2nlow,             0.100E-01,   0.100E-01,   0.100E-01,   0.100E-01,   0.100E-01,
:r2nhgh,             0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
# wetland or bank porosity
:thetadlt,          -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:thetalow,           0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
:thetahgh,           0.600    ,   0.600    ,   0.600    ,   0.600    ,   0.600    ,
# wetland/bank lateral conductivity
:kconddlt,          -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:kcondlow,           0.100    ,   0.100    ,   0.100    ,   0.100    ,   0.100    ,
:kcondhgh,           0.900    ,   0.900    ,   0.900    ,   0.900    ,   0.900    ,
# in channel lake retardation coefficient
:rlakedlt,          -0.100    ,  -0.100    ,  -0.100    ,  -0.100    ,  -0.100    ,
:rlakelow,            0.00    ,    0.00    ,    0.00    ,    0.00    ,    0.00    ,
:rlakehgh,            3.00    ,    3.00    ,    3.00    ,    3.00    ,    3.00    ,
:EndRoutingParLimits
#
:GlobalParLimits
 # precip lapse rate
:rlapsedlt,         -0.100
:rlapselow,          0.100
:rlapsehgh,           1.00
 # temperature lapse rate
:tlapsedlt,         -0.100
:tlapselow,          0.100
:tlapsehgh,           1.00
 # radius of influence
:radinfldlt,          1.00
:radinfllow,          0.00
:radinflhgh,          400.
 # smoothing distance
:smoothdisdlt,        1.00
:smoothdislow,        0.00
:smoothdishgh,        100.
:EndGlobalParLimits
#
```

NEW – used by RAGMET.exe and TMP.exe

Note: The names of the land cover classes are used as keys for certain classes. Currently, the '**glacier**' '**wetland**' and '**water**' classes depend on the proper name in the proper place. The last 3 classes should be wetland, water & impervious in that order if present. The par file is a CSV file. Also, the keywords are case sensitive. All upper case, all lower case or first letter capitalized are accepted.

New: The initial values for optimization are no longer in the last section of the par file – i.e. they are not repeated and appear only in the top part of the file. Only the limits and flags to indicate which parameters will be optimized are in the bottom part of the file.

New: The section :GlobalParLimits has been added as of Jul. 26/11

New: fratio has been added as of Dec. 2/11. This ratio is a multiplier for the interception capacity for each class. All monthly values are multiplied on a class by class basis and fratio can be optimized with DDS

4.2 General Parameters in the .par File

- lines starting with a number sign are comment lines. These can only be used at the top of the file.

Ver is the file version number. New versions of the par file require up-to-data executables. Old par files can be read with current executables (up to a point).

IOPT is a debugging option ranging from 0 to 5. The higher the number, the more stuff is printed out. Almost all relevant variables can be printed out this way. The IOPT=2, the program will print its whereabouts to the screen and is used to find errors while coding and so is not of much use to the user. When IOPT>=1, the rffnn.txt files are written. When NUMA is set to a value > 1, iopt is set to 0 and all debug output is suppressed.

ITYPE refers to the type of valley in the watershed. When the rivers have flood plains, ITYPE = 0, and when there are none, ITYPE = 1. This might seem backwards, but most rivers have flood plains, so this is the default. For ITYPE = 1, the land is very flat and channels are incised. When the channel is full, no more water is drained from the land – i.e., overland flow is shut off and water remains ponded but can infiltrate.

NUMA is a flag that is used to set the mode of operation of the program. These options can be set in the WATFLOOD menu. When NUMA > 0, IOPT is set to 0 and theGreenKenue flag is set to off. I.e. all debug and visualization output is suppressed to help speed the optimization rum. Within the program, NUMA is re-assigned a value = the number of parameters being optimized by counting how many delta values in part 2 of the PAR file are > 0.

NUMA= 0	Single run - no optimization at all. The length of the rainfall period is set in the STRMFW file by MHTOT. For instance, if NL = 96 and MHTOT = 24, 24 hours of rainfall is used and a 96 hour hydrograph is calculated and compared to a measured 96 hour hydrograph if available.
> 1	Optimization is turned on. Number of parameters to be optimized will be calculated in the program and will depend on which parameters are selected for optimization. See Sec. 4.3 for more details.
= -11	The soil moisture is optimized for the period that data is available as given by MHTOT. For instance, when MHTOT (in the .STR file) = 24, the soil moisture is adjusted on a sub-basin by sub-basin (up to five) basis. The sub-basins are delineated by the NBSN variable in the .MAP and .SHD files. The optimization error is calculated for the MHTOT period and is the least squared error of the computed flows. In other words, the soil moisture is adjusted to match the initial part of the computed hydrograph to the measured hydrograph. The optimized soil moistures are written to a new EVENT file. The last run is for the entire forecast period but uses only the first MHTOT hours of rainfall. The SPLPLT output will show the time of the forecast with a vertical line followed by a broken line for the remaining measured flows. The calculated flows are shown by solid line.

= -1 The program is run once on the forecast mode. Previously optimized soil moistures are used (listed in the EVENT file) and rainfall until MHTOT are used. The SPLPLT output will show the time of the forecast with a vertical line followed by a broken line for the remaining measured flows. The calculated flows are shown by solid line. This mode is used after using NUMA = -11.

= -12 The precipitation field is optimized by scaling the entire MET file. This is an option designed specifically for the use of RADAR, when often the entire RADAR precipitation field is underestimated. The optimization is done for the first MHTOT hours of data. The calculated SCALE is written to the EVENT file. The last run is for the entire forecast period but uses only the first MHTOT hours of rainfall. The SPLPLT output will show the time of the forecast with a vertical line followed by a broken line for the remaining measured flows. The calculated flows are shown by solid line.

= -2 Same as -1 but the soil moistures in the MET file are used if present and the SCALE parameter in the EVENT file is used to scale the rainfall fields. This is used when RADAR data is adjusted by scaling the entire RADAR field. The program is in the forecast mode with just one run. The SPLPLT output will show the time of the forecast with a vertical line followed by a broken line for the remaining measured flows. The calculated flows are shown by solid line.

The other parameters (NPER,KC,MAXN)are described in Sec. 4.4.

IW is an undocumented parameter.

In the next line, shown above, the first number is soil porosity, and the second is an exponent. When IX = 1, it does nothing, and that is probably the best way to have it. When it has other values, the effects are unknown. TYPEO, and NBSN are described under "**Optimization" Section.**

4.2.1 Example of Global Parameters

:GlobalParameters	Typical value	Description
:iopt	1	# debug level
:itype	0	# channel type - floodplain/no
:itrace	4	# Tracer choice
:a1	-999.999	# ice cover weighting factor
:a2	1	# Manning`s correction for instream lake
:a3	0.05	# error penalty coefficient
:a4	0.03	# error penalty threshold
:a5	0.985	# API coefficien
:a6	900	# Minimum routing time step in seconds
:a7	0.9	# weighting - old vs. new sca value
:a8	0.1	# min temperature time offset
:a9	0.333	# max heat deficit /swe ratio
:a10	1	# exponent on uz discharce function
:a11	0.01	# bare ground equiv. veg height for ev
:a12	1	# min precip rate for precip disaggregation
:fmadjust	0	# snowmelt ripening rate
:fmalow	0	# min melt factor multiplier
:fmahigh	0	# max melt factor multiplier
:gladjust	0	# glacier melt factor multiplier
:rlapse	0.01	# precip lapse rate mm/m
:tlapse	0.004	# temperature lapse rate dC/m
:elvref	0	# reference elevation
:rainsnowtemp	0	# rain/snow temperature
:radiusinflce	300	# radius of influence km
:smoothdist	35	# smoothing diatance km
:flgevp2	2	# 1=pan;2=Hargreaves;3=Priestley-Taylor
:albe	0.11	# albedo????
:tempa2	50	#
:tempa3	50	#
:tton	0	#
:lat	50	# latitude (of centre of watershed)
:chnl(1)	1	# manning`s n multiplier**
:chnl(2)	0.9	# manning`s n multiplier**
:chnl(3)	0.7	# manning`s n multiplier**
:chnl(4)	0.7	# manning`s n multiplier**
:chnl(5)	0.6	# manning`s n multiplier**
:EndGlobalParameters		

**Special parameter for channel efficiency – 5 values only (not 4, not 6)

Ch = Channel efficiency factor – more channels through the grid mean lower velocities. First entry is for 1 main channel while the last entry is for headwater grids and 5 channels are assumed.

4.2.2 River and Basin parameters

The following 11 lines are dimensioned for river classes. The river roughness and ground water classes are grouped together. In the case where a river class cannot be associated with a ground water class, you would have two river classes with the same river roughness but different ground water parameters.

lzf* = lower zone drainage function parameter (**optimized)**
pwr* = lower zone drainage function exponent (**optimized)**
R1n* = flood plain Manning's n **(NOTE: R1n = case sensitive !!!)**
R2n* = river channel Manning's n (**optimized) (R2n = case sensitive !!!)**
mndr Meandering factor. 1.0 for straight rivers,
and a higher number to reflect the extra length of river
compared to a straight one.
aa2, aa3 & aa4 constants in Equations 2.41 and 2.42
theta = porosity of the wetland or channel bank
widep = width/depth ratio for the **bankfull** channel
kcond = conductivity of the wetland(bank) – channel interface
pool = average area of zero flow in channels with riffles & pools
rlake = a multiplier for channel resistance depending on the lake area in each grid

FLZ, PWR, R2n, kcond, theta & rlake are normally determined through optimization or manual fitting.

Note:. The value to be used in any specific grid is set in the fourth field in the bsn.map file under the heading 'basin number'. For instance, meandering rivers can be specified as 1, intermediate rivers with flood plains can be listed as 2, and upland rivers can be listed as 3. Determine which rivers can be grouped from a roughness point of view. The slope is explicitly taken care of already in the _shd.r2c file.

4.2.3 Hydrological (Surface) Parameters

The following 11 lines are parameters dimensioned for up to 16 land cover classes, not including water. In the case where you would have a land cover class that has two or more distinct soil types, you would have two classes with the same vegetation parameters but different soil parameters. Similarly, two land cover classes on the same soil would have the same soil parameters but different vegetation parameters.

DS, REC, AK, RETN, AK2, R3 and R4 are grouped by land use/cover classes while R1n, R2n, lzf and pwr are grouped by river type. The name extension fs refers to the snow covered ground parameters.

The parameter names are listed and are defined as follows:
nel roughness (**optimized**)

For each of the land cover classes:

```
:HydrologicalParameters
:LandCoverClasses        #classcount
:ClassName               # class name
:ds                      # depression storage bare ground mm
:dsfs                    # depression storage snow covered area mm
:rec                     # interflow coefficient
:ak                      # infiltration coefficient bare ground
:akfs                    # infiltration coefficient snow covered ground
:retn                    # upper zone retention mm
:ak2                     # recharge coefficient bare ground
:ak2fs                   # recharge coefficient snow covered ground
:r3                      # overland flow roughness coefficient bare ground
:r3fs                    # overland flow roughness coefficient snow covered grnd
:r4                      # overland flow roughness coefficient impervious area
:fpet                    # interception evaporation factor * pet
:ftall                   # reduction in PET for tall vegetation
:flint                   # interception flag  1=on  <1=off
:fcap                    # not used - replaced by retn (retention)
:ffcap                   # wilting point - mm of water in uzs
:spore                   # soil porosity
:fratio                  # int. capacity multiplier
:EndHydrologicalParameters
```

REC, AK, AKFS, RETN, AK2, AK2FS, fratio (and sometimes fpet & ftall) are normally determined through optimization or manual fitting.

4.2.4 Snowmelt Parameters

:SnowParameters	
:fm	# Melt factor (mm/oC/hr) (optimized)
:base	# Base Temp. for melt calculations (oC) (optimized)
:fmn	# -ve melt factor
:uadj	# Wind function
:tipm	# ATI Decay/Attenuation parameter
:rho	# Snow density for converting WE to depth for use in SDC's (relative to rho H2O)
:whcl	#a factor between approximately 0.5 and 1.0 to reduce the melt rate in the early melt season.
:alb	# albedo
:sublim_factor	# sublimation factor ratio
:idump	# receiving class for snow redistribution
:snocap	# max swe before redistribution
:nsdc	# no of points on scd curve - only 1 allowed
:sdcsca	# snow covered area - ratio=1.0
:sdcd	# swe for 100% snow covered area
:EndSnowParameters	

Additional Snowmelt parameters:

Fmadjust	=	a factor between approximately 0.5 and 1.0 to reduce the melt rate in the early melt season.
Fmalow	=	lower limit on melt factor reduction
Fmahigh	=	upper limit on melt factor reduction (<1.0) or melt factor enhancement (>1.0)
Gladjust	=	a glacier melt enhancement factor. Will melt glacier ice at gladjust*(melt potential) after the fresh snow has melted. A factor of 1.5 – 2.0 seems appropriate. Once the snow is melted off a glacier, the ice will melt at a rate gladadj times the rate of snow melt.

MF, BASE, NMF are normally determined through optimization.

4.2.5 Monthly ET data

The columns are by land cover class and the rows by month in the section starting with:

:MonthlyEvapotranspirationTable

in the par.csv file.

4.2.6 Interception Parameters

The columns are by land cover class and the rows by month in the section starting with:

:InterceptionCapacityTable

In the par.csv file.

fratio has been added as of Dec. 2/11. This ratio is a multiplier for the interception capacity for each class. All monthly values are multiplied on a class by class basis and fratio can be optimized with DDS

4.3 Monthly_climate_normals

This now a separate file called monthly_climate_normals.txt

```
month  jan  feb  mar  apr  may  jun  jul  aug  sep  oct  nov  dec
mxmn  10.2 12.3 12.1 12.3 14.3 14.2 13.8 14.0 13.1 10.6  8.2  9.3
humid 59.5 60.5 62.5 55.5 50.0 54.5 59.0 58.5 63.5 58.0 64.5 62.5
pres  95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1
```

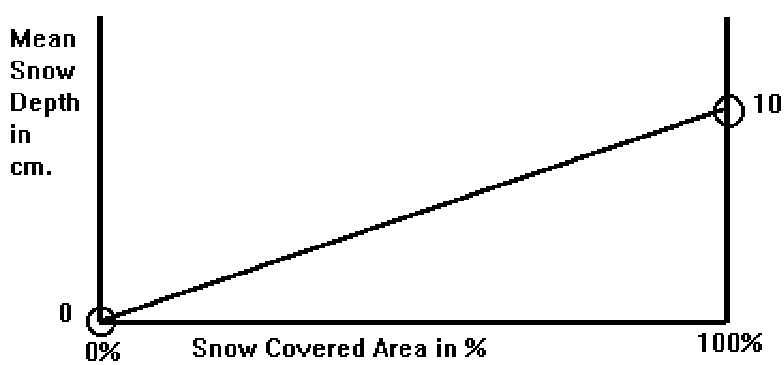
mxmn = the difference between the mean monthly maximum and mean monthly minimum temperatures in ^oC (it is converted to ^oF in the program).

humid = mean monthly relative humidity in percent

pres = mean monthly atmospheric pressure in kPa

4.4 Snow Cover Depletion Curve (SDC)

This is part of the parameter file that characterizes the snow cover. The data consists of two points on a simplified snow cover depletion graph as shown below:



The maximum snow accumulation that is allowed in each land cover class is SDCD Generally this is 150 cm but in forested areas the limit is set to infinity (sort of). . Each SDCD value has a corresponding value for SDCSCA. The SDC can have any number of points up to 10 but generally 2 will suffice **and only 2 are allowed in the current par file format**. The snow covered area is given as a ratio, in this case either 0% for a snow depth =0.0 cm and 1.0 for a snow depth of 10 cm in the above diagram.

The program expects one set of values for each land cover class, including the impervious area.

idump	=	is the class number where snow is relocated if the snocap for the class is exceeded. If –ve, no redistribution.
snocap	=	the maximum snow accumulation before redistribution
nsdc	=	number of points on the sdc curve = 2
sdcsca	=	snow covered area associated with a value for sdcd
sdcd	=	amount of snow for associated sdcsca

4.5 Optimization (Updated April 10, 2010)

Two methods are available for optimization: the Pattern Search (PS) (Hooke and Jeeves, 1961) and the Dynamically Dimensioned Search (DDS) (Tolson and Shoemaker (2007). The PS is completely internal to the WATFLOOD model executable SPLX.exe. The DDS method is external and required two additional executables namely DDS.exe and DDS_wfld_rev1.exe. Some additional files are also needed. However, both methods depend on the same part of the par file to set initial values, upper and lower constraints and flags for selecting the parameters to be optimized.

Optimization can be performed over a specific duration or part of the hydrograph. The value of the objective function is calculated for only those events and streamflow stations which have a value of 1 in the data line beginning with the keyword Value1

The last section of data in the parameter file is for optimization. The columns correspond to the land cover columns as in the upper part of the file. This section is identical for both the PS and DDS schemes. For the PS, the delta value provides the initial step size for the search and acts as a flag +ve/-ve to activate the PS or not. For DDS, the delta value acts only as a flag +ve/-ve to activate the DDS or not.

In the example below, MF and BASE will be optimized if either NUMA or DDSFL is given a value = 1. If one is set = 1 the other must be set = 0!!

Note: - there is just one value for A5

4.5.1 Hints for Successful Optimization

Anderson (1973) outlines the do's and don'ts when using optimization and his comments are adopted to the present case:

a) Select initial values for each parameter. (Parameters from previously calibrated watershed are a very good start. Average river roughness can be used.)

b) Simulate the entire calibration data period and look for obvious problems. Perhaps the rainfall is very "spotty" and the gauge record does not represent the rainfall field very well. Such events are useless for calibration. A very good check on the precipitation is to perform a run for the calibration period and animate the precipitation in GreenKenue. In GreenKenue, plot the cummulative precipitation for the run and check for unrealistic patterns.

c) Perform a trial-and-error calibration of the model. This gives an indication how sensitive the model is to the various parameters. Use IOPT = 1 (debug level) and look at the output in \RESULTS\RFFnn.txt, where nn is the class number (1-9). All state variables and some fluxes for each class in the designated debug grids are written to this file and you can check if the processes are being modeled properly. You can see where the water goes. You can change any parameter in the parameter file, including those not included in the automatic optimization. (Grapher templates are available, contact kouwen@uwaterloo.ca)

Trial and error:

- Adjust Manning's n (R2n) so the hydrograph peaks coincide in time.
- If you have coupled wetlands, use textbook Manning's n values and adjust the wetland conductivity kcond and porosity (theta).
- Adjust the base temperature so the initial rise of the computed melt hydrograph coincides in time with the observed hydrograph. Initially, you can keep the base temperature the same for all classes and let PS or DDS find their best values.
- Adjust the sublimation factor sublm to get roughly the right amount of water in the melt hydrograph.
- Adjust temp3 so you get about the right amount of melt runoff in the summer & fall.
- Adjust pwr and lzf so the low flow recession curves have the same slope on a plot of Log(flow) vs. time.

Once you have reasonable results, you can tweak the parameters automatically. Always make sure the processes are reasonable: use the rff*nn* plots and GreenKenue animations & time series of the state variables to ensure they are realistic, You can also use the tracer option (Section 13.4) to plot the base flow hydrograph as well as the observed and computed hydrographs.

d) Perform the Pattern Search or the Dynamically Dimensioned Search optimization for fine tuning the parameters.

e) Analyze the results and repeat steps c) and d) if necessary.

As with Anderson's snow model: "most of the parameters are so interrelated that it is impossible to change one and hold all the others constant". The PS technique, as opposed to other methods, handles this situation fairly well. However, as with other steepest ascent methods, if you are not on the right hill to begin with, you will not get to the global optimum. Anderson (1973, Sect. 5.6) gives a detailed account of how to optimize the model parameters. With DDS, it is recommended that a number or trials are done, each with several hundred to a thousand evaluations. The parameter set with the most realistic and/or scores can then be chosen.

4.5.2 Pattern Search

4.5.2.1 Selecting Parameters for Optimization

The following values need to be defined for optimization:

```
numa          0     optimization 0=no 1=yes
nper          1     opt delta 1-absolute  0-fraction
kc            5     no of times delta halved
maxn       1010     max no of trials
```

```
ddsfl          0     DDS optimization
trce           1     tracer flag - under construction
```

NUMA is used as a flag for optimization. When NUMA is not equal to 0, all debugging output is suppressed. NUMA is calculated in the program when set to 1.

KC is the resolution sought in the optimization. The change DDELTA is halved KC times when the error can no longer be reduced for a given DDELTA level.

MAXN is the maximum number of evaluations of the model allowed in a single run. Usually 1000 is appropriate.

The parameter files will be updated whenever an iteration produces a lower error as a new parameter file called NEW.PAR, which can then be renamed to be the parameter file specified in the event file event\yymmdd.evt. The new.par file will be a parameter set that produced the lowest error value. However, the user must always check that the parameter set is viable by looking at the process plots (from the rff*n*.txt files) and be validating on other data.

DDELTA has a dual purpose. It is the incremental change of the parameters, as a ratio of the initial value of the parameter. If -ve, the parameter will not be optimized. If +ve, the parameter will be included in the list of optimized parameters. Up to 50 parameters can be optimized in one run but this large number is discouraged. It is better to select a process and optimize the parameters associated with that process. E.g., melt: Optimize only MF and BASE.

NPER = 1, the delta values are a fraction of the parameter value.
= 0, the delta value is an absolute amount. ($1/10^{th}$ of the par value = a good start)

CHECKL & CHECKH are the lower and upper constraints on the parameters. The values shown above were found to be reasonable limits for the Grand River basin in Ontario.

PARAMETER - the initial value is given in the last column of the parameters being optimized. If ddelta is +ve, the values in the top part of the table are used. If ddelta is -ve, values in the bottom part of the table will be used.

Note: The parameter table will be changed as follows: for -ve ddelta's, the parameter values in the lower part will be ***synchronized*** with the top part; for +ve ddelta's, the parameter values in the top part will be synchronized with the lower part. In the example above, only the first two values of AK will be optimized if IOPT ≥ 1.

Often during optimization, some parameter values will drift to their limits. It is important that the limits be reasonable. For instance, in forests, if the permeability is set so low that all rainfall becomes surface runoff, the value has to be wrong because most rainfall, if not all, is infiltrated. So actually, there is not much point optimizing AK for a forest class – just make sure all rain infiltrates. For AKFS you may want to have a lower value as there can be frozen soil impeding infiltration during the melt period.

When optimizing parameters, it is a good idea to gradually extend the limits if it is found that the parameters are drifting to the limits. However, this should be done manually, all the while checking that the processes are properly modeled. This can be checked by setting NUMA = 0 and IOPT = 1 (line 1).

Optimization data is written to the results\opt.txt file and can be used to plot the error versus iteration number for each of the parameters optimized. This will show the progress of the optimization. Ideally, the parameters do not drift to the specified limits.

4.5.2.2 Error Criterion

The optimization criterion is to minimize the normalized RMS error of the flows. The total error is calculated by:

$$\sum_{i=1}^{n} \frac{\text{RMS}}{Meanflow}$$

where n is the number of streamflow stations used for comparison.

4.5.2.3 Error calculation

A provision is made to select the stations to include in the error calculation by a sequence of binary flags in the first line of data of the strfw\XXXXXX.str file.

Example:

```
#
:ColumnMetaData
   :ColumnUnits              m3/s         m3/s         m3/s         m3/s         m3/s
   :ColumnType              float        float        float        float        float
   :ColumnName          GRND/GALT    W._MONTROSE  GRND/MARSVIL ERAMOSA/GUEL CONEST/DRAYT
   :ColumnLocationX       554000.      545000.      556000.      570000.      530000.
   :ColumnLocationY      4801000.     4833000.     4860000.     4823000.     4849000.
   :Coeff1              0.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
   :Coeff2              0.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
   :Coeff3              0.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
   :Coeff4              0.000E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
   :Value1                      1            1            1            0            1
:EndColumnMetaData
:EndHeader
```

In this example, there are 5 streamflow stations and all but the 4^{th} station are used in the error calculation. These flags can change from one event to the next. If all values in the highlighted line are 0, no error will be calculated for that event.

Example:

These are the flag lines in each of three .str files for three events that are chained:

```
0     0     0     0     0     0     0     0     0
1     1     1     0     1     1     1     1     1
1     1     1     0     1     1     1     1     1
```

In this example, the error for all stations used for comparison will not be included in the total error for the first event. The error for stations 1, 2, 3, 5, 6, 7, 8, and 9 will be used for the second and third events. Thus, flow station 4 is ignored (so could be used for validation).

4.5.3 Optimization – Dynamically Dimensioned Search DDS

4.5.3.1 Specifying Parameters for Optimization

The following values need to be defined as follows for DDS optimization in the par file:

```
:numa,         0,# PS optimization 1=yes 0=no
:ddsflg,       1,# 0=single run  1=DDS
:errflg,       5,# 1=wMSE 2=SSE 3=wSSE 4=VOL 5=weighted volume
```

numa = 0 disables the pattern search
ddsflg = 1 activates and deactivates components of SPLX.exe for the DDS search. It disables all non-essential output and ensures the objective function value is written in the DDS directory (folder)
errflg = 1-8: stipulated which objective function to employ

First create an additional directory called **DDS** at the same level as basin\\, event\\, etc.

The following additional files are required in the DDS directory:

4.5.3.2 **DDS_init.txt** – 15 lines initially, lines are truncated here:

```
!    Comment lines 1 & 2:  READ WITH WORD WRAP OFF.  Input control fil . . .
!                       <- Text inputs must in columns 1-24, otherwise . . .
basinname               !3 compact name for DDS output file subdirecto . . .
watflood_batch.bat      !4 .exe or .bat application name (no file exte . . .
10                      !5 number of optimization trials to run (1 to  . . .
300                     !6 maximum number of objective function evalua . . .
134382176
0                       !8 Print flag: "0" saves all DDS outputs (max  . . .
3                        !9  DDS initialization procedure. Enter 1, 2 . . .
!!!!!!!!!!!!!!!!!!!!!!! !10 On NEXT LINE, enter any other comments to  . . .
test1
1                       !12 MAX problem (enter "-1") or MIN problem (e . . .
0.2                     !13 r_val, DDS neighborhood size parameter (0. . . .
!!!!!!!!!!!!!!!!!!!!!!! !14 BLANK LINE.
save_best.bat           !15 Watclass specific input, can be blank - na . . .
```

Once the DDS program sequence is started, more lines will be added to this file. To initialize the DDS process, only these 15 lines are needed. Above, the lines are truncated. Below, the whole line is shown. Each row is for one line in the DDS_init.txt file. In the table below, the complete explanation is given for each line. The example is for the Fork Rivers in Minnesota. "!*n*" refers to the line number in the DDS_init.txt file.

! Comment lines 1 & 2:	READ WITH WORD WRAP OFF. Input control file for Fortran DDS ver1.1 algorithm. Inputs start on line 3.
!	<- Text inputs must in columns 1-24, otherwise free format for numeric inputs. Some lines can be blank.
basinname	!3 compact name for DDS output file subdirectory to be created (24 characters max)
watflood_batch.bat	!4 .exe or .bat application name (no file extension) to generate obj func value. Leave BLANK if User compiles DDS1 program & their objective function together.
1	!5 number of optimization trials to run (1 to 1000)
300	!6 maximum number of objective function evaluations per optimization trial (7 is minimum)
134382176	!7 seed value
0	!8 Print flag: "0" saves all DDS outputs (max # files) or "1" to save only summary info (min # of files)
3	!9 DDS initialization procedure. Enter 1, 2 or 3. Three options: 1) use random initial solutions 2) Use "initials.txt" to initialize via DDS program structure, initials.txt is matrix of initial sol's: rows-> #sol's, cols-> DVs 3) Use Watclass model input files to extract initial decision variables (coding in user obj. func evaluator program handles case 3
!!!!!!!!!!!!!!!!!!!!!!!	!10 On NEXT LINE, enter any other comments to save about this run (100 char max):
test1	
1	!12 MAX problem (enter "-1") or MIN problem (enter "1")
0.2	!13 r_val, DDS neighborhood size parameter (0.2 is default). Allowable range is (0.0, 1.0]. Controls std dev of perturbation.
!!!!!!!!!!!!!!!!!!!!!!!	!14 BLANK LINE.
save_best.bat	!15 Watclass specific input, can be blank - name of .exe or .bat application (no file extension) to run every time DDS finds a new best solution.
0	!16 Always 0 for WATFLOOD[***]
20	!17 No of parameters to be optimized
1	!18 Always 1 for WATFLOOD
!!!!!!!!!!!!!!!!!!!!!!!	!19 Decision variable limits follow (20 in this case):
0.5000000E-01	
4.000000	
1	3 lines for each parameters to be optimized by DDS
0.5000000E-01	
4.000000	
1	
etc. 18 more sets of 3	

[***]For WATFLOOD, there is no differentiation for individual, river or cover classes. Line 17 is used to specify the total number of parameters to be optimized. This is different from other DDS applications.

4.5.3.3 Variables_in.txt – example:

```
3.000000
1.500000
```

```
   4.690000
   4.840000
  0.6410000
  0.4440000
.
.  etc.  one value for each parameter to be optimized by DDS
```

This file is used to pass the parameters being optimized between DDS.exe, DDS_WFLD.exe and SPLX.exe.

For DDS, the parameter values for each evaluation are decided by **DDS.exe** and are passed to **SPLX.exe** in the **variables_in.txt** file. The constraints and flags are in the **DDS_init.txt** file which remains unchanged throughout the DDS run (hey – it's an initialization file).

First time through, the coupler **DDS_WFLD.exe** extracts the parameters to be optimized from the WATFLOOD par file and converts the parameters to the first **variables_in.txt file.** This file is then read by **DDS.exe** only at the start of the optimization trial.

Subsequently, **DDS.exe** creates new sets of parameters which are then used by **SPLX.exe** (evaluations) to compute the sum of squared errors. These sets of parameters from **DDS.exe** are converted from the variables_in.txt file written by **DDS.exe** to an new WATFLOOD par file that can be read by **SPLX.exe**.

The function of each of the executables is:

- **DDS.exe** is the master program controlling the flow of the process and produces a sequence of parameters to be tried based on the successive values of the objective function calculated by **SPLX.exe**
- **SPLX.exe** is the WATFLOOD model
- **DDS_WFLD.exe** is the coupler between DDS.exe and SPLX.exe – i.e. it converts the DDS parameter file format to WATFLOOD parameter file format and vice versa.

4.5.3.4 Watflood_batch.bat

```
coupler.exe
cd ..
splx64.exe
cd dds
```

With radius of influence and smoothing distance also being optimized:

```
DDS_WFLD_rev1.exe
cd ..
ragmet64.exe
splx64.exe
cd dds
```

The par_csv file has been modified as of Jul. 26/11 to have the limits to the precipitation and temperature lapse rates, the radius of influence and the smoothing distance.

DDS.exe is the controlling program and has the DDS directory as its working directory. It is loaded once and remains in charge. However, it shells out and runs the **watflood_batch.bat** file which first runs the coupler DDS_WFLD.exe, then moves up one directory level to the watershed working directory (where SPLX.exe is normally executed), runs SPLX.exe (which spews out a new value of the objective function) and then goes back to the DDS directory to some more work itself. If DDS_exe finds a better solution, it then shells out to run the commands in **save_best.bat :**

save_best.bat

```
copy variables_in.txt            best\variables_in.txt
copy ..\basin\gr10k_par.csv      best\gr10k_par.csv
copy ..\results\spl.csv          best\spl.csv
copy ..\stats.txt                best\stats.txt
You can add other files you wish to keep
```

DDS.exe creates a directory called **DDS_gr10k** and another **best** where it saves its work as specified in the **save_best.bat** file. (It is up to you what you want to save)

1. DDS is the active program and shells out to runs two batch files
    a. watflood_batch.bat -> runs the coupler & splx
    b. save best .bat -> takes best files to now and saves them in the dds\best directory
2. DDS reads the objective function written by splx in function_out.txt

4.5.3.5 Function_out.txt (objective function)

```
0.6245
```

This file has just one entry: the value of the objective function calculated by SPL.exe and read by DDS_p.exe

Different objective functions can be specified by the line in the par file with the keyword **errfl.**

Eight objective functions are available.

1. Weighted sum of Squared errors recommended by Brian Tolson - DDS originator:

$$DDS_{error} = \sum_{l=1}^{no}\left[\sum_{j=1}^{nhr}(O_{j,l} - P_{j,l})^2\right] * sw_l$$

where

O = observed flow for hour j
P = predicted flow for hour j
nhr = no if hours of record
l = station number
no = no of flow stations

and station weight $= sw_l = \frac{\overline{O_l}}{\sum_{l=1}^{no} \overline{O_l}}$

2. Sum of squared errors SSE:

$$DDS_{error} = \sum_{l=1}^{no}\left[\sum_{j=1}^{nhr}(O_{j,l} - P_{j,l})^2\right]$$

3. Sum of squared errors weighted with mean flow:

$$DDS_{error} = \sum_{l=1}^{no}\left[\sum_{j=1}^{nhr}\left(\frac{O_{j,l} - P_{j,l}}{\overline{O_l}}\right)^2\right]$$

4. Volume only unweighted (*does not work too well*):

$$DDS_{error} = \sum_{l=1}^{no}\left[\frac{\sum_{j=1}^{n} O_{l,j} - \sum_{j=1}^{n} P_{l,j}}{n_l}\right]^2$$

where n_l = number of observations for station l

5. Volume weighted:

$$DDS_{error} = \sum_{l=1}^{no}\left[\frac{\sum_{j=1}^{n} O_{l,j} - \sum_{j=1}^{n} P_{l,j}}{n_l * \sum_{j=1}^{n} O_{l,j}}\right]^2$$

6. Weighted sum of absolute errors:

$$DDS_{error} = \sum_{l=1}^{no}\sum_{j=1}^{n}\frac{|O_{l,j} - P_{l,j}|}{\overline{O_l}}$$

7. Nash Efficiency (to be minimized)

$$DDS_{error} = \sum_{l=1}^{no}\left[\frac{\sum_{j=1}^{n}(O_{l,j} - P_{l,j})^2}{\sum_{j=1}^{n}(O_{l,j} - \overline{O})^2}\right]$$

8. Nash Efficiency using log($O_{l,j}$) and log($P_{l,j}$) - emphasizes low flows

4.5.3.6 DDS process

The coupler runs in two modes: first to write the dds_init.txt file and an initial par file and then to modify the par file. Here is the sequence:

1. Edit the dds_init file to have the proper values in lines 3, 5 & 6. You need only the first 15 lines to start.
2. The first 15 lines of the dds_init.txt file have to be there to initialize a run. The other lines from 16 on are written by the connector (=coupler)
3. The coupler reads the initial par file and based on what pars are flagged for optimization and writes the flagged parameter limits in dds_init.txt in lines 20 & on (lower limit, upper limit & a flag =1 to optimize this par – the 3rd entry is always 1) (in the original MESH setup, you set your limits and picked you pars here) (The initial values and limits are set in an initial par file that could be called **basin\bsnm_start_par.csv**
4. The coupler reads the variables_in.txt file and it has to have -999.0 as the value to start the run. The coupler then replaces the -999.0 with the actual par values it digs out of the par files – those that are flagged. So the variables_in.txt files has the actual parameters while the dds_init.txt file has the limits.
5. You can now run the coupler while in the dds directory and you should see a rewritten dds_init.txt file and a variables_in.txt file with the limits and par values respectively filled in. This is a good check before running DDS. The basin\bsnm.par file should now be rewritten and be the same as before. If this works then:
6. Edit the variables_in.txt files to have -999.0 again.
7. Now run DDS and it should go on and on and on and on and on and on and on and on and on and on and on and on and on
    a. DDS shells out and runs watflood_batch.bat
        i. This runs the coupler which I have called dds_wfld.exe This creates the
            1. dds_init.txt file and
            2. variables_in.txt file and a new
            3. basin\forks.par file
        ii. And hey, it runs splx which writes function_out.txt
    b. Back in DDS, it ingest the value of the objective function
        i. it ingest the value of the objective function
        ii. and spews out a new set of parameters in values_in.txt
        iii. and IF the objective function has improved, will shell out and run save_best.bat to save the best par file so far. I also keep the spl.csv file so I can use grapher to see how things are going.
    c. DDS shells out again and runs watflood_batch.bat
        i. This runs the coupler again and so creates new
            1. Basin\forks.par file using the values in variables_in.txt file from DDS
            2. note the dds_init.txt file is no longer needed
        ii. And hey, it runs splx with the new par file and writes function_out.txt
    d. Back to b.
8. You can use the **go.bat** file as shown below to automate this process.

Go.bat:

```
copy ..\basin\gr10k_start_par.csv    ..\basin\gr10k_par.csv
copy variables_in_start.txt    variables_in.txt
copy c:\spl\splx64.exe ..\splx64.exe
del dds_log.txt
del pre-emption_value.txt
dds_wfld_rev3
dds_p
```

For just testing the set up use a bat file:

Test.bat:

```
copy ..\basin\gr10k_start_par.csv    ..\basin\gr10k_par.csv
copy variables_in_start.txt    variables_in.txt
copy c:\spl\splx64.exe ..\splx64.exe
del dds_log.txt
del pre-emption_value.txt
dds_wfld_rev3
```

- Put go.bat in the \dds directory
- bsnm_start.par is the WATFLOOD parameter file you want to start with (in the \basin directory)
- variables_in_start.txt has the value -999.9 in line one.
- dds is the pre-emptions enables DDS executable

4.5.3.7 Monitoring a DDS run

A number of files are created during a DDS run. Some self explanatory files are in the dds\dds_bsnm and dds\best directories. In the \dds dirrectory a file called dds_log.txt file shows the SSE valueafter each event. A blank line is between each evaluation. This file can be plotted to show the progress of the trial. Copy the first evaluation to a separate file called dds_log_run1.txt so the first trial can be shown on the plot a below:

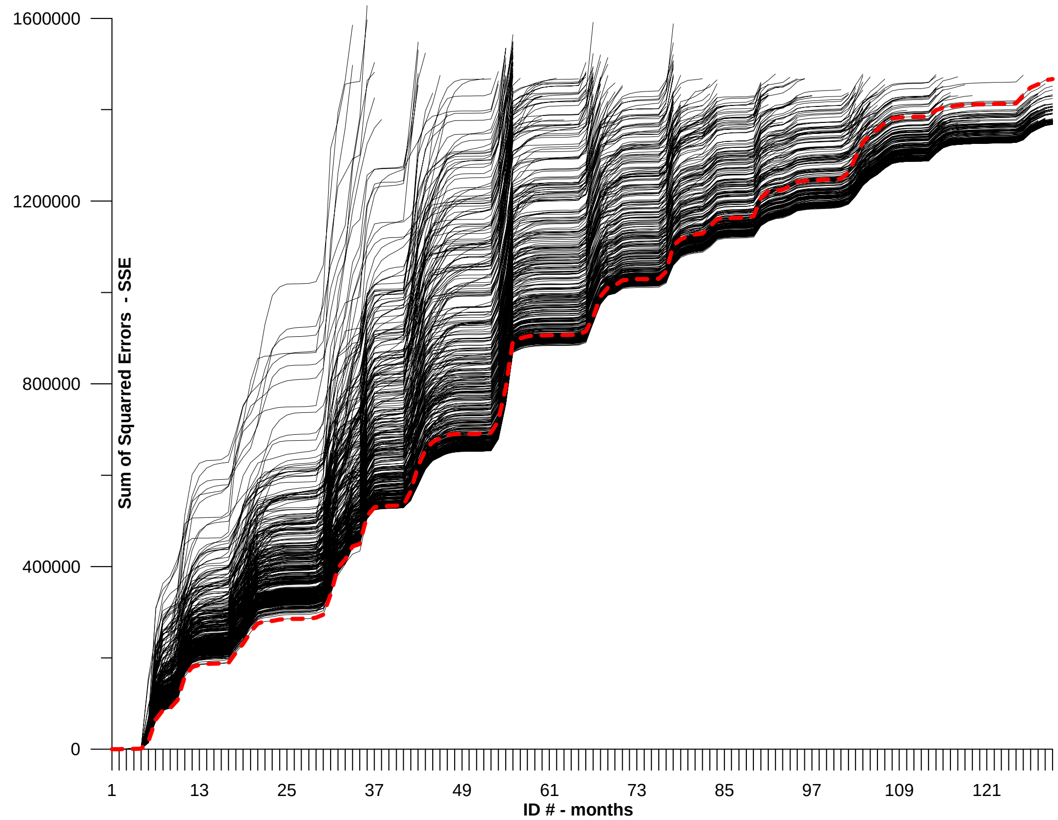


Figure 4.4.1. - Each line is the SSE of an evaluation. Red line = 1st evaluation. Lines to the left of the red line are for evaluations terminated early with pre-emption.

4.5.3.8 Speeding up DDS

You can make multiple simultaneous DDS runs by setting up multiple identical watershed files e.g. gr10k_1 gr10k_2 etc. Just give each run a different seed value in line 7 of the DDS_init.txt file

4.5.3.9 Analysis of multiple trials

Three trials of DDS usually suffices to indicate some sonsistency in the outcomes. However, when analyzing the results, it is useful to see the range of each optimized parameter and their value wrt. Other land cover classes. The files summary.txt found in each DDS trial report can be combined into one file as below (one line for each trial):

```
     variable        theta          kcond          radin          smoot
       obj_fn            1              1             -1             -1
 0.242454E+06 0.387656E+00  0.582581E+00  0.355959E+03  0.204289E+02
 0.261004E+06 0.443512E+00  0.197076E+00  0.390479E+03  0.274989E+02
 0.244470E+06 0.736029E+00  0.680491E+00  0.318999E+03  0.178311E+02
 0.253440E+06 0.184952E+00  0.265174E+00  0.180663E+02  0.649235E+02
 0.225530E+06 0.161244E+00  0.534536E+00  0.263214E+03  0.174199E+02
 0.230213E+06 0.514956E+00  0.640026E+00  0.315302E+03  0.232514E+02
 0.245022E+06 0.684374E+00  0.688238E+00  0.343077E+03  0.248711E+02
 0.247493E+06 0.418768E+00  0.695592E+00  0.364348E+03  0.166421E+02
```

The headings can be found in a file called ……\dds\summary_header.txt written by the coupler each time DDS is started. The headings match the parameter names with the columns. With this file you can look at the ranges and you could even try to average the values for all trial for each variable and make up a par file with these averages. Trials with unreasonable parameter values can be thrown out.

4.6 Optimization Case Study and Hints

4.6.1 Optimization for the BOREAS Southern Study Area (SSA)

1. To optimize a parameter set for any area, it is probably best to first set the river roughness parameter R2 so that the peaks of the computed hydrographs coincide with the peaks of the observed hydrographs. This is most easily done manually but can be refined automatically later. However, these parameters are fairly independent – i.e. they do not interact too much with other parameters.
2. The first parameters to adjust are the lower zone function (LZF) and the lower zone exponent (PWR). These parameters have a great effect on the recession curve and the peak flow because they can be viewed as the foundation for the hydrograph. Sometimes LZF and PWR can ***only*** be optimized automatically if the volume of runoff in the computed hydrograph is correct (or at least close). If the volume of the hydrograph is not correct, the values of LZF and PWR will compensate for the incorrect runoff volume by simply increasing or depleting the groundwater storage. You can check this by plotting LZS in any of the rff*nn* .txt files. *To chose parameters for optimization in the bsnm.par file, set the delta values to a +ve number. Parameters with a –ve delta value will not be optimized in the run.* The best way to adjust LZF and PWR is to plot the hydrograph with the log of the computed and observed flows plotted against time. You have the correct values when the groundwater recession curves of the computed and observed hydrographs are parallel. If the hydrograph volumes are incorrect, step 4 should be carried out first. **WARNING**: *It is very important that for a long term simulation the lower zone storage (LZS) does not continually increase. In an automatic optimization run, the LZS can be traded off with evaporation. If the evaporation is too low, the LZS can wrongfully compensate!!!!*
3. Next, in cold regions, the melt factor (MF) and the base temperature (BASE) should be optimized. These parameters really affect the timing and the rate of the melt. The base temperature affects the initial rise of the hydrograph while the melt factor has more affect on the peak flow. These parameters do trade off somewhat in that if the base temperature is low, the melt factor should also be low, other wise the snow would melt too rapidly.
4. In mountainous terrain, the lapse rates for precipitation and temperatures should also be optimized unless you have these values from other sources. If glaciers are present, the glacier adjustment factor should also be optimized.
5. The radius of influence & smoothing distance can be done in conjunctin with 4.
6. Then the evaporation should be checked by looking at the total annual runoff volume in the results\precip.txt. If the runoff volume is too large, and assuming that the precipitation and stream flow data is reasonably correct, the evaporation can often be increased by simply raising the soil moisture retention (RETN). Usually this is done manually although it can be part of an optimization run. However, as with the river roughness, this

is a fairly independent parameter. The interception storage capacity (H1, H2, …H*n*) also dramatically affects evaporation as all the intercepted water is evaporated. However, we do not have that much latitude in choosing this number because these values are closely associated with vegetation type.

7. Next, you are probably ready for an optimization run with just the wetland parameters for porosity and conductivity (THETA and KCOND) if wetlands are present and you have delineated them in the land cover map. To run the wetland option, the wetland flag has to be set to 'y' and the values for THETA have to be +ve.
8. If all the above steps are successful, you are ready for a full blown optimization run. Below is an example of the optimization of six parameter sets in one run for a total of 32 parameters. In this case there are 6 land cover classes for MF and BASE and 5 river classes for LZF, PWR, THETA, and KCOND.

4.6.2 Pattern Search (Currently not operational)

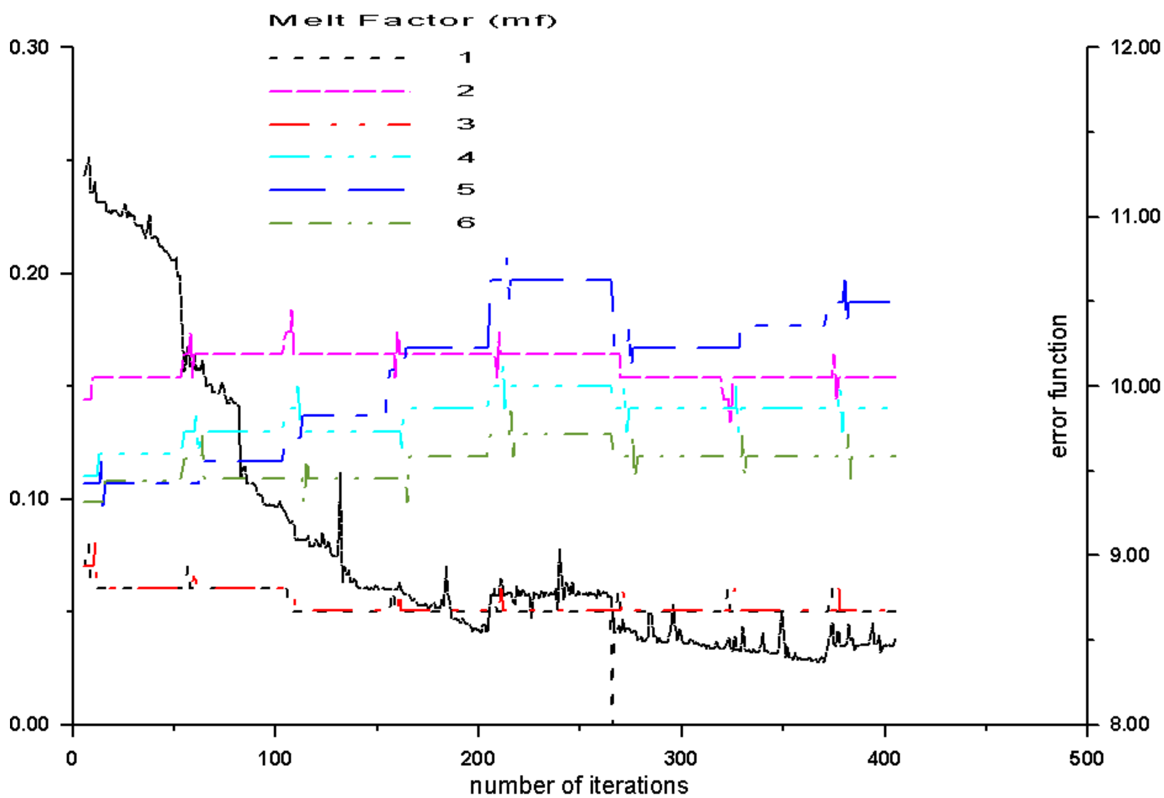
For the Pattern Search, it is ***very*** important to monitor the optimization process. First of all, reasonable lower and upper constraints need to be set on each parameter. Next, is seems more useful to use absolute values for the parameter increments DELTA. This is set in the parameter file by setting NPER = 0

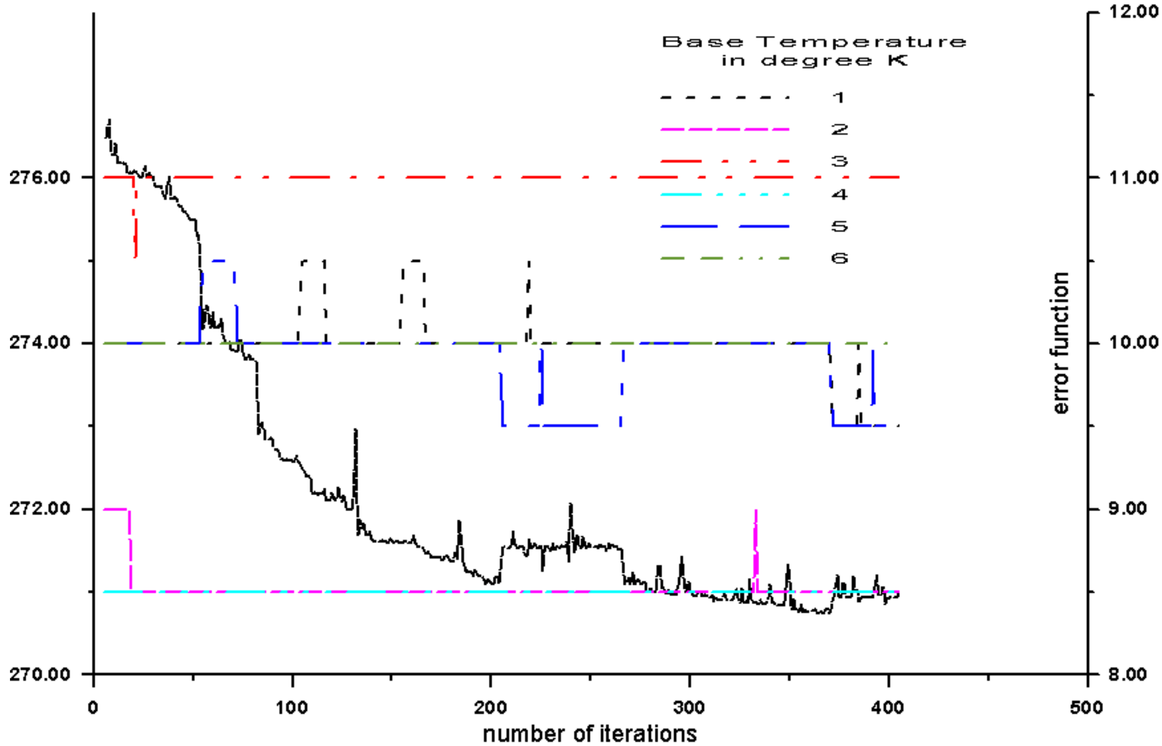
Before starting an optimization run, the upper and lower portion of the parameter file should be synchronized. This is done by setting all delta values except one to a –ve number and setting the parameter value whose delta is +ve to the same value in both the top and the lower part of the parameter file. Then run just one iteration of the program – i.e. start an optimization run on just that one parameter and then just hit ctrl C after the first iteration and the appearance of the message "new parameter file written". This will synchronize the upper and lower part of the table.

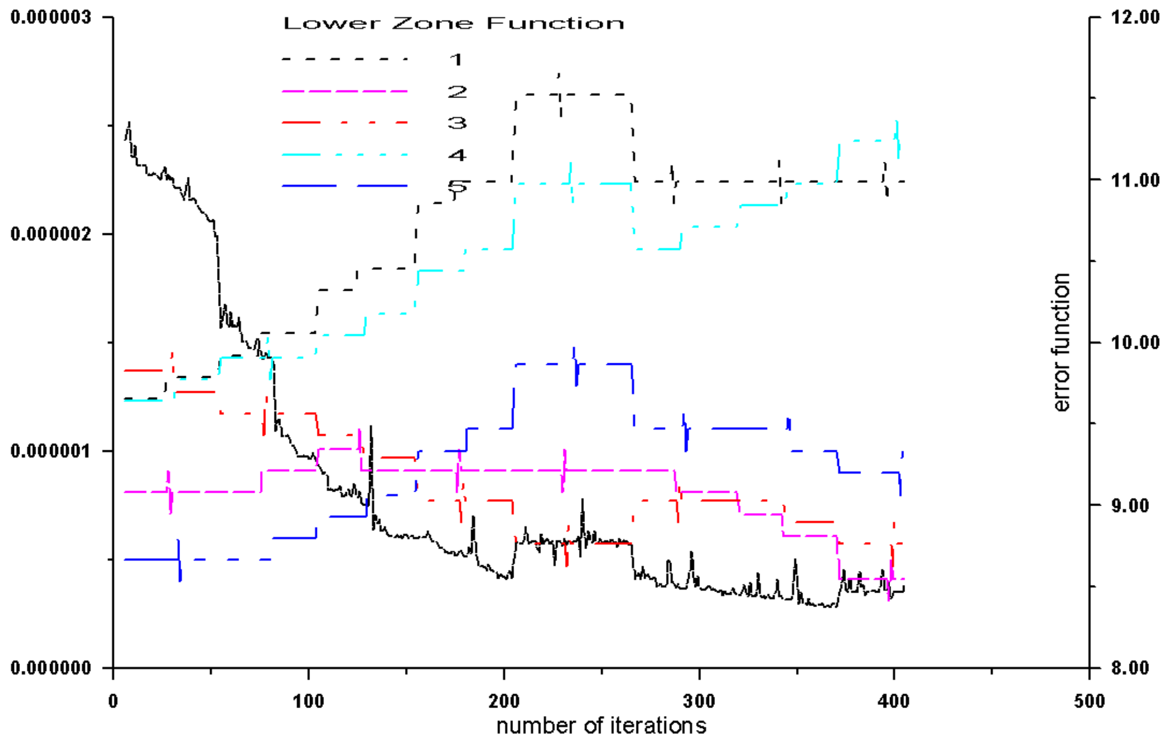
Once you have selected your parameters to be optimized, set the limits and the intervals, start the program. Often an optimization run can takes days if not weeks, depending on the size of the watershed and the duration of the simulation. Usually a two or three year run will do nicely if the run covers both a wet and a dry year. Once you have a number of evaluations approximately equal to the number of parameters times 10, you will have a good idea of where the run is headed. Below is an example of an optimization run once steps 1 to 5 were completed for the BOREAS SSA watershed (White Gull). The heavy descending dark line is the error value and is the same in each of the six plots. Each of the six plots is for one parameter in each of the land or river classes. In this case, there are six land cover classes and five river classes. There are as many wetland classes as there are river classes. The data is in the output file results\opt.txt

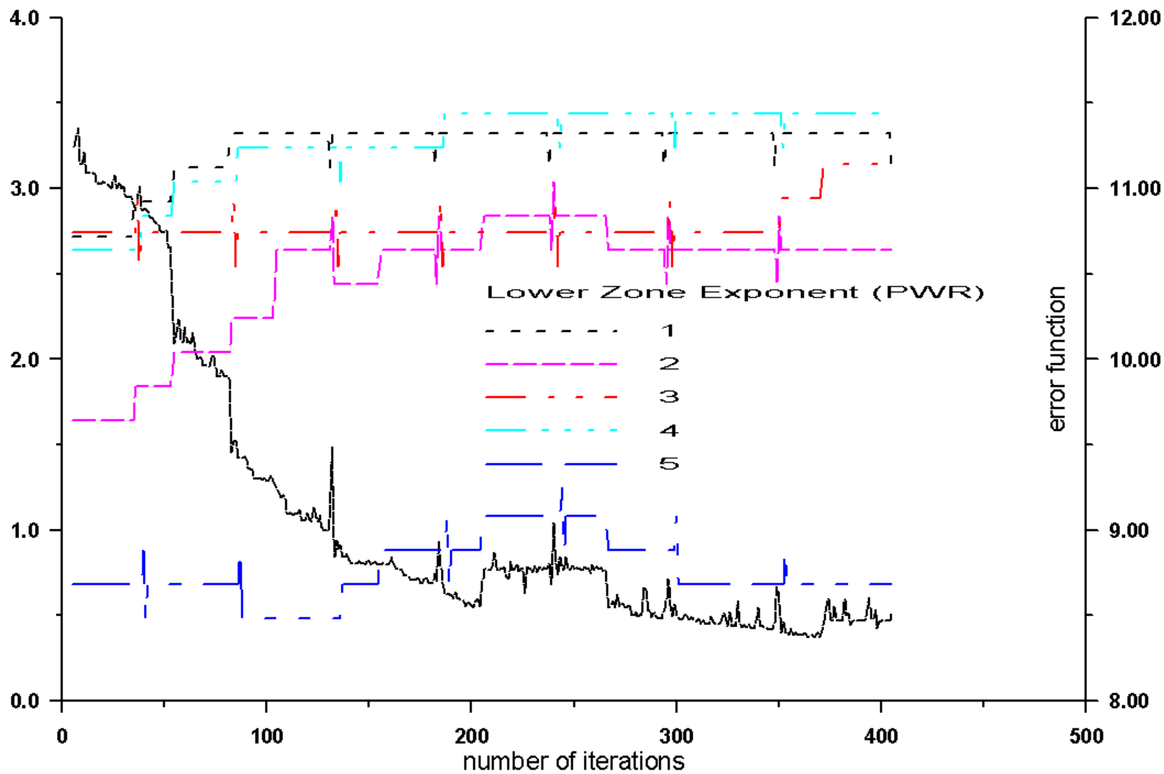
With luck, you will see the dramatic kind of reduction in the error that is shown in these plots. After about 200 evaluations, the error is still being reduced but at a much slower rate. In this example, the melt factor MF has hit a lower constraint of 0.05 for classes 1 and 3. Similarly, some of the base temperatures have hit the upper and lower constraints of 276 and 271 degree Kelvin. The base temperature increment is one degree K (or C) which is too large and should be reduced to 0.1^{O}.

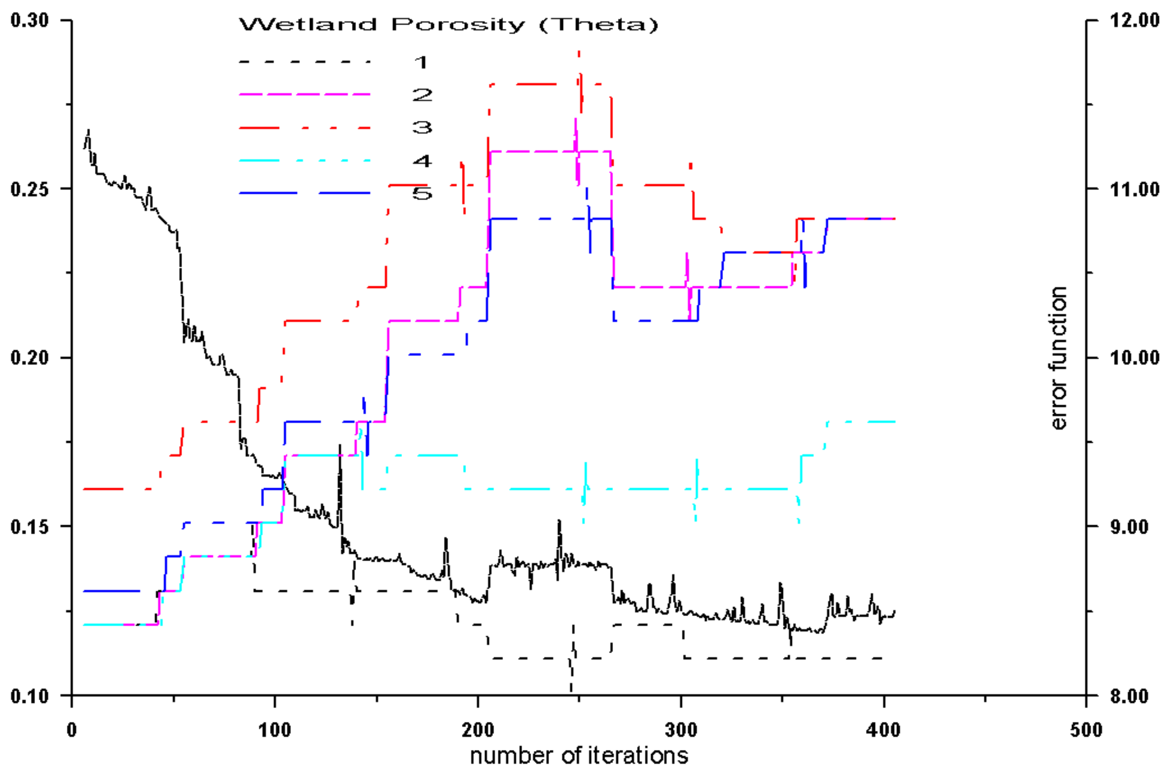
At you own discretion, other parameters can be included in the optimization. There are no hard and fast rules for doing this work but this approach works in this case. The basic presumption is that the initial parameter set is reasonable. The GRU method to some extent precluded a problem that many people experience, namely, that there are multiple parameter sets the fit the data equally well. However, this problem is largely avoided with the GRU method ***as long as multiple stream flow gauges*** are used for the optimization. In addition, the more varied the sub-watersheds are, the more likely you are to obtain a unique parameter set. The parameters will uniquely be associated with a land cover or river class. In the future, we hope to have a ***universal parameter set*** which will greatly reduce the need for lengthy calibrations.

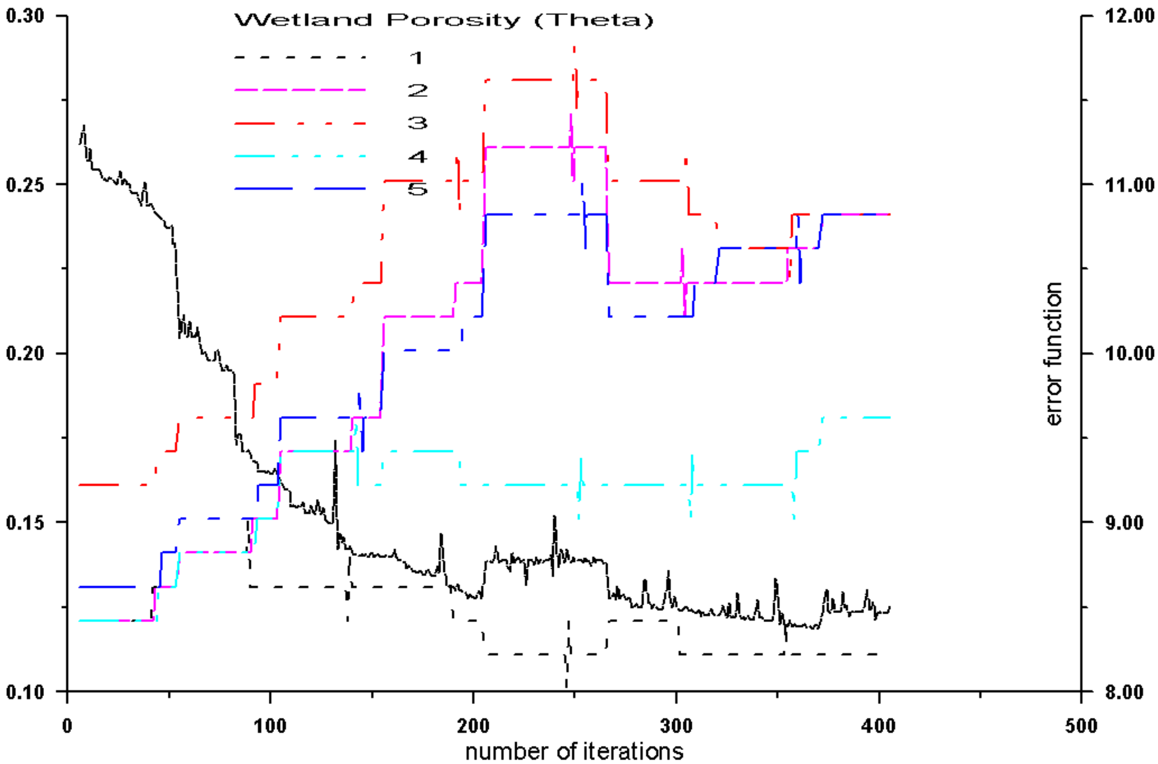



Base Temperature
in degree K
1
2
3
4
5
6
276.00
274.00
272.00
270.00
12.00
11.00
10.00
9.00
8.00
error function
0
100
200
300
400
500
number of iterations


Lower Zone Function
1
2
3
4
5
0.000003
0.000002
0.000001
0.000000
12.00
11.00
10.00
9.00
8.00
error function
0
100
200
300
400
500
number of iterations


Lower Zone Exponent (PWR)
1
2
3
4
5
error function
number of iterations
4.0
3.0
2.0
1.0
0.0
12.00
11.00
10.00
9.00
8.00
0
100
200
300
400
500


Wetland Porosity (Theta)
1
2
3
4
5
error function
number of iterations
0.30
0.25
0.20
0.15
0.10
12.00
11.00
10.00
9.00
8.00
0
100
200
300
400
500


Wetland Porosity (Theta)
1
2
3
4
5
0.30
0.25
0.20
0.15
0.10
12.00
11.00
10.00
9.00
8.00
error function
0
100
200
300
400
500
number of iterations

4.6.3 Dynamically Dimensioned Search DDS

While the PS incrementally changes the parameter values, the DDS does a random search of the parameter set. One has to be much more patient. With the pattern search when using the plots shown above, you can generally see when the best value of the objective function is being approached and you can cut off the search. With DDS this is not so evident as there is no pattern to the evaluations (guess why!?)

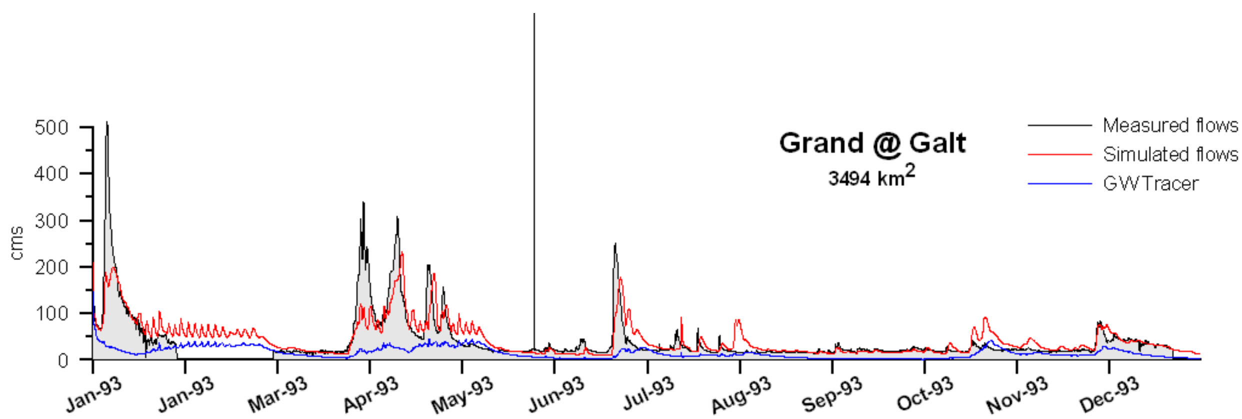
There are no hard and fast rules about for instance how many evaluations to run for say a DDS run with 30 parameters but something like 300 evaluations for 10 trials is not unreasonable. (Each trial produces a parameter set). For a run on say 1500 grids for a 10 year calibration period this can take several weeks. The originator of the DDS program suggest the number usually reflects your deadline.

Based on limited experience with DDS and WATFLOOD, a strategy that seems to work is to do a short run with say 200-300 evaluations on the most important parameters (i.e. the ones that are most likely to produce the greatest gains and perhaps 10-15 parameters or fewer) and then to free up other parameters and run more evaluations. Your own experience in this will be the most valuable as each situation is different.

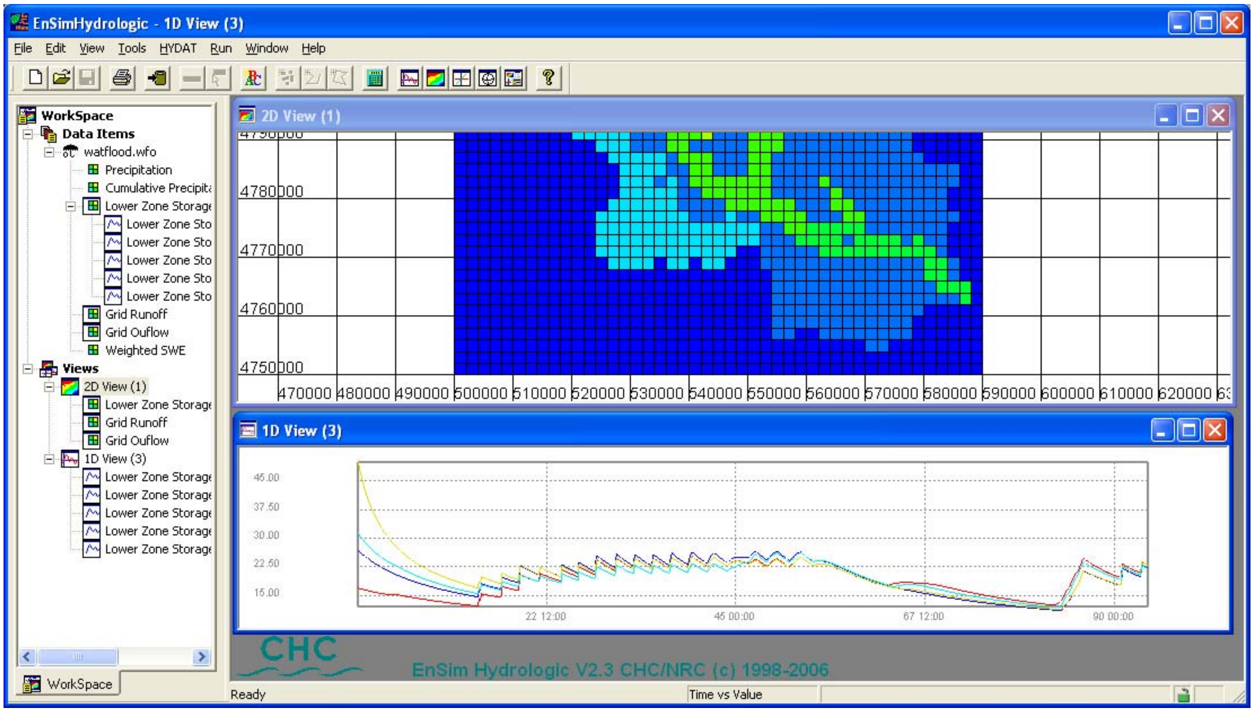
Ideally, as with the PS, the constraints should not be too loose. First of all, the initial values need to reflect the processes reasonably well. A manual fitting should be carried out as described in Section 4.6.1 or a parameter set from a previously calibrated similar watershed should be used. As the evaluations continue, the best-so-far par set is saved in the **best/** directory. Ideally, the parameters should not be at the constraints, or at least not remain there. If they do, the constraints should be re-examined. However, occasionally, there may be a problem with the data. For instance, if the evaporation seems unreasonable high, the precipitation may have been over estimated, or visa versa.

4.7 Trouble shooting

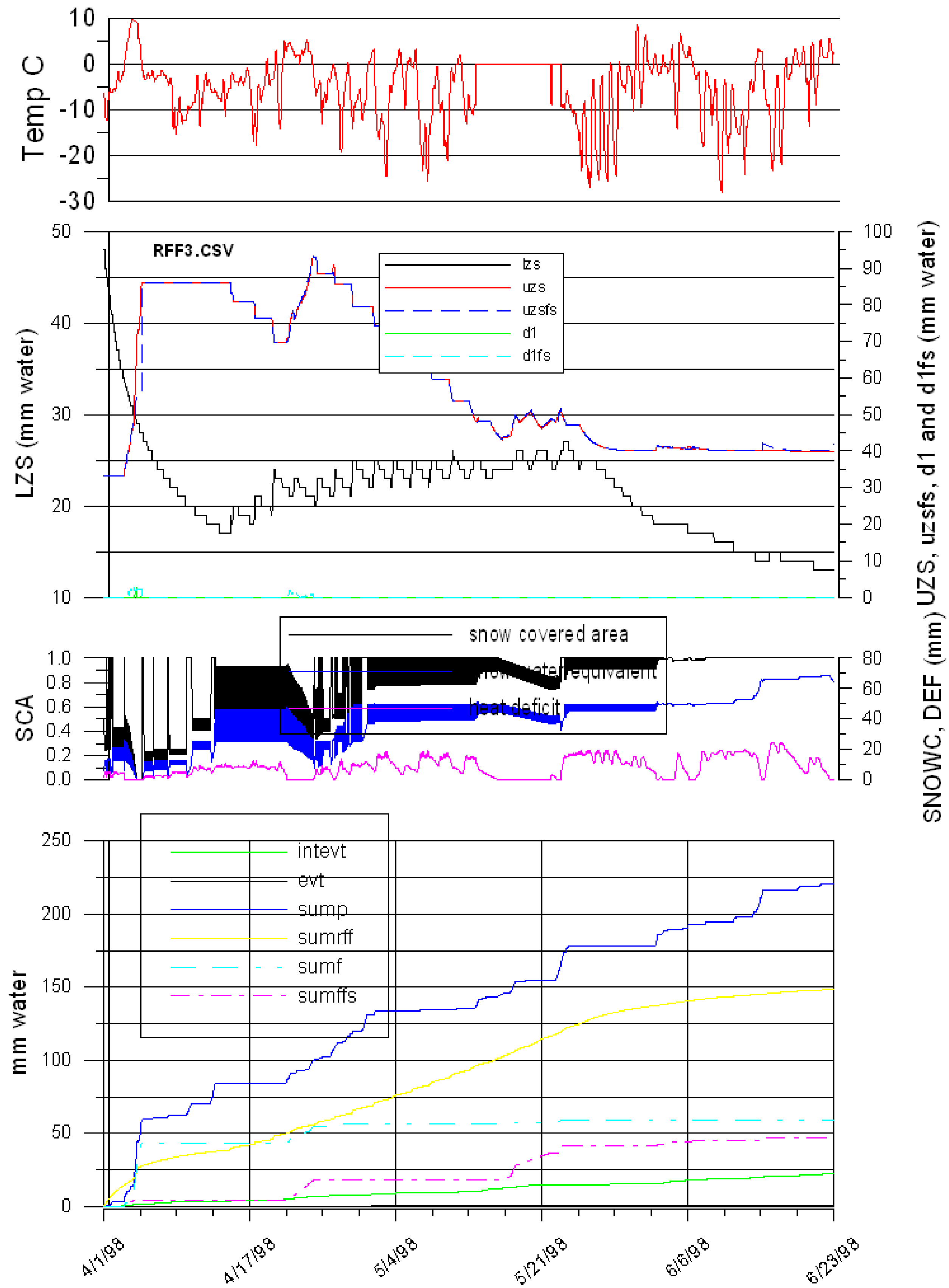
Occasionally, weird things happen. For instance, in the plot below, odd undulations appeared in the hydrographs throughout an entire watershed as shown in figure below:



At first glance, it would appear that these undulations would have their origin in the routing scheme. At check of the routing parameters revealed nothing unusual. In this case, the modeller has to drill down into the model to determine the origin of the problem. Various state variables are loaded into GreenKenue (below) where time series can be extracted and plotted. After checking a few variables, the lzs was found to be undulating in the same manner as the river flow and it appeared throughout the watershed.



Next, with iopt set to 1, all state variables are plotted as in the next figure. This can be done for each land cover class. It turned out that the problem originated in class 3, in this case the agricultural area, which is the most dominant in this watershed. Everything appears normal in the bottom two plots which show the snow cover information and the inputs. The lzs shows the undulations and the unusual item that stands out is that the uzs for both the bare and snow covered areas are way above the retention of 40 mm although eventually they settle down to this value. But note that the uzs drops in steps! In the model, drainage of the uz ca not occur when the temperature is below 0^{o}C and we note that periodically, the temperature, shown in the top plot is just above this value. The problem was caused by a value for the upper zone to lower zone drainage parameter ak2 and ak2fs that was much too low. This caused an initial buildup of water in the uz which could then drain at intervals when the temperature rose above. Thus a problem that appeared to be a routing problem was not that at all.


Temp C
10
0
-10
-20
-30
RFF3.CSV
lzs
uzs
uzsfs
d1
d1fs
LZS (mm water)
UZS, uzsfs, d1 and d1fs (mm water)
snow covered area
heat deficit
SCA
SNOWC, DEF (mm)
intevt
evt
sump
sumrff
sumf
sumffs
mm water
4/1/98
4/17/98
5/4/98
5/21/98
6/6/98
6/23/98

4.8 Parameter Sensitivity Analysis (beta version)

When deciding which parameter should be used in an optimization run, it is helpful to optimize just those parameters to which the outcome is sensitive. First chose which erro criteria is to be used. The routing and snow parameters most affect timing of the hydrograph so the error criteria should be one which reflects timing. The RMS error and the Nash-Sutcliffe efficiency are sensitive to hydrograph timing. The hydrological parameters mostly affect the volume of runoff. The objective functions dealing with volume are most sensitive to volumetric errors. Of course RMS errors to a large extent cover both timing and volumetric errors.

To do a sensitivity study, set the DDS flag ddsfl = -1 and pick the appropriate objective function errfl = ?? in the basin\bsnm.par file. Also, chose a suitable number of events, The number of times SPLX.exe has to execute is 12 * (# optimizable flow parameters) + 24 *(# optimizable hydrological parameters). For a larg watershed with many river types and land cover classes this can add up to a long run time (weeks even) so it is prudent to carefully chose the number of events.

When ddsfl is set to -1, you will be confronted by two questions as below. Depending on your priority, you can chose to run the sensitivity sequence on one or the other or both, The routing sensitivity is performed first. **y/n** is case sensitive.

Example:

```
 Do you want sensitivities on the routing parameters? y/n
y

 Do you wnat sensitivities on the hydrol. parameters? y/n
y

 Please enter the % delta you would like to use:
 10% is not a bad value
10

 OK, thank you

 base value =   25.44884
 -----------------------
 flz:
 sensitivity -10%(           1 =  6.4995199E-02   25.43230
 sensitivity +10%(           1 = -5.5694107E-02   25.46302
 sensitivity -10%(           2 =  7.6132521E-02   25.42947
.
.
 Please see `sensitivities.txt` in working directory
 for a summary of the sensitivities

 pwr:
 sensitivity -10%(           1 =   1.234047       25.13479
 .
```

Output file: **sensitivity.txt** in the working directory:

```
Routing parameters:
param upper_gr  conestoga speed     eramosa   lower_gr
flz
-10%     0.065     0.076     0.259    -1.127    -0.013
+10%    -0.056    -0.075    -0.225     1.005     0.011
pwr
-10%     1.234     0.223     4.098   -18.711    -0.227
+10%    -0.509    -1.089    -2.000    12.560     0.097
r2n
-10%    -0.046    -0.010    -0.089     0.121    -0.009
+10%     0.040    -0.009     0.083    -0.126     0.010
theta
-10%     0.069    -0.176     0.133    -0.032    -0.022
+10%    -0.003     0.119    -0.076     0.000     0.024
kcond
-10%    -0.171     0.115     0.016     0.188     0.006
+10%     0.149    -0.119    -0.013    -0.168    -0.005
rlake
-10%     0.000     0.000     0.000     0.000     0.000
+10%     0.000     0.000     0.000     0.000     0.000
 Hydrological parameters:
param bare_soil forest    crops     wetland   water
imperv
 rec
-10%     0.000     0.071     0.284     0.000     0.000     0.000
+10%     0.000    -0.064    -0.276     0.000     0.000     0.000
 ak
-10%     0.000     0.000    -0.033     0.000     0.000     0.000
+10%     0.000     0.000     0.041     0.000     0.000     0.000
.
.
.
 r3
-10%     0.000     0.000    -0.001     0.000     0.000     0.000
+10%     0.000     0.000    -0.001     0.000     0.000     0.000
 mf
-10%     0.000    -0.001    -0.321    -0.017     0.000     0.000
+10%     0.000    -0.014     0.376     0.002     0.000     0.000
 base
-1dC     0.000    -0.041     0.737    -0.014     0.000     0.000
+1dC     0.000     0.088    -0.116    -0.029     0.000     0.000
.
.
```

5 MODEL INITIALIZATION

5.1 Initial Snow Cover

Please see Section 4.2.4 for a description of the snow parameters.

The initial snow data is obtained from snow course located in and near the watershed. The snow course values are distributed over the watershed according to a distance squared weighting scheme using SNW.exe program. The grid information is obtained from the bsnm_shd.r2c file as specified in the event file.

5.1.1 Sample Initial Point Snow Water Equivalent File (yyyynndd_crs.pt2):

The file header is self explanatory. In this file, the class count **includes** the impervious class. In this example there are 2 snow courses and 6 land cover classes. The unitConversion can be used to convert any measurement to mm of snow water equivalent.

The **initial** heat deficit factor can be used to control the beginning of the melt. If the snow pack is ripe at the time the measurements were taken, the value should be 0.0. The snow will melt as soon as the temperature rises above 0^{o}C. The maximum value accepted is set by the A9 parameter in the parameter file. A9 is used as an upper limit throughout the snow simulation period.

The program SNW.EXE will read the snow course data and create the gridded snow water equivalent file (yyyymmdd_swe.r2c). There is a line of data for each snow gauge location. First the easting and northing and then station name, followed by the snow water equivalent (SWE) for each land cover class. Missing data is denoted by a –ve number.

```
#########################################################################
:FileType pt2 ASCIIGreenKenue 1.0
#
# DataType               GreenKenue PT2 Set
#
:Application             GreenKenue
:Version                  2.1.23
:WrittenBy                NK
:CreationDate             Fri, Jul 14, 2006 08:08 AM
#
#-----------------------------------------------------------------------
#
:Name  Point Snow Water Equivalent
#
:Projection  UTM
:Zone        17
:Ellipsoid   GRS80
#
:SampleTime   1993/01/01 0:00:00.000
#
:UnitConversion             1.0
```

```
:InitHeatDeficit            0.33
#
:AttributeName 1 StationName
:AttributeType 1 text
:AttributeName 2 Class1
:AttributeType 2 float
:AttributeName 3 Class2
:AttributeType 3 float
:AttributeName 4 Class3
:AttributeType 4 float
:AttributeName 5 Class4
:AttributeType 5 float
:AttributeName 6 Class5
:AttributeType 6 float
:AttributeName 7 Class6
:AttributeType 7 float
:EndHeader
556000.0 4799000.0 "Cambridge" 1.0 3.0 20.0 1.0 0.0 3.0
547000.0 4932000.0 "Wormwood" 20.0 3.0 1.0 1.0 3.0 0.0
```

5.1.2 Sample of Gridded Snow Water Equivalent Map

The following data is based on the snow course values listed for the UTM coordinates in Section 5.1.1. The gridded snow cover file is created when the program SNW.EXE is run to distribute the snow. The grid information is obtained from the bsnm_shd.r2c file as specified in the event file to ensure that the swe grid matches the _shd file.

AGreenKenue format file called yyyymmdd_swe.r2c is produced by SNW.EXE and can be loaded intoGreenKenue where it can be viewed for each land cover class.

Note: the fields for each class are not separated by headers as in the time series yyyymmdd_met.r2c and yyyymmdd_tem.r2c files. It all runs together. **South is at the top of each class segment.**

```
########################################
:FileType r2c  ASCII GreenKenue 1.0
#
# DataType               2D Rect Cell
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          snw.exe
:CreationDate       2006-10-19  11:40
#
#---------------------------------------
#
:Name               Snow Water Equivalent
#
:Projection         UTM
:Ellipsoid          GRS80
:Zone               17
#
:xOrigin              500000.000
:yOrigin             4790000.000
```

```
#
:SourceFile                    snow1\19930101_crs.pt2
#
:AttributeName    1 Class    1
:AttributeName    2 Class    2
:AttributeName    3 Class    3
:AttributeName    4 Class    4
:AttributeName    5 Class    5
:AttributeName    6 Class    6
#
#
:xCount                          9
:yCount                         12
:xDelta                  10000.000
:yDelta                  10000.000
#
:SampleTime
#
:UnitConverson               1.000
:InitHeatDeficit             0.330
#
:endHeader
   3.4   2.8   2.2   1.7   1.3   1.1   1.0   1.3   1.6  < class 1
   3.6   2.9   2.3   1.7   1.3   1.0   1.0   1.2   1.6
   4.0   3.3   2.6   1.9   1.5   1.2   1.2   1.4   1.8
   4.7   3.9   3.2   2.5   2.0   1.7   1.7   1.9   2.3
   5.7   4.9   4.2   3.5   3.0   2.7   2.6   2.8   3.2
   6.9   6.3   5.6   5.0   4.5   4.2   4.1   4.3   4.6
   8.4   8.0   7.5   7.1   6.6   6.3   6.2   6.3   6.5
  10.1  10.0   9.7   9.5   9.2   9.0   8.8   8.7   8.7
  11.9  12.0  12.0  12.0  12.0  11.8  11.6  11.4  11.1
  13.6  13.9  14.2  14.4  14.5  14.5  14.2  13.9  13.4
  15.1  15.6  16.1  16.5  16.7  16.7  16.4  16.0  15.4
  16.3  16.9  17.5  18.0  18.2  18.3  18.0  17.5  16.9
   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0  < class 2
   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0
   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0
   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0   3.0
.
.
.etc.
```

5.2 Initial Soil Moisture

The initial soil moisture data can be obtained obtained from various sources such as remote sensing, other models or the Antecedent Precipitation Index (API). The program MOIST.EXE will read the point soil moisture data yyyymmdd_psm.pt2 and create the gridded initial soil moisture file yyymmdd_gsm.r2c for all land covers.

5.2.1 Sample Point Initial Soil Moisture File (_PSM.r2c) (Soil Moisture Data):

The file header is self explanatory. The unitConversion can be used to convert any measurement to the fraction of soil water present.

There is line of data for each gauge location. First the easting and northing , then the station namefollowed by the soil moisture for each land cover class. The initial soil moisture can be obtained using the API method as described in Section 2.2.3

```
#########################################################################
:FileType pt2 ASCIIGreenKenue 1.0
#
# DataType               GreenKenue PT2 Set
#
:Application             GreenKenue
:Version                  2.1.23
:WrittenBy                watsond
:CreationDate             Mon, Feb 28, 2005 12:08 PM
#
#-------------------------------------------------------------------------
#
:Name  Point Soil Moisture
#
:Projection  UTM
:Zone        17
:Ellipsoid   GRS80
#
:SampleTime   1993/01/01 0:00:00.000
#
:UnitConversion  1.0
#
:AttributeName 1 StationName
:AttributeType 1 text
:AttributeName 2 Class1
:AttributeType 2 float
:AttributeName 3 Class2
:AttributeType 3 float
:AttributeName 4 Class3
:AttributeType 4 float
:AttributeName 5 Class4
:AttributeType 5 float
:AttributeName 6 Class5
:AttributeType 6 float
:AttributeName 7 Class6
:AttributeType 7 float
:EndHeader
558000.0 4820000.0 "GuelphCol" 0.1 0.2 0.3 0.4 0.5 0.6
535000.0 4814000.0 "Waterloo" 0.12 0.22 0.32 0.42 0.52 0.62
554000.0 4843000.0 "ShandDam" 0.15 0.25 0.35 0.45 0.55 0.65
```

5.2.2 Sample of Gridded Initial Soil Moisture Map (_gsm.r2c)

The following data is based on the initial soil moisture values listed for the UTM coordinates in Section 5.2.1. This file is created when the program MOIST.EXE is run to distribute the initial soil moisture. The grid information is obtained from the bsnm.shd file as specified in the event file.

AnGreenKenue format file called yyyymmdd_gsm.r2c is produced by MOIST.EXE and can be opened byGreenKenue where it can be viewed for each land cover class.

Note: the fields for each class are not separated by headers as in the time series yyyymmdd_met.r2c and yyyymmdd_tem.r2c files. It all runs together. **South is at the top of each class segment.**

```
:Name               Initial Soil Moisture
#
:Projection         UTM
:Ellipsoid          GRS80
:Zone               17
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:SourceFile                   moist\19930101_gsm.r2c
#
:AttributeName    1 Class    1
:AttributeName    2 Class    2
:AttributeName    3 Class    3
:AttributeName    4 Class    4
:AttributeName    5 Class    5
:AttributeName    6 Class    6
#
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
:SampleTime
#
:UnitConverson             1.000
#
:endHeader
  0.12  0.12  0.12  0.12  0.11  0.11  0.11  0.11  0.12  < class 1
  0.12  0.12  0.12  0.12  0.11  0.11  0.11  0.11  0.12
  0.12  0.12  0.12  0.12  0.10  0.10  0.11  0.12  0.12
  0.12  0.12  0.12  0.12  0.12  0.12  0.12  0.12  0.12
  0.12  0.13  0.13  0.14  0.15  0.15  0.13  0.13  0.13
  0.13  0.13  0.13  0.14  0.15  0.15  0.14  0.13  0.13
  0.13  0.13  0.13  0.14  0.14  0.14  0.14  0.13  0.13
```

```
  0.13  0.13  0.13  0.13  0.14  0.14  0.13  0.13  0.13
  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13
  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13
  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13
  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13  0.13
  0.22  0.22  0.22  0.22  0.21  0.21  0.21  0.21  0.22  < class 2
  0.22  0.22  0.22  0.22  0.21  0.21  0.21  0.21  0.22
  0.22  0.22  0.22  0.22  0.20  0.20  0.21  0.22  0.22
  0.22  0.22  0.22  0.22  0.22  0.22  0.22  0.22  0.22
  0.22  0.23  0.23  0.24  0.25  0.25  0.23  0.23  0.23
  0.23  0.23  0.23  0.24  0.25  0.25  0.24  0.23  0.23
.
.
.etc.
```

5.3 Initial Channel Storage

The initial flow conditions in the drainage network are computed by pro-rating the initial flow given in the yyymmdd_str.tb0 file according to the relative values of the drainage areas of a grid and the flow station. A multy-pass proceedure is used to gica an initial flow for each grid. Then these flows are used to compute an initial channel storage based on the storage-discharge curve entered with the r2n parameters in the bsnm.par file.

For this reason, it is useful (if not very important) to enter initial flows in the yyyymmdd_str.tb0 file for the first event. If flows are not known, a monthly average for the locatin might work.

5.4 Initial Lower Zone Storage

The initial lower zone storage storage is computed based on the initial flow in each grid. The lzf and pwr parameters are used to derive the initial lower zone storage. (In a future version it will be possible to read a yyyymmdd_lzs.r2c file to initialize the lower zone storage).

6 RAINFALL DATA PROCESSING

In WATFLOOD, gauge rainfall amounts are primarily used as a basis for adjusting radar rainfall measurements and to fill in missing radar rainfall measurements..

The weight parameter is entered as a program argument for CALMET.EXE, RAGMET.EXE,

The default weighting for distributing precipitation is distance squared. I.e. the default weight parameter is 2. However, if you want the distribution pf precip to be more like Thiessen poligons, you can make the weight = 10 by issuing the command:

calmet 10 or
ragmet 10

6.1.1 Introduction

A number of rainfall files are used by WATFLOOD. The files have the following extensions:
.SCN .RAD _RAG.tb0 _MET.r2c

File Type	Directory Location	Usage
.SCN	\RADAR	RADAR ASCII file in resolution of the radar for the whole radar field
.RAD	\RADUC	RADAR ASCII files converted to the SPL grid for the modeling area
_RAG.tb0	\RAIN	Point rain gauge data
_MET.r2c	\RADCL	Distributed rain gauge data or adjusted radar data

SPL9 uses the _MET.r2c file as the rainfall input file for the hydrologic simulation. The MET file can be created from rain gauge information alone using RAGMET, from radar data (_RAD.r2c) alone by copying the file, or from a radar file that is adjusted with rain gauge data with CALMET. The RAD file is the data extracted from the RADAR data by a program called RADMET for the particular watershed being modeled. The raw radar data has file extension .SCN. RADMET has to be customized for each radar source because of the different formats in use. The _RAD.r2c file has the same format as the _MET.r2c file but the format of SCN depends on the radar source.

For many recent applications of WATFLOOD, precipitation and temperature files have been generated by numerical weather models (NWM). Often these data are produced in a format very similar to the RAG files and on a grid different from the watershed file. For these cases, the RAGMET program can be used to convert the NWM files to MET files by using each NWM grid as a precip gauge. Please contact N. Kouwen for details.

6.1.2 Rain Gauge Data File (_RAG.tb0)

The rain gauge data file yyyymmdd_rag.tb0 is used by the program RAGMET to create a georeferenced rainfall data file yymmdd_met.r2c for SPL9. It is also used by CALMET.EXE (Calibrate Radar in the Run menu) to adjust radar data files. The _RAG.tb0 file for an event over the Grand River watershed is formatted as follows:

```
########################################
:FileType tb0  ASCII GreenKenue 1.0
#
# DataType              GreenKenue Table
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          nk
:CreationDate       2006-09-29  08:52
#
#---------------------------------------
#
:SourceFile         grca data
#
:Name               Precipitation
#
:Projection         UTM
:Ellipsoid          NAD83
:Zone               17
#
:StartDate          13-10-1954
:StartTime          02:00
:DeltaT                        1
#
:UnitConversion             1.0
#
:ColumnMetaData
   :ColumnUnits               mm          mm          mm
   :ColumnType               float         float      float
   :ColumnName              GuelphCol   Waterloo    ShandDam
   :ColumnLocationX            558000.    535000.    554000.
   :ColumnLocationY           4820000.   4814000.   4843000.
   :Elevation                  1400.       915.       1490.     ←optional
:EndColumnMetaData
:EndHeader
```

This format is more or less self explanatory.

The coordinate system is UTM, LATLONG or Cartesian. All lines in this header are **required** eventhough data may not excist for some entries. If the Datum or Zone are not known, the word UNKNOWN will be accepted. This data is just for information for the user. The program only requires an acceptable entry for CoordSys. The remaining headings are all required. The UnitConversion allows data to be converted by the program. For instance, if the measurement units are in 1/10ths of mm, the conversion factor is 10.0

The station names and coordinates are also space delimited so do not leave blanks in the names.

Note: The initial soil moisture is no longer the first line in this file. It is now in a separate file as described in Section 5.2.

What follows is the hourly rainfall in the units specified above. A unitConversion of 1.0 indates that the values are in mm. Each column corresponds to one station listed above.

```
  0.80    0.50    2.00
 19.70   12.00   20.00
  0.80    1.50    2.50
 10.70   10.00    8.00
  1.80    2.00    1.00
  2.00    2.00    2.00
  5.30    3.00    2.00
  0.80    2.00    1.50
  0.50    1.00    0.50
  0.50    1.00    0.50
  0.30    0.50    0.00
  0.80    0.50    0.00
  2.80    2.00    1.50
    .
    .
  0.00    0.00    0.00
  1.00    0.50    1.00
  0.30    0.30    0.30
  0.50    0.50    0.50
  1.00    0.50    0.50
  0.00    0.00    0.00
  0.00    0.00    0.00
  2.00    0.50    1.50
  0.80    0.30    0.30
  0.50    0.30    0.20
```

The data format is free format but a column with of 10 makes the file readable.

Notes:

1. Missing data is entered as -1. Missing data and zero rainfall are treated differently in the rainfall distribution program. -ve values are ignored while zero values are distributed as such. When there is missing data at a precipitation station, the value of nearby gauges will used for the grid.
2. The line length is limited to 4096 characters
3. If the elevation of the first station is greater than 0 then all stations must have an elevation and the lapse rate (rlapse) should have a value in the par file

6.1.3 Distribution of Gauge Precipitation

RAGMET.EXE is for distribution of gauge rainfall. Rainfall amounts for each square grid element of the watershed were determined using a modified version of the Reciprocal Distance Weighting Technique (Wei and McGuiness, 1973). The weights were assumed to be an inverse function of the distance between the grid element midpoint and the rain gauge (Wei and McGuiness, 1973; Dean and Snyder, 1977).

The major limitation of this method is that the estimation of rainfall never results in values greater than the largest amount observed or less than the smallest (NWS, 1972). This method also assigns rainfall to each grid element regardless of the areal extent of the actual rain event (Dalezios, 1982).

RAGMET.EXE will read the yymmdd.rag file and create a yymmdd_met.r2c file. The yymmdd_met.r2c can be laoded intoGreenKenue and animated. Timeseries of precipitatin can be extracted also.

Caution: Each time RAGMET.exe is executed, the existing yyyymmdd_met.r2c file is overwritten. If the existing file is the one created by another program or imported from outside WATFLOOD, it should be renamed prior to running RAGMET.exe or the filename in the event file should be changed..

6.1.4 Modified Distribution of Precipitation

This section is identical to section8.1.2 6.1.46.1.4 for temperature..

For straight distance weighting, distant stations can have an influence at a grid, especially grids at watershed boundaries where the grid is well outside the group of precipitation stations. Another problem arises when a station consistently over or underestimates precipitation which results in "bullseyes" when cumulative precip is plotted in 2D.

NEW
To overcome this, two coefficients can be used by RAGMET.exe. These are read from **basin\bsnm_par.csv** in the appropriate line**:**

```
:radiusinflce,   300.000,# radius of influence km
:smoothdist,      35.000,# smoothing diatance km
```

To include all stations in the weights for all grids, chose a large min. radius of influence, e.g. a distance larger than the largest dimension of the watershed.

To smooth the precipitation field, insert a distance from each station location where you want its effect to be reduced. The greater this number, the more smoothing of the precip field will be effected. It is best to try different values until the cumulative precipitation field for the complete simulation period looks acceptably smooth.

Set the radius of influence **just** large enough so the whole watershed will have precipitation.
Set the minimum distance **just** large enough to get a nice looking interpolation between stations.
(Check this in loading the cumulative precipitation in a wfo file into GreenKenue)

The radius of influense & the smoothing distance can be optimized using DDS.

6.1.5 Precipitation lapse rate (rlapse)

The lapse rate and a reference elevation (usually sea level) can be set in the par file. When Rlapse ≠ 0.0 the precipitation will be adjusted depending on the grid elevation. This came into effect with rev. 9.5.63 Sept. '09. Prior, the lapse rate would only be used for snow melt but the base temp can be used in addition to account for large elevation changes where land cover is correlated to elevation as in high mountains.

The elevation of each precip. Station must be given in the yyyymmdd_rag.tb0 file. If not present, sea level is assumed.

rlapse = lapse rate in mm / 1 m elevation

Example - how to determine the precipitation lapse rate:

At each gauging station, the point (or gauge) precip is reduced to a sea level (or other reference) value by

precip(n)= precip (n)/(1+sta_elv(n)*rlapse)

So the higher the lapse rate, the lower will be the sea level value. With rlapse = 0, no change.

Then after the sea level precip is distributed with a value for each grid, the correction is reversed for each grid

precip (i,j)= precip (i,j)*(1.0+elev_grid(i,j)*rlapse)

So if the change is say +610 mm for 1 km (1000 m) higher than a value of say 9150 mm at a gauge, we have at 1000 m higher

9150 + 610 = 9150 * (1.0 + 1000 * rlapse)

(9760/9150 – 1.0)/1000 = .00007 = rlapse

If the precipitatin lapse rate is not known, it can be optimized with DDS.

6.2 Disaggregation of rainfall (smrflg=y)

If daily precipitation is entered in the rag file, the amounts will be disaggregated by entering rainfall in the yyyymmdd_met.r2c file in hourly amounts until the total amount is entered. If the daily amount is greater than 24 mm, the amount will be divided by 24 and 24 equal hourly amounts will be used. To use this feature, the smrflg must be 'y' in the event files and a value for **A12** must be specified in the par file. If A12 = 0.0 or -1.0 a value of 1 mm/hr will be assumed.

Smaller time increments can also be used, for instance deltat = 6 hrs. In this case 6 equal mounts will be used if the 6 hour precipitation is 6 mm or greater.

If you would like a different method of disaggregation (e.g. SCS 12 hr. S curve), you can do this by converting your 24 hr values to disaggregated hourly values in the rag file before running RAGMET.exe.

6.3 Precipitation Data (yyyymmdd_met.r2c) - Input to SPL

The _MET.r2c file for an event over the Grand River Watershed follows:

TheGreenKenue format file called yyyymmdd_met.r2c is produced by RAGMET.exe and can be loaded intoGreenKenue where it can be animated and time series extracted for each grid. The watershed dimensions are taken from the bsnm_shd.r2c file.

Hours with no data are simply missing frames. Zero precipitation is assumed when a frame is missing.

```
########################################
:FileType r2c  ASCII GreenKenue 1.0
#
# DataType               2D Rect Cell
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          ragmet.exe
:CreationDate       2008-07-03  10:32
#
#---------------------------------------
#
:Name               Precipitation
#
:Projection         UTM
:Ellipsoid          NAD83
:Zone               17
#
:xOrigin              500000.0000000
:yOrigin             4790000.0000000
#
:SourceFile                   raing\19541013_rag.tb0
#
:AttributeName 1    precipitation
:AttributeUnits     mm
#
:xCount                            9
:yCount                           12
:xDelta               10000.0000000
:yDelta               10000.0000000
#
:UnitConverson            1.0000000
#
:endHeader
:Frame         1         1   "1954/10/13  3:00:00.000"
   0.77   0.70   0.65   0.68   0.79   0.86   0.92   0.97   1.02
   0.77   0.66   0.50   0.50   0.79   0.85   0.92   0.99   1.05
```

```
   0.81   0.71   0.50   0.50   0.80   0.80   0.94   1.05   1.10
   0.91   0.88   0.89   1.06   1.23   1.15   1.17   1.19   1.19
   1.03   1.08   1.21   1.51   2.00   2.00   1.51   1.35   1.28
   1.14   1.22   1.37   1.63   2.00   2.00   1.62   1.45   1.35
   1.20   1.29   1.41   1.57   1.68   1.68   1.58   1.47   1.38
   1.24   1.31   1.39   1.49   1.55   1.55   1.51   1.44   1.38
   1.25   1.30   1.37   1.42   1.46   1.47   1.44   1.41   1.36
   1.25   1.29   1.34   1.37   1.40   1.41   1.39   1.37   1.34
   1.25   1.28   1.31   1.34   1.35   1.36   1.36   1.34   1.32
   1.24   1.27   1.29   1.31   1.32   1.33   1.32   1.32   1.30
:EndFrame
:Frame         2          2   "1954/10/13  4:00:00.000"
  14.68  14.10  13.70  14.27  16.12  17.52  17.95  18.01  17.98
  14.54  13.63  12.00  12.00  16.86  18.73  18.64  18.40  18.23
  14.80  13.97  12.00  12.00  19.70  19.70  19.06  18.67  18.43
  15.46  15.17  15.22  16.63  18.64  19.23  19.07  18.79  18.56
  16.21  16.40  17.07  18.46  20.00  20.00  19.22  18.89  18.64
  16.81  17.19  17.89  18.89  20.00  20.00  19.25  18.91  18.66
  17.20  17.57  18.11  18.72  19.16  19.24  19.05  18.82  18.62
  17.42  17.73  18.11  18.49  18.77  18.86  18.80  18.67  18.53
  17.54  17.78  18.05  18.30  18.49  18.58  18.57  18.51  18.42
  17.59  17.78  17.98  18.16  18.30  18.37  18.39  18.36  18.31
  17.61  17.76  17.91  18.04  18.15  18.22  18.24  18.24  18.21
  17.62  17.73  17.85  17.95  18.04  18.09  18.12  18.13  18.12
:EndFrame
:Frame         3          3   "1954/10/13  5:00:00.000"
   1.50   1.49   1.47   1.43   1.31   1.22   1.23   1.30   1.37
   1.52   1.50   1.50   1.50   1.20   1.02   1.12   1.27   1.38
   1.54   1.52   1.50   1.50   0.80   0.80   1.10   1.32   1.43.
.
.etc.
```

The starting hour and date is used to coordinate the radar and precipitation gauge data. In CALMET, the radar adjustment program, the radar and rain gauge data are matched up. If there is no radar data but there is rain gauge data, the rain gauge data (raing/yymmdd_rag.tb0) is used as in RAGMET, the rainfall distribution program. If there is radar but no rain gauge, the radar data is used unadjusted.

6.4 Radar Precipitation Data

6.4.1 Unadjusted Radar File (.RAD)

The program RADMET reads the watershed grid information and extracts the radar data for the default watershed from the SCN file in \SPL\RADAR and converts the data to the grid layout of the watershed. At this stage, the 2 km by 2km data of the SCN file is converted to the 4 by 4 or 10 km by 10 km grid of the watershed data. The resulting file has the extension RAD and has the same format as the MET files. It is located in the RADUC (unadjusted radar data) subdirectory. Since this file has the same format as a MET file, it can be copied into the RADCL subdirectory and used directly (unadjusted) by SPL9 to simulate an event.

The area covered may be larger than the grid required to cover the watershed so that the rain gauges located outside the watershed can be included for the purpose of adjusting the radar data. The grid information is stored in the XXXX.GRD and XXXX.SHD files in the BASIN sub-directory of each watershed.

```
BASIN\GRAND10K.PAR
BASIN\GRAND10K.SHD
RESRL\8609A.REL
STRFW\8609A.STR
                    86 09 10 06
              0   .00      9   1.0
 HOUR=    1    0
   .1   .1   .1   .1   .0   .1   .2   .6   .4
   .1   .1   .1   .0   .1   .1   .3   .5   .3
   .1   .1   .0   .0   .1   .1   .2   .6   .6
   .0   .0   .0   .1   .2   .2   .2   .7   .7
   .0   .0   .0   .1   .2   .3   .3   .2  1.6
   .0   .0   .0   .1   .2   .3   .3   .2   .6
   .0   .0   .1   .1   .2   .3   .3   .2   .2
   .0   .0   .0   .1   .2   .2   .2   .1   .1
   .0   .0   .0   .1   .1   .2   .1   .0   .0
   .0   .0   .0   .2   .1   .1   .0   .0   .0
   .1   .1   .1   .2   .1   .1   .1   .1   .0
   .2   .1   .1   .1   .0   .4   .2   .3   .0
 HOUR=    2    0
   .6   .4   .2   .1   .0   .0   .0   .5   .0
   .4   .2   .2   .1   .0   .0   .1   .4   .0
   .2   .2   .2   .1   .1   .0   .1   .5   .4
   .1   .1   .1   .1   .0   .0   .0   .8   .7
   .0   .0   .0   .0   .0   .0   .0   .0  2.5
   .0   .0   .0   .0   .0   .0   .0   .0   .5
   .
   .
   .5   .8   .4  1.0   .6   .3   .3   .3   .5
   .4   .3   .3   .7   .5   .2   .2   .3   .3
   .2   .1   .2   .1   .1   .1   .1   .2   .1
 HOUR=   16    0
  3.4  1.4  1.0   .9   .7  1.1  1.3  2.0  1.6
  1.1   .8  1.0   .9   .8  1.8  1.8  1.9   .6
   .6   .9   .8  1.9  3.3  3.4  1.3  1.1   .4
   .9  1.4  2.5  2.1  1.7   .7   .5  1.3   .7
  1.0  1.0   .9   .8   .4   .3   .5   .4  2.2
   .7   .4   .4   .5  1.1  1.8  1.9  1.6  2.0
   .4   .6   .6  2.3  3.7  4.5  3.9  2.4  2.2
```

```
    .9  1.0  1.3  2.5  3.7  2.7  3.6   .9  2.2
    .2   .2   .1   .2   .2   .3   .4  1.0  2.2
    .0   .0   .0   .0   .4   .3   .5   .8  1.0
    .2   .1   .1   .0   .2   .1   .1   .1   .1
    .4   .3   .1   .0   .1   .0   .0   .1   .1
 HOUR=   17    0
   1.3  2.1  1.6  1.7  2.7  2.1  1.5  2.1  3.5
   2.0  1.8  2.6  2.3  2.1  1.2  3.1  4.3  4.8
    .9   .8  1.0  1.2  1.3  3.7  5.9  6.2  4.7
    .3   .4   .4  1.0  2.0  1.5  1.1  1.5  1.5
    .6   .5   .5   .5   .7   .4   .3  1.0  3.3
    .8   .6   .6   .4   .5   .4   .4  2.2  4.5
    .7   .5   .4   .3   .3   .4  1.6  4.7  3.7
    .5   .4   .3   .3   .2   .3  2.0  3.7  2.3
    .8   .6   .4   .2   .1   .1   .0   .2   .5

             continued
```

Clutter file (.CLT)

For each rainfall event, the radar clutter is obtained from the RAD file. Clutter is due to reflections from land of buildings and result in false rainfall readings. The file is created by the RADMET program. The minimum value of rainfall in each element is recorded in a CLT file for each event. The false rainfall is deducted from the radar rainfall data for each hour. In the table below, the non-zero values are due to clutter.

```
 clutter raduc\8609a.clt
    .0   .0   .0   .0   .0   .0   .0   .5   .0
    .0   .0   .0   .0   .0   .0   .1   .4   .0
    .0   .0   .0   .0   .0   .0   .1   .5   .3
    .0   .0   .0   .0   .0   .0   .0   .7   .6
    .0   .0   .0   .0   .0   .0   .0   .0  1.6
    .0   .0   .0   .0   .0   .0   .0   .0   .5
    .0   .0   .0   .0   .0   .0   .0   .0   .2
    .0   .0   .0   .0   .0   .0   .0   .0   .1
    .0   .0   .0   .0   .0   .0   .0   .0   .0
    .0   .0   .0   .0   .0   .0   .0   .0   .0
```

6.4.2 Adjustment of Radar Data

Radar measurements of precipitation are subjected to a number of errors. Wilson (1976) provides a good discussion of the problems. The problems include radar (hardware) errors, signal attenuation, terrain echoes (clutter), beam blocking, wind drift, variations in the radar equation, interception of the freezing layer, and anomalous propagation. It is difficult to correct the radar data deterministically. So, hydrologists often wish to adjust radar data by comparing it to rain gauge data. Radar data is adjusted in order to accurately reflect the point measurements of rain gauges and yet still retain the spatial variation in rainfall intensities as measured by radar. The gauge amounts are used as the absolute amounts while the radar provides the relative values for the area between the gauges. The resulting rainfall field is referred to as adjusted or calibrated radar data.

Analysis of experimental projects reported by the World Meteorological Organization on the use of radar for purposes of estimation of areal distribution of rainfall intensity supports the adjustment of radar data. This is particularly true if "the conditions of measurement are not optimal" (Nemec, 1985).

Advancements have been made in methods of calibrating radar rainfall data with rain gauges (Dalezios, 1982; Collier et al., 1983; Krajewski et al., 1983), but the use of Brandes method is sufficient (Brandes, 1975). This deterministic correction technique created a matrix of adjustment factors that reflect the spatial variability of radar-rainfall estimates. These adjustment factors, G_i, were based on comparison between rain gauge and the radar measurements averaged over an area surrounding the location of each rain gauge. The weight each of these adjustment factors received at a particular grid point was varied exponentially:

$$WT_i = \exp(-r^2/EP) \tag{5.1}$$

where r is the distance between the gauge and the grid point in kilometers and EP is the area of influence of the rain gauge. The matrix of adjustment factors was obtained using a two-pass process. The first pass produced a first estimate, F1, for each grid point:

$$F1 = \frac{\sum_{i=1}^{N} WT_i G_i}{\sum_{i=1}^{N} WT_i} \tag{5.2}$$

where N is the number of rain gauges. The difference D_i between the first estimate grid point calibration F1 and the initial rain gauge calibration G1 was then calculated for each gauge location:

$$D_i = G_i - F1 \tag{5.3}$$

where F1 was taken at the grid point nearest the rain gauge rather than at the gauge itself.

The second pass reduced the area of influence EP in the weighting function by 1/2 and the second pass estimate of the adjustment factor was then computed as:

$$F2 = F1 + \frac{\sum_{i=1}^{N} WT_i D_i}{\sum_{i=1}^{N} WT_i} \tag{5.4}$$

Significant changes were introduced into the Brandes' calibration technique. Brandes performed his objective technique on storm totals, which had been smoothed using a spatial filter. Radar and gauge rainfall amounts show great variations when compared for short durations. When storm totals are used, the agreement improves. Non-smoothed hourly rainfall data were used to preserve the areal and temporal rainfall variations. These variations are important for hydrologic simulation because of the non-linearity of the rainfall- runoff process. The rainfall at a rain gauge must have exceeded 2.5 mm while the adjustment factor was limited to the range from 0.1 to 10 in order to concentrate on hydrologically significant rainfall amounts and to eliminate unrealistic ratios. It has also been determined that Brandes method can lead to erroneous adjustment factors when high precipitation gradients are present in the rainfall field. The above limits on the adjustment values alleviate problems which might be caused by gradients.

6.4.3 CALMET.PAR File

This file is used only for radar calibration using the CALMET.EXE program.

Copy this file from the gr10k\basin example:

```
#
:NoHoursMovingAverage          1
:GaugeAreaOfInfluence        100
:DebugLevel                    0
:Gauge/RadarLowerBound       0.5
:Gauge/RadarUpperBound       1.5
:RadarThreshold             0.00
#
```

ma - the no. of hours of the moving average
ep1 - the area of influence of the gauge – 100 km^2 is a good start
ibug - the debug level
rlow - the lowest acceptable gauge/radar ratio
rhigh - is the highest acceptable ratio
cutoff - the radar cutoff value

Special notes:

- If data from the precip. gauges is available, it will be distributed in the same way it is distributed in the ragmet.exe program.
- If you do not want to adjust the radar data with precip.gauge data but just fill in missing radar data, set rlow = 1.0 and rhigh = 1.0 as in the example above.
- If ma is set to a value greater than 1, the adjustment factors are calculated for the period lasting ma hours before the current time but applied only to the current hour of precip. data. The adjustment factor applied this hour is based on the last ma hours of observed data.

6.4.4 Calibrated Radar File (_MET.r2c)

Radar precipitation data is notoriously inaccurate as far as the absolute amounts of rainfall are concerned. For a single measurement, the radar measurement may be off by a factor of five and even more. However, as the data is averaged over time and space, the errors are reduced and accuracies within 30% have been reported for the total rainfall during an event over a medium sized watershed. Typically, results within 60% are considered good and are usable for hydrologic purposes. For a very good discussion on accuracy of radar precipitation measurement, see Collier (1987).

This example is the old format but is still accepted for UTM coordinates only.

```
BASIN\gr10k.PAR
BASIN\gr10k.SHD
RESRL\930103.REL
STRFW\930103.STR
                  93 01 03 00         starting time of simulation
            115  0.33      1   1.0 =   # hrs,smc,month,conv
 HOUR=    0    0     moist
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
 HOUR=    1    1     Radar
  1.0  1.0  1.0  0.1  0.0  0.0  0.0  0.0  0.0
  1.0  1.0  1.0  0.8  0.3  0.0  0.0  0.0  0.1
  1.0  1.0  1.0  1.0  0.6  0.0  0.0  0.0  0.0
  1.0  1.0  1.0  1.0  0.8  0.0  0.0  0.0  0.0
  1.0  1.0  1.0  1.0  1.0  0.4  0.0  0.0  0.0
  1.0  1.0  1.0  1.0  1.0  1.0  0.3  0.0  0.3
  1.0  1.0  1.0  1.0  1.0  1.0  0.8  0.0  0.0
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  0.4  0.2
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  0.8  0.1
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  0.6
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
  1.0  1.0  1.0  1.2  1.2  1.0  1.0  1.0  1.0
 HOUR=    2    1     Radar
  1.0  1.0  1.1  1.2  1.1  1.0  1.0  1.0  1.0
  1.0  1.0  1.1  1.2  1.1  1.0  1.0  1.0  1.0
  1.0  1.0  1.0  1.0  1.0  1.1  1.0  1.0  1.0
  1.0  1.0  1.0  1.1  1.4  1.2  1.0  1.0  1.0
  1.0  1.0  1.0  1.0  1.4  1.2  1.0  1.0  1.0
  1.0  1.0  1.0  1.0  1.0  1.1  1.0  1.0  1.0
  1.0  1.0  1.0  1.0  1.1  1.2  1.6  1.3  1.0
  1.0  1.0  1.0  1.0  1.0  1.3  1.4  1.9  1.4
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.2  1.0
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
 HOUR=    3    1     Radar
```

```
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
   .
   .
   .
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 HOUR=  -58    1      Radar
 HOUR=  -59    1      Gauge
 HOUR=   60    1      Radar
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   .
   .
   .
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 HOUR=  115    1      Radar
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 hour= -999                Summary of rainfall:
  64.  68.  70.  71.  69.  66.  58.  60.  54.
  62.  67.  72.  73.  70.  69.  67.  61.  57.
  58.  64.  74.  79.  78.  79.  72.  69.  61.
  60.  65.  71.  77.  79.  75.  67.  64.  57.
  66.  68.  72.  74.  78.  77.  68.  66.  61.
  68.  72.  76.  74.  74.  76.  70.  67.  75.
  68.  71.  73.  72.  74.  73.  74.  69.  64.
  66.  69.  69.  68.  68.  75.  74.  70.  70.
  66.  67.  68.  65.  66.  67.  73.  75.  74.
  66.  63.  65.  65.  66.  67.  77.  79.  79.
  67.  64.  65.  67.  70.  76.  76.  80.  79.
  64.  64.  65.  70.  72.  74.  77.  80.  72.
```

Notes on the gridded rain file:

1. The adjusted radar file and the distributed rainfall file are mutually exclusive. They have the same name and only one or the other can be used in SPL9. The adjusted radar file is created by CALMET and the distributed rainfall file is created by RAGMET.
2. The adjusted radar file can have segments of data originating from rain gauges, as might be required when radar data is not available. In the record, in the header for each hour, the origin of the data is noted in columns 22-26.
3. The entire radar rainfall field can be scaled to match observed hydrograph. This can be done manually by changing the scale variable in the event file or automatically by running the automatic scaling option in the run menu in WATFLOOD.

4. When scaling is used, only the data originating from radar is affected. Hourly data fields headed by ‘Gauge’ labels are not affected.
5. To scale data originating from other sources, the ‘conv’ factor in line 5 of the .met file can be changed. For instance, a factor of 2 will double the amount of rainfall applied. (Please experiment to ensure program behaves as intended.)
6. The last hour shown as -999 is the total rainfall for the event.

7 FLOW DATA

Streamflow data is used for the following purposes:

1) Model calibration
2) Soil moisture or radar precipitation adjustment
3) Validation of the simulations
4) Channel storage initialization
5) Initialization of lower zone storage

The model can run without streamflow data but in this way there is no way of telling how well the model is performing or if gross errors might exist in the input data.

The simulation length of an event is set by the number of hours of streamflow in the yyyymmdd_str.tb0 file.

Reservoir releases are also required.

7.1 Streamflow Files

7.1.1 Example streamflow file

The yyyymmdd_str.tb0 file contains recorded flows at various sites in the watershed inGreenKenue format. This file can be loaded intoGreenKenue and plotted as a time series and compared to computed flows extracted from the WFO file.

The header contains the geographical reference and the start time and date.

The station coordinates are entered as shown in the usual x-y order. The next four lines are the coefficients that are needed to convert stage to flow.

The next line of data in the yyyymmdd_STR.tb0 file is used to select the stations to be included in the error calculation for optimization. 1 indicates calculate the error, and a 0 means to pass over the station but plot the results anyways. (Variable is NOPT).

```
########################################
:FileType tb0  ASCII GreenKenue 1.0
#
# DataType              GreenKenue Table
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          translate.
:CreationDate       2006-09-28  15:42
#
```

```
#----------------------------------------
#
:SourceFile                   strfw\19930101.str
#
:Name                Streamflow
#
:Projection          UTM
:Ellipsoid           NAD83
:Zone                17
#
:StartTime            00:00:00.00
:StartDate            1993/01/01
:DeltaT                         1
:RoutingDeltaT                  1
#
:FillFlag            -
#
:ColumnMetaData
   :ColumnUnits             m3/s         m3/s         m3/s
   :ColumnType             float        float        float
   :ColumnName          GRND/GALT    W. MONTROSE  GRND/MARSVIL
   :ColumnLocationX        554000.      545000.      556000.
   :ColumnLocationY       4801000.     4833000.     4860000.
   :Coeff1              0.000E+00    0.000E+00    0.000E+00
   :Coeff2              0.000E+00    0.000E+00    0.000E+00
   :Coeff3              0.000E+00    0.000E+00    0.000E+00
   :Coeff4              0.000E+00    0.000E+00    0.000E+00
   :Value1                      2            2            2
:EndColumnMetaData
:EndHeader
                           -1.100       -1.000       33.000
                           -1.100       -1.000       32.700
                           -1.000       -1.000       31.200
                           -1.000       -1.000       30.500
                           -1.000       -1.000       29.100
                           -1.000       -1.000       19.800
                           -1.000       -1.000       27.000
                           -1.000       -1.000       26.300
                           -1.000       -1.000       25.000
                           -1.000       -1.000       25.600
                           .
                           .
```

The coefficients can be used for applications where only stage data is available which can be converted to flows using a polinomial function. (Section 1.3.9)

Value1 is used to flag whether the observed flows will be used to calculate the error function for DDS or the pattern search.
value1(n) = 0   station not included for objective function calculation
value1(n) = 1   station is included for objective function calculation
These values must be set in each str file in a continuous simulation.
Shortcut:
To avoid having to edit a number of str files, value1 can be set in the first event's str file by setting just one of the values = -1

Thus having a line like:

```
:Value1                       -1             0             1
```

will mean that for ALL events, the first and third set of observed flows will be used to calculate the objective function and station 2 will be ignored through out. For subsequent events, the line with Value1 will be ignored.

Value1 is also used to indicate whather the flows should be "nudged" at flow stations. See also Section 1.3.8.

For Value1 = 2 for any flow station, then the computed values for flow are replaced by the observed value for the designation stations for the current event only. This can be -1.0 for missing flows so be careful with this. However, a –ve value in the first event for any station will mean only the numbers in the first event will be used. I.e. you can nudge the flows at a partuculat station by setting Value1= -2 in the str file for the first event.

You can alo accomplish this by setting Value1 = 2 for the **first event with the nudgeflg = 1** (one) in the first event file will nudge all the flows for the designated flow stations for **all** events in this run.

Note: In the event file, for nudgeflg = a , all computed flows at all flow stations will be replaced by observed flows. All entries for Value1 are over ridden by this flag and set to 2

7.1.2 Water Survey Card format

Streamflow files may also be read using the Canada Water Survey Card format. The header is the same as for the COLUMN format but for the FileFormat flag. Use WS_CARD instead of COLUMN as the flag. The example below is for daily flows. The data is taken directly from HYDAT for the month of January, 2002.

```
#
:FileType                  .str
:CoordSys            CARTESIAN
:datum               unknown
:Zone                unknown
:FileFormat          WS_CARD
:FillFlag            n
#
:StartDate           01-01-2002
:StartTime            0 :00
#
:NoFlowStations          2
:NoHoursData           744
:NoHoursUsed           744
:DeltaT                 24
:Routing DeltaT          1
:UnitConversion          0.
#
FtMcMurry   Athabasca
     947000.     1014000.
     342000.      597000.
 0.00000E+00  0.00000E+00
```

```
 0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00
           1            1
#
:endHeader
107BE001002011 65.4B 66.8B   66B 66.3B 66.7B   66B 65.1B 64.4B   66B 69.4B    31
107BE001002012   70B   70B   68B   66B   63B   60B   60B   60B   61B   62B
107BE001002013   60B   59B   57B   55B   53B   52B   51B   50B   50B   51B   52B
107DA001002011  120B  118B  117B  117B  115B  113B  110B  111B  114B  116B    31
107DA001002012  117B  118B  119B  118B  120B  115B  118B  120B  119B  116B
107DA001002013  116B  116B  116B  116B  112B  109B  108B  110B  109B  109B  109B
```

7.1.3 Observed Stage Input – Under construction

WARNING #1: IY and JX are the coordinates of the stream gauging stations. Some care must be taken so that the layout of the elements (drainage directions) is realistic. Check that the drainage areas computed by BSN agree reasonable well with the drainage areas associated with the gauge locations. A gauge location placed on the east or north grid limit is actually placed in the grid to the east or north respectively. A location placed on the west and south limit of the grid or anywhere within the grid will include the area of that grid in the upstream basin area.

WARNING #2: Only the gauge locations listed in the first event of a chained set of events is used to locate the flow station for the whole run. If a station is relocated partway through a run, it would have to be entered as a separate station. This is rev. 9.2.18 Oct. 16/05.

Next is the streamflow data, of stations across in the order listed above, in cms. The first flow value must be one time increment after the beginning of the simulation. The flow at time = 0 is not read in. The flows during the first time step are assumed steady in all grids and set equal to the flows at the end of the time step (the ones read in). The time increment for the flows may be larger than one hour.

7.1.4 Flow Station Area Check

If the file `..\basin\flow_station_info.txt` with the station name, y and x coordinates (UTM or LATLONG) and the drainage area in km^2 is provided, SPLX will create a file called `area_check.xyz` in the working directory. This new file allows the drainage areas to be checked very easily for any run. It is written as an xyz file so the file can be entered intoGreenKenue to plot the modeled flow station locations. This is useful if the actual flow station locations are plotted also and the model flow stations have been moved to obtain the proper drainage areas.

Example input file: ..\basin\flow_station_info.txt

```
BLACK_WASH   -79.282   44.713   1520
JOCK_RIVER   -75.85    45.25     539
GULL_RIVER   -78.819   44.732   1280
BURNT_RIVER   -78.65   44.701   1270
MADAWASKA    -77.467   45.283   5800
MISSISSIPPI  -76.286   45.053   2620
MAGNETWAN    -80.479   45.772   2850
TRENT_RIVE   -77.767   44.371   9090
NAPANEE_R    -76.838   44.334    694
PETAWAWA     -77.417   45.888   4120
BLANCHE_RIV  -79.879   47.889   1780
DUMOINE      -77.817   46.35    3760
.
.
.
```

The location can be 12 characters maximum.
The data is space delimited so be sure there are no spaces in the names.

Example output file: area_check.xyz

```
     x          y                               actual  model      % diff
  -79.283      44.700    1  BLACK_WASH       1520.     1569.        3. %
  -75.850      45.250    2  JOCK_RIVER        539.      531.       -2. %
  -78.817      44.733    3  GULL_RIVER       1280.     1243.       -3. %
  -78.650      44.700    4  BURNT_RIVER      1270.     1267.        0. %
  -77.517      45.333    5  MADAWASKA        5800.     5393.       -8. %
  -76.283      45.050    6  MISSISSIPPI      2620.     2280.      -15. %
  -80.483      45.767    7  MAGNETWAN        2850.     2739.       -4. %
  -77.783      44.367    8  TRENT_RIVE       9090.     9291.        2. %
  -76.830      44.340    9  NAPANEE_R         694.      676.       -3. %
  -77.350      45.883   10  PETAWAWA         4120.     4126.        0. %
  -79.883      47.883   11  BLANCHE_RIV      1780.     1694.       -5. %
  -77.817      46.350   12  DUMOINE          3760.     3723.       -1. %
  .
  .
```

A third file `changed_areas.txt` is created if the drainage areas in the flow files are different from the drainage areas in the resume file.

7.2 Reservoir Release File

The yyyymmdd_REL.tb0 file has the reservoir locations and releases.

If this file does not exist, the no of reservoirs is assumed to be 0.
If there are no reservoirs, do not have a yyyymmdd_rel.tb0 file.

If ***all*** lakes have rule curves (values for Coeff1 – Coeff5)and there are ***no*** release data in the rel files, do not enter any data under the **:EndHeader line (not even 0's)**
OR, if you do, be sure to put in the proper number of lines for that event. (event no of hours/DeltaT) ForSPL, the event length is not known until the program has read to the end of the precip files. For WATROUTE, the event length is not known until the program has read to the end of the runoff files.

```
########################################
:FileType tb0  ASCII GreenKenue 1.0
#
# DataType              GreenKenue Table
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          translate.exe
:CreationDate       2006-09-28  15:42
#
#---------------------------------------
#
:SourceFile                   resrl\19930101.rel
#
:Name               ReservoirReleases
#
:Projection                                        UTM
:Ellipsoid                                         NAD83
:Zone                                              17
#
:StartTime
:StartDate
:DeltaT                        1
#
:ColumnMetaData
   :ColumnUnits             m3/s         m3/s         m3/s
   :ColumnType             float        float        float
   :ColumnName        BELWOOD      CONESTOGO     GUELPH
   :ColumnLocationX        554000.      523000.      559000.
   :ColumnLocationY       4843000.     4836000.     4827000.
   :Coeff1               0.000E+00    0.000E+00    0.000E+00
   :Coeff2               0.000E+00    0.000E+00    0.000E+00
   :Coeff3               0.000E+00    0.000E+00    0.000E+00
   :Coeff4               0.000E+00    0.000E+00    0.000E+00
   :Coeff5               0.000E+00    0.000E+00    0.000E+00
:EndColumnMetaData
:EndHeader
                            7.500        1.000        1.000
                            7.500        1.000        1.000
                            7.800        1.000        1.000
                            7.500        1.000        1.000
                            7.500        1.000        1.000
                            7.500        1.000        1.000
                            7.500        1.000        1.000
```

.

.
.

The header is the usual and self explanatory. The locations are the location of the reservoir or lake outlet. Care has to be taken that they are on the river as modeled.

Notes:
SPL accepts 24 hour data: 1 line of data for each day witht eh deltat set = 24
Do not have 23 lines with -1.0 for the 'missing' data.
The value is assumed to be the release at the beginning of the time step.

7.2.1 Natural lakes and uncontrolled reservoirs

The 5 coefficients give the operating rule a for each lake or uncontrolled reservoir– see Section 3.6.1. The operating rule has to be programmed for each individual reservoir but five parameters are reserved for this purpose. Controlled reservoirs need a table of the releases in cms. Values are not required for each time step. If there is a negative value, the last positive value is carried forward by the program. The storage-discharge rules for natural lakes can be entered by way of the 5 coefficients. If the coefficients are specified, releases are omitted. If controlled ***and*** natural lakes are present, the controlled reservoirs ***must*** be listed ahead of the natural lakes.

Below is an example for Tabacco Creek for a watershed with many farm ponds. An Excel spreadsheet is used to fit polinomials or power functions to each of the storage-discharge curves.

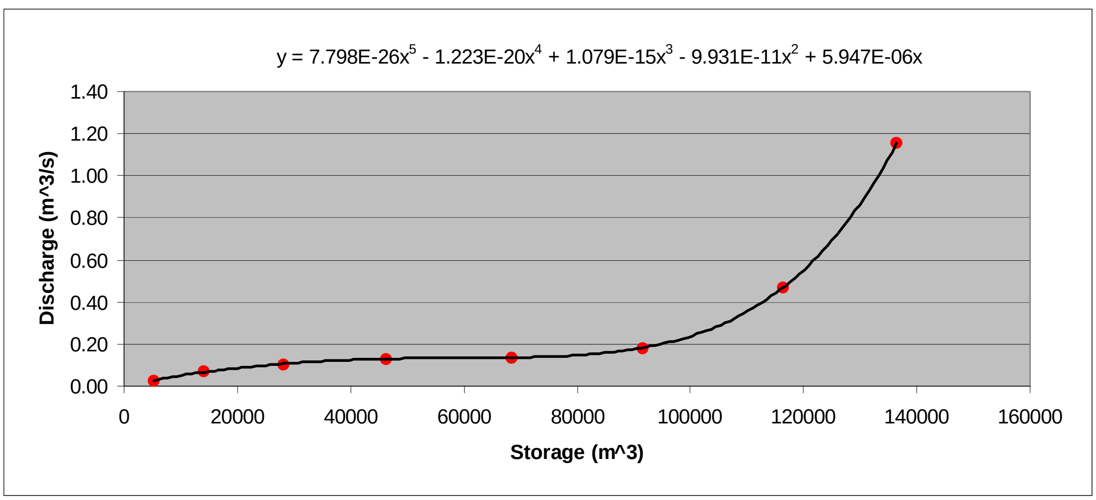


Figure 6.1 Example of a storage-discharge curve (Subbasin 55 below)
(**Please note that the order of the terms is reversed below**)

Subbasin_56	Subbasin_55	Subbasin_53	Subbasin_50	Subbasin_13	Subbasin_5	Subbasin_6	Subbasin_4
545000	548000	549000	545000	545000	542000	544000	545000
5462000	5462000	5462000	5463000	5469000	5471000	5471000	5471000
6.05E-05	5.95E-06	4.06E-10	1.50E-04	3.72E-04	2.29E-02	3.33E-08	1.13E-04
1.27E-09	-9.93E-11	4.80E-10	-2.10E-08	-1.51E-07	2.21E-01	1.54E+00	-1.71E-08
-4.10E-13	1.08E-15	-1.71E-14	-1.26E-12	2.72E-11	0.00E+00	0.00E+00	1.52E-12
1.40E-17	-1.22E-20	1.73E-19	5.77E-17	0.00E+00	0.00E+00	0.00E+00	-8.50E-17
0.00E+00	7.80E-26	0.00E+00	5.46E-20	0.00E+00	0.00E+00	0.00E+00	2.42E-21

If a power function provides the best fit, only the first two parameters are used (B1 and B2). If a polinomial is used, it must be a 3, 4 or 5 parameter polinomial. It is **important** that the polinomial be monotomically increasing and the it does not dip down after the last point. For this reason, the coeficient for the highest order term must be positive and the function should be plotted to ensure is is monotomically increasing. A 3rd, 4th or 5th order function can be tried and the best one meeting these requirements can be chosen. Sometimes extra points added to the data set can be used to force the function to behave.

Important:

- You must ensure that the curve is monotomically increasing!!!!
- The curve **must** go through the origin (0,0) of the graph!!!!

For this case, the coefficients will look like:

```
:ColumnLocationX    5462000.    5462000.    5462000.    5471000.    ETC.→
:ColumnLocationY     545000.     548000.     549000.     542000.
:Coeff1             9.35E-05    5.95E-06    3.45E-06    2.29E-02    STORE
:Coeff2            -1.34E-08   -9.93E-11    2.01E-10    2.21E-01    STORE 2
:Coeff3             6.45E-13    1.08E-15   -1.05E-14    0.00E-00    STORE 3
:Coeff4             0.00E+00   -1.22E-20    1.26E-19    0.00E-00    STORE 4
:Coeff5             0.00E+00    7.80E-26    0.00E+00    0.00E-00    STORE5
```

Notes:

1. the first three have polynomial functions of different orders while the 4th is a power function (with just 2 values)
2. USE MORE SIGNIFICANT FIGURES – e.g. 9.085703E-07
3. If you have a stage-discharge curve, you can convert it it a storage-discharge curve using the lake area(s) given in results\res.txt

7.2.2 Initial reservoir levels

There are also situations where the initial reservoir levels and/or storages as well as the elevation-storage curve need to be entered so the the lake_sd.csv file can provide useful lake elevation and storage data. For instance, computed lake or reservoir levels can be compared to observed values and used for calibration or validation of the model. Below is an example of how the coefficients are entered for the reservoir at LG4. Note that the 2nd reservoir has no data and the last three are natural lakes with power functions to perform the lake routing as described in Section 7.2.1

The elevation-storage function is:

Elevation = coeff3(datum) + coeff4*storage^{coeff5}

Notes:

The datum is the elevation of the reservoir when the storage = 0.0
The value of coeff1 must be 0.000E+00

Example storage-elevation for a reservoir:

```
:ColumnMetaData
   :ColumnUnits             m3/s         m3/s         m3/s         m3/s         m3/s
   :ColumnType             float
   :ColumnName               LG4          LF1          lk1          lk2          lk3
   :ColumnLocationX      601253.8      656836.      790000.      770000.      700000.
   :ColumnLocationY     5966798.7     6005960.     5880000.     5900000.     5940000.
   :Coeff1              0.000E+00    0.000E+00    0.200E-13    0.200E-13    0.200E-13
   :Coeff2              2.800E+02    0.000E+00    0.175E+01    0.175E+01    0.175E+01
   :Coeff3              2.595E+02    0.000E+00    0.000E+00    0.000E+00    0.000E+00
   :Coeff4              0.220E-05    0.000E+00    0.000E+00    0.000E+00    0.000E+00
   :Coeff5              0.750E+00    0.000E+00    0.000E+00    0.000E+00    0.000E+00
:EndColumnMetaData
```

7.2.3 Natural flows

There may be situations where presently lakes and reservoirs are regulated and you have rel files with releases, but you would like carry out a simulation for flows under natural conditions.

If there were no lakes or reservoirs originally, you may simply move the rel files out of the resrl folder (save them somewhere) and run with a shd file with no reaches specified.

For the case where pre-existing lakes became regulated, you may run with natural flows by using the ntrlflg in the **first** event file:

```
:ntrlflg                     y
```

AND

the yyyymmdd_rel.tb0 file for the first event must have the coefficients for each lake or reservoir.

The rel file will be read ONLY for the first event and the coefficients kept for the entire run. This is a nice feature for climate change scenarios, where operating rules are not known and only the water availability is required.

7.3 Reservoir Inflow Files

Reservoir inflows if known can be entered as a set of observed flows with a format similar to the streamflow file. An output file called results\resin.csv similar to the spl.csv file will be created so reservoir observed and computed inflows can be easily compared. Errors can also be calculated.

- To use this option, the resinflg in the event files must be set to 'y' and the .rin file must exist for all events. This flag is set in event.evt and used for all subsequent events.
- The time increment in the resin.csv file is the same as the interval in the input yyyymmdd.rin file.

The following is an example of a reservoir inflow file yyyymmdd.rin

```
#
:FileType           .rin                    <<<needs to be changed to a tb0 file


:CoordSys           CARTESIAN
:Datum              unknown
:Zone               unknown
:FileFormat            COLUMNS
:FillFlag           n
#
:StartDate      01-08-1993
:StartTime          00:00
#
:NoReservoirs                   1
:NoHoursData                  744
:NoHoursUsed                  744
:DeltaT                         1
:Routing DeltaT                 1
:UnitConversion               1.0
#
LaggoCapri
           1
#
:endHeader
      39.403
           .
           .
           .
           .
           .
           .
     125.753
```

744 values are required. More reservoirs can be added.

7.4 Diversions (BETA Jan/09)

This feature has had limited testing. Please report any problems.

To divert flow from one grid to another, the program will automatically divert flow if the file `diver\yyyymmdd_div.tb0` is present and listed in the event file such as:

.

```
#
:streamflowdatafile      strfw\19900101_str.tb0
:reservoirreleasefile    resrl\19900101_rel.tb0
:reservoirinflowfile     resrl\19900101_rin.tb0
:diversionflowfile       diver\19900101_div.tb0
:snowcoursefile          snow1\19900101_crs.pt2
#
.
.
```

An example of a diversion file is:

```
########################################
:FileType tb0  ASCII  EnSim 1.0
#
# DataType               Time Series
#
:Application             EnSimHydrologic
:Version                 2.1.23
:WrittenBy          mh_write_flow_tb0.f=MH3.exe
:CreationDate       2009-01-23  09:20
#
#---------------------------------------
:SourceFile                   flow_data
#
:Name               diversion(s)
#
:Projection         LATLONG
:Ellipsoid          WGS84
#
:StartDate          1990/01/01
:StartTime          00:00:00.0
#
:AttributeUnits            1.0000000
:DeltaT               24
#
:ColumnMetaData
   :ColumnUnits             m3/s
   :ColumnType             float
   :ColumnName           05QB006
   :ColumnLocationX     -91.4583
   :ColumnLocationY      50.8694
   :ColumnLocationX1    -91.4500
   :ColumnLocationY1     50.8330
   :value1                     1
:EndColumnMetaData
:endHeader
                        87.200
                        87.900
                        87.200
                        86.400
                        85.700
                           .
                           .
```

.
.

In this case, it is the Lake St. Joseph diversion into the English River at water survey station 05QB006. The first X-Y location is the grid where the flow is taken and the second location X1 and Y1 is the grid where the water is diverted to.

There are some serious rules associated with diversions:

1. If the origin of the water is grid within the watershed it must be in a grid that is part of a lake or reservoir and the grid will have to have a reach number. (Running out of water in the lake has consequences).
2. If the origin of the flow is outside the watershed, the origin of the water X & Y must be one of the outlet grids (the very last grid in the shd file is the safest).
3. If the destination of the water is within the watershed, the flow can be added to any X1 Y1 grid – it does not have to be a lake or reservoir.
4. If the destination of the water is outside the watershed, it must be added to one of the outlet grids (again, the very last grid in the shd file is the safest).

Notes:

- If you make the origin or destination of the flow to a grid that is not part of the watershed (as in the shd.r2c file) you will get an error of some sort.
- The value of value1 is meaningless. Any value will do. It is used to count the number of columns of data.
- If the value of the flow diversion is always the same, all you have to do is have a `yyyymmdd_div.tb0` file for the first event and the program will divert the last flow value in the file for the remainder of the simulation run. If the diverted flow changes some number of events later, just have a new `yyyymmdd_div.tb0` file for that event with the proper flows, which will be used from that time onwards.
- Don’t get funny & reverse the origin and destination and have –ve flows as these flows will be set to 0.0. Reversible flows (such as pumped storage) can be accommodated by having 2 diversions with the origin & destinations in reverse order and having only +ve flows in each column.
- The events.exe program will put the diversion file name in the list of files but if the yyyymmdd_div.tb0 file is not present, the diversion code will just be bypassed.

8 TEMPERATURE DATA

As with rainfall, temperatures are required for each grid. In old versions, only daily maximum and minimums are required and the program calculates hourly data using a simple cosine function between highs and lows. In the current SPL9 version, only hourly temperatures are used.

Since climate data is generally collected or predicted at specific point locations, this data needs to be converted into a grid format. SPL9 reads only gridded data. The example files below show the temperature data in point and gridded formats. The program TMP.EXE converts point temperature time series to gridded temperature time series. The tag file has not been converted to theGreenKenue format yet.

The default weighting for distributing temperature is distance squared. I.e. the default weight parameter is 2. However, if you want the distribution of temperature to be more like Thiessen poligons, you can make the weight = 10 by issuing the command:

tmp 10

8.1.1 Example of Point Temperature File:

FLN = tempr\yymmdd_tag.tb0

```
########################################
:FileType tb0  ASCII GreenKenue 1.0
#
# DataType              GreenKenue Table
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          nk
:CreationDate       2006-09-29  08:52
#
#---------------------------------------
#
:SourceFile         wormwood_data
#
:Name               Temperature
#
:Projection         UTM
:Ellipsoid          NAD83
:Zone               17
#
:StartDate          01-01-1993
:StartTime          01:00
:DeltaT                        1
#
:UnitConversion             0.0
#
:ColumnMetaData
   :ColumnUnits             dC         dC
   :ColumnType             float        float
   :ColumnName            Wormwood   Logan_farm
```

```
   :ColumnLocationX          530000.   560000.
   :ColumnLocationY         4900000.  4800000.
   :Elevation                1700.      1140.       <- Optional
:EndColumnMetaData
:EndHeader
   -7.92   -4.92
   -9.73   -6.73
  -10.85   -7.85
  -12.00   -9.00
  -12.97   -9.97
  -13.57  -10.57
      .
```

The format is similar to the rain gauge file described in Sec. 6.1.2

Notes:

1. Missing data should be entered as –99.9 (or anything less than -99.0, e.g. -999.0).
2. The line length is limited to 4096 characters
3. If the elevation of the first station is greater than 0 then all stations must have an elevation and the lapse rate (tlapse) should have a value in the par file

8.1.2 Modified Distribution of temperature

This section is identical to section 6.1.46.1.4 for precipitation.

For straight distance weighting, distant stations can have an influence at a grid, especially grids at watershed boundaries where the grid is well outside the group of precipitation stations. Another problem arises when a station consistently over or underestimates precipitation which results in “bullseyes” when cumulative precip is plotted in 2D.

To overcome this, two coefficients can be used by TMP.exe. These are read from **basin\bsnm_par.csv** in the appropriate line**:**

```
:radiusinflce,   300.000,# radius of influence km
:smoothdist,      35.000,# smoothing diatance km
```

To include all stations in the weights for all grids, chose a large min. radius of influence, e.g. a distance larger than the largest dimension of the watershed.

To smooth the temperature field, insert a distance from each station location where you want its effect to be reduced. The greater this number, the more smoothing of the precip field will be effected. It is best to try different values until the cumulative precipitation field for the complete simulation period looks acceptably smooth.

Set the radius of influence **just** large enough so the whole watershed will have precipitation.
Set the smoothing distance **just** large enough to get a nice looking interpolation between stations.
(Check this in loading the precipitatin field in a wfo file into GreenKenue)

The radius of influense & the smoothing distance can be optimized using DDS.
NEW

8.1.3 Temperature lapse rate (tlapse)

The lapse rate and a reference elevation (usually sea level) can be set in the par file. When tlapse ≠ 0.0 the temperature will be adjusted depending on the grid elevation. In addition to the lapse rate, the base temp for the snow routine can be used in addition to account for large elevation changes where land cover is correlated to elevation as in high mountains.

rlapse = lapse rate in dC / 1 m elevation
elvref = elevation reference for temperature data.

The temperature lapse rate can be optimized with DDS. Reasonable limits should be set.

8.1.4 Example of a Gridded Temperature File tempr\yyyymmdd_tem.r2c

The TMP.EXE program produces anGreenKenue format r2c file with a file name yyyymmdd_tem.r2c This file can be loaded inGreenKenue where it can be animated and time series extracted on each grid.

For missing frames, the temperature of the last frame is in the simulation.

```
########################################
:FileType r2c  ASCII GreenKenue 1.0
#
# DataType               2D Rect Cell
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          translate.exe
:CreationDate       2006-09-28  15:42
#
#---------------------------------------
#
:Name               Mackenzie
#
:Projection         UTM
:Ellipsoid          UTM
:Zone               17
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:SourceFile                   tempg\19930101_tem.tb0
#
  :AttributeName 1  Temperature
  :AttributeUnits
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
#
:endHeader
:Frame    1    1   "   0/1/1  1:00:00.000"
  -5.1  -5.0  -5.0  -4.9  -5.0  -5.0  -5.1  -5.3  -5.4
  -5.1  -5.0  -4.9  -4.9  -4.9  -5.0  -5.1  -5.3  -5.4
  -5.2  -5.1  -5.0  -5.0  -5.0  -5.1  -5.2  -5.4  -5.5
```

```
  -5.4  -5.2  -5.1  -5.1  -5.1  -5.2  -5.4  -5.5  -5.7
  -5.6  -5.5  -5.4  -5.4  -5.4  -5.5  -5.6  -5.8  -5.9
  -6.0  -5.9  -5.9  -5.8  -5.9  -5.9  -6.0  -6.1  -6.1
  -6.4  -6.4  -6.4  -6.4  -6.4  -6.4  -6.4  -6.4  -6.4
  -6.8  -6.9  -7.0  -7.0  -7.0  -6.9  -6.8  -6.8  -6.7
  -7.2  -7.3  -7.4  -7.5  -7.4  -7.3  -7.2  -7.1  -7.0
  -7.5  -7.6  -7.7  -7.7  -7.7  -7.6  -7.5  -7.3  -7.2
  -7.6  -7.8  -7.8  -7.9  -7.8  -7.8  -7.6  -7.5  -7.3
  -7.7  -7.8  -7.9  -7.9  -7.9  -7.8  -7.7  -7.6  -7.4
:EndFrame
:Frame    2    2   "   0/1/1  2:00:00.000"
  -6.9  -6.8  -6.8  -6.8  -6.8  -6.8  -6.9  -7.1  -7.2
.
.
etc.
```

9 RADIATION DATA

The format of the radiation input is the same as that for the gridded temperature input. Radiation data can be gridded using the same utility program (TMP.EXE) as the one used to grid the temperature data. The gridded radiation data will eventually reside in the following file:

\spl\BSNM\RFLUX\YYMMDD.FLX

10 OUTPUT FILES

Most output from SPL is written to the \RESULTS directory and overwrites previous output files. If you want to save any of these files (for instance the plot and list files), they have to be renamed and/or saved in another directory. Please see Section 10.2 for details and examples.

Most of the files are used for program development and in general, the higher the value of IOPT in the parameter file, the more data will be printed to these files.

The default filenames are set in the program and each time SPL is executed, a file called outfiles.new (Section 10.4) will be written with these default names each time the SPL program is executed. The outfiles.new file can be edited and renamed outfiles.txt. When SPL finds the outfiles.txt file, the output will be written in to the files listed. This feature can be used to direct the output files to another location (disk or directory). This can be useful if you wish to run SPL on more than one watershed on one disk at a time. Also, all the GRAPHER files are set up to read the C: drive. So, it is easy to direct the output to C: by changing filename(51)='results/spl.txt' to filename(51)= results/spl.txt'. Similar changes can be made to the other filenames. Files can be sent to different locations. Just be sure that the directories exist for the files, as SPL cannot make directories on-the-fly.

SPL.TXT is a listing of the most important output as it provides a summary of the modeling parameters, the initial soil moisture, the total precipitation on each element, the runoff at each streamflow gauge station and the errors. **SPL.PLT, SPL.CSV, STG.PLT,** and **SPL.PIC** are the files for hydrograph plots, stage plots and the animation programs, respectively. The SPL.CSV file can be imported to EXCEL, GRAPHER or other programs for subsequent analysis of the output. Other files are written when the DEBUG mode is set to 1 or higher.

A brief description of each file and/or its use follows. Most of the files have headings that relate to topics covered in Chapter 2. In the table below, a ** indicates a very useful, frequently used file, a * represents a file used by other programs and a blank entry is a file used for serious debugging. These files by default are written in the \results directory:

File Name		Purpose
Spl.txt	**	Diagnostic output file. Input data is echoed and a summary of precipitation and flow is written in gridded format as well as in a station format. Flags used in the program are listed. For higher values of the IOPT flag (Section 4.1), more information is written to this file. Used by splplt.exe.
Opt.txt		Parameter values and errors are written for each iteration when optimizing
Res.txt		Reservoir information when running with IOPT >0
Rff.txt		Runoff information for impervious areas
Rte.txt		Echoed streamflow data and gridded information about the initialization of streamflow and lower zone storage based on streamflow. Shows more data with higher IOPT.
Pic.txt	*	Gridded bankfull index values used by the mapper.exe program to do the watershed animation
Snw.txt		Diagnostic data for the melt routines
Spl.plt	*	Pairs of observed/computed streamflow used by splplt.exe (DOS) to plot flow hydrographs
Stg.plt	*	Computed streamflow used by stgplt.exe (DOS) to plot stage hydrographs
Spl.csv	**	Similar to spl.plt but with comma's between the columns. For use as import files to other programs (e.g., Excel™, Grapher™). The columns in spl.csv are measured, observed, measured, observed, ... for stations 1, 2, 3, ... respectively.
Snw1.txt		Diagnostic file for melt routines with IOPT>0
Snw.plt		Gridded initial snow data
Strout.(1 - 10)		Streamflow output in the same format as the input streamflow strfw\yymmdd.str. This file can be used as input to subsequent SPL runs and these data can then be compared to the new results using the plotting programs, spreadsheets or GRAPHER.
Evapout.txt		Not used now.
Sed.csv		Sediment routine output. Sediment concentration graphs. (Not for general use).
Qdwpr.txt		Reach inflows that can be used directly as input to DWOPER - the NWS Dynamic Wave Operational Model. These reaches can also be lakes or reservoirs.
Junk.txt		As the name implies. Used for program development.
Qout.txt		For program development.
Resin.txt		Reservoir inflows. Used if reservoir inflow (yymmdd.rin) files are used and resinflg is set ='y'. Compares computed to observed reservoir inflows. Similar to spl.csv file.
Evap.txt		For program development.
Rff(1 - 10).txt	**	Runoff process written to files for each land cover class. Can be used to plot graphs of UZS, LZS and many other variables. Used as an information and diagnostic tool.

Tot.txt		Diagnostic tool for program development.
Watbal(1&2).txt	**	Water balance calculations. This file is a summary of the starting and final state variable values for the run. It provides some reassurance that all water is accounted for. A discrepancy of approximately 1% is acceptable and is due to round-off.
Watflood.wfo	**	File read byGreenKenue Hydrologic for displaying results. Use the wfo_spec.txt file to specify the time step and which element should be included. Please see Chapter 0
wetland.csv	**	Lists all wetland state variables for the debug grid specified in the bsnm_shd.r2c file. Time series can be plotted in Excel or Grapher. Some of the state variable can also be included in the Watflood.wfo file and so animated.
lake_sd.csv	**	Lake elevation, storage, inflow and outflows and some other derived variables are listed & can be plotted as time series. For instance, computed lake levels can be compared with observed lake leves in a separate file.

10.1 Plotting hydrographs (observed vs. computed)

Observed and computed hydrographs can be easily plotted with Excel™ or GRAPHER™ using the results\spl.csv file. The first column is the time in hours from the beginning of the simulation and thereafter pairs of columns are the observed and computed hydrographs at flow stations. A file in the working directory called **flowstation_location.xyz** lists the stations and the column letters for plotting:

```
554000.000 4801000.000    1 GRND_GALT       b    c       3520.
545000.000 4833000.000    2 W_MONTROSE      d    e       1170.
556000.000 4860000.000    3 GRND_MARSVIL    f    g        694.
570000.000 4823000.000    4 ERAMOSA_GUEL    h    i        235.
530000.000 4849000.000    5 CONEST_DRAYT    j    k        365.
559000.000 4833000.000    6 SPD_ARMST_MI    l    m        167.
560000.000 4820000.000    7 GUELPH          n    o        593.
539000.000 4830000.000    8 ELMIRA          p    q        118.
556000.000 4860000.000    9 WALDERMAR       r    s        694.
```

For example, to plot the observed and computed hydrographs for Elmira, just open the results\spl.csv file in Excel™ and plot columns p & q in the same line plot.

The plotting program called GRAPHER™ from Golden Software is highly recommended for this purpose as it allows the use of templates for creating many plots on one page and single plots with data from different files.

10.2 Spl.txt File – IOPT=1

The spl.txt file is the most important initial diagnostic tool. When iopt=1, it repeats much of the crucial watershed input data and the first check is to see that this data is ingested properly.

10.2.1 File Names from the Event File

```
 Event no.     1
Input files from event.evt
 Unit no. = 31 file no  1 = BASIN\GR10K_shd.r2c
 Unit no. = 32 file no  2 = BASIN\GR10K.par
 Unit no. = 33 file no  3 = BASIN\GR10K.pdl
 Unit no. = 43 file no 13 = BASIN\GR10K.sdc
 Unit no. =290 file no 40 = BASIN\GR10K.wqd
 Unit no. =289 file no 39 = moist\19930101_psm.pt2
 Unit no. = 35 file no  5 = raing\19930101_rag.tb0
 Unit no. = 44 file no 14 = tempg\19930101_tag.tb0
 Unit no. = 50 file no 20 =
 Unit no. =276 file no 26 =
 Unit no. =277 file no 27 =
 Unit no. =278 file no 28 =
 Unit no. =279 file no 29 =
 Unit no. =280 file no 30 =
 Unit no. = 36 file no  6 = strfw\19930101_str.tb0
 Unit no. = 37 file no  7 = resrl\19930101_rel.tb0
 Unit no. = 38 file no  8 = resrl\19930101_rin.tb0
 Unit no. =285 file no 35 = snow1\19930101_crs.pt2
 Unit no. = 39 file no  9 = raduc\19930101.rad
 Unit no. = 41 file no 11 = radar\19930101.scn
 Unit no. = 42 file no 12 = radar\19930101.clt
 Unit no. =286 file no 36 = snow1\19930101_swe.r2c
 Unit no. =287 file no 37 = moist\19930101_gsm.r2c
 Unit no. =288 file no 38 =
 Unit no. = 40 file no 10 = radcl\19930101_met.r2c
 Unit no. =284 file no 34 =
 Unit no. = 45 file no 15 = tempr\19930101_tem.r2c
 Unit no. = 49 file no 19 =
 Unit no. =271 file no 21 =
 Unit no. =272 file no 22 =
 Unit no. =273 file no 23 =
 Unit no. =274 file no 24 =
 Unit no. =275 file no 25 =
 Unit no. =281 file no 31 = runof\19930101_rff.r2c
 Unit no. =282 file no 32 = rchrg\19930101_rch.r2c
 Unit no. =283 file no 33 = lkage\19930101_lkg.r2c
EVENT\19930201.EVT
EVENT\19930301.EVT
EVENT\19930401.EVT
EVENT\19930501.EVT
EVENT\19930601.EVT
EVENT\19930701.EVT
EVENT\19930801.EVT
EVENT\19930901.EVT
EVENT\19931001.EVT
EVENT\19931101.EVT
EVENT\19931201.EVT
```

10.2.2 Land cover by Sub-basin

SPL writes a file called class_distribution.txt file in the working directory:

```
      yy          xx     l name    frac  imp classes 1-    9
  -114.183      49.814    1 AA023   1.00 0.00 0.00 0.20 0.00 0.11 0.45 0.18 0.00 0.05 0.00
  -115.569      51.175    2 BB001   1.00 0.00 0.03 0.00 0.12 0.35 0.38 0.00 0.00 0.07 0.04
  -114.139      52.028    3 CB001   1.00 0.00 0.00 0.12 0.00 0.02 0.03 0.80 0.00 0.03 0.00
  -108.479      49.844    4 HD036   1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.94 0.06 0.00 0.00
  -112.875      49.708    5 AD007   1.00 0.00 0.00 0.14 0.01 0.02 0.07 0.72 0.01 0.03 0.00
  -112.844      49.333    6 AE006   1.00 0.00 0.00 0.01 0.08 0.00 0.23 0.61 0.04 0.00 0.02
  -110.678      50.043    7 AJ001   1.00 0.01 0.00 0.07 0.00 0.02 0.05 0.75 0.08 0.01 0.01
  -114.050      51.050    8 BH004   1.00 0.07 0.01 0.14 0.04 0.19 0.16 0.29 0.00 0.08 0.02
  -113.816      52.277    9 CC002   1.00 0.00 0.00 0.14 0.03 0.09 0.21 0.48 0.00 0.03 0.01
  -112.711      51.467   10 CE001   1.00 0.00 0.00 0.01 0.00 0.00 0.00 0.97 0.01 0.00 0.01
  -110.297      50.903   11 CK004   1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.61 0.38 0.00 0.01
  -106.643      52.140   12 HG001   1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.74 0.21 0.00 0.03
  -105.806      52.924   13 HH001   1.00 0.01 0.00 0.02 0.00 0.00 0.00 0.95 0.00 0.02 0.00
```

This file shows the percent cover of each land cover class for each of the sub_basins in the watershed. This is very helpful for optimizing the parameters as the dominant class in the sub watershed should yield he greatest sensitivity in the hydrograph. Keep in mind also the upstream watersheds which also have an influence of course.

10.2.3 Information on Flags

```
precip data not smeared

temperature fields changed by 0.0 degrees C

ID=    1 Lapse rate set to 0.0, Ref. Elv. set to 0.0
   744    1   1.   0.

qlzfrac =      1.00  in runof5 <<<<<<<
```

10.2.4 Reservoir Locations and Operating Rules

```
i  ires(i) jres(i)    b1(i)     b2(i)     b3(i)     b4(i)
1       6       6   0.00000   0.00000   0.00000   0.00000BELWOOD

2       5       3   0.00000   0.00000   0.00000   0.00000CONESTOGO

3       4       6   0.00000   0.00000   0.00000   0.00000GUELPH
```

.
.
.

10.2.5 Information for Each Grid

```
lst: the maximum calculated flows are:
```

n	yyy(n)	xxx(n)	da(n)	qmax(n)	sump(n)
1	11	5	10.0	4.8	140.5
2	11	6	60.0	30.1	133.9
3	10	6	160.0	48.2	139.7
4	10	5	30.0	6.8	146.7
5	9	6	290.0	76.3	134.9
6	9	7	68.0	15.3	126.4
.					
.					
44	3	6	693.0	100.6	129.3
45	2	5	2628.0	302.2	140.2
46	2	6	3520.0	434.5	147.1

10.2.6 Summary for Grids

```
 final soil moisture for each element is:
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.25 0.24 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.21 0.25 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.21 0.20 0.18 0.30 0.30
0.30 0.30 0.30 0.21 0.21 0.19 0.18 0.30 0.30
0.30 0.30 0.23 0.22 0.21 0.20 0.19 0.30 0.30
0.30 0.20 0.21 0.21 0.20 0.20 0.19 0.19 0.30
0.30 0.21 0.20 0.20 0.19 0.20 0.19 0.18 0.30
0.30 0.30 0.20 0.18 0.19 0.19 0.19 0.20 0.30
0.30 0.30 0.20 0.19 0.19 0.19 0.21 0.21 0.30
0.30 0.30 0.30 0.20 0.20 0.21 0.20 0.30 0.30
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30
 precip. on each element in mm, scaled by  1.00
    0.     0.     0.     0.     0.     0.     0.     0.     0.
    0.     0.     0.     0.   141.   134.     0.     0.     0.
    0.     0.     0.     0.   147.   140.     0.     0.     0.
    0.     0.     0.     0.   144.   135.   126.     0.     0.
    0.     0.     0.   141.   145.   135.   128.     0.     0.
    0.     0.   145.   142.   142.   146.   140.     0.     0.
    0.   132.   138.   140.   143.   140.   137.   133.     0.
    0.   137.   142.   138.   134.   139.   134.   131.     0.
    0.     0.   139.   127.   127.   129.   132.   136.     0.
    0.     0.   129.   134.   131.   129.   140.   146.     0.
    0.     0.     0.   132.   140.   147.   144.     0.     0.
    0.     0.     0.     0.     0.     0.     0.     0.     0.
 runoff from each grid in mm
    0.     0.     0.     0.     0.     0.     0.     0.     0.
    0.     0.     0.     0.   153.   111.     0.     0.     0.
    0.     0.     0.     0.    96.    87.     0.     0.     0.
    0.     0.     0.     0.    95.    93.    85.     0.     0.
    0.     0.     0.    89.   100.    92.    84.     0.     0.
    0.     0.   100.    87.    87.    97.    89.     0.     0.
    0.    92.    95.    85.    93.    94.    96.    90.     0.
    0.    93.    93.    75.    91.   101.    97.    90.     0.
    0.     0.    90.    87.    86.    87.    90.    93.     0.
    0.     0.    87.    90.    90.    85.    93.    95.     0.
    0.     0.     0.    90.    94.    98.    91.     0.     0.
```

```
     0.     0.     0.     0.     0.     0.     0.     0.     0.
  losses from each grid in mm
     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     1.     1.     0.     0.     0.
     0.     0.     0.     0.     1.     1.     1.     0.     0.
     0.     0.     0.     1.     1.     1.     1.     0.     0.
     0.     0.     1.     1.     1.     1.     1.     0.     0.
     0.     1.     1.     1.     1.     1.     1.     1.     0.
     0.     1.     1.     1.     1.     1.     1.     1.     0.
     0.     0.     1.     1.     1.     1.     1.     1.     0.
     0.     0.     1.     1.     1.     1.     1.     1.     0.
     0.     0.     0.     1.     1.     1.     1.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.
  runoff coefficient
     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.   109.    83.     0.     0.     0.
     0.     0.     0.     0.    65.    63.     0.     0.     0.
     0.     0.     0.     0.    66.    69.    67.     0.     0.
     0.     0.     0.    63.    69.    68.    65.     0.     0.
     0.     0.    69.    61.    61.    66.    64.     0.     0.
     0.    69.    69.    61.    65.    67.    70.    68.     0.
     0.    68.    65.    54.    68.    73.    72.    69.     0.
     0.     0.    65.    69.    67.    68.    68.    68.     0.
     0.     0.    68.    67.    69.    66.    66.    65.     0.
     0.     0.     0.    68.    67.    67.    63.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.
 runtime   0: 0: 0   0/ 0/   0
```

10.2.7 Cummilative Statistics for Each Event

```
 runtime  14:13:58  2007-02-13
 location      area  precip   o/ro<->c/ro c/ro(t)   Dv%  nash  qp/m     qp/c
 GRND           3520.   137.    57.    56.    78.    -2.    0.8    507.    451.
 OSA/GUEL CON   1170.   141.    58.    46.    65.   -22.    0.7    219.    109.
 DERMAR          694.   -10.    51.    46.    76.   -10.    0.7    262.    154.
                 235.   133.    52.    58.    90.    11.    0.3     29.     52.
                 365.   141.    26.    42.    83.    64.    0.9     98.     88.
                 167.   137.    81.    65.   100.   -20.    0.6     60.     29.
                 593.   130.    49.    67.    95.    36.    0.6     54.     74.
                 118.   138.     0.     0.    54.    -1.  -99.0      0.     28.
                 694.   137.    42.    52.    76.    23.    0.8    181.    154.
```

.

.

10.2.8 Repeated for Each Event

.

.

```
     0.     0.    68.    69.    67.    59.    59.    70.     0.
     0.     0.    68.    68.    34.    65.    65.    60.     0.
     0.     0.     0.    70.    68.    90.    63.     0.     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.
 runtime  14:13:59  2007-02-13
 location      area  precip   o/ro<->c/ro c/ro(t)   Dv%  nash  qp/m     qp/c
 GRND           3520.   182.    57.    56.    98.    -2.    0.8    507.    451.
 OSA/GUEL CON   1170.   186.    61.    46.    76.   -24.    0.7    219.    109.
 DERMAR          694.   -10.    51.    46.    98.   -10.    0.7    262.    154.
                 235.   184.    54.    60.   127.    10.    0.3     29.     52.
```

```
                 365.   187.    26.    43.   109.    65.    0.9     98.     88.
                 167.   184.    81.    65.   134.   -20.    0.6     60.     29.
                 593.   180.    51.    68.   121.    34.    0.6     54.     74.
                 118.   182.     0.     0.    75.    -1.  -99.0      0.     28.
                 694.   183.    44.    53.    98.    19.    0.8    181.    154.
 :filetype                    .ev
 :fileversionno                  9.300000
 :year                                1993
 :month                                  3
 :day                                    1
```

Statistics are given at the end of each event and the final statistics at the end of the file.

10.2.9 Gridded channel flows Spl_flow.r2c

A gridded r2c file is written continuously for the entire run (so it can become very large). This file is viewable inGreenKenue.

10.2.10 Supplementary files

Flow_station_location.xyz
Spl_info.txt

10.3 Rff.txt File

The results\rff*n*.txt file can be used the plot the time series of the **state variables** (in **bold** red) and many other variables in one of the *n* land cover classes in one grid. The file can be imported to Excel or Grapher for plotting the time series. The headings of the columns are shown in the table on the next page.

Variable	**Units**	**Variable description**
Time	hours	
intevt	mm	interception evaporation
evt	mm	soil evaporation
p	mm	precipitation
sump	mm	cumulative precipitation
sumr	mm	net precipitation (hitting the ground)
fake	mm/hour	infiltration capacity
fakefs	mm/hour	infiltration capacity under snow
sca	**fraction**	**snow covered area**
snowc	**mm**	**snow water equivalent**
d1	**mm**	**surface storage**
d1fs	**mm**	**surface storage under snow**
sumf	mm	cumulative infiltration
sumffs	mm	cumulative infiltration under snow
uzs	**mm**	**upper zone storage**
uzsfs	**mm**	**upper zone storage under snow**

lzs	**mm**	**lower zone storage (ground water)**
q1	cms	surface flow from land cover class n
q1fs	cms	surface flow from snow covered area for land class n
qint	cms	interflow (to channels) from class n
qintfs	cms	interflow from snow covered areas in class n
qlz	cms	lower zone outflow
drng	mm	upper zone drainage in time step
drngfs	mm	upper zone drainage under snow covered area in time step
qr	cms	flow contribution from grid = q1+q1fs+qint+qintfs+qls for all classes in grid
qstream	cms	precipitation input to water surface (rivers & lakes)
strloss	cms	evaporation from water surfaces (rivers & lakes)
sumrff	mm	cumulative runoff
fexcess	mm	available heat for snow melt
glmelt	mm	glacier melt maybe
fmadjust		melt factor adjustment for ripeness
sq1	mm	cumulative surface runoff
sq1fs	mm	cumulative surface runoff under snow
sqint	mm	cumulative interflow
sqintfs	mm	cumualtive interflow under snow
sdrng	mm	cumulative drainage
sdrngfs	mm	cumulative interflow under snow
slzinflw	mm	cumulative lower zone inflow for all classes in a grid cell
sqlz	mm	cumulative lower zone outflow for a grid
Month		month
jul_day		Julian day
heat_def	mm	heat deficit in snow pack
Tempv	^{o}C	temperature in degree Celcius
Tempvmin	^{o}C	minimum temperature for the day set at 00:00 + A8 hours
Rh	Percent	calculated relative humidity
Psmear	mm	Amount of precip smeared
Punused	mm	Amount of precip remaining
API		**Antecedent precipitation index = m_o in the model**
Sublim	mm	Amount of new snow sublimated
sumsublim	mm	Cummilative sublimated snow.
v	**mm**	**Interception storage**
wcl	**mm**	**Free water in the snow pack**

10.4 Outfiles.txt File

This file is a list of all output files created by the SPLxx.EXE program. It can be edited and used to redirect the output to any desitred drive and directory. This can be usedfull if more than one watershed is being modelled at the same time. After editing the file. Rename or copy this file to outfiles.txt. The SPLxx.EXE program will look for this file and use it if it exists. The FORnnn files are scratch files or unused unit numbers. See Section 1.8 for a description of the output files.

```
results/spl.txt
results/opt.txt
results/res.txt
results/rff.txt
results/rte.txt
results/pic.txt
results/snw.txt
results/spl.plt
results/stg.plt
results/spl.csv
results/snw1.csv
results/snw.csv
results/strout.1
results/snwdebug.txt
results/watflood.wfo
results/error.xyz
results/error.r2s
results/wetland.csv
results/sed.csv
results/qdwpr.txt
results/spl_dly.csv
results/qout.txt
results/resin.txt
results/evap.txt
results/evt_means.csv
results/peaks.txt
results/volumes.txt
results/spl_mly.csv
results/leakage.dat
results/lake_sd.txt
results/rff1.txt
results/rff2.txt
results/rff3.txt
results/rff4.txt
results/rff5.txt
results/rff6.txt
results/rff7.txt
results/rff8.txt
results/rff9.txt
results/tracer.csv
results/tracerMB.csv
results/tracer_debug.csv
results/tracerWET.csv
results/tracerWETMB.csv
scratch4
results/watbal1.csv
results/watbal2.csv
spl.err
scratch5
scratch6
```

11 WATROUTE

WATROUTE is a gridded routing model made up of a subset of the SPL program. It does not incorporate wetland routing as the wetland incorporates hydrological as well as routing processes. As a stand-alone model the executable is **rte.exe**

To run WATROUTE one or two of the three files are required as input and need be be entries in the event file.

:griddedrunoff	**runof\19930101_rff.r2c**	**Required**
:griddedrecharge	**rchrg\19930101_rch.r2c**	**Optional**
:griddedleakage	**lkage\19930101_lkg.r2c**	**Optional**

These files may be generated by any hydrological model or land surface scheme. The files are gridded hourly data sets inGreenKenue r2c format as shown below.

In addition, a flow_init.r2c file is required in the working directory. This file can be generated by executing WATFLOOD with the routeflg= y or with **flowinit.exe.** To initialize the WATROUTE program, initial flows in the yyyymmdd_str.tb0 file are required for **flowinit.exe**

The _rff file is the sum of surface runoff and interflow (including snow melt) from all land cover classes in a grid in mm. The runoff is normalized for the nominal grid (i.e. frac=1.0).

The _rch file is the recharge from the upper zone to the lower zone in mm

The _lkg file is the leakage (lower zone discharge) to the stream in mm. The sum of these two files is the total inflow to the stream in each grid. The leakage is normalized for the nominal grid (i.e. frac=1.0).

SPL can create these files by setting the routeflg in the event file = y as shown in Section 11.2

Similarly, **runof.exe** will create these files.

The parameter file is the same for WATROUTE and SPL if splx.exe or spld.exe area used as the executables. For **rte.exe**, the **bsnm_ch_par.r2c** file is the parameter file. It is generated by bsn.exe when a **new_shd.r2c** file is created. At the same time, bsn.exe will combine the map & par file into a gridded par file – for **rte.exe** only.

To use WATROUTE **(rte.exe)**, simply create files of surface runoff and groundwater discharge in this format.

Example _rff.r2c file (routeflg=y)

```
########################################
:FileType r2c  ASCII GreenKenue 1.0
#
```

```
# DataType               2D Rect Cell
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          spl.exe
:CreationDate       2006-07-25  09:07
#
#---------------------------------------
#
:Name               Gridded Channel Inflow
#
:Projection         UTM
:Zone               17
:Ellipsoid          NAD83
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:SourceFile                   radcl\19930101_met.r2c
#
  :AttributeName 1  channel_inflow
  :AttributeUnits   mm
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
:UnitConverson             0.000
#
:endHeader
:Frame    1    1   "1993/1/1  1:00:00.000"
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
:EndFrame
:Frame    2    2   "1993/1/1  2:00:00.000"
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
.
.
```

Example _rch.r2c file (routeflg=y)

```
########################################
:FileType r2c  ASCII GreenKenue 1.0
#
# DataType               2D Rect Cell
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          spl.exe
:CreationDate       2006-07-25  09:07
#
#---------------------------------------
#
:Name               Gridded Recharge
```

```
#
:Projection         UTM
:Zone               17
:Ellipsoid          NAD83
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:SourceFile                    radcl\19930101_met.r2c
#
  :AttributeName 1  recharge
  :AttributeUnits   mm
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
:UnitConverson             0.000
#
:endHeader
:Frame    1    1   "1993/1/1  1:00:00.000"
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
:EndFrame
:Frame    2    2   "1993/1/1  2:00:00.000"
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
.
.
```

Example _lkg.r2c file (routeflg=y)

```
########################################
:FileType r2c  ASCII GreenKenue 1.0
#
# DataType               2D Rect Cell
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          spl.exe
:CreationDate       2006-07-25  09:07
#
#---------------------------------------
#
:Name               Gridded Leakage
#
:Projection         UTM
:Zone               17
:Ellipsoid          NAD83
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:SourceFile                    radcl\19930101_met.r2c
#
  :AttributeName 1  leakage
```

```
  :AttributeUnits   mm
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
:UnitConverson             0.000
#
:endHeader
:Frame    1    1   "1993/1/1  1:00:00.000"
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.06034  0.06034  0.06034  0.06034  0.00000  0.00000
  0.00000  0.00000  0.06034  0.06034  0.06034  0.06034  0.06034  0.06034  0.00000
  0.00000  0.00000  0.06034  0.06034  0.06034  0.04250  0.04250  0.07966  0.00000
  0.00000  0.06034  0.06034  0.00360  0.04923  0.09269  0.09269  0.07966  0.00000
  0.00000  0.06034  0.06034  0.04537  0.04923  0.04923  0.09269  0.07966  0.00000
  0.00000  0.00000  0.06034  0.04537  0.04537  0.04923  0.04923  0.00000  0.00000
  0.00000  0.00000  0.00000  0.04537  0.05187  0.05187  0.05187  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.05187  0.05187  0.05187  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.05187  0.05187  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.05187  0.05187  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
:EndFrame
:Frame    2    2   "1993/1/1  2:00:00.000"
  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
  0.00000  0.00000  0.00000  0.06006  0.06006  0.06006  0.06006  0.00000  0.00000
  0.00000  0.00000  0.06006  0.06006  0.06006  0.06006  0.06006  0.06006  0.00000
  0.00000  0.00000  0.06006  0.06006  0.06006  0.04234  0.04234  0.07922  0.00000
.
.
.
.
.
```

Example flow_init.r2c file (routeflg=y)

```
########################################
:FileType r2c  ASCII GreenKenue 1.0
#
# DataType               2D Rect Cell
#
:Application            GreenKenue
:Version                 2.1.23
:WrittenBy          spl.exe (sub)
:CreationDate       2006/11/13  14:25
#
#---------------------------------------
:SourceFileName              strfw\19930101_str.tb0
#
:Projection
#
:xOrigin              500000.000
:yOrigin             4790000.000
#
:AttributeName 1 qi1
:AttributeName 2 qo1
:AttributeName 3 store1
:AttributeName 4 over
:AttributeName 5 lzs
#
:xCount                        9
:yCount                       12
:xDelta                10000.000
:yDelta                10000.000
#
:EndHeader
  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  0.000E+00  0.000E+00  0.000E+00  0.353E+00  0.292E+02  0.470E+02  0.399E+00  0.000E+00  0.000E+00
```

0.000E+00	0.000E+00	0.756E+00	0.258E+01	0.267E+02	0.133E+02	0.171E+01	0.214E+00	0.000E+00
0.000E+00	0.000E+00	0.471E+01	0.591E+01	0.161E+02	0.379E+01	0.112E+02	0.426E+01	0.000E+00
0.000E+00	0.176E+00	0.993E+01	0.998E+00	0.121E+02	0.310E+01	0.577E+00	0.301E+01	0.000E+00
0.000E+00	0.614E+00	0.756E+01	0.488E+01	0.179E+01	0.105E+02	0.181E+01	0.107E+01	0.000E+00
0.000E+00	0.000E+00	0.105E+01	0.349E+01	0.129E+01	0.974E+01	0.694E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.858E+00	0.921E+00	0.776E+01	0.823E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.845E+00	0.301E+01	0.710E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.309E+00	0.163E+01	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.101E+00	0.602E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.399E+00	0.296E+02	0.473E+02	0.422E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.766E+00	0.284E+01	0.272E+02	0.134E+02	0.195E+01	0.224E+00	0.000E+00
0.000E+00	0.000E+00	0.474E+01	0.594E+01	0.162E+02	0.476E+01	0.115E+02	0.428E+01	0.000E+00
0.000E+00	0.176E+00	0.300E+01	0.999E+00	0.122E+02	0.311E+01	0.608E+00	0.302E+01	0.000E+00
0.000E+00	0.613E+00	0.758E+01	0.490E+01	0.179E+01	0.780E+01	0.182E+01	0.107E+01	0.000E+00
0.000E+00	0.000E+00	0.106E+01	0.350E+01	0.130E+01	0.975E+01	0.695E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.862E+00	0.925E+00	0.777E+01	0.827E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.851E+00	0.302E+01	0.714E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.313E+00	0.163E+01	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.102E+00	0.604E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.505E+04	0.313E+06	0.424E+06	0.619E+04	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.117E+05	0.294E+05	0.249E+06	0.117E+06	0.294E+05	0.643E+04	0.000E+00
0.000E+00	0.000E+00	0.818E+05	0.109E+06	0.176E+06	-0.142E+07	0.219E+06	0.346E+05	0.000E+00
0.000E+00	0.381E+04	0.997E+07	0.183E+05	0.103E+06	0.378E+05	0.213E+05	0.188E+05	0.000E+00
0.000E+00	0.129E+05	0.676E+05	0.513E+05	0.205E+05	0.210E+08	0.412E+05	0.119E+05	0.000E+00
0.000E+00	0.000E+00	0.162E+05	0.418E+05	0.263E+05	0.102E+06	0.105E+05	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.139E+05	0.154E+05	0.893E+05	0.137E+05	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.230E+05	0.380E+05	0.189E+05	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.154E+05	0.330E+05	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.299E+04	0.125E+05	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	-0.427E+00	-0.819E+02	-0.109E+03	-0.439E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	-0.660E+00	-0.313E+01	-0.837E+02	-0.182E+02	-0.200E+01	0.159E-01	0.000E+00
0.000E+00	0.000E+00	-0.250E+02	-0.282E+02	-0.450E+02	0.000E+00	-0.101E+02	-0.676E+01	0.000E+00
0.000E+00	-0.159E+00	0.000E+00	-0.389E+01	-0.401E+02	-0.351E+01	0.680E+00	-0.554E+01	0.000E+00
0.000E+00	-0.916E+00	-0.163E+02	-0.107E+02	-0.322E+01	0.000E+00	-0.154E+01	-0.150E+01	0.000E+00
0.000E+00	0.000E+00	-0.141E+01	-0.763E+01	-0.178E+01	-0.258E+02	-0.121E+01	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	-0.182E+01	-0.167E+01	-0.210E+02	-0.184E+01	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	-0.158E+01	-0.878E+01	-0.170E+01	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	-0.309E+00	-0.369E+01	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	-0.241E+00	-0.144E+01	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.190E+03	0.190E+03	0.189E+03	0.192E+03	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.190E+03	0.189E+03	0.188E+03	0.190E+03	0.191E+03	0.191E+03	0.000E+00
0.000E+00	0.000E+00	0.189E+03	0.187E+03	0.187E+03	0.787E+02	0.789E+02	0.117E+03	0.000E+00
0.000E+00	0.187E+03	0.187E+03	0.471E+02	0.176E+03	0.912E+02	0.913E+02	0.114E+03	0.000E+00
0.000E+00	0.642E+02	0.653E+02	0.633E+02	0.173E+03	0.175E+03	0.899E+02	0.115E+03	0.000E+00
0.000E+00	0.000E+00	0.646E+02	0.614E+02	0.608E+02	0.172E+03	0.171E+03	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.588E+02	0.601E+02	0.584E+02	0.575E+02	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.581E+02	0.558E+02	0.553E+02	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.555E+02	0.551E+02	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.549E+02	0.543E+02	0.000E+00	0.000E+00	0.000E+00
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

11.1 How to use WATROUTE

WATROUTE is a sub-set of SPL modules and has three options. It is activated by setting **modelflg** = **r**, **l** or **i** in the event file and the **routeflg** *must be* set to **n**. The **routeflg** overrides the **modelflg**. WATROUTE can be used for channel and lake routing only. The wetland option can not be used with WATROUTE because wetland computations involve hydrological processes that are not included in WATROUTE.

WATROUTE Options:

Routing option l: Route surface, interflow and ground water (lower zone discharge or leakage) through the channel network using the **_rff** and **_lkg** files. For example, the **_rff** file could be generated by SPL or another model (why would you?) and the **_lkg** file could be generated by a groundwater model and routed through the lower zone and channel by WATROUTE. For testing, WATFLOOD will produce the **_rff** and **_lkg** files if the routeflg is set to **y**. In the event file set:

```
:modelflg                    l
```

or

Routing option r: If an external model produces runoff **_rff** and recharge **_rch,** WATROUTE will add the recharge to the lower zone and route it to the stream where surface water and interflow will be added for the total channel inflow. These flows will then be routed through the channel network. Both the rff and rch files are generated by WATFLOOD and routed through the lower zone and channel by WATROUTE for testing purposes. In the event file set:

```
:modelflg                    r
```

or

Routing option i: Route only surface flow through the channel network using the **_rff** file. This might be needed if a model produced only one channel inflow per grid (combined surface, interflow and groundwater flow). For a single input, only the **i** option can be used. In the event file set:

```
:modelflg                    i
```

11.2 RUNOFF (_rff) RECHARGE (_rch) and and LEAKAGE (_lkg) file creation with WATFLOOD

These files are created to allow WATFLOOD to be linked to other software or models.

This data already can be incorporated in the watflood.wfo file for viewing inGreenKenue

To create these files:

1. Set flag the **routeflg** in the event file = 'y'
2. Create a ***runoff, rchrg*** and ***lkage*** subdirectories in the working directory e.g. *spl\gr10k\runof, spl\gr10k\rchrg* and *spl\gr10k\lkage*
3. Provide names for files in the event files as shown below:

```
:griddedrunoff            runof\yyyymmdd_rff.r2c
:griddedrecharge          rchrg\yyyymmdd_rch.r2c
:griddedleakage           lkage\yyyymmdd_lkg.r2c
```

Note: The reason the files are not in the **results** directory and are not included in the outfiles.new file is that they are out put files of WATFLOOD and input files for WATROUTE or other models and are part of the information flow of the modeling. The results (or other user specified directory) directory is reserved just for non-reusable model output.

The **rff** file is a file of hourly grids of the sum of surface runoff and interflow. It is the direct runoff resulting from rainfall or snow melt. It is formatted to be read by WATROUTE. The units are mm averaged for the nominal grid size..

The .rch file is a file of hourly grids of recharge in mm. When SPL is run in this mode, the water is added to the lower zone storage as usual.

The .lkg is a file of hourly grids of groundwater flow (from the lower zone) to the channel. The user may like to run SPL with the lower zone outflow (leakage) turned off. Simply set the LZF = -ve in the parameter file. The units are mm averaged for the nominal grid size.

There are 12 flags:

	Flag:	Result if 'y'
1	Snwflg	snowmelt routines will be used
2	Sedflg	sediment production and routing routines will be used
3	Vapflg	Evaporation turned on (need temperature files)
4	Smrflg	Precip. data will be smeared - e.g., daily precip. entered once every 24 hours will be disaggregated or 'smeared' over part or all of the whole day instead of taken as an hourly amount for the first hour of the day. Please see Section 6.2
5	Resinflg	reservoir inflow data required and computed reservoir inflows will be compared
6	Tbcflg	a resume.txt file containing all state variable values at program termination will be written
7	Resumflg	the resume files will be used to initialize state variables - allows the program to resume a time series as if it was executed as a continous run resume.txt, flow_init.r2c & soil_init.r2c files will be used to initialize state variables - allows the program to resume a time series as if it was executed as a continous run NEW: for resumflg = 's', only the soil_init.r2c file will be read but the lzs and all flow variables will be initialized with streamflow.
8	Contflg	continue the statistics from previous run via resume.txt file

9	***Routeflg***	***= 'y' write for watroute.exe*** ***\spl\bsnm\runof\yyyymmdd_rff.r2c and*** ***\spl\bsnm\rchrg\yyyymmdd_rch.r2c*** ***\spl\bsnm\lkage\yyyymmdd_lkg.r2c*** ***\spl\bsnm\flow_init.r2c*** = 'q' write the tb0 files for flow 1D (no outflow from designated reaches)
10	crseflg	read snow course data to replace resume file data
11	Kenueflg	Create a \results\watflood.wfo file forGreenKenue
12	Picflg	write the results/pic.txt file for mapper
13	Wetflg	Use coupled wetland-channel routing
14	modelflg	if ='i' run watroute with surface flow only if ='l' run watroute for surface and groundwater **l**eakage routing if ='r' run watroute for surface to channel and **r**echarge thru lz
15	shdflg	replace the watershed file basin\bsnm.shd for next event
16	trcflg	use the tracer module
17	frcflg	use isotope fractionation
19	grdflg	if='y' will write r2c files for flow, swe & evaporative loss gridflow.r2c, swe.r2c & evap.r2c respectively
20	ntrlflg	If='y' and the rel file for the first event has coefficients for ALL lakes and reservoirs, any release data in the rel file will be ignored and flows routed according to the rule (coefficients)
21	nudgeflg	If='a' all computed flows for all events this run will be replaced by observed flows at all flow stations. If='1' computed flows as designated in event no=1 will be replaced by observed flows. (Designation is by setting value1 = 2 in the yyyymmdd_str.tb0 file for the **first** event) The default = 'n' if not specified in the event file. However, if Value1 = 2 in any yyyymmss_str.tb0 file for any station, the computed flow for that station and that event (only) will replaced by the observed flow. See Section 7.1.1 also.

Example of an EVENT file to *create* the runoff, leakage and recharge files with the relevant entries bolded:

```
#
:fileType                     .evt
:fileVersionNo                9.7
:year                         2000
:month                        10
:day                          01
:hour                         00
#
:snwflg                       y
```

```
:sedflg                        n
:vapflg                        y
:smrflg                        n
:resinflg                      n
:tbcflg                        n
:resumflg                      n
:contflg                       n
:routeflg                      y
:crseflg                       n
:Kenueflg                      a
:picflg                        n
:wetflg                        n
:modelflg                      n
:shdflg                        n
:trcflg                        y
:frcflg                        n
:initflg                       n
#
:intSoilMoisture               0.25 0.25 0.25 0.25 0.25
:rainConvFactor                1.00
:eventPrecipScaleFactor        1.00
:precipScaleFactor             0.00
:eventSnowScaleFactor          0.00
:snowScaleFactor               0.00
:eventTempScaleFactor          0.00
:tempScaleFactor               0.00
#
:hoursRainData                 744
:hoursFlowData                 744
:deltat_report                  24
#
:basinFileName                 BASIN\glake_shd.r2c
:parFileName                   BASIN\glake.PAR
:channelparfile                BASIN\glake_ch_par.r2c
:pointDataLocations            BASIN\glake.pdl
:snowCoverDepletionCurve       BASIN\glake.sdc
:waterqualitydatafile          BASIN\glake.wqd
#
:pointsoilmoisture             moist\20001001_psm.pt2
:pointprecip                   raing\20001001_rag.tb0
:pointtemps                    tempg\20001001_tag.tb0
:pointnetradiation
:pointhumidity
:pointwind
:pointlongwave
:pointshortwave
:pointatmpressure
#
:streamflowdatafile            strfw\20001001_str.tb0
:reservoirreleasefile          resrl\20001001_rel.tb0
:reservoirinflowfile           resrl\20001001_rin.tb0
:snowcoursefile                snow1\20001001_crs.pt2
#
:radarfile                     raduc\20001001.rad
:rawradarfile                  radar\20001001.scn
:clutterfile                   radar\20001001.clt
:griddedinitsnowweq            snow1\20001001_swe.r2c
```

```
:griddedinitsoilmoisture      moist\20001001_gsm.r2c
:griddedinitlzs
:griddedrainfile              radcl\20001001_met.r2c
:griddedsnowfile
:griddedtemperaturefile       tempr\20001001_tem.r2c
:griddednetradiation
:griddedhumidity
:griddedwind
:griddedlongwave
:griddedshortwave
:griddedatmpressure
:griddedrunoff                runof\20001001_rff.r2c
:griddedrecharge              rchrg\20001001_rch.r2c
:griddedleakage               lkage\20001001_lkg.r2c
#
:noeventstofollow                 0
#
```

Example of an EVENT file to *use* the runoff, leakage and recharge files with the relevant entries bolded:

```
#
:snwflg                       y
:sedflg                       n
:vapflg                       y
:smrflg                       n
:resinflg                     n
:tbcflg                       n
:resumflg                     n
:contflg                      n
:routeflg                     n
:crseflg                      n
:Kenueflg                     a
:picflg                       n
:wetflg                       n
:modelflg                     i, r or l
:shdflg                       n
:trcflg                       y
:frcflg                       n
:initflg                      n
#
:intSoilMoisture              0.25 0.25 0.25 0.25 0.25
:rainConvFactor               1.00
:eventPrecipScaleFactor       1.00
:precipScaleFactor            0.00
:eventSnowScaleFactor         0.00
:snowScaleFactor              0.00
:eventTempScaleFactor         0.00
:tempScaleFactor              0.00
#
:hoursRainData                744
:hoursFlowData                744
:deltat_report                 24
#
:basinFileName                BASIN\glake_shd.r2c
```

```
:parFileName                   BASIN\glake.PAR
:channelparfile                BASIN\glake_ch_par.r2c    << gridded par file
:pointDataLocations            BASIN\glake.pdl
:snowCoverDepletionCurve       BASIN\glake.sdc
:waterqualitydatafile          BASIN\glake.wqd
#
:pointsoilmoisture             moist\20001001_psm.pt2
:pointprecip                   raing\20001001_rag.tb0
:pointtemps                    tempg\20001001_tag.tb0
:pointnetradiation
:pointhumidity
:pointwind
:pointlongwave
:pointshortwave
:pointatmpressure
#
:streamflowdatafile            strfw\20001001_str.tb0
:reservoirreleasefile          resrl\20001001_rel.tb0
:reservoirinflowfile           resrl\20001001_rin.tb0
:snowcoursefile                snow1\20001001_crs.pt2
#
:radarfile                     raduc\20001001.rad
:rawradarfile                  radar\20001001.scn
:clutterfile                   radar\20001001.clt
:griddedinitsnowweq            snow1\20001001_swe.r2c
:griddedinitsoilmoisture       moist\20001001_gsm.r2c
:griddedinitlzs
:griddedrainfile               radcl\20001001_met.r2c
:griddedsnowfile
:griddedtemperaturefile        tempr\20001001_tem.r2c
:griddednetradiation
:griddedhumidity
:griddedwind
:griddedlongwave
:griddedshortwave
:griddedatmpressure
:griddedrunoff                 runof\20001001_rff.r2c
:griddedrecharge               rchrg\20001001_rch.r2c
:griddedleakage                lkage\20001001_lkg.r2c
#
:noeventstofollow                  0
#
```

11.3 Recharge files for MODFLOW

WATFLOOD can write files in the format for MODFLOW (a groundwater model). If MODFLOW and WATFLOOD have same grid. To create this file, set the route flag to **m**.

Example .rch file (routeflg=m)

```
Recharge in mm: ju=     1 rows=    11 columns=     9
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0     1     0  /jz,ju-1
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0     1     0  /jz,ju-1
```

```
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    1    0  /jz,ju-1
 Recharge in mm: ju=    2 rows=   11 columns=    9
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   24    1  /jz,ju-1
 Recharge in mm: ju=    3 rows=   11 columns=    9
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   48    2  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   48    2  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   48    2  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   48    2  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   48    2  /jz,ju-1
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0   48    2  /jz,ju-1
.
.
.
```

11.4 Combining WATFLOOD runoff and MODFLOW leakage

Under construction

12 Interfacing with GREEN-KENUE

GREEN-KENUE is a pre- and post-processor for WATFLOOD/SPL. It can create the bsnm.map input file from DEMs and Landcover maps. It can also display all the important state variables and the runoff produced in each grid as well as each grid outflow for each timestep. To do this, SPL creates the *\results\watflood.wfo* file that can be opened fromGreenKenue. This file tends to get very large so the *wfo_spec.new* file is created in the basin folder whenever bsn.exe is used:

```
    3.0 Version Number
  102 AttributeCount
    1 ReportingTimeStep Hours
    0 Start Reporting Time forGreenKenue (hr)
 8784 End Reporting Time forGreenKenue (hr)       <<< see note below****
0   1 Temperature
1   2 Precipitation
1   3 Cumulative Precipitation
1   4 Lower Zone Storage Class
1   5 Ground Water Discharge m^3/s
1   6 Grid Runoff
1   7 Grid Outflow
1   8 Weighted SWE
1   9 Wetland Depth
1  10 Channel Depth
0  11 Wetland Storage in m^3
0  12 Wetland Outflow in m^3/s
0  13 Depression Storage Class  1
0  14 Depression Storage Class  2
0  15 Depression Storage Class  3
0  16 Depression Storage Class  4
0  17 Depression Storage Class  5
0  18 Depression Storage Class  6
0  19 Depression Storage (Snow) Class  1
0  20 Depression Storage (Snow) Class  2
0  21 Depression Storage (Snow) Class  3
0  22 Depression Storage (Snow) Class  4
0  23 Depression Storage (Snow) Class  5
0  24 Depression Storage (Snow) Class  6
0  25 Snow Water Equivalent Class  1
0  26 Snow Water Equivalent Class  2
0  27 Snow Water Equivalent Class  3
0  28 Snow Water Equivalent Class  4
0  29 Snow Water Equivalent Class  5
0  30 Snow Water Equivalent Class  6
0  31 Snow Covered Area Class  1
0  32 Snow Covered Area Class  2
0  33 Snow Covered Area Class  3
0  34 Snow Covered Area Class  4
0  35 Snow Covered Area Class  5
0  36 Snow Covered Area Class  6
0  37 Upper Zone Storage Class  1
0  38 Upper Zone Storage Class  2
0  39 Upper Zone Storage Class  3
0  40 Upper Zone Storage Class  4
0  41 Upper Zone Storage Class  5
0  42 Upper Zone Storage Class  6
```

```
0  43 Upper Zone Storage (Snow) Class  1
0  44 Upper Zone Storage (Snow) Class  2
0  45 Upper Zone Storage (Snow) Class  3
0  46 Upper Zone Storage (Snow) Class  4
0  47 Upper Zone Storage (Snow) Class  5
0  48 Upper Zone Storage (Snow) Class  6
0  49 Surface Flow m^3/s Class  1
0  50 Surface Flow m^3/s Class  2
0  51 Surface Flow m^3/s Class  3
0  52 Surface Flow m^3/s Class  4
0  53 Surface Flow m^3/s Class  5
0  54 Surface Flow m^3/s Class  6
0  55 Surface Flow (snow) m^3/s Class  1
0  56 Surface Flow (snow) m^3/s Class  2
0  57 Surface Flow (snow) m^3/s Class  3
0  58 Surface Flow (snow) m^3/s Class  4
0  59 Surface Flow (snow) m^3/s Class  5
0  60 Surface Flow (snow) m^3/s Class  6
0  61 Interflow m^3/s Class  1
0  62 Interflow m^3/s Class  2
0  63 Interflow m^3/s Class  3
0  64 Interflow m^3/s Class  4
0  65 Interflow m^3/s Class  5
0  66 Interflow m^3/s Class  6
0  67 Interflow (snow) m^3/s Class 1
0  68 Interflow (snow) m^3/s Class 2
0  69 Interflow (snow) m^3/s Class 3
0  70 Interflow (snow) m^3/s Class 4
0  71 Interflow (snow) m^3/s Class 5
0  72 Interflow (snow) m^3/s Class 6
0  73 Recharge mm Class  1
0  74 Recharge mm Class  2
0  75 Recharge mm Class  3
0  76 Recharge mm Class  4
0  77 Recharge mm Class  5
0  78 Recharge mm Class  6
0  79 Recharge mm (snow) Class  1
0  80 Recharge mm (snow) Class  2
0  81 Recharge mm (snow) Class  3
0  82 Recharge mm (snow) Class  4
0  83 Recharge mm (snow) Class  5
0  84 Recharge mm (snow) Class  6
0  85 PET (average) mm Class  1
0  86 PET (average) mm Class  2
0  87 PET (average) mm Class  3
0  88 PET (average) mm Class  4
0  89 PET (average) mm Class  5
0  90 PET (average) mm Class  6
0  91 ET (cummulative) mm Class  1
0  92 ET (cummulative) mm Class  2
0  93 ET (cummulative) mm Class  3
0  94 ET (cummulative) mm Class  4
0  95 ET (cummulative) mm Class  5
0  96 ET (cummulative) mm Class  6
0  97 Sublimation Cummulative) mm (snow) Class  1
0  98 Sublimation Cummulative) mm (snow) Class  2
0  99 Sublimation Cummulative) mm (snow) Class  3
```

```
0 100 Sublimation Cummulative) mm (snow) Class  4
0 101 Sublimation Cummulative) mm (snow) Class  5
0 102 Sublimation Cummulative) mm (snow) Class  6
```

The above file is file used for the example in Section 12.1. To use this file, rename wfo_spec.new (which is produced by BSN.EXE each time it is executed) to wfo_spec.txt and place it in the working directory. SPLX.EXE will use this file if present and if theGreenKenue flag = y in the event file. The user can edit colum 1 in each line: a 0 indicates that the attribute will be turned off and a 1 instructs the program to write the values of the attributes to the watflood.wfo file at the time step in line 3.

In the header:

```
  2.0 Version Number
   72 AttributeCount
    1 ReportingTimeStep Hours
    0 Start Reporting Time forGreenKenue (hr)
 8784 End Reporting Time forGreenKenue (hr) ****
```

The third line can be edited to change the reporting time step. For instance, if the values are to be written every 24 hours, the line would read:

```
   24 ReportingTimeStep Hours
```

The 24 must be right justified in columns 1-5. Only the precipitation is summed for the chosen time step. All the other values are instantaneous values and not averaged for the time step.
The grid runoff is the total runoff produced within the grid. The grid outflow is the river flow leaving the grid.

The start and end reporting time step forGreenKenue is calculated from the start of the first event in the simulation. So if you would like to see year 5 of a 10year run, you would enter 35064 (at least one leap year) for the start and 43824 for the end. In addition, theGreenKenue flag in the event file must be set to a (for all).

******** *If you want a period longer than 99999 hours (11.4 years) just enter a 0 and the program will run up to 1000 years.*

12.1 How to debug withGreenKenue:

Figure 11.1 shows howGreenKenue can be used to carry out diagnostics. In this case, a user wished to check if the Actual Evapotranspiration was calculated properly from the Potential Evapotranspiration which was calculated from the Hargreaves formula (Sections 2.3.2 and 2.4.4)

First, the watershed data (DEM,channels and watershed outline) are loaded intoGreenKenue. Next the map file is overlaid to show the grid. Finally, the WATFLOOD.WFO file is opened and the portential evapotranspiration and actual evapotranspiration are put into the 2-D view with the PET having a larger point in blue and the AET a smaller point in green so both can be seen. Then the animation bar is turned on and time series are extracted for the PET in blue and AET in green. The time series view shows the AET is about 75% of the PET as defined by the ftall parameter and there is now AET during the winter months. All this is reassuring to the user.

The use of points for this example is very useful because several variables can be shown in a superimposed fashion. The point size is decreased towards the top layer.

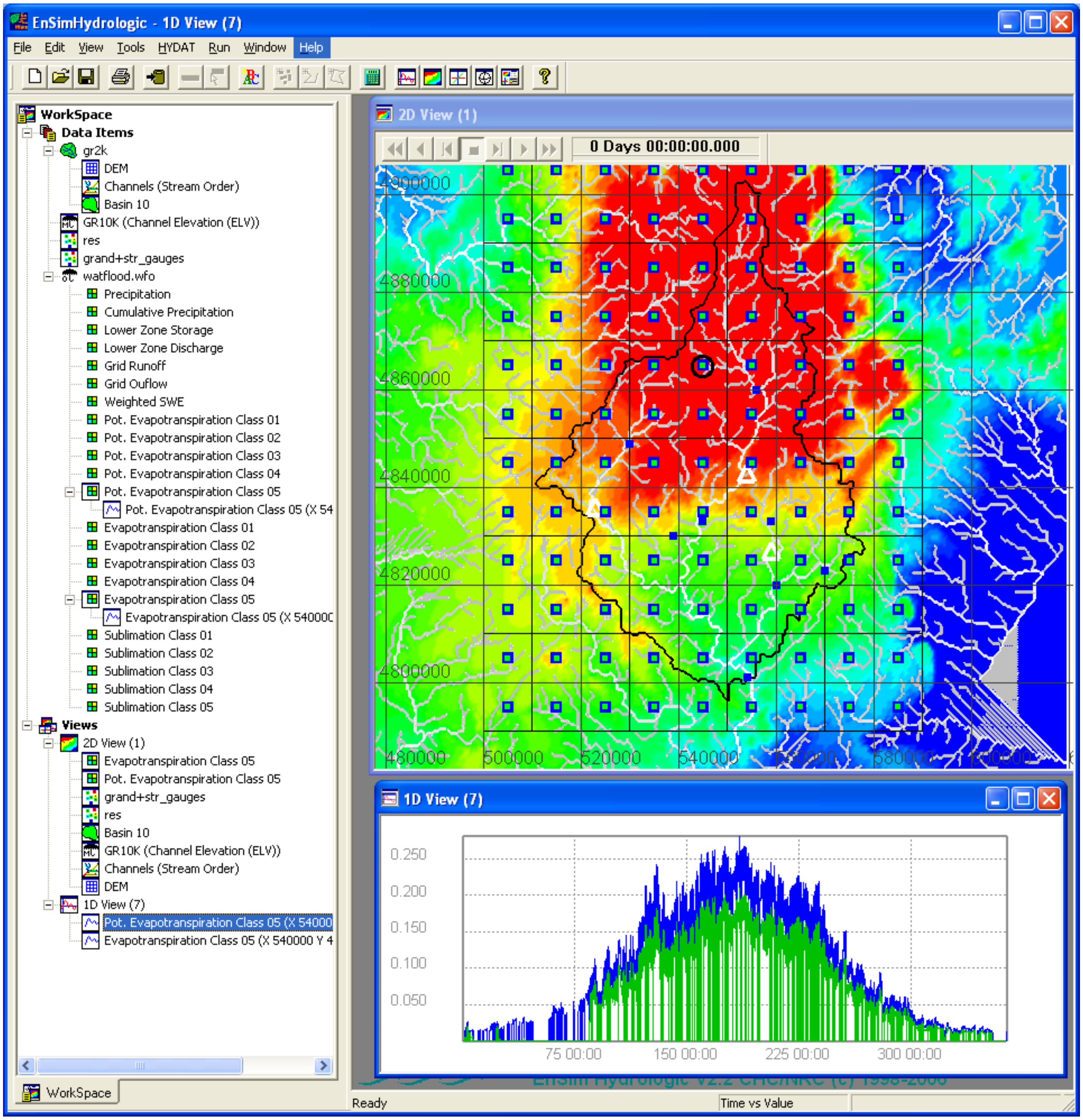


Fig. 11.1 – Example GREEN-KENUE[1)] interface for debugging

[1)]GreenKenue Hydrologic is available from the Canadian Hydraulics Centre through Martin Serrer martin.serrer@nrc-cnrc.gc.ca

Anoter example is to compare runs. Figure 11.2 shows three runs made with different programs.GreenKenue is able to show where the difference originates by comparing animated plots. The hydrograph at the watershed outlet is different for the 2-D plot on the right. Both the left and middle plots fall on the green hydrograph but the right plot produces the blue hydrograph. By extracting a time series and syncronizing a view to get the red line superimposed on the hydrograph, you can freeze the 2-D plots at the same time to help find the origin of the problem.

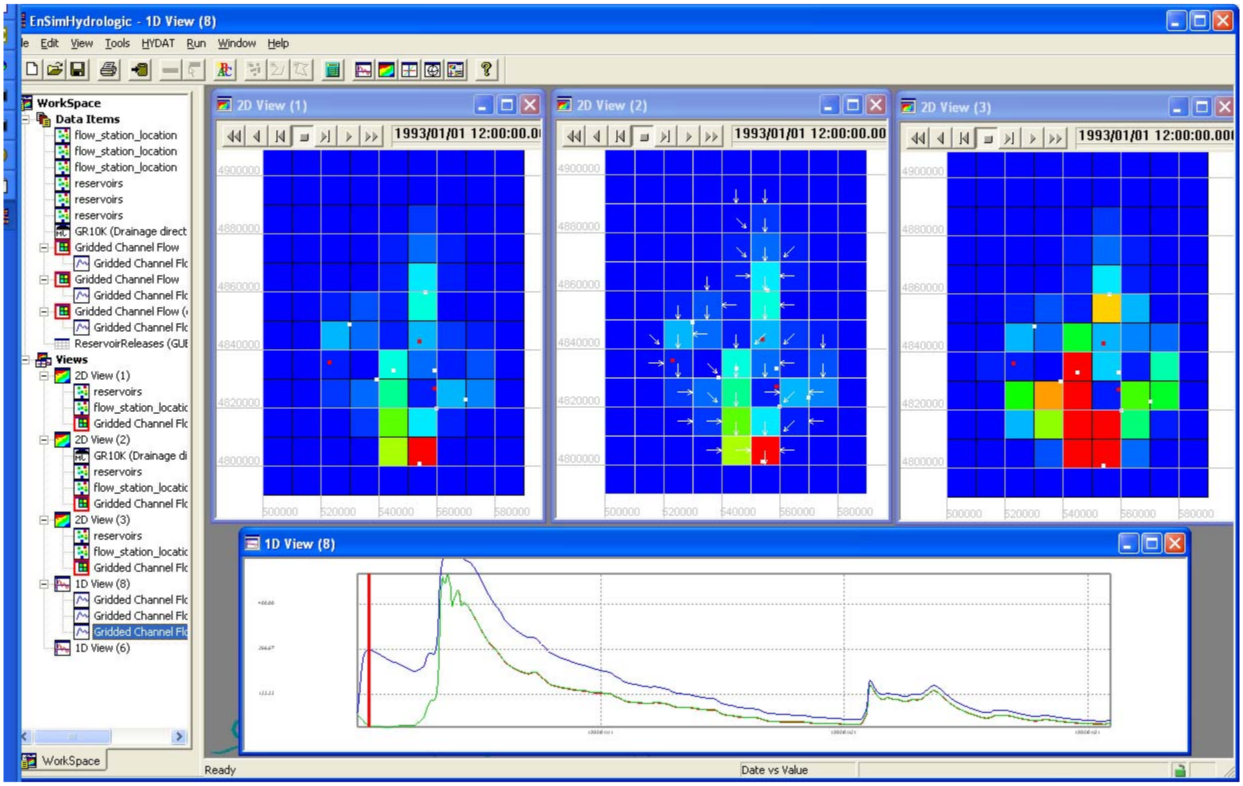


Fig. 11.2 Looking for differences withGreenKenue

13 WATFLOOD OPTIONS

13.1 Precipitation Adjustment File (PAF)

PAF files are not something that you should be proud of but are sometimes necessary for practical applications. They can be used where a known bias exists, for instance where you have a range dependency when using radar data, especially with snow. Or for instance, in mountainous area where the precip. measurements are at low elevations and you want to adjust the higher elevations by some height dependent factor.

When you run the SPLX.EXE program, two files called newerror.txt and error.xyz are created in the working directory. Either of these can be used with SURFER and the r2s file is compatible withGreenKenue. An example of the newerror.txt file for the Grand River is below:

```
    1 Errors in %.Runtime  0: 0: 0   0/ 0/   0
-999.-999.-999.-999.-999.-999.-999.-999.-999.
-999.-999.-999.-999.   1.   1.-999.-999.-999.
-999.-999.-999.-999.   1.   1.-999.-999.-999.
-999.-999.-999.-999.   1.   1.   1.-999.-999.
-999.-999.-999.  31.   1.   1.   1.-999.-999.
-999.-999.  -2.  31.  31. -50. -50.-999.-999.
-999.  -2.  -2.  31. -50. -50. -29.  10.-999.
-999.  -2.  -2.  64. -50. -29. -29.  10.-999.
-999.-999.  -2.  -2.  -2. 101. 101.  10.-999.
-999.-999.  -2.  -2.  -2.  -2.  -2.  -2.-999.
-999.-999.-999.  -2.  -2.  -2.  -2.-999.-999.
-999.-999.-999.-999.-999.-999.-999.-999.-999.
    l    i    j      error imax,jmax:   12    9
    1 4800  530     -2.27
    1 4800  540     -2.27
    1 4800  550     -2.27
      etc.
```

The newerror.txt file shows the percent error in each grid on the basis of the sub-watershed in which it is located. Subwatersheds are defined by the locations of the streamflow stations. The error is for just the sub-basin, not the entire area above the station. -999. means the grid is outside the basin.

Next, the newerror.txt file is renamed or copied to the error.txt file and the program is rerun. It will calculate a precipitation adjustment factor for each grid and calculate new flows. The computed flow volumes at each station will be much closer to the observed volumes. The program creates a newpaf.txt file which are the PAF used in the run. If the newpaf.txt file is renamed or copied to paf.txt, it will be used in subsequent runs. Some editing of the files is required as noted below.

1. Run splx.exe making sure there is no error.txt or paf.txt file. This creates a newerror.txt file
2. Copy the newerror.txt file to error.txt
3. Edit the error.txt file and replace ***** and -999. by 00000
4. Run splx.exe This creates a newpaf.txt file. You can stop this run with ^C as soon as the file is written.
5. Run fill.exe It reads the newpaf.txt file and spits out a fill.txt file
6. Copy the fill.txt file to paf.txt if it looks ok. (It looks ok when the PAF's look ok)
7. Run splx.exe for the last time with the paf.txt file.

Note:

SPLX.EXE will first look for a paf.txt file. If it does not exist, it will look for a error.txt file. If neither exists, the precip will be unadjusted.

You can repeat steps 2-7 as many times as you like. Each time it will reduce the error in the hydrographs until no error exist and your results will be highly unrealistic. One pass is nice to remove any bias but leaves some scatter in the computed vs observed plot.

The error is based on the rms error of the flows.

13.2 Wetland Model

Section 2.12 describes the theory of the wetland model. Ref. Trish Stadnyk's work report.

The wetland model is turned on in the event file. Set the wetland flag:

```
:wetflg                       y
```

The bold text sections apply to the wetlands. The word "wetlands" must be shown exactly as below above the column of wetland parameters.

Wetlands can be shut off for a particular river class be setting theta –ve.

```
# runtime    11:07:40
# rundate  2004-04-29
ver       9.200     parameter file version number
iopt         01     debug level
itype         0
numa          0     PS optimization 0=no 1=yes
nper          0     opt delta 0-absolute
kc            5     no of times delta halved
maxn         10     max no of trials
ddsfl         0     DDS optimization 0=no  1=yes
```

```
trce        100
iiout         4
typeo         4     no of land classes optimized(part 2)
nbsn          5     no of river classes optimized (part 2)
a1     -999.999     ice factor
a2          1.0     Manning's n correction for instream lakes
a3     -999.999
a4     -999.999
a5        0.985     API coefficient
a6      900.000     Minimum routing time step in seconds
a7        0.500     weighting factor - old vs. new sca value
a8        0.100     min temperature time offset
a9        0.333     max heat deficit to swe ratio
a10       1.000     uz discharge function exponent
a11       0.010
a12       0.000     min precip rate for smearing
     rivtype1  rivtype2  rivtype3  rivtype4  rivtype5
lzf   0.100E-05 0.100E-05 0.100E-05 0.100E-05 0.100E-05
pwr   0.300E+01 0.300E+01 0.300E+01 0.300E+01 0.300E+01
R1n   0.040E+01 0.040E+01 0.040E+01 0.040E+01 0.040E+01
R2n   0.017E+00 0.019E+00 0.013E+00 0.010E+00 0.016E+00
mndr  0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01
aa2   0.110E+00 0.110E+00 0.110E+00 0.110E+00 0.110E+00
aa3   0.430E-01 0.430E-01 0.430E-01 0.430E-01 0.430E-01
aa4   0.100E+01 0.100E+01 0.100E+01 0.100E+01 0.100E+01
theta-0.100E+01-0.100E+01-0.100E+01 0.100E+01-0.100E+01
widep 0.200E+02 0.200E+02 0.200E+02 0.200E+02 0.200E+02
kcond 0.100E+00 0.100E+00 0.100E+00 0.100E+02 0.100E+00
     bare_soil forest    crops     wetland   water     impervious
ds    0.100E+01 0.100E+02 0.200E+01 0.100E+10 0.000E+00 0.100E+01
dsfs  0.100E+01 0.100E+02 0.200E+01 0.100E+10 0.000E+00 0.100E+01
Re    0.400E+00 0.800E+00 0.600E+00 0.100E+00 0.100E+00 0.100E+00
AK    0.300E+01 0.120E+02 0.300E+01 0.400E+03-0.100E+00 0.100E-32
AKfs  0.300E-01 0.120E+01 0.300E+00 0.400E+03-0.100E+00 0.100E-32
retn  0.400E+02 0.700E+02 0.400E+02 0.400E+00 0.100E+00 0.100E-32
ak2   0.200E-02 0.320E-02 0.200E-02 0.200E+00 0.100E-02 0.100E-32
ak2fs 0.800E-02 0.120E-01 0.800E-02 0.750E-10 0.100E-02 0.100E-32
R3    0.197E+00 0.848E-01 0.197E+00 0.898E-01 0.400E-01 0.400E-00
R3fs  0.100E+00 0.100E+00 0.200E+00 0.100E+00 0.400E-01 0.400E-00
r4    0.100E+01 0.100E+02 0.100E+02 0.100E+02 0.100E+02 0.100E+02
ch    0.100E+01 0.900E+00 0.700E+00 0.700E+00 0.600E+00 0.600E+00
MF    0.110E+00 0.100E+00 0.110E+00 0.110E+00 0.150E+00 0.150E+00
BASE -0.250E+01-0.150E+01-0.200E+01-0.200E+00-0.250E+01 0.000E+00
NMF   0.100E+00 0.100E+00 0.100E+00 0.100E+00 0.100E+00 0.100E+00
UADJ  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
TIPM  0.100E+00 0.100E+00 0.100E+00 0.100E+00 0.100E+00 0.100E+00
RHO   0.333E+00 0.333E+00 0.333E+00 0.333E+00 0.333E+00 0.333E+00
WHCL  0.350E-01 0.350E-01 0.350E-01 0.350E-01 0.350E-01 0.350E-01
fmadj     0.000     0.000     0.000     0.000     0.000     0.000
flgev      2.00     1 = pan; 2 = Hargreaves; 3 = Priestley-Taylor
albed      0.11
aw-a       0.18      0.11      0.11      0.11      0.11
fpet       1.00      3.00      2.00      2.00      0.00
ftall      1.00      0.70      0.90      1.00      0.75      0.75
flint        1.        1.        1.        1.        1.
fcap       0.15      0.15      0.15      0.15      0.15
ffcap      0.10      0.10      0.10      0.10      0.10
```

```
spore       0.30       0.30       0.30       0.30       0.30
sublm        00.        00.        00.        00.        00.
tempa        50.
temp3        50.
tton          0.
lat.         50.
mxmn  10.2 12.3 12.1 12.3 14.3 14.2 13.8 14.0 13.1 10.6  8.2  9.3
humid 59.5 60.5 62.5 55.5 50.0 54.5 59.0 58.5 63.5 58.0 64.5 62.5
pres  95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1 95.1
ti2    jan  feb  mar  apr  may  jun  jul  aug  sep  oct  nov  dec
h1    0.04 0.04 0.04 0.04 0.53 0.53 0.53 0.53 0.53 0.28 0.04 0.04
h2    1.13 1.13 1.13 1.13 1.53 1.83 1.83 1.83 1.83 1.13 1.13 1.13
h3    0.58 0.58 0.58 0.58 0.78 0.93 0.93 0.93 0.93 0.58 0.58 0.58
h4    0.58 0.58 0.58 0.58 0.78 0.93 0.93 0.93 0.93 0.58 0.58 0.58
h5    0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
ti3       delta       low       high parameter
AK   -0.200E-01 0.400E+00 0.500E+02 0.300E+01
.
.
.
R2n  -0.200E-01 0.010E+00 0.100E+00 0.040E+00
theta-0.200E-01 0.100E+00 0.600E+00-0.100E+01
theta-0.200E-01 0.100E+00 0.600E+00-0.100E+01
theta-0.200E-01 0.100E+00 0.600E+00-0.100E+01
theta-0.200E-01 0.100E+00 0.600E+00 0.100E+01
theta-0.200E-01 0.100E+00 0.600E+00-0.100E+01
kcond-0.200E-01 0.100E+00 0.900E+00 0.100E+00
kcond-0.200E-01 0.100E+00 0.900E+00 0.100E+00
kcond-0.200E-01 0.100E+00 0.900E+00 0.100E+00
kcond-0.200E-01 0.100E+00 0.900E+00 0.100E+02
kcond-0.200E-01 0.100E+00 0.900E+00 0.100E+00
a5   -0.100E-02 0.980E+00 0.999E+00 0.985E+00
```

The order of the parameters has to be wetland, water & impervious as the last 3 land classes in the par file. In the map file, impervious is first and wetland and water are last.

13.3 Shifting Precipitation Grids? (grid shifting)

The precipitation and temperature fields can be equal in size or larger than the watershed (.shd) domain. This allows the user to create precipitation and temperature files for a large domain and then run any number of small watersheds within this domain using the same meteorological data. Of course the grid size must be the same and the grids should coincide.

This feature is very useful for carrying out a space-based ensemble forecast. The what-if question regarding the path of a predicted storm can be answered by shifting the predicted met and tem files in various directions and calculating the resulting hydrographs. Figure 12.1 shows an example of a grid shifting exercise for an event predicted by MC2 for the Toce River at Candoglio in Italy during the Mesoscale Alpine Project (MAP). The figure shows what would happen if the storm should be centered in various directions away from it's predicted path. The Toce river is in a deep valley in the European Alps and so the storm tract is quite restricted. In flatter terrain of course there would be less topographical influence.

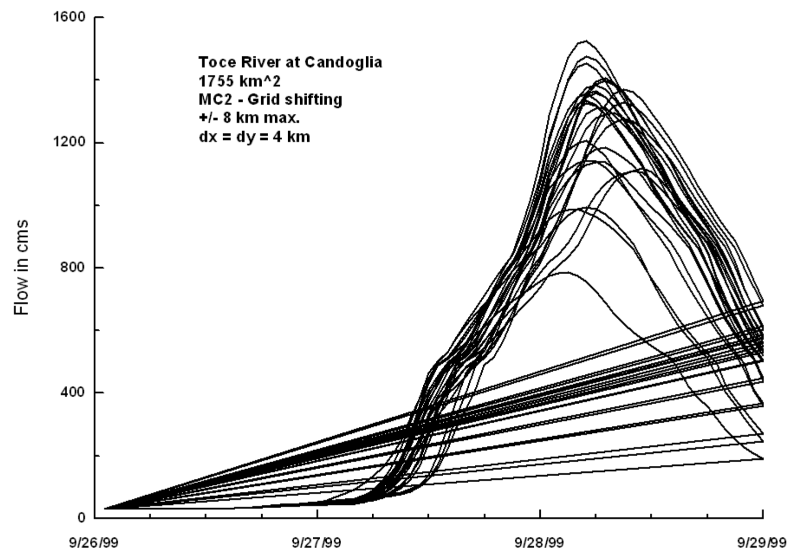


Figure 12.1 – Example of a grid shifting exercise during MAP

The met data (& eventually, temperature grids) can be moved around using a `grdshift.txt` file in the working directory. The file (which is optional) looks like this:

```
    1
 xmin xmax ymin ymax   dx   dy
   -8    8   -8    8    4    4
```

The first line has an interger flag in col 5. For a 0, or for *no file*, there will be no grid shifting and SPL will extract the data for the watershed and ignore the extra data (if any) around the edges. The third line gives the range of the shifting and the step size. In this example, the met data will be shifted up to 8 grid points in all directions in steps of 4 grid points. In other words, SPL will be executed 25 times.

13.4 Tracer Model (Trish Stadnyk's PhD)

Eventually, all sources of water in a computed hydrograph will be traced through the routing process. This will allow the various components to be plotted and compared to isotope data. To use this option, set the trcflg=y in the event file (flag no. 16) and chose the tracer in the par file as shown below. Tracer 100 will trace the ground water (lower zone) contribution to streamflow. The result will be written to the results\tracer.csv file.

Example event file:

```
#
:fileType                    .evt
```

```
:fileVersionNo               9.2
:year                        2000
:month                       10
:day                         01
:hour                        00
#
:snwflg                      y
:sedflg                      n
:vapflg                      y
:smrflg                      n
:resinflg                    n
:tbcflg                      n
:resumflg                    y
:contflg                     n
:routeflg                    n
:crseflg                     y
:Kenueflg                    n
:picflg                      n
:wetflg                      n
:modelflg                    n
:shdflg                      n
:trcflg                      y
:frcflg                      n     (undocumented)
#
.
.
```

Example par file for tracer 100 :

```
# runtime    09:16:00
# rundate  2002-12-16
# from Al - modified classes - Mar 12/06
ver       9.200     parameter file version number
iopt          1     debug level
itype         0
numa          0     optimization 0=no 1=yes
nper          1     opt delta 1-absolute
kc            5     no of times delta halved
maxn          9     max no of trials
ddsflg        0     DDS optimization flag
itrc        100     tracer choice
.
.
.
```

Currently, only the glacier melt and groundwater tracer are available:

0 SUB-GAUGE TRACER
1 GLACIER MELT TRACER
2 LANDCOVER TRACER
3 RAIN-ON-STREAM TRACER AS FXN OF SUB-BASIN
4 FLOW TYPE TRACER (SW+IF+GW) AS FXN OF SUB-BASIN
5 SNOWMELT TRACER (SW+IF) AS FXN OF SUB-BASINgl
100 ORIGINAL GW TRACER (NK) AS FXN OF SUB-BASIN

101 WETLAND FLOW TRACER (qowet2)

13.5 Climate Input Sensitivity << new!!

A common application of WATFLOOD is to model the effect of climate change on the hydrograph. Before carrying out these runs, it may be helpful to determine the sensitivity of the model output. If SPLX.exe finds the file **basin\monthly_climate_deltas.txt the** delta values there will be applied to the temperature and precipitation input.

Example file:

```
+1.0  +1.0  +1.0  +1.0  +1.0  +1.0  +1.0  +1.0  +1.0  +1.0  +1.0  +1.0    dC
10.0  10.0  10.0  10.0  10.0  10.0  10.0  10.0  10.0  10.0  10.0  10.0    %
```

In this case, 1 degree C will be added to each temperature and 10% will be added to each precipitation amount during the corresponding 12 months. The values can be varied by month and can be +ve or –ve.

14 Conversion toGreenKenue Formats (translate)

This Chapter expalins the steps requied to convert old WATFLOOD files to the newGreenKenue formats. The old Formats are no longer supported.

Examples are taken from various watersheds.

- Version 10 and higher will only read theGreenKenue format files tb0, pt2 and r2c
- The file naming convention is **yyyymmdd_xxx.yyy** where xxx denotes the type of data (psn, rag, tag, str, rel, rin, crs, swe, gsm, met ,tem , rff, rch and lkg) and yyy the type of file (tb0, pt2 and r2c)
- A program **trns.exe** is a program that will convert the str, rel, rin, met and tem files from the old formats to the newGreenKenue formats. **trns.exe** will use the same event file as splx.exe simple converting all the files in a run to the new formats.

Steps to convert files toGreenKenue formats:

14.1 STEP 1

BACK UP ALL FILES before you begin!!!!!
Run splx.exe on your existing files and create a reference set of output files.
Copy all files in a watershed folder like SSRB to a new folder SSRB_EF

14.2 STEP 2

With BSN.EXE make a **new_shd.r2c** file and at the same time make a **new_format.map** file if the existing map file is the old format.

If the file is a really old format (non-KENUE format), load it intoGreenKenue and save it as bsnm_ef.map. This will update the format to theGreenKenue format which the bsn.exe program can read.

Edit the bsnm _ef.map file: change the **classCount** to *n*+1 (where *n* was the old class count). The impervious class is now counted a one of the classes. Move the block of data for the impervious class from being the **first** class to the **last.**

Copy or rename **new_shd.r2c** to **bsnm_shd.r2c (**and **new_format.map** file to **bsnm.map** if needed).

Edit the first event file (only) to change the shed file name to the new name:
from **bsnm.shd** to **bsnm_shd.r2c**

14.3 STEP 3

Run **trns.exe** the same way you would run **splx.exe** for one event or a set of events.
This converts the str, rel, rin, met, and tem files to theGreenKenue formats with new extensions _str.tbo, _rel.tbo, _rin.tbo, _met.r2c, and _tem.r2c.

Important notes:

- For UTM coordinates the Zone and Ellipsoid are required in the file headers.
- For LATLONG only the Ellipsoid is required, do not use the Zone line.
- For CARTESIAN coordinates, do not use Zone or Ellipsoid lines.

Use the event file for the files you would like converted. Run the program **trns.exe** just as you would run splx.exe You will see something like this for each event:

I:\spl\ssrb_ef>trns ↵

```
 *******************************************************
 *                                                     *
 *                  WATFLOOD (TM)                      *
 *                                                     *
 *  Program TRANSLATE Version 9.3.00  Jul. 12, 2006    *
 *                                                     *
 *           (c) N. Kouwen, 1972-2006                  *
 *                                                     *
 *******************************************************

 Please see file translate_info.txt for information

 outfiles.txt file not found, defaults used


 New free format shd file expected

 Allocations done in rdpar           9           5


 $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

 Opened event file event\900901.evt
 really old .met format found

 old .met format with comment lines found


 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 IMPORTANT NOTE:
 A new filename        radcl/900901_met.r2c
 has been created from radcl/900901.met
 in accordance with the newGreenKenue compatible file formats

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

```
 Opened unit=         510  filename= radcl/900901_met.r2c

 Old format temperature  file found

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 IMPORTANT NOTE:
 A new filename        tempr/900901_tem.r2c
 has been created from tempg/900901_tag.tb0
 in accordance with the newGreenKenue compatible file formats

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 Opened unit=         515  filename= tempr/900901_tem.r2c

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 IMPORTANT NOTE:
 A new filename        resrl/dummy_rel.tb0
 has been created from resrl/dummy.rel
 in accordance with the newGreenKenue compatible file formats

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 opening fln(537): resrl/dummy_rel.tb0          ---

 Closed unit          537  Filename =   resrl/dummy_rel.tb0
GreenKenue compatible tb0 file format written


 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 IMPORTANT NOTE:
 A new filename        strfw/900901_str.tb0
 has been created from strfw/900901.str
 in accordance with the newGreenKenue compatible file formats

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 opening fln(536): strfw/900901_str.tb0         ---

 Closed unit          536  Filename =   strfw/900901_str.tb0
GreenKenue compatible tb0 file format written

Translating id=348/348 mz=   72/  720
Translating id=348/348 mz=  144/  720
Translating id=348/348 mz=  216/  720
Translating id=348/348 mz=  288/  720
Translating id=348/348 mz=  360/  720
Translating id=348/348 mz=  432/  720
Translating id=348/348 mz=  504/  720
Translating id=348/348 mz=  576/  720
Translating id=348/348 mz=  648/  720
Translating id=348/348 mz=  720/  720
 Closed unit          510  Filename =   radcl/900901_met.r2c
GreenKenue compatible r2c file format written

 Closed unit          515  Filename =   tempr/900901_tem.r2c
GreenKenue compatible r2c file format written
```

```
In .par file, temp3 set too low
Results in underestimated evaporation
Please see manual section 2.4.2
```

14.4 STEP 4

Rename all files to the new yyyymmdd_???.??? formats using a batch command if the names are not in the yyyymmdd format. This renaming is not essential but a really good idea if you do not want to edit all the event files for the new names. The make_evt.exe program will make new event files if you can stick to the yyyymmdd_???.??? Convention – see **step 5**.

Example for the met files:

1. In DOS, make I:\spl\ssrb_ef\radcl the working directory (or on whatever drive you use)

2. Run the command **dir *.met > met_lst.txt** to create a file with a list of the files:

```
 Volume in drive I is allyson250
 Volume Serial Number is 345F-C027

 Directory of I:\spl\ssrb_ef\radcl

10/17\2006  03:12 PM    <DIR>          .
10/17\2006  03:12 PM    <DIR>          ..
10/17\2006  01:02 PM         7,315,422 611001_met.r2c
10/17\2006  01:02 PM         7,079,478 611101_met.r2c
10/17\2006  01:02 PM         7,315,422 611201_met.r2c
10/17\2006  01:02 PM         7,314,678 620101_met.r2c
10/17\2006  01:02 PM         6,606,918 620201_met.r2c
10/17\2006  01:02 PM         7,314,678 620301_met.r2c
10/17\2006  01:02 PM         7,078,758 620401_met.r2c
10/17\2006  01:02 PM         7,314,678 620501_met.r2c
10/17\2006  01:02 PM         7,078,758 620601_met.r2c
10/17\2006  01:02 PM         7,314,678 620701_met.r2c
10/17\2006  01:02 PM         7,314,678 620801_met.r2c
10/17\2006  01:03 PM         7,078,758 620901_met.r2c
10/17\2006  01:03 PM         7,315,422 621001_met.r2c
10/17\2006  01:03 PM         7,079,478 621101_met.r2c..
.
```

3. Edit the **met_lst.txt** file to get something like the following and save the edited list as **met_rn.bat** (an editor with a column mode really helps here – otherwise you can resort to Excel):

```
ren  611001_met.r2c   19611001_met.r2c
ren  611101_met.r2c   19611101_met.r2c
ren  611201_met.r2c   19611201_met.r2c
ren  620101_met.r2c   19620101_met.r2c
ren  620201_met.r2c   19620201_met.r2c
ren  620301_met.r2c   19620301_met.r2c
ren  620401_met.r2c   19620401_met.r2c
ren  620501_met.r2c   19620501_met.r2c
```

```
ren  620601_met.r2c   19620601_met.r2c
ren  620701_met.r2c   19620701_met.r2c
ren  620801_met.r2c   19620801_met.r2c
ren  620901_met.r2c   19620901_met.r2c
ren  621001_met.r2c   19621001_met.r2c
ren  621101_met.r2c   19621101_met.r2c.
.
.
```

4. In DOS, run this batch file:
   I:\spl\ssrb_ef\radcl>**met_rn** ↵

5. Do the same in the tempr, strfw and resrl directories. Use the same met_rn.bat file but replace met with tem, str and rel respectively

14.5 STEP 5

Run the program make_evt.exe in the working directory eg. i:\spl\ssrb_ef

The old event files have old event names that are not compatible with theGreenKenue formats. Instead of editing all the old evt files, just run make_evt.exe in the working directory and a complete set of event files will be created.

```
I:\spl\ssrb_ef>make_evt
 *******************************************************
 *                                                     *
 *                  WATFLOOD (TM)                      *
 *                                                     *
 *         Program make_evt   Apr. 20, 2006            *
 *                                                     *
 *           (c) N. Kouwen, 1972-2006                  *
 *                                                     *
 *******************************************************

 Please see file evt_info.txt for information re: this run
 event selection program
 warning: no damage yet, but if you enter the name
 of an existing event, all old files by that name
 and the series of events following
 will be over written. enter ^c or ^break to stop

 Enter the no of events to create:
360

 No. of months per event file (1 or 12)
1
```

```
 type in start of event - eg. yyyy mm dd hh
 please stick with this convention so radar files work
1960 01 01 00

  will you be running the snow melt  routines? y/n
  Note: temperature data needed for this option
y
 enter the snow conversion factor
 e.g.  1.0 is snow wat. eq. in mm, 25. if in inches

1

  will you be running the evaporation routines? y/n
  Note: temperature data needed for this option
y

 name of shd & par files: eg. gr10k, saug 8 char max

ssrb


 enter the initial soil moisture (0.0-0.33):

 enter -1 if you have antecedent precip. data at precip. gauges
 or enter average watershed value between .0 and .33

.25
 event\19600101.evt              created
 event\event.evt                 created
 event\19600201.evt              created
 event\19600301.evt              created
 event\19600401.evt              created
 event\19600501.evt              created
 event\19600601.evt              created
 event\19600701.evt              created
 event\19600801.evt              created
 event\19600901.evt              created
 event\19601001.evt              created
 event\19601101.evt              created
 event\19601201.evt              created
 event\19610101.evt              created
 event\19610201.evt              created
.
.
.
.
```

Copy **event\event.evt** to **event\1960.evt** and edit to add the list of events to follow after this one. Please see Section 1.3.10

14.6 STEP 6

Create new initial swe and soil moisture tables in the snow1 & moist subdirectories
You can use this example as a template.

Template for the **\snow1\yyyymmdd_crs.pt2** file:
Note: the impervious class is now the last class (11)

```
########################################################################
:FileType pt2 ASCIIGreenKenue 1.0
#
# DataType               GreenKenue PT2 Set
#
:Application             GreenKenue
:Version                  2.1.23
:WrittenBy                NK
:CreationDate             Fri, Jul 14, 2006 08:08 AM
#
#-----------------------------------------------------------------------
#
:Name  Point Snow Water Equivalent
#
:Projection  UTM
:Zone        17
:Ellipsoid   GRS80
#
:SampleTime   1993/01/01 0:00:00.000
#
:UnitConversion             1.0
:InitHeatDeficit            0.33
#
:AttributeName 1 StationName
:AttributeType 1 text
:AttributeName 2 Class1
:AttributeType 2 float
:AttributeName 3 Class2
:AttributeType 3 float
:AttributeName 4 Class3
:AttributeType 4 float
:AttributeName 5 Class4
:AttributeType 5 float
:AttributeName 6 Class5
:AttributeType 6 float
:AttributeName 7 Class6
:AttributeType 7 float
:EndHeader
556000.0 4799000.0 "Cambridge" 1.0 3.0 20.0 1.0 0.0 3.0
547000.0 4932000.0 "Wormwood" 20.0 3.0 1.0 1.0 3.0 0.0
```

Note: Do NOT leave blank characters in any names or key words!!!
Note: the impervious class is now the last class.

Template for the **\moist\yyyymmdd_psm.pt2** file:

```
########################################################################
:FileType pt2 ASCIIGreenKenue 1.0
#
# DataType               GreenKenue PT2 Set
#
:Application             GreenKenue
:Version                  2.1.23
:WrittenBy                watsond
:CreationDate             Mon, Feb 28, 2005 12:08 PM
#
#-----------------------------------------------------------------------
#
:Name  Point Soil Moisture
#
:Projection  UTM
:Zone        17
:Ellipsoid   GRS80
#
:SampleTime   1993/01/01 0:00:00.000
#
:UnitConversion  1.0
#
:AttributeName 1 StationName
:AttributeType 1 text
:AttributeName 2 Class1
:AttributeType 2 float
:AttributeName 3 Class2
:AttributeType 3 float
:AttributeName 4 Class3
:AttributeType 4 float
:AttributeName 5 Class4
:AttributeType 5 float
:AttributeName 6 Class5
:AttributeType 6 float
:AttributeName 7 Class6
:AttributeType 7 float
:EndHeader
558000.0 4820000.0 "GuelphCol" 0.1 0.2 0.3 0.4 0.5 0.6
535000.0 4814000.0 "Waterloo" 0.12 0.22 0.32 0.42 0.52 0.62
554000.0 4843000.0 "ShandDam" 0.15 0.25 0.35 0.45 0.55 0.65
```

Note: Do NOT leave blank characters in any names or key words!!!
Note: the impervious class is now the last class.

14.7 STEP 7

In the working directory (such as I:\spl\gr10k>) run snw.exe and moist.exe to distribute the swe and initial soil moisture for the first event. Both these data sets are gridded for each land cover class in r2c files.

14.7.1

14.8 STEP 8

14.8.1

You should now have all the files necessary to run splx version 10. All the files should be viewable inGreenKenue. You may have to fix the par file – need all values for impervious and convert r2 to r2n (divide by 10) Cross your fingers and run spld.exe

15 PROGRAM REVISIONS

15.1 List of Revisions

```
!     rev. 7.2      sept. 19/94 - added ireach(n) for dwoper input
!     rev. 7.3      dec.  20/94 - added uz & lz drainage in runof4
!     rev. 7.31     jan.  08/95 - set record length for 40 flow sta
!     rev. 7.31.1   jan.  08/95 - set met data source for lapse rate
!     rev. 7.32     feb.  07/95 - added nopt to select opt flow sta
!     rev. 7.33     feb.  20/95 - fixed flow initialization
!     rev. 7.4      feb.  24/95 - added 4 classes - max = 10
!     rev. not completed
!     rev. 7.41     apr.  15/95 - calc strmfl output /w inp fmt
!     rev. 7.42     may.  15/95 - check for div. by 0 in runof4
!     rev. 7.5      seperate snow covered and bare ground
!                   modified for separation of snowcovered ground and
!                   bare ground by Frank Seglenieks  Feb/1995  new
!                   runof5 debugged and intergrated by NK July/1995
!     rev. 7.51     oct.  08/95 - revise init channel flow in SUB
!     rev. 7.52     oct.  23/95 - check for opt constraints in main1
!     rev. 7.6      nov.  13/95 - added andrea's sediment routines
!     rev. 7.7      dec.  25/95 - added Allyson's Columbia routing
!     rev. 7.71     jan.  15/95 - fixed bug in uzs calculation
!                                 uzs-retn =freely draining water
!     rev. 7.72     feb.  04/96 - took flowinit.for from sub.for
!     rev. 7.73     feb.  21/96 - fixed sca-continuity / runof5
!     rev. 7.74     may.  23/96 - include lapse rate & elv ref
!                                 as part of .tmp file
!     rev. 7.75     may.  27/96 - added ak2fs in param & runof5
!     rev. 7.76     jun.  11/96 - # classes increased to 16 + urban
!     rev. 7.77     Jul.  02/96 - fixed snow redistribution
!     Rev. 7.78     Sept. 29/96 - fileio: modified for error checking

!     rev. 7.80     Oct.  29/96 - spl7 added yymmdd.rin for res inflows
!                               - unit = 39   fln = 09
!     rev. 7.81     Nov.  07/96 - rdevt: added flags for stuff
!     rev. 7.83     Nov.  30/96 - fix div. by 0 - check - in lst.for
!     rev. 7.84     Dec.  16/96 - changed pmelt so that snowmelt only
!                                 occurs on snow covered area

!     rev. 8.0     Dec   18/96  - Added Todd Neff's evaporation
!     rev. 8.1     Feb.  15/97  - TBC & RSM (to be continued & resume)
!     rev. 8.2     Feb.  15/97  - parameter selection for opt in main1
!     rev. 8.21    Mar.  15/97  - rain/snow choice tied to base temp
!     rev. 8.22    Mar.  15/97  - glacier MF 2X when new snow=gone
!     rev. 8.23    Mar.  25/97  - fixed bug in route - keep qo2 for res
!     rev. 8.24    Apr.  07/97  - added glacier melt multiplier gladjust
!                               - used uzs-retn to determine freely
!                                 draining water
!     rev. 8.25    May.  22/97  - fixed allocating the basin # in
!                                 flowinit
!     rev. 8.3     May.  22/97  - added the results/outfiles capability
!     rev. 8.31    June   3/97  - added initial uzs values in evap.par
!     rev. 8.32    June  13/97  - bypassed non-flagged parameters in OPT
!     rev. 8.4     July  16/97  - fixed melt routine and added init def
!     rev. 8.41    July  21/97  - added tipm to the optimization table
!     rev. 8.5     Oct.  09/97  - deleted the old interception stuff
!     rev. 8.51    Oct.  09/97  - fixed -ve qr() problem in runof5
!     rev. 8.52    Nov.  14/97  - replaced x4()= in runof
!     rev. 8.60    Nov.  14/97  - added sl2 to the interflow calculation
!     rev. 8.61    Dec.  12/97  - added contflg for statistics cont'n
!     rev. 8.62    Dec.  30/97  - fixed param s/r comb'd et & par flgs
!     rev. 8.70    Jan.  23/98  - added precip adjustment in rain.for
```

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!     rev. 8.71    Feb.  24/98  - added evpflg2 to rdevt.for
!     rev. 8.72    Mar.   5/98  -tw: moved flgevp2 data statement to
!                                spl.for
!     rev. 8.73    Mar.   1/98  - changed mhrd to mhtot in flowinit
!     rev. 8.74    Mar.  31/98  - reinvented fs stuff in opt
!     rev. 8.75    Apr.  27/98  - took da out of the resume file
!     rev. 8.76    May   26/98  - added precadj diagnostic to rain.for
!     rev. 8.77    June   1/98  - added sub-basin error calculation
!     rev. 8.78    July   7/98  - added scalesnw and scaletem to rdevt
!     rev. 8.79    July   7/98  - added 24 water survey format in strfw
!     rev. 8.80    July   9/98  - fixed precip shutdown after smearing
!     rev. 8.81    July  17/98  - precip adjust for T > 0 C only
!     rev. 8.82    July  10/98  - added runoff output option: routeflg
!     rev. 8.83    Sep.  23/98  - moved step args to area2.for
!     rev. 8.84    Sep.  28/98  - added runoff and evap fields to
!                                 spl.txt
!     rev. 8.85    Oct.  12/98  - fixed rain & snow on water class
!     rev. 8.86    Nov.  02/98  - fixed opt problem found by ted.
!                               - fixed tto(n)=0 problem in etin
!     rev. 8.87    Nov.  17/98  - added watbal.for for water balance
!     rev. 8.88    Nov.  23/98  - fmadjust function of degree days
!     rev. 8.89    Nov.  30/98  - simplified uzs parameters
!     rev. 8.90    Dec.  04/98  - input to memory for opt runs
!     rev. 8.91    Dec.  07/98  - read rdevt in sub as well as spl!
!     rev. 8.92    Dec.  24/89  - check for 100% aclass coverage
!     rev. 8.93    Jan.  17/99  - sub modified for spl & watroute
!     rev. 8.94    Feb.  01/99  - crseflg to read resume & snow course
!     rev. 8.94a   Feb.  02/99  - reset heat deficit to 0.0 on Sept.01
!     rev. 8.94b   Feb.  06/99  - temperature correction and stop cmd
!     rev. 8.94c&d Feb.  20/99  - made paf.txt/error.txt default order
!     rev. 8.94e   Feb.  24/99  - added surfer output for error in lst
!     rev. 8.95    Mar.  15/99  - computed mean flows for time increment
!                               - involved getting rid of /kt throughout
!     rev. 8.96    Apr.  26/99  - lower zone function related to nbsn
!     rev. 8.96.1  May   12/99  - added ireport for reporting interval
!     rev. 8.97    July  12/99  - demonstration copy addition
!     rev. 8.98    July  15/99  - met grid shifting for weather models
!     rev. 8.99    Aug.  18/99  - replaced err= with iostat= for f90
!     rev. 8.99a   Jul.     99  - lat-long watershed data
!     rev. 8.99b   Sept. 27/99  - divvy up interflow & drainae
!     rev. 8.99c   Oct.   5/99  - irough -> sl2 input in shed
!     rec. 8.99e   Nov.  29/99  - heat deficit initatialization
!     rev. 8.99f   Jan.   7/00  - changed uzs calcs re: shari's data
!     rev. 8.99g   Feb.   7/00  - added ttoinit to init evaporation
!     rev. 8.99k  feb. 15\2001  - fixex deficit calc in melt.for see9.06k
!     rev. 8.99l  Oct.    2001  - fixed reservoir release timing in spl8
!     rev. 8.99mm Dec. 13\2001-     added check for <= 0 init res flow
!     rev. 8.99n  Dec. 31\2001-     fixed nat. res initial flow (JW)
!     rev. 9.0     Mar.  21/00  - ts: converted to Fortran 90
!                               - added dynamic memory allocation
!                               - added wfo file forGreenKenue
!                  Fall   2000  - added wetland routing model
!     rev. 9.01    Aug.   1/00  - added look up for minimum temperature
!                                 and function to calculate RH
!     rev. 9.02    Oct.   5/00  - added option to debug on one grid
!     rev. 9.03    Jan.   7/01  - set min precip rate for smearing
!     rev. 9.04    Jan    16/01 - fixed grid diagnosis in flowinit
!     rev. 9.05    Feb.   6/01  - chngd unit 61 to snw1.csv for surfer
!     rev. 9.06k   Feb.  15/01  - fixed deficit calc in melt (rem. qlz.txt) =8.99k
!     rev. 9.07    Mar.  14/01  - fixed use of opt par's  for numa=0
!     rev. 9.08    Mar.  26/01  - checked limits on heat def.
!     rev. 9.08.01 Apr.   3/01  - check wetland designation in param
!     rev. 9.1     May    7/01  - updated Luis's sed & nutrient stuff
!     rev  9.1.02  July  12/01  - put in dacheck in flowinit for wetland flag
!     rev  9.1.03  July  24/01  - added polinomial to reservoir routing
!     rev. 9.1.04  Oct.   4/01  - added A7 for weighting old/new sca in melt
!                               - fixed Jan. 17/02 - didn't work before
!     rev. 8.99n   Dec.31\2001  -     fixed nat. res initial flow (JW)
!     rev. 9.1.05  Oct.   4/01  - new format parameter file
!     rev. 9.1.06  Oct.  16/01  - nrvr added to area3 to set # river types
!     rev. 9.1.07  Jan.   3/02  - check that outlet is in a lake
```

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!     rev. 9.1.08  Jan.  17/02  - fixed rev. 9.1.04
!     rev. 9.1.09  Jan.  21/02  - fixed reservoir release timing in spl9 see8.99l
!     rev. 9.1.10  Jan.  29/02  - flow nudging added for nopt(l)=2
!     rev. 9.1.11  Feb.  07/02  - fixed bug in reservoir routing
!     rev. 9.1.12  Mar.  15/02  - added xdelta and ydelta forGreenKenue
!     rev. 9.1.13  Mar.  23/02  - fixed resv. timing, moved to beginning of dt
!     rev. 9.1.14  Mar.  24/02  - fixed wetland min time step & outflow
!     rev. 9.1.15  Apr.  02/02  - Luis' sediment stuff runs. Not checked with old version.
!     rev. 9.1.16  Apr.  03/02  - Added wetland conditional to select river w/wo wetland
!     rev. 9.1.17  May   05/02  - Some tidying up
!     rev. 9.1.18  Jun.  03/02  - Added sub-watershed modelling capability
!     rev. 9.1.19  Jun.  22/02  - Added A9 as the max heat deficit/swe ratio
!     rev  9.1.20  Jun.  25/02  - Added A10 as the power on the UZ discharge function
!     rev. 9.1.21  Jun.  28/02  - Added wetland storage & outflow to the wfo file
!     rev. 9.1.22  Jul.  22/02  - Added results\error.r2s file forGreenKenue_Hydrologic
!     rev. 9.1.23  Jul.  23/02  - Added control for nudging in event #1
!     rev  9.1.24  Sep.  11/02  - Added scaleallsnw to set snw scale in event 1
!     rev  9.1.25  Sep.  11/02  - Added A11 as bare ground equiv. vegn height
!     rev. 9.1.26  Sep.  11/02  - fixed wetland evaporation re: uzsi
!     rev. 9.1.27  Sept. 19/02  - Added isbaflg
!     rev. 9.1.28  Sept. 19/02  - Added shedlfg to replace the bsnm.shd file
!     rev. 9.1.29  Nov.  07/02  - Changed the threshold flow values for error calculations
!     rev. 9.1.30  Nov.  08/02  - added q1, qint, drng & qlz to the wfo file
!     rev. 9.1.31  Nov.  13/02  - Fixed the wetland Q to account for wetland area
!     rev. 9.1.32  Nov.  20/02  - Fixed fpetmon() wrt. h()
!     rev. 9.1.33  Dec.  05/02  - Fixed instability in wetland flow
!     rev. 9.1.34  Dec.  23/02  - AddedGreenKenue1flg - if kenueflg='a' for 1st id then 'y' for
all events
!     rev. 9.1.35  Dec.  26/02  - Added wetland & channel heights to the wfo file
!     rev. 9.1.36  Jan.  28/03  - Fixed wetland init condition in flowinit
!     rev. 9.1.37  Mar.  22/03  - Option to turn off leakage by setting LZF < 0.0
!     rev. 9.1.38  Mar.  31/03  - revised str header and routing dt selectable
!     rev. 9.1.39  Apr.  06/03  - Fixed wetland routing when channel is dry
!     rev. 9.1.40  Apr.  24/03  - Min time step A6 read in strfw over rides the A6 from the par
file
!     rev. 9.1.41  May   15/03  - Event average flows output to unit=75
!     rev. 9.1.42  May   31/03  - Tracer module added - first try
!     rev. 9.1.43  Jun.  01/03  - Fixed the qdwpr.txt function - re: last grid in lake
!     rev. 9.1.44  Jun.  11/03  - Added Cumulative precip to the wfo file
!     rev. 9.1.45  Jun.  11/03  - WATROUTE: runoff, recharge and leakage files added
!     rev. 9.1.46  Jul.  17/03  - WATFLOOD LITE incorporated
!     rev. 9.1.47  July  24/03  - TS: Tracer s/r deallocations added
!     rev. 9.1.48  Dec.  08/03  - NK: sumrechrge() added to get total recharge
!     REV. 9.1.49  Nov.  23/03 - TS: Added wetlands to GW Tracer + Wetland Tracer
!     rev. 9.1.50  Jan.  14/04  - NK: version number added to the wfo_spec.txt file
!     rev. 9.1.51  Jan.  28/04  - NK: added iz.ne.jz conditional toGreenKenue output
!     rev. 9.1.52  Mar.  11/04  - NK: continuous water quality modelling
!     rev. 9.1.53  Mar.  14/04  - NK: hasp key configured
!     rev. 9.1.54  Apr.  12/04  - NK: SEDFLG set for multiple events at event No. 1
!     rev. 9.1.55  Jun.  12/04  - NK: write new str files to strfw\newfmt folder.
!     rev. 9.1.56  Jun.  18/04  - NK: write new rel & rin files to resrl\newfmt folder.
!     rev. 9.1.57  Jul.  06/04  - NK: Fixed major bug in shed.for max instead of min
!     rev. 9.1.58  Jul.  12/04  - NK: New header for the .shd file
!     rev. 9.1.59  Jul.  15/04  - NK: split rerout into two parts: rdresv & rerout
!     rev. 9.1.60  Jul.  27/04  - NK: reversed definitions for sl1 & sl2 Int. Slope
!     rev. 9.1.61  Aug.  25/04  - NK: Check for repeated met data in RAIN
!     rev. 9.1.62  Sep.  08/04  - NK: Fixed the conversion factor in SNW.FOR  (cnv)
!     rev. 9.1.63  Sep.  29/04  - NK: Added iopt_start as an arg for quick filecheck
!     rev. 9.1.64  Oct.  03/04  - NK: Coded up new header in ragmet.for
!     rev. 9.1.65  Oct.  03/04  - NK: Coded up new header for snow course file
!     rev. 9.1.66  Oct.  17/04  - NK; pet*ftall for loss from water instead of pet
!     rev. 9.1.67  Oct.  21/04  - NK; added unit 80 for lake_stor & lake_flow
!     rev. 9.1.68  Dec.  19/04  - NK: rewrote rdflow c/w memory allocation
!     rev. 9.1.69  Dec.  19/04  - NK: rewrote rdresv c/w memory allocation
!     rev. 9.1.70  Dec.  21/04  - NK: rewrote rdrain c/w memory allocation
!     rev. 9.1.71  Dec.  28/04  - NK: rewrote rdtemp c/w memory allocation
!     rev. 9.1.72  Dec.  28/04  - NK: fix bug in rdresv setting reach #
!     rev. 9.1.73  Jan.  25/05  - NK: rewrote rdcrse c/w memory allocation
!     rev. 9.1.74  Feb.  08/05  - NK: trashed rscrse replaced with rdswe
!     rev. 9.1.75  Feb.  08/05  - NK: added rdgsm (gridded soil moisture)
!     rev. 9.1.76  Mar.  09/05  - NK: separated glacier parameters in par file
```

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!     rev. 9.1.77  Mar.  07/05  - NK: added .psm .gsm & .glz  files
!     rev. 9.1.78  Mar.  15/05  - NK: added WQD file to event file
!     rev. 9.1.79  Mar.  30/05  - NK: ktri to area2 for reservoir inflow dt
!     rev. 9.1.80  Mar.  31/05  - NK: added sublimation   (sublim)
!     rev. 9.1.81  Apr.  04/05  - NK: added sublimation,et and etfs to wfo file
!     rev. 9.2     Jun.  02/05  - NK: Numerous changes to program organization
!     rev. 9.2.01  Jun.  29/05  - NK: Added write_r2s
!     rev. 9.2.02  Jun.  29/05  - NK: Added read_r2s
!     rev. 9.2.03  Jul.  11/05  - NK: Added s/r precip_adjust
!     rev. 9.2.04  Jul.  13/05  - NK: allocation check for resrl
!     rev. 9.2.05  Jul.  15/05  - NK: reversed order of reading resume file
!     rev. 9.2.05  Jul.  27/05  - NK: initialized delta in s/r compute_error
!     rev. 9.2.06  Jul.  28/05  - NK: normalized error with da for optimization
!     rev. 9.2.07  Jul.  29/05  - NK: soilinit moved from runoff to sub
!     rev. 9.2.08  Jul.  29/05  - NK: opt work-around in options
!     rev. 9.2.09  Sep.  11/05  - NK: removed write_par.for from rdpar.for
!     rev. 9.2.10  Sep.  11/05  - NK: unlimited comments on .shd & .map files
!     rev. 9.2.11  Sep.  15/05  - NK: added Manning's n  r1n & r2n
!     rev. 9.2.12  Sep.  15/05  - NK: added EXCEL eqn to flowinit
!     rev. 9.2.13  Sep.  28/05  - NK: added freeze and break up to route
!     rev. 9.2.14  Sep.  29/05  - NK: Added control for opt in event #1
!     rev. 9.2.15  Sep.  30/05  - NK: Fixed bug for opt in flowinit
!     rev. 9.2.16  Oct.  10/05  - NK: Fixed bug for widep in rdpar
!     rev. 9.2.17  Oct.  11/05  - NK: Fixed bug for .str bounds in route
!     rev. 9.2.18  Oct.  27/05  - NK: Fixed bug in flowinit (init spike)
!     rev. 9.2.19  Oct.  28/05  - NK: Compute daily & monthly flows
!     rev. 9.2.20  Oct.  28/05  - NK: WFO_SPEC - reporting start & finish times
!     rev. 9.1.21  Jun.  28/02  - Added wetland storage & outflow to the wfo file
!     rev. 9.1.22  Jul.  22/02  - Added results\error.r2s file forGreenKenue_Hydrologic
!     rev. 9.1.23  Jul.  23/02  - Added control for nudging in event #1
!     rev  9.1.24  Sep.  11/02  - Added scaleallsnw to set snw scale in event 1
!     rev  9.1.25  Sep.  11/02  - Added A11 as bare ground equiv. vegn height
!     rev. 9.1.26  Sep.  11/02  - fixed wetland evaporation re: uzsi
!     rev. 9.1.27  Sept. 19/02  - Added isbaflg
!     rev. 9.1.28  Sept. 19/02  - Added shedlfg to replace the bsnm.shd file
!     rev. 9.1.29  Nov.  07/02  - Changed the threshold flow values for error calculations
!     rev. 9.1.30  Nov.  08/02  - added q1, qint, drng & qlz to the wfo file
!     rev. 9.1.31  Nov.  13/02  - Fixed the wetland Q to account for wetland area
!     rev. 9.1.32  Nov.  20/02  - Fixed fpetmon() wrt. h()
!     rev. 9.1.33  Dec.  05/02  - Fixed instability in wetland flow
!     rev. 9.1.34  Dec.  23/02  - AddedGreenKenue1flg - if kenueflg='a' for 1st id then 'y' for
all events
!     rev. 9.1.35  Dec.  26/02  - Added wetland & channel heights to the wfo file
!     rev. 9.1.36  Jan.  28/03  - Fixed wetland init condition in flowinit
!     rev. 9.1.37  Mar.  22/03  - Option to turn off leakage by setting LZF < 0.0
!     rev. 9.1.38  Mar.  31/03  - revised str header and routing dt selectable
!     rev. 9.1.39  Apr.  06/03  - Fixed wetland routing when channel is dry
!     rev. 9.1.40  Apr.  24/03  - Min time step A6 read in strfw over rides the A6 from the par
file
!     rev. 9.1.41  May   15/03  - Event average flows output to unit=75
!     rev. 9.1.42  May   31/03  - Tracer module added - first try
!     rev. 9.1.43  Jun.  01/03  - Fixed the qdwpr.txt function - re: last grid in lake
!     rev. 9.1.44  Jun.  11/03  - Added Cumulative precip to the wfo file
!     rev. 9.1.45  Jun.  11/03  - WATROUTE: runoff, recharge and leakage files added
!     rev. 9.1.46  Jul.  17/03  - WATFLOOD LITE incorporated
!     rev. 9.1.47  July  24/03  - TS: Tracer s/r deallocations added
!     rev. 9.1.48  Dec.  08/03  - NK: sumrechrge() added to get total recharge
!     REV. 9.1.49  Nov.  23/03 - TS: Added wetlands to GW Tracer + Wetland Tracer
!     rev. 9.1.50  Jan.  14/04  - NK: version number added to the wfo_spec.txt file
!     rev. 9.1.51  Jan.  28/04  - NK: added iz.ne.jz conditional toGreenKenue output
!     rev. 9.1.52  Mar.  11/04  - NK: continuous water quality modelling
!     rev. 9.1.53  Mar.  14/04  - NK: hasp key configured
!     rev. 9.1.54  Apr.  12/04  - NK: SEDFLG set for multiple events at event No. 1
!     rev. 9.1.55  Jun.  12/04  - NK: write new str files to strfw\newfmt folder.
!     rev. 9.1.56  Jun.  18/04  - NK: write new rel & rin files to resrl\newfmt folder.
!     rev. 9.1.57  Jul.  06/04  - NK: Fixed major bug in shed.for max instead of min
!     rev. 9.1.58  Jul.  12/04  - NK: New header for the .shd file
!     rev. 9.1.59  Jul.  15/04  - NK: split rerout into two parts: rdresv & rerout
!     rev. 9.1.60  Jul.  27/04  - NK: reversed definitions for sl1 & sl2 Int. Slope
!     rev. 9.1.61  Aug.  25/04  - NK: Check for repeated met data in RAIN
!     rev. 9.1.62  Sep.  08/04  - NK: Fixed the conversion factor in SNW.FOR  (cnv)
```

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!     rev. 9.1.63  Sep.  29/04  - NK: Added iopt_start as an arg for quick filecheck
!     rev. 9.1.64  Oct.  03/04  - NK: Coded up new header in ragmet.for
!     rev. 9.1.65  Oct.  03/04  - NK: Coded up new header for snow course file
!     rev. 9.1.66  Oct.  17/04  - NK; pet*ftall for loss from water instead of pet
!     rev. 9.1.67  Oct.  21/04  - NK; added unit 80 for lake_stor & lake_flow
!     rev. 9.1.68  Dec.  19/04  - NK: rewrote rdflow c/w memory allocation
!     rev. 9.1.69  Dec.  19/04  - NK: rewrote rdresv c/w memory allocation
!     rev. 9.1.70  Dec.  21/04  - NK: rewrote rdrain c/w memory allocation
!     rev. 9.1.71  Dec.  28/04  - NK: rewrote rdtemp c/w memory allocation
!     rev. 9.1.72  Dec.  28/04  - NK: fix bug in rdresv setting reach #
!     rev. 9.1.73  Jan.  25/05  - NK: rewrote rdcrse c/w memory allocation
!     rev. 9.1.74  Feb.  08/05  - NK: trashed rscrse replaced with rdswe
!     rev. 9.1.75  Feb.  08/05  - NK: added rdgsm (gridded soil moisture)
!     rev. 9.1.76  Mar.  09/05  - NK: separated glacier parameters in par file
!     rev. 9.1.77  Mar.  07/05  - NK: added .psm .gsm & .glz  files
!     rev. 9.1.78  Mar.  15/05  - NK: added WQD file to event file
!     rev. 9.1.79  Mar.  30/05  - NK: ktri to area2 for reservoir inflow dt
!     rev. 9.1.80  Mar.  31/05  - NK: added sublimation   (sublim)
!     rev. 9.1.81  Apr.  04/05  - NK: added sublimation,et and etfs to wfo file
!     rev. 9.2     Jun.  02/05  - NK: Numerous changes to program organization
!     rev. 9.2.01  Jun.  29/05  - NK: Added write_r2s
!     rev. 9.2.02  Jun.  29/05  - NK: Added read_r2s
!     rev. 9.2.03  Jul.  11/05  - NK: Added s/r precip_adjust
!     rev. 9.2.04  Jul.  13/05  - NK: allocation check for resrl
!     rev. 9.2.05  Jul.  15/05  - NK: reversed order of reading resume file
!     rev. 9.2.05  Jul.  27/05  - NK: initialized delta in s/r compute_error
!     rev. 9.2.06  Jul.  28/05  - NK: normalized error with da for optimization
!     rev. 9.2.07  Jul.  29/05  - NK: soilinit moved from runoff to sub
!     rev. 9.2.08  Jul.  29/05  - NK: opt work-around in options
!     rev. 9.2.09  Sep.  11/05  - NK: removed write_par.for from rdpar.for
!     rev. 9.2.10  Sep.  11/05  - NK: unlimited comments on .shd & .map files
!     rev. 9.2.11  Sep.  15/05  - NK: added Manning's n  r1n & r2n
!     rev. 9.2.12  Sep.  15/05  - NK: added EXCEL eqn to flowinit
!     rev. 9.2.13  Sep.  28/05  - NK: added freeze and break up to route
!     rev. 9.2.14  Sep.  29/05  - NK: Added control for opt in event #1
!     rev. 9.2.15  Sep.  30/05  - NK: Fixed bug for opt in flowinit
!     rev. 9.2.16  Oct.  10/05  - NK: Fixed bug for widep in rdpar
!     rev. 9.2.17  Oct.  11/05  - NK: Fixed bug for .str bounds in route
!     rev. 9.2.18  Oct.  27/05  - NK: Fixed bug in flowinit (init spike)
!     rev. 9.2.19  Oct.  28/05  - NK: Compute daily & monthly flows
!     rev. 9.2.20  Oct.  28/05  - NK: WFO_SPEC - reporting start & finish times
!     rev. 9.2.21  Nov.  11/05  - NK: Set nopt in first event .str file
!     rev. 9.2.22  Nov.  15/05  - NK: Fixed hmax bug in rdpar
!     rev. 9.2.23  Nov.  22/05  - NK: Fixed res(n)=0 bug in route
!     rev. 9.2.24  Dec.  07/05  - BT: DDS optimization
!     rev. 9.2.25  Dec.  13/05  - NK:GreenKenue r2c gridded soil moisture
!     rev. 9.2.26  Dec.  23/05  - NK: Fixed reservoir outlet location bug
!     rev. 9.2.27  Jan.  20/06  - NK: Separated header read in rdtemp
!     rev. 9.2.28  Jan.  30/06  - NK: Added low slope a4 for grids with water
!     rev. 9.2.29  Feb.  07/06  - NK: Read resv coeff first event only
!     rev. 9.2.30  Feb.  07/06  - NK: Added class_distribution.txt to output
!     rev. 9.2.31  Feb.  09/06  - NK: Added area check to rdresume
!     rev. 9.2.32  Feb.  10/06  - NK: Added area_check.csv to output
!     rev. 9.2.33  Feb.  14/06  - NK: str stations from first event ONLY!!
!     rev. 9.2.34  Mar.  21/06  - NK: Activated glacier tracer1
!     rev. 9.2.35  Mar.  22/06  - NK: Glacier flow bypasses wetlands
!     rev. 9.2.36  Mar.  30/06  - NK: Scaleallsnow changed to change precip snow
!     rev. 9.2.37  Mar.  31/06  - NK: Removed impervious area as special class
!     rev. 9.2.38  Apr.  28/06  - NK: Lower bound set on a12 for smearing
!     rev. 9.2.39  May.  09/06  - NK: t added to route & rerout arg list
!     rev. 9.2.40  Jun.  09/06  - NK: added tto(),ttomin(),ttomax() to resume
!     rev. 9.2.41  Jun.  15/06  - NK: changed the resin.txt file to resin.csv
!     rev. 9.2.42  Jun.  20/06  - NK: water class included in the water balance
!     rev. 9.2.43  Jun.  21/06  - NK: fixed spikes in route
!     rev. 9.3.02  Jul.  18/06  - NK: converted runof, rchrg & lkage to r2c
!     rev. 9.3.03  Sep.  09/06  - NK: read s(i,j) from table instead of grid
!     rev. 9.3.04  Oct.  24/06  - NK: routing parameters dim to na in rte
!     rev. 9.3.05  Nov.  13/06  - NK: adder write_flowinit.for to flowinit.for
!     rev. 9.3.06  Dec.  17/06  - NK: added precip adjustment for bias
!     rev. 9.3.07  Dec.  29/06  - NK: added sum_precip for whole domain
!     rev. 9.3.08  Jan.  15/07  - NK: added lzs_init_new.r2c output to sub.for
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!     rev. 9.3.09  Jan.  17/07  - NK: all file name lenghts = 60 in area12
!     rev. 9.3.10  Jan.  29/07  - NK: routing pars changed to gridded values
!     rev. 9.3.11  Feb.  28/07  - NK: ch_par added / event file ver = 9.5
!     rev. 9.4.01  Apr.  17/07  - NK: added deltat_report for gridflow.r2c
!     rev. 9.4.02  Apr.  18/07  - NK: moved rf, rffs from areawq to area1
!     rev. 9.4.03  Apr.  18/07  - NK: For water ev(n,ii)=pet(n,ii)*fpet(ii)
!     rev. 9.4.04  Apr.  23/07  - NK: moved allocate for melt from melt > spl
!     rev. 9.4.05  May.  04/07  - NK: revised timer for julian day calc.
!     rev. 9.4.06  May.  09/07  - NK: replaced por with spore(n,ii) in runof6
!     rev. 9.4.07  May.  15/07  - NK: converted opt to gridded routing parameters
!     rev. 9.4.08  May.  29/07  - NK: changed baseflow argument list
!     rev. 9.4.09  Jun.  19/07  - NK: added lake_area as a variable for iso
!     rev. 9.4.10  Jun.  19/07  - NK: adjusted frac for channel water area
!     rev. 9.4.11  Jun.  22/07  - NK: reordered rerout for glake
!     rev. 9.4.12  Jul.  06/07  - NK: put qr + qstream - strloss back in runof6
!     rev. 9.4.13  Jul.  09/07  - NK: modified lzs to account for lake area (flowinit)
!     rev. 9.4.14  Jul.  09/07  - NK: added lake loss file
!     rev. 9.4.15  Jul.  31/07  - NK: moved stuff from resume -> soil & flow init
!     rev. 9.5     Sep.  07/07  - NK: changed wetland/channel routing
!     rev. 9.5.01  Oct.  15/07  - NK: added wetland continuity check
!     rev. 9.5.02  Oct.  21/07  - NK: set init qdwpr=0.0 in route
!     rev. 9.5.03  Dec.  09/07  - NK: added reads for precip isotopes
!     rev. 9.5.04  Dec.  27/07  - NK: fixed bug in wetland routing
!     rev. 9.5.05  Jan.  13/08  - NK: added check for rec() in spl
!     rev. 9.5.06  Feb.  05/08  - NK: added pool and pool_o in rdpar & route
!     rev. 9.5.07  Feb.  05/08  - NK: fixed double counting of strloss & qstream
!     rev. 9.5.08  Feb.  08/08  - NK: new event parser
!     rev. 9.5.09  Feb.  12/08  - NK: added evap.r2c to the output files
!     rev. 9.5.10  Feb.  12/08  - NK: added water_area in lake_evap
!     rev. 9.5.11  Feb.  12/08  - NK: added -ve storage check for reservoirs
!     rev. 9.5.12  Feb.  13/08  - NK: added evaporation input file with read_r2c
!     rev. 9.5.13  Feb.  25/08  - NK: changed tolerance for coordinate check to .gt.0.001
!     rev. 9.5.14  Feb.  26/08  - NK: padded rel file for missing data
!     rev. 9.5.15  Feb.  28/08  - NK: fixed tdum & xdum for proper grid area in lat-long
!     rev. 9.5.16  Feb.  28/08  - NK: moved precip_adjust to sub
!     rev. 9.5.17  Feb.  28/08  - NK: moved scale snow from sub to process rain
!     rev. 9.5.18  Mar.  03/08  - NK: added conv to options & sub argument list
!     rev. 9.5.19  Mar.  05/08  - NK: prevented use of tracer * iso models with nudging
!     rev. 9.5.20  Mar.  06/08  - NK: added resvstore for iso model
!     rev. 9.5.21  Mar.  06/08  - NK: fixed dtmin for first time step each event
!     rev. 9.5.22  Mar.  12/08  - NK: added grdflg to print gridded flow, swe & evap
!     rev. 9.5.23  Mar.  12/08  - NK: fixed allocation error in read_resv_ef
!     rev. 9.5.24  Mar.  18/08  - NK: fixed missing data in read_resl_ef.f
!     rev. 9.5.25  Mar.  20/08  - NK: fixed lake initiation - moved code route -> flowinit
!     rev. 9.5.26  Apr.  04/08  - NK: added Julian day calc. to read_evt
!     rev. 9.5.27  Apr.  15/08  - NK: fixed allocation for chnl in rdpar
!     rev. 9.5.28  Apr.  15/08  - NK: fixed allocation for inbsnflg in flowinit
!     rev. 9.5.29  May.  26/08  - NK: fixed initialization in read_resv_ef
!     rev. 9.5.30  May.  26/08  - NK: conv back in read_rain & process_rain arg. list
!     rev. 9.5.31  May.  27/08  - NK: moved totsnw(n) computation in sub
!     rev. 9.5.32  Jun.  04/08  - NK: compute reservoir levels
!     rev. 9.5.33  Sep.  12/08  - NK: added column labels for grapher
                                    in flow_station_location.xyz
!     rev. 9.5.34  Sep.  17/08  - NK: fixed lake area in flowinit
!     rev. 9.5.35  Sep.  22/08  - NK: moved flow_sta_location to flowinit
!     rev. 9.5.36  Oct.  01/08  - NK: fixed ires bug for unevent dx & dy in read_resv
!     rev. 9.5.37  Oct.  14/08  - NK: added deltat_report to lake_sd.csv file write
!     rev. 9.5.38  Oct.  14/08  - NK: added optional coef6 & 7 to rel file for lake levels
!     rev. 9.5.39  Oct.  15/08  - NK: fixed bug in reservoit routing
!     rev. 9.5.40  Oct.  21/08  - NK: added diversions to rerout
!     rev. 9.5.41  Oct.  22/08  - NK: read in reservoir coefficients each event
!     rev. 9.5.42  Oct.  22/08  - NK: added b7() as the initial lake surface elevation
!     rev. 9.5.43  Oct.  27/08  - NK: changed bottom part of par file to be free format
!     rev. 9.5.44  Oct.  27/08  - NK: removed code & obj modules for hasp & rainbow
!     rev. 9.5.45  Dec.  16/08  - NK: added various error calculations –
                                    user's choice with errflg
!     rev. 9.5.46  Dec.  23/08  - NK: trying to fix problem with -ve storage.
                                    Changed conditional   to .lt.
!     rev. 9.5.47  Dec.  26/08  - NK: add flwinitflg to warn about initial flows
!     rev. 9.5.48  Dec.  26/08  - NK: added event_fln() to allow unlimited events
!     rev. 9.5.49  Dec.  31/08  - NK: changed conditional to read releases in rerout
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!     rev. 9.5.50  Jan.  05/09  - NK: read evap data for reaches only
!     rev. 9.5.51  Jan.  13/09  - NK: added reading yyyymmdd_ill.pt2 for all lakes
!     rev. 9.5.52  Jan.  20/09  - NK: added reading yyyymmdd_div.pt2 for diversions
!     rev. 9.5.53  Jan.  20/09  - NK: undid rev. 9.5.40
!     rev. 9.5.54  Feb.  11/09  - NK: undid rev. 9.2.28
!     rev. 9.5.55  Feb.  11/09  - NK: Correct R2n for instream lakes
!     rev. 9.5.56  Mar.  26/09  - NK: Fix bug with month in yearly events
!     rev. 9.5.57  Apr.  13/09  - NK: added ntrlflg for natural lake flows
!     rev. 9.5.58  Apr.  16/09  - NK: added nudgeflg for forcing gauge flows
!     rev. 9.5.59  Jul.  26/09  - NK: added fpet_lake for each lake in ill file
!     rev. 9.5.60  Sep.  01/09  - NK: added deltat_report for lake_sd.csv file
!     rev. 9.5.61  Sep.  03/09  - NK: bug/eloss - added water class for wfo weighted et
!     rev. 9.5.62  Sep.  04/09  - NK: new tb0 file for DW routing
!     rev. 9.5.63  Sep.  04/09  - NK: moved lapse rate from melt.f to process_temp.f
!     rev. 9.5.64  Sep.  16/09  - NK: corrected nudging wrt first event
!     rev. 9.5.65  Sep.  26/09  - NK: lapse rate changed from dC per 100 m to dC per m
!     rev. 9.5.66  Oct.  06/09  - NK: fixed bug in flowinit for init flows < 1.0
!     rev. 9.5.67  Oct.  06/09  - NK: fixed bug in rerout
!     rev. 9.5.68  Oct.  07/09  - NK: debugged read_resvin_ef.f
!     rev. 9.5.69  Oct.  10/09  - NK: added xcount & ycount to error & paf files
!     rev. 9.5.70  Oct.  11/09  - NK: fixed timer for r2c frames (use year_now)
!     rev. 9.5.71  Oct.  12/09  - NK: fixed bug in lst for setting value for nhyd(,)
!     rev. 9.5.72  Oct.  12/09  - NK: fixed bug in rdpar setting init values for fpet & ftal
!     rev. 9.5.73  Oct.  12/09  - NK: bypass using lake levels when optimizing
!     rev. 9.5.74  Oct.  21/09  - NK: in opt - made optim abs(optim)
!     rev. 9.5.75  Oct.  26/09  - NK: commented "deallocate in sub for watroute reads
!     rev. 9.5.76  Oct.  26/09  - NK: fixed basin exclusion for opt if resin present
!     rev. 9.5.77  Oct.  26/09  - NK: fixed some inits for out of basin gauges
!     rev. 9.5.78  Nov.  04/09  - NK: matched resvin locations to reach numbers
!     rev. 9.5.79  Nov.  04/09  - NK: added resumflg='s' for read_soilinit ONLY
!     rev. 9.5.80  Dec.  20/09  - NK: added swe_locations.txt file for swe input
!     rev. 9.5.81  Jan.  16/10  - NK: allow reservoirs outside watershed in resv file
!     rev. 9.5.82  Jan.  26/10  - NK: replaced error check for inflow locations
!     rev. 9.5.83  Feb.  17/10  - NK: non_basin exclusion for dds_flag=1
!     rev. 9.6.01  Mar.  01/10  - NK: DDS capability added
!     rev. 9.6.01  Mar.  01/10  - NK: rlake parameter added for Manning n correction
!     rev. 9.6.02  Mar.  15/10  - NK: add sublimation to optimization
!     rev. 9.6.02  Mar.  23/10  - NK: add cumm_domain_precip
!     rev. 9.6.03  Mar.  31/10  - NK: replaced leakage.dat by nbs.tb0 fln(79)
!     rev. 9.6.04  Apr.  05/10  - NK: fixed filename carry over in read_evt
!     rev. 9.6.05  Apr.  06/10  - NK: added store_error_flag for -ve storage grids
!     rev. 9.6.06  Apr.  18/10  - NK: added glacier adjust for optimization
!     rev. 9.7.00  May.  26/10  - NK: dds with pre-emption
!     rev. 9.7.01  Jun.  09/10  - NK: fixed error.xyz & error.r2s
!     rev. 9.7.02  Jun.  24/10  - NK: fixed bug in rdpar for ntype for imp area
!     rev. 9.7.03  Jun.  24/10  - NK: normalized SSE with station Qmean**2
!     rev. 9.7.04  Aug.  30/10  - NK: added to error message in read_rain & read_temp
!     rev. 9.7.04  Aug.  31/10  - NK: changed # decimal points for r2c files header
!     rev. 9.7.05  Aug.  31/10  - NK: changed error.r2s to error.r2c
!     rev. 9.7.06  Sep.  01/10  - NK: fixed subscript out of range errors in flowinit
!     rev. 9.7.07  Sep.  05/10  - NK: increased allowed # flow stations from 128 to 512
!     rev. 9.7.08  Sep.  21/10  - NK: revised mean squared error weighting for DDS
!     rev. 9.7.09  Sep.  29/10  - NK: corrected error.r2c file for sub-basin errors
!     rev. 9.7.09  Oct.  02/10  - NK: ensure fpet_lake is not assigned unintended values
!     rev. 9.7.10  Oct.  11/10  - NK: update flowflag in lst.f for subsequent events
!     rev. 9.7.11  Nov.  22/10  - NK: added monthly_climate_deltas.txt file
!     rev. 9.7.12  Nov.  10/10  - NK: fix array bugs for reservoir inflows
!     rev. 9.7.13  Nov.  22/10  - NK: Changed the outfiles.txt for more 30 rff classes
!     rev. 9.7.14  Nov.  22/10  - NK: Allow 30 land cover classes
!     rev. 9.7.15  Dec.  14/10  - NK: Create reduced precip & temp files for sub-basins
!     rev. 9.7.16  Jan.  05/11  - NK: Fixed init flows outside sub-basin
!     rev. 9.7.17  Jan.  05/11  - NK: Fixed diversions outside sub-basin
!     rev. 9.7.18  Jan.  17/11  - NK: Changed tolerance on the grid check in read_rain &
read_temp
!     rev. 9.7.19  Jan.  18/11  - NK: Added sensitivity analysis
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17 WATFLOOD/KENUE Workshop (2 days)

This workshop was held at Quebec Hydro using the LG4 watershed in Northern Quebec. The watershed name used was **LGDEMO**, the DEM was named **DEM_LG4_200m.grd** and the land cover map was named **Land_Cover_UTM.tif**

You can substitute these names with your own.

17.1 Installing Watflood &GreenKenue

1. Copying stuff (you may use a different drive for executables & data)

   a. Make folders

   c:\spl (all executables go here – see d. below)
   c:\spl\lgdemo\results
   c:\spl\lgdemo
   c:\spl\lgdemo\basin
   .
   You can do this by copying the files from the CD

   b. Files needed in the c:\spl\lgdemo\data folder:

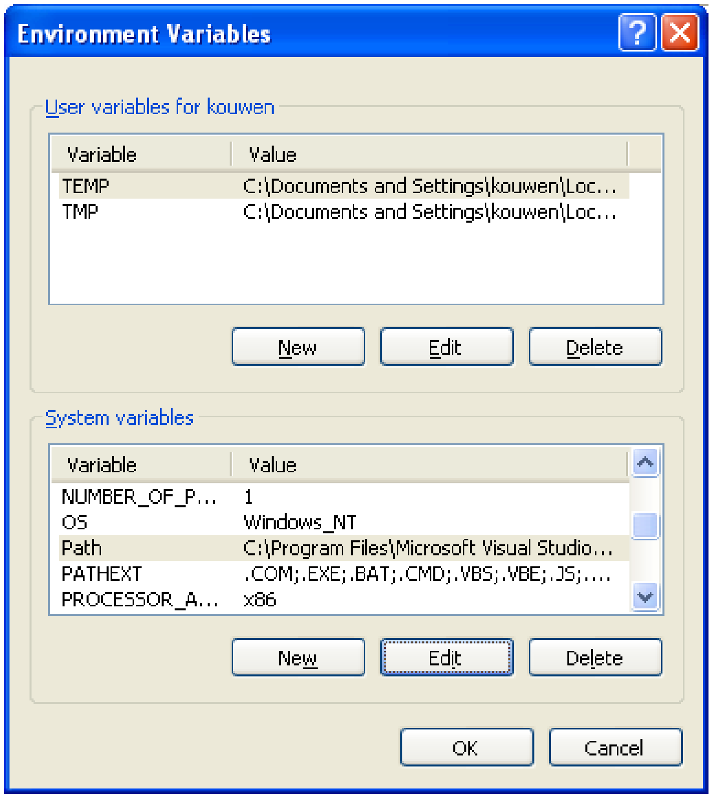
   As on the cd

   c. Files (on the CD) needed in the c:\spl folder:
   bsn.exe
   make_evt.exe
   moist.exe
   ragmet.exe
   snw.exe
   spld.exe
   splx.exe
   tmp.exe

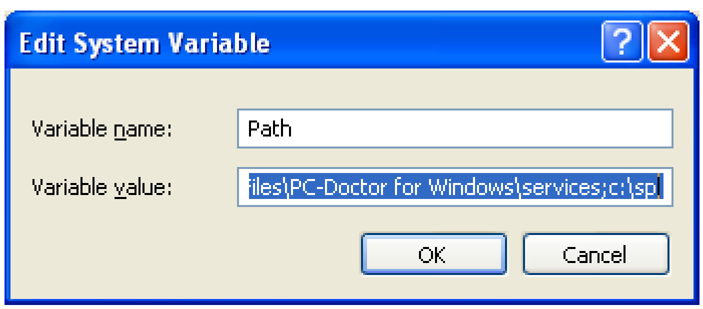
   d. Files needed in the c:\spl\lgdemo\data folder:
   lgdemo.par
   lgdemo.sdc

   e. **Copy the folders** event, moist, radcl, resrl, snow1, strfw and tempr into the spl\lgdemo folder

   f. **Set the path:** Right click on **My Computer** and go to **Properties.** Click on **Advanced** and go to **Environment Variables** and select Path under System variables:



Click on **EDIT** and add ;c:\spl to the end of the Path line and click OK:



g. If you have the USB key, the HASP device driver **HDD32.zip** may be downloaded from: http://www.ealaddin.com/support/hasp/enduser.asp - also on the cd

17.2 Working withGreenKenue

17.2.1 Creating the watershed file for WATFLOOD

2. OpenGreenKenue & make it full screen.
   a. Import the Goetiff file Land_Cover_UTM.tif and drag into 2D view (open view if not already there) It will be all black This is raw data (value ranging from 0 to 8 (9 land cover class with and no data value of 239).

b. To display the real color, copy and paste the file LG4.thm in yourGreenKenue directory (for me, its C:\Program Files\CHC\KENUE\Templates\GeoTIFF)
c. In the workspace, double click on the Land_Cover_UTM item and, in the Classes tab, choose custom theme and select the LG4 from the list (it should appear if the file is in the right directory - you may have to restartGreenKenue).
d. Import the DEM as surfer grid DEM_LG4_200m.grd and drag into 2D view
e. change the display from wireframe to surface & make it transparent & apply. (This is just to learn about views & importing data)
f. Save your workspace in \spl\lgdemo\lgdemo.ews (KENUEWorkSpace)

3. Creating a New Watershed Object. **P. 118GreenKenue manual**.
   a. Remove the land cover map from the 2D view (just right click and make it invisible)
   b. Set the colour scale for the DEM: double click on the file name & click on ColorScale
      i. Set min = 350 (lowest elevation on the DEM)
      ii. Interval = 20
      iii. Levels = 40 (the max allowed)
      iv. Adjust the colour scale (apply)
      v. Also just look at what the other buttons show: data, spatial & mete data
      vi. Apply
      vii. Save your workspace in \spl\lgdemo\lgdemo.ews
   c. Create a new watershed object:
      i. File → New → watershed ↵
      ii. Drag the DEM_LG4_200m into the DEM under New Watershed
      iii. A window appears: Properties of new watershed and click on generate. The channels & the largest watershed in the view have now been delineated.
      iv. Drag the channels * basin 1 into the 2D view (shows stream order)
      v. We don't care about stream order so click on the channels icon & in the display tab make the colours monochrome (I like dark blue or white – depending on the back ground colour. Also make the point size 1. Apply & OK if you like it.
      vi. Bring in some features: Import the dra_UTM18.shp and pva_UTM18.shp file and drag into the view. These are the Water Survey drainage layers – to check the generated channels.
      vii. File → open & pick files of type .xyz in the spl\lgdemo\data folder, cntrl click on xyz files in the basin folder & open
      viii. Drag the flow_station_location icon into the 2D view & make the points triangles, white, monocrome with line width 3 & point size 10 - apply & ok if happy. ☺
      ix. Bring in some more features: snow_stations, diversions, precip_tmp_location, and reservoirs. Zoom out to get the whole picture.
      x. Save your workspace in \spl\lgdemo\lgdemo.ews (**KENUEW**ork**S**pace)

d. Delineate watersheds for the WATFLOOD model – one for each streamflow gauge
    i. Zoom in on the outlet. **Note** that part of the watershed is not included in the original watershed outline.
    ii. Left click on the west channel there & add basin
    iii. Save your workspace in \spl\lgdemo\lgdemo.ews Answer yes to saving the new watershed object if asked.

4. Creating a new WATFLOOD map file **P. 155GreenKenue Manual**
    a. Generate map file spatial attributes
        i. File → New → Watflood Map
        ii. Drag the lgdemo watershed object into the new Watflood map
        iii. Double click on new Watflood map, click on Calculate Frac & hit collect.
        iv. Save the new_watflood file lgdemo.map: File → Save copy as ***lgdemo*** → save (note: make a new folder "basin" and save lgdemo.map in it.)
        v. Drag lgdemo into the 2D view & drag basins & channels & reservoir_location over top.
        vi. Click on the lgdemo watflood map file & make it transparent & show drainage directions.
        vii. Click on the colour scale & make it the same as for the DEM: min-350; Intvl=20; levels-40 and adjust the colour scale. Reset the colourscheme & put a check mark in show legend. In options you can insert a title for the legend = m asl
        viii. Check that the arrows follow the channels & do not cross basin boundaries. (Here & there the generated flow directions take a few detours or shortcuts. We will fix these later.)At this point you can bring in other shape files for stream channels & watershed boundaries (if you have them) to check on what was automatically generated.
        ix. Have a look at the data in the map file: Double click on lgdemo & click on the data tab – e.g countour density. (Contour density is also known as the ***internal slope.*** It refers to the overland slope in a grid. (Channel slope is not in the file – it is computed later with the program bsn.exe) Note that grids with the higher contour density occur on higher ground – a good sign!) **P. 162GreenKenue manual**.
    b. Adding land cover information to the map file.
        i. **Follow the directions in theGreenKenue manual in Section 2.4.4.5.2 Mapping Land Use Data to the Land Classes.** The Lg4 land cover map is already in your workspace.
        ii. Right click on the lgdemo map file and select **Map Land Use Data from GeoTIFF in the shortcut menu**
        iii. Click on the lgdemo map file and Save copy as lgdemo.map
        iv. Save your workspace in \spl\lgdemo\lgdemo.ews
    c. **Edit** the map file with an editor (eg. Edit, wordpad (txt mode) or some other editor) to delete unwanted classes
        i. Delete the blocks of data with class = nodata

ii. Reorder so the blocks of data are in the order: (this is to match the existing parameter file) ** **wetland, water & impervious always have to be the last 3 classes in that order!!!!!!!**

1 Deciduous
2 Coniferous
3 Mixed
4 Regen (open forest)
5 Taiga
6 Wetland **
7 Water **
8 impervious (rock and roads)**

iii. In the header, change the number of classes to 8
iv. Save the file in the basin folder lgdemo.map
v. Save your workspace in \spl\lgdemo\lgdemo.ews
vi. Reload the workspace
vii. Open the lgdemo.map file

d. Create the shd file for WATFLOOD lgdemo_shd.r2c
i. Open a DOS window Run cmd
ii. Go to whatever drive spl\demo is on dr:↵
iii. Cd \spl\lgdemo\basin
iv. Run the program bsn.exe: bsn ↵ **(there will likely be an error to fix!)**

Please note that when BSN.exe is run for the first time, the responses are written to a file called "bsn_responses.txt". When you run BSN.exe again, you will be asked if you want to use the same responses as before and you can answer 'y' to avoid entering the data again.

```
I:\spl\lgdemo\basin>bsn
 ********************************************************
 *                                                      *
 *                  WATFLOOD (TM)                       *
 *                                                      *
 *     Program BSN Version 10      Mar 13, 2008         *
 *                                                      *
 *           (c) N. Kouwen, 1972-2008                   *
 *                                                      *
 ********************************************************

 Please see file bsn_info.txt for information re: this run

 VERY IMPORTANT CHANGE:

 In the bsnm.map file
 the impervious area is now the LAST class - not the first
 The no of classes is now the TOTAL number - including the
 impervious class
```

```
 Please change the .map file accordingly if you have not
 yet done so.  Sorry for the inconvenience  NK

Hit enter to continue - Ctrl C to abort

  input the basin (map) file name:
lgdemo.map
  input the parameter (par) file name:
lg4.par
 Enter your name
nk
 lg4.par

  Enter the grid you would like included
  in the simulation
  This should NOT be the receiving grid!!!!
  There can only be one (1) outlet with this option
  example:  6639   Hit Return to use whole dataset
hit enter
GreenKenue compatible free format map file expected
 :CoordSys           CARTESIAN
 :CoordSys           CARTESIAN
 #
 :xOrigin               569000.0
 :yOrigin               5791000.
 :xCount                       30
 :yCount                       26
 :xDelta                10000.00
 :yDelta                10000.00
 :contourInterval       1.000000
 :imperviousArea                0
 :classCount                    8
 :elevConversion        1.000000
 #--------------------
 :endHeader
  Computed nominal grid size=    10000.00
please check above numbers & hit enter to continue

 Enter the split: % of wetland coupled to channel
 only if you have two identical sets of wetland
 land cover gridsas the 2 classes before the
 water class in the land use section of the map file
 Enter 0 if you have just 1 block of wetland land cover

 Split =
0
 Number of classes now includes the impervious class
 Number of classes stipulated =            8

 Is this correct?  y or n
y
 before allocating area17
 area17 allocated

  Often DEM have flat spots filled and you end up with
  unwanted flat spots in your river profile
  It causes severe flattening of the hydrographs
```

```
  Enter the minimum allowable river slope
  that you have in your sustem - e.g. 0.0001
  Min accepted value = 0.0000001
  Max value accepted is 1.0 (45 degrees!)

.001
 gone to arrange
 back from arrange
 gone to grade
 back from grade
 No of river classes found in the map file =           1
 This should match the number specified in the par file

 nrvr=           1
Decidous forest
Coniferous forest
Mixed forest
Opened forest
Taiga
Wetland
Water
Roc

  end of map file reached
 Note:    impervious area > 0 in the header
           0 % of the impervious class (urban)
 has been subtracted from class           8
 and added to class 1
 Class 1 should be a land cover compatible with
 the pervious areas in urban areas (eg. grass)

 ios=          -1

  No bankfull values found
  Default assumed

 frac_2d(   18    4)=     0.000 - please check
   Basin # not coded @ grid #   351 @     18     4
elv=370.000
# contours not coded @ grid #   351 @     18     4
elv=370.000
# channels not coded @ grid #   351 @     18     4
elv=370.000
       next grid = 0 @ grid #   351 @     18     4
elv=370.000
Possible cause: wrong drainage direction
Errors OK if last receiving grid !!!!!!!!!!!!!

Please see new_format.shd file for -ve slope location
 nrvr=           1
 ver     9.300000     parameter file version number
 in rdpar - problem opening BASIN\evap.dat file
          zero values are inserted for evap.dat

 parameter file read
 na,naa/         351          350
  frame=            1  written
```

```
 frame=           2  written
 frame=           3  written
 frame=           4  written
 frame=           5  written
 frame=           6  written
 frame=           7  written
 frame=           8  written
 frame=           9  written
 frame=          10  written
 frame=          11  written
 frame=          12  written
 frame=          13  written
 frame=          14  written
 frame=          15  written
 frame=          16  written
 frame=          17  written
 frame=          18  written
 frame=          19  written
 frame=          20  written
new_shd.r2c written
 frame=           1  written
 frame=           2  written
 frame=           3  written
 frame=           4  written
 frame=           5  written
 frame=           6  written
 frame=           7  written
 frame=           8  written
 frame=           9  written
 frame=          10  written
 frame=          11  written

new_ch_par.r2c written

wfo_spec.new  written

new.pdl  written

finished writing profil01.dat
finished writing river01.dat
finished writing profil02.dat
finished writing river02.dat
finished writing profil03.dat
finished writing river03.dat
finished writing profil04.dat
finished writing river04.dat
finished writing profil05.dat
finished writing river05.dat
finished writing profil06.dat
finished writing river06.dat
finished writing profil07.dat
finished writing river07.dat
finished writing profil08.dat
finished writing river08.dat
finished writing profil09.dat
finished writing river09.dat
finished writing profil10.dat
```

```
finished writing river10.dat

No. of errors found in the map file =           0
No. of errors found in the map file =           0
No. of errors found in the map file =           0

new_shd.r2c has been written
Please rename new_shd.r2c or replace the bsnm_shd.r2c

Normal ending I:\spl\lgdemo\basin>
```

e. Load the file New_shd.r2c intoGreenKenue & have a look
f. Save as lgdemo_shd.r2c in the dr:\spl\basin\ folder
g. Save your workspace

5. Setup event for WATFLOOD
   i. Copy additional folders from the cd in spl\lggdemo to spl\lgdemo in your pc. (These are rainfall, temperature, initial snow and moisture and streamflow files as well as event files.
   ii. Copy & rename spl\lgdemo\basin**wfo_spec.new** to spl\lgdemo**wfo_spec.txt**
   iii. In a Windows window, change the properties of the files in **c:\spl\lgdemo*** from read only to read/write (select all the files & right click to get the properties dialog box – make sure the read only box is not checked off)
   iv. In a dos window in folder dr:\spl\lgdemo, change the event: copy event\2001.evt event\event.evt
   v. Distribute data from point form to gridded form:
      1. distribute snow **snw** ↵
      2. distribute moisture **moist** ↵
      3. Usually also do: distribute rainfall **ragmet** ↵
      4. Usually also do: distribute temperature **tmp** ↵

b. Initial run
   i. Edit the **event\event.evt** file to pick the flags you want (See Sec. 1.3.9 in the WATFLOOD manual)

```
:snwflg                         y
:sedflg                         n
:vapflg                         y
:smrflg                         n
:resinflg                       n
:tbcflg                         n
:resumflg                       n
:contflg                        n
:routeflg                       n
:crseflg                        n
:Kenueflg                       a
:picflg                         n
:wetflg                         n
:modelflg                       n
:shdflg                         n
:trcflg                         n
:frcflg                         n
```

ii. Edit the **wfo_spec.txt** file & select the state variables you would like to view inGreenKenue. Probably you would like:

```
  3.0 Version Number
  132 AttributeCount
    6 ReportingTimeStep Hours
    0 Start Reporting Time forGreenKenue (hr)
    0 End Reporting Time forGreenKenue (hr)
1   1 Temperature
1   2 Precipitation
1   3 Cumulative Precipitation
1   4 Lower Zone Storage Class
1   5 Ground Water Discharge m^3/s
1   6 Grid Runoff
1   7 Grid Outflow
1   8 Weighted SWE
0   9 Wetland Depth
0  10 Channel Depth
0  11 Wetland Storage in m^3
0  12 Wetland Outflow in m^3/s
```

iii. Edit the outfiles.new file & change the path of the output files (use replace) and save as outfiles.txt

..

.. ect.

iv. Save as outfiles.txt in the lgdemo directory (folder)

v. Temporarily remove the reservoir & lake rules: change the name of the resrl folder to res_rl

6. Run the model: **splx ↵ (or if you did not set your path: c:\spl\splx ↵**

17.3 Post processing withGreenKenue

7. **New files today**
   - **a.** Snow course data – time series ts3 files in snow1 folder
   - **b.** str.tb0 files
   - **c.** splx.exe
   - **d.** lg4.par file
   - **e.** met.r2c files
8. **Run 1 year of data for LGDEMO (above)**
   - a. Follow the instructor to look at stuff.
     - i. In ENSIN load the file **watflood.wfo**
     - ii. Follow the instructor to look at stuff: make the `Grid Outflow` the top layer
     - iii. Right click on Grid Outflow in the 2D view & activate “animate”
     - iv. Double Click on Grid Outflow -> colour scale and set NLOG & 40 levels & Apply
     - v. Fix the colour scale
     - vi. Drag the Water Survey Drainage layer dra_UTM18 into the 2D view & see if the flows follow the channels.

vii. Drag the lgdemo map file into the 2D view and make it a wireframe with directions visible.
viii. Extract some time series for points along the river going upstream from LG4 (no lakes coded yet)
ix. Open a 1D view and drag each grid outflow time series into the 1D view
x. Fix the scale: hold left click & drag graph; use thumb wheel to zoom in and out
xi. Synchronize animation: Cliclick on **View** and then **Select Sync View** and select view & hit **OK**
xii. Try the play, pause, rewind buttons in the animation toolbar
xiii. Animate to the peak flow time
xiv. Note the discontinuity in the flow near the small off-line lake (probably caused by a flat spot in the river – see grapher plot)

b. Sensitivity
i. Edit the basin\lg4.par file and double the R2n value
ii. Run the model: **splx** ↵
iii. In GreenKenue, leave the previous watflood.wfo file and load the new watflood.wfo file (note: same name)
iv. Follow the instructor to look at stuff: make the new `Grid Outflow` the top layer and extract time series for the same points along the river going upstream from LG4
v. Note that you can see a bit of damping
vi. Delete the first watflood.wfo file from the data items

c. Editing the map file: add lakes
i. delete the watflood map from **Data Items**
ii. open **lgdemo.wsd**
iii. open **lgdemo.map** (if not present) in the basin folder and drag into 2D view
iv. In 2D view, raise landcover map, lgdemo.map and dra_UTM18 in that order
v. change the colours in the land cover map to grey except the water class – so it stands out.
vi. In the properties of lgdemo.map activate the reach Number
vii. Set the colour scale to 6 items & fix the colour scale
viii. Edit the lakes: lg4 = 1, LF1 =2 (do nothing – it's a diversion) then lakes 3, 4 & 5 as we go upstream. Mark all grids that are part of the lake – it doesn't depend on how much of the grid is in the lake.
ix. Fix the drainage direction NE of first small lake so river bypasses the lake.
x. Add a grid to the LG4 lake
xi. Check drainage directions & falling channel elevation in the outlet area (follow arrows)
xii. Save the lgdemo map file
xiii. In the lgdemo\basin folder, run bsn.exe as before & if ok, change the name of the file new_shd.r2c lgdemo_shd.r2c

- xiv. Rename of the **res_rl** folder to **resrl**
- xv. Run splx & look at results. Compare with previous run without lakes.

d. Looking at snow water equivalent
- i. Edit the event\event.evt file and add the line:
  :grdflg y
- ii. Edit the c:\spl\lgdemo\wfo_spec.txt file and make the reporting time step = 24 and the end reporting time forGreenKenue = 0
- iii. Run the model **splx**
- iv. InGreenKenue, while it's running, open the 5 ts3 files in the snow1 folder
- v. Open the file results\swe.r2c – letGreenKenue translate it to a binary file (*the reason we use an r2c file is that r2c files have the data and time stamp for each frame of data. The wfo file just has the hour from the start of the run)*
- vi. Drag the snow water equivalent object in to the 2D view
- vii. Drag the snow_station locations into the 2D view
- viii. Extract a time series at location #3 and
- ix. drag it in to a 1D view
- x. drag the 3rd swe time series into the 1D view
- xi. change to point (click on the object etc.)

e. Fixing the model
- i. Edit the basin\lg4.par file and change the max heat deficit to 0.333 from 1.000 (being careful to keep the formatting intact)
- ii. Save the par file & run splx
- iii. Open Open the file results\swe.r2c – letGreenKenue translate it to a binary file (again)
- iv. Repeat vii to ix above – you see an earlier melt now
- v. Edit the basin\lg4.par file and change all base temperatures to -4 and repeat vii to ix above

  Hydrological modellers NOTE: This is the way to calibrate a model – look at each process. Ideally we have a snow course in each land cover class!!!!

9. Optimization (The wrong way?) Pattern search optimization coded by Monro NWS

a. Set up the par file
- i. In line 6 set numa = 1
- ii. Make the **Base +ve**
- iii. Check limits
- iv. Save par file & run splx
- v. Monitor the results\opt.txt file
- vi. When the error no longer reduces, kill the run
- vii. Edit the event\event.evt file replace lg4.par by new.par
- viii. Run splx
- ix. Compare with previous watflood.wfo file

10. **Question period**

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