WATFLOOD® / CHARM®

Canadian Hydrological And Routing Model

SINCE 1972

WATFLOOD is open source

Developed for

Surveys and Information Branch
Ecosystem Science and Evaluation Directorate
ENVIRONMENT CANADA

by

Nicholas Kouwen, Ph.D., P.Eng., F.ASCE
Distinguished Professor Emeritus
Department of Civil Engineering
University of Waterloo
Waterloo, Ontario, Canada
N2L 3G1
519-922-2602

E-mail:
kouwen@uwaterloo.ca

http://www.watflood.ca

First Edition: March 1986

Last Revision:
October 26, 2024

IMPORTANT NOTES

WATFLOOD® & CHARM® are registered trademarks

The original model (1972) was called "Simplicity" but it did not stay simple for too long. So the executable were abbreviated to "SPL" As time passed, utilities were added that were once part of the model. I.e. precipitation and temperature distribution functions were separated from the model and became stand-alone executables (late 1970's). The whole system is called WATFLOOD (1990) and its various components have their own names. The hydrological and routing model is now called CHARM (Canadian Hydrological And Routing Model) (2006).

WATFLOOD programs now read only Green Kenue format files. Old file formats are no longer supported. A program called trns.exe can convert old formats to the Green Kenue formats. See Chapter 15.

NETcdf formats have been added for FEWS

LICENSE

DISCLAIMER

WATFLOOD/CHARM - 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 land cover data, digital elevation models and numerical weather data. These distributed data can thus be directly incorporated in the hydrologic modeling without loss of their inherent detail..

CHARM 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 cell to basin cell. 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.

Environment Canada has funded the link to the Green Kenue pre and post processor for WATFLOOD. Included in this link is portions of WATFLOOD I/O code written by NRC to create this link.

WATFLOOD & FORTRAN

Why FORTRAN??

Answer from GoParallel:

In the past here at Go Parallel, we've focused primarily on C++. But Intel has created an excellent Fortran compiler, which is the preferred language for many scientists and engineers—with good reason. Although scientists and engineers are often brilliant people, their focus is on their scientific and engineering field of study, not mastering a programming language like C++ that requires users to become experts just to do simple tasks. They want to focus on their actual work of science and engineering, not spending months writing code to support their work. C++ requires dedication to being a programmer. But Fortran can be learned more quickly, making it an excellent choice for people who don't have time to become expert programmers and prefer to focus on being experts in their own fields.

TABLE OF CONTENTS

TRADEMARKS

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.

ACKNOWLEDGEMENTS

Development of WATFLOOD was begun in 1972 while I was employed as a visitor at the Conservation Authorities Branch of the Ontario Ministry of Natural Resources as a flood forecasting system. Mr. Don McMullen in his capacity as hydrometeorologist for the Province of Ontario initiated this project.

WATFLOOD/CHARM has been made possible through:

1. The University of Waterloo through computing and office facilities.
2. The National Engineering and Science Research Council of Canada through Grant No. 7982, from 1972 -2010.
3. The Ontario Ministry of Natural Resources who provided the initial incentive and support to undertake the work.
4. The Grand River Conservation Authority through access to flow records and now, field testing.
5. The Alberta Research Council by providing radar data and support for a field evaluation.
6. Surveys and Information Systems Branch, Ecosystem Science and Evaluation Directorate of Environment Canada for providing contract funding to demonstrate and implement the WATFLOOD system. The support of Shin Young Shiau and Raymond Bordages are appreciated.
7. Atmospheric Environment Service, King City Radar Observatory. Drs. Paul Joe and Cliff Crozier, John Scott, Ron Ruff and Marie Falla deserve special thanks for the Radar Data Acquisition system that they have developed especially for testing the WATFLOOD flood forecasting system.
8. Environment Canada through the Water Survey of Canada for supporting the linkage between WATFLOOD and Green Kenue.

Thesis work at the University of Waterloo by Jack Gorrie, Greig Garland, Ted Cooper, Tao Tao, John Donald, Al Pietroniro, Frank Seglenieks, Todd Neff, Luis Leon, Bob McKillop and Trish Stadnyk has provided part of the research incorporated in the WATFLOOD/CHARM software. The snow routines were written by Dr. John Donald and the evaporation component was written by Todd Neff under co-supervision with Prof. Ric Soulis. These two parts are major components of the WATFLOOD system. Tricia Stadnyk converted the program from F77 to F95 with dynamic memory allocation during a work term, wrote the wetland – bank storage module, and has written the tracer model as part of her thesis work. Thesis work by Tegan Holmes supervised by Dr. Trish Stadnyk at the University of Manitoba has contributed to the lake evaporation model.

Aleksey Naumov of 4DM has provided a great deal of input to this revised edition.

These contributions are gratefully acknowledged.

N. Kouwen.
October 26, 2024

1 WATFLOOD / CHARM USER'S MANUAL

1.1 Introduction

The model CHARM 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 90/95 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 CHARM, there are a number of support programs to provide for data preparation and output presentation. The programs RADMET.exe and RAGMET.exe may be used to convert radar and rain gauge data to the square grid CHARM input format; BSN.exe is used to assemble a 'watershed (shd) file' for CHARM; and MAKE_EVT.exe may be used to create event files.

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 model 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 channel 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 1/3rd 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 (or better), 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 Figure 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.

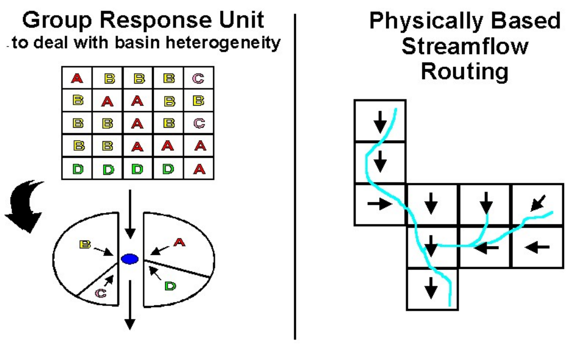


Figure 1.1 - Group response unit and runoff routing concept (Donald, 1992).

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.

While in the literature the debate about computing runoff from ungauged watersheds continues, the GRU method offers the best hope for doing so correctly. Given the DEM and a landcover map, parameters for the land covers present will be available from gauged watersheds. The important point is that with the GRU method, the parameters are not associated with the makeup of the relative amounts of each land cover.

One important requirement for the model is that it is a necessity to always model a goodly number of watersheds simultaneously – whether they be nested or not. The number will depend on the number of land covers present. The greater the number of land covers, the greater the need for a larger number of stream gauges included in the modeling.

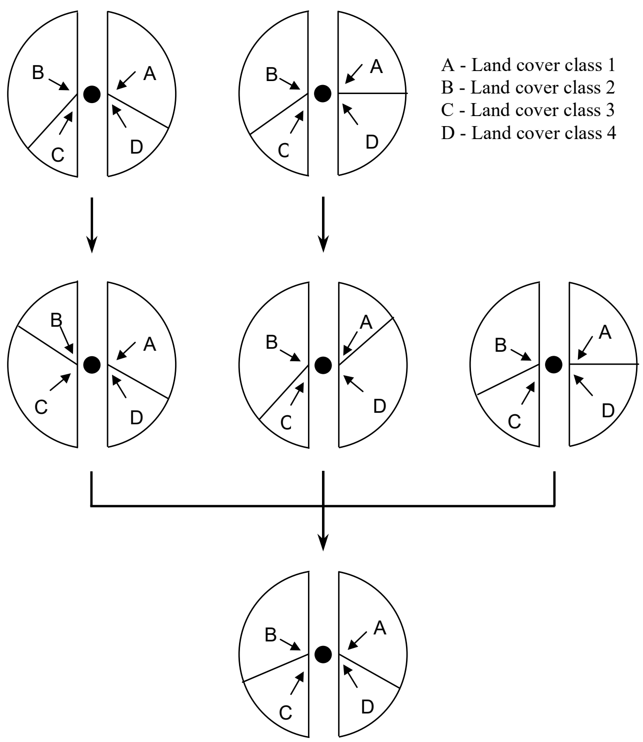


Figure 1.2 - Schematic of the GRU pixel grouping model and channel routing scheme.

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. All executables for WINDOWS/DOS are available free at www.watflood.ca. For UNIX applications, the programs will need to be re-compiled on specific platforms.

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

1.3.2 Installation

1.3.2.1 Windows

Currently, because of the new file formats (described in this manual) the MS Windows GUI version of WATFLOOD is no longer available. The programs can be executed using the WINXX interface but it is actually easier to use the WATFLOOD model on DOS.

1.3.2.2 DOS

You can extend your path with a DOS command: Set PATH=%PATH%;C:\WATFLOOD

1.3.2.2.1 Windows 10

By default, in Windows 10 there is a path to the folder:
Users\YourUserName\AppData\Local\Microsoft\WindowsApps
This is a hidden folder but you can copy executables there in DOS by entering the whole path. When you copy your execs and bat files as well, they are accessible from anywhere on your computer.

1.3.2.2.2 Windows XP & 7

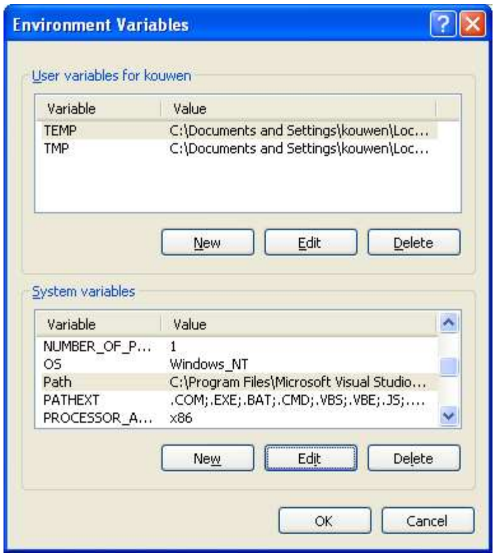
Create a directory (folder), called *watflood*. It works best if it is in the root directory of any drive (easier to find).

Download all executables from the Executables link (32 or 64 bit as appropriate)**,** *gr10k.zip* (gr10k example data set) and *manualNN.pdf* files to the *spl* directory.

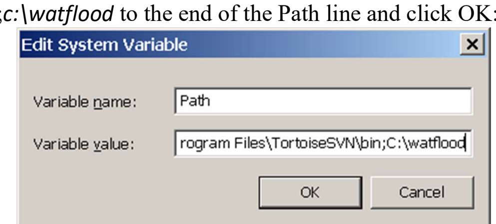
Log to the *watflood* directory and unzip *gr10k.zip* to put the demo files in the *watflood* directory. The directory structure should look like in Section 0.

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 0.

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:\watflood* to the end of the Path line and click OK:



It is usually sufficient to open a new instance of the Command Prompt (DOS terminal window), however, you may have to restart your computer.

Note: You can ignore setting your path and do like some users: have the executables in the working directories. But it often leads to trouble with out of date executables strewn throughout computers and backups.

1.3.3 File Structure in WATFLOOD

The entire WATFLOOD system is installed under the *watflood* directory. It is convenient to locate this directory in the root directory as it can be added to the path and then used to centrally locate all WATFLOOD current executables.

The following file structure works well:

```
Drive:\watflood
    |---  gr10k             Sample basin
          |---  basin       - watershed files, parameter files
          |---  dds         - DDS working directory                          [new]
                |---  dds_BSNM    - DDS output                               [new]
                |---  dds_best    - best DDS input/output files              [new]
          |---  event       - event files
          |---  diver       - diversion and withdrawal files                 [new]
          |---  level       - initial lake level and recorded lake level files [new]
          |---  lkage       - leakage (groundwater 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 runoff & interflow files
          |---  snow1       - snow course and climate data
          |---  strfw       - streamflow or river stage files
          |---  tempg       - point temperature files                        [new]
          |---  tempr       - gridded temperature files
          |---  winds       - wind direction and speed files                 [new]
    |---  saug              Another basin
          |---  basin
          |---  ...
```

The reason for the use of the *drive:\watflood\BSNM\results* directory if to make the use of post processors easier. If the results are always in the same place, programs such as Green Kenue™ or GRAPHER™ can always find the required files once you create a workspace for a watershed. Some users prefer to use a *results* folder in another directory. For this, edit the *outfiles.new* (Section 11.4) file and insert the proper path and save the file as *outfiles.txt* in the working directory.

1.3.4 Minimum File Requirements

In addition to files for specific events, the following files are ***required*** before the WATFLOOD (*SPL.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* (basin name).

With the exception of *BSNM.map* and *BSNM_shd.r2c* files, these files may be modified copies from the gr10k demonstration files if the files are created manually (i.e. use existing headers and modify the data as needed.

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

Streamflow file	*strfw*_str.tb0*
Gridded precipitation file	*radcl*_met.r2c*

Normally a temperature file is required (for evaporation and snowmelt routines):

Gridded temperature file	*tempr*_tem.r2c*

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

Gridded snow water equivalent file	*snow1*_swe.r2c*

If reservoirs and/or lakes are present:

Reservoir release data or rule file	*resrl*_rel.tb0*

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 other's setup. (And over 44 years of experience has shown it to be efficient).

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

1.3.5 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.r2c 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*
Gridded static files	*xxxxx\19930101_xxx.r2c*

Any file that refers to an event has the date *in the YYYYMMDD* format (first day in the file) 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.

Notes:

- The event file names *** 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 **_tem.r2c* etc. if the event starts on a specific day.
- **As of 2006, all data files are Green Kenue compatible file formats and the names reflect the type of file.** For instance, *tempr\19930101.tem* has become *tempr\19930101_tem.r2*.

1.3.6 Green Kenue Compatibility

With the exception of a few files, all files in the WATFLOOD system will be the Green Kenue formats (pt2, tb0, r2c, etc.). Thus all files can be displayed in *Green Kenue*. *Green Kenue* creates the *BSNM.map* file – **which is arguably 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 or Ellipsoid lines.

1.3.7 Event Configuration File

The event file (*event\event.evt*) 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 *_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 precipitation 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 SPL 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.

Note: ***Although events longer than one year MAY execute without problems, this feature is NOT supported.***

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 3.2.1 also shows which files are **Mandatory** and which are **Optional** for each program.

1.3.7.1 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**.

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.

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.

```
#
:filetype                     .evt
:fileversionno                9.9
:year                         1993
:month                        01
:day                          01
:hour                          0
#
:snwflg                       y
:sedflg                       n
:vapflg                       y
:smrflg                       y
: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
:initflg                       n
:hdrflg                        n
:grdflg                        n
:ntrlflg                       n
:nudgeflg                      n
:resetflg                      n
:divertflg                     n
:pafflg                        n
:fliflg                        n
:lakeflg                       n
:iceflg                        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
:disaggregate                   1.00
#
:hoursraindata                   744
:hoursflowdata                   744
:deltat_report                     1
#
:basinfilename                 basin\gr10k_shd.r2c
:parfilename                   basin\gr10k_par.csv
:channelparfile                basin\gr10k_ch_par.r2c
:pointdatalocations            basin\gr10k.pdl
:snowcoverdepletioncurve       basin\gr10k.sdc
:waterqualitydatafile          basin\gr10k.wqd
#
:pointsoilmoisture             moist\19930101_psm.pt2
:pointprecip                   raing\19930101_rag.tb0
:pointtemps                    tempg\19930101_tag.tb0
:pointnetradiation
:pointhumidity                 humid\19930101_hum.tb0
:pointwindspd                  winds\19930101_spd.tb0
:pointwinddir                  winds\19930101_dir.tb0
:pointlongwave
:pointshortwave
:pointatmpressure
:pointsnow                     snowg\19930101_snw.tb0
:pointdrain                    drain\19930101_drn.tb0
:pointdsnow                    dsnow\19930101_dsn.tb0
#
:streamflowdatafile            strfw\19930101_str.tb0
:reservoirreleasefile          resrl\19930101_rel.tb0
:reservoirinflowfile           resrl\19930101_rin.tb0
:diversionflowfile             diver\19930101_div.tb0
:observedlakelevel             level\19930101_lvl.tb0
```

```
:snowcoursefile               snow1\19930101_crs.pt2
:initlakelevel                level\19930101_ill.pt2
:observedlakelevel            level\19930101_lvl.tb0

#
:radarfile                    raduc\19930101.rad
:rawradarfile                 radar\19930101.scn
:clutterfile                  radar\19930101.clt
:griddedinitsnowweq           snow1\19930101_swe.r2c
:griddedinitsoilmoisture      moist\19930101_gsm.r2c
:griddedinitlzs
:griddedrainfile              radcl\19930101_met.r2c
:griddedsnowfile
:griddedtemperaturefile       tempr\19930101_tem.r2c
:griddeddailydifference       tempr\19930101_dif.r2c
:griddednetradiation
:griddedhumidity              humid\19930101_hum.r2c
:griddedwindspd               winds\19930101_spd.r2c
:griddedwinddir               winds\19930101_dir.r2c
:griddedlongwave
:griddedshortwave
:griddedatmpressure
:griddedsnow                  snowg\19930101_snw.r2c
:griddeddrain                 drain\19930101_drn.r2c
:griddeddsnow                 dsnow\19930101_dsn.r2c
:griddedrunoff                runof\19930101_rff.r2c
:griddedrecharge              rchrg\19930101_rch.r2c
:griddedleakage               lkage\19930101_lkg.r2c
#: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
```

1.3.7.2 Meaning of the Flags in the Event File

Table 1.1 documents event file flags and their valid values. Note that the value **n** is customarily used to set a flag to 'false', i.e. to disable the associated model feature. A setting that is not a valid flag value may not have the desired effect as some checks may act on a "n" value. The flags may be in any order.

Table 1.1. Event file flags.

Flag	Description and Valid Values
snwflg	**y** – Snowmelt routines will be used
sedflg	**y –** Sediment production and routing routines will be used
vapflg	**y –** Evaporation turned on (need temperature files)

Flag	Description and Valid Values
smrflg	Precipitation data will be smeared - e.g., precipitation entered once every 24 hours will be 'disaggregated' over the whole time increment of the data instead of taken as an hourly amount in the first hour. **y –** Precipitation is disaggregated only for that event **a –** Subsequent *smrlflg* entries will be ignored and *smrlflg* set to **y** for the whole run
resinflg	**y –** Reservoir inflow data required and computed reservoir inflows will be compared. This flag is set in *event.evt* and used for all subsequent events.
tbcflg	**y** – 'To be continued': 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* *lake_level_init.pt2* [new] Note: if there are chained event files (see next section), this flag only takes effect if specified in the final chained event, in all other event files it is ignored (so the files above will not be written partway through a run even if the *tbcflg* = **y**).
resumflg	Resume from a previously saved state **y** – The *resume.txt*, *flow_init.r2c* and *soil_init.r2c* files will be used to initialize state variables – this allows the program to resume a time series as if it was executed as a continuous run. **s** – Only the *soil_init.r2c* file will be read but the LZS and all flow variables will be initialized with streamflow. [new]
contflg	**y** – Continue the statistics from previous run via *resume.txt* file
routeflg	Generate files for flow routing with WATROUTE or FLOW 1D programs. **y** – Write files for WATROUTE: *\spl\bsnm\runof*_rff.r2c* *\spl\bsnm\rchrg*_rch.r2c* *\spl\bsnm\lkage*_lkg.r2c* *\spl\bsnm\flow_init.r2c* **q** – Write the tb0 files for FLOW 1D (no computed outflow from designated reaches) This flag is set in *event.evt* and used for all subsequent events.
crseflg	Read snow course data to replace snow water equivalent (SWE) data obtained from resume file data **y** – Update the SWE at the beginning of any event with this value **u** – Update SWE at any time with **_swe.r2c* [new] SPL checks each day if there is a SWE update file when *crseflg* = **u**
kenueflg	**y** – Create *\spl\bsnm\results\watflood.wfo* file for Green Kenue
picflg	**y** – Create *\spl\bsnm\results\pic.txt*file for flow animation with MAPPER.exe

Flag	Description and Valid Values
wetflg	**y** – Use coupled wetland-channel routing. This flag is set in *event.evt* and used for all subsequent events.
modelflg	**i** – Run WATROUTE with surface flow & **i**nterflow only **l** – Run WATROUTE for surface and groundwater **l**eakage routing **r** – Run WATROUTE for surface to channel and **r**echarge through the lower zone This flag is set in *event.evt* and used for all subsequent events.
shdflg	**y** – Replace the watershed file *basin\bsnm.shd* for next event
trcflg	**y** – Use the tracer module. This flag is set in *event.evt* and used for all subsequent events.
frcflg	**y** – Use fractionization module (under development). This flag is set in *event.evt* and used for all subsequent events.
initflg	**y** – Write *flow_init.r2c* file for WATROUTE (Initial flow for each grid), write *lzs_init.r2c* file for WATROUTE (Initial LZS for each grid)
hdrflg	**Y –** Write column heasers on spl.csv, resin.csv & evapsep.txt files
grdflg	**y** – Write r2c files for flow, SWE & evaporative loss: *gridflow.r2c*, *swe.r2c* and *evap.r2c* respectively
ntrlflg	Use 'natural flows' instead of the specified reservoir releases **y** – If the reservoir release file for the first event has coefficients for **<u>ALL</u>** lakes and reservoirs, any release data in the reservoir release file will be ignored and flows will be released according to the rule (coefficients). All event files will have to have *ntrlflg* = **y**. If *ntrlflg* ≠ **y** in a subsequent event, the coefficients will be reset to the coefficients in that event. **a** – The subsequent *ntrlflg* entries will be ignored and *ntrlflg* is set to **y** for the whole run.

nudgeflg	'Nudge' the model: replace computed flows with the observed flows
	a – All computed flows for all events in this run will be replaced by observed flows at all flow stations.
	1 – Computed flows as designated in event no. 1 will be replaced by observed flows. (Designation is by setting value1 = 2 in the **_str.tb0* file for the **first** event)
	The default value is **n** if not specified in the event file.
	However, if Value1 = 2 in any **_str.tb0* file for any station, the computed flow for that station and that event (only) will replaced by the observed flow. See Section 8.1 also.
	OR
	The file strfw\nudge_flags.xyz can be used to set the nudgeflg and overrides the values in the str file e.g.
	`-113.835 50.760 1 05BL024 "HIGHWOOD RIVER NEAR THE MOUTH" 3950.`
	`-113.445 50.823 2 05BM002 "BOW RIVER BELOW CARSELAND DAM" 15700.`
	`-112.542 50.750 1 05BM004 "BOW RIVER BELOW BASSANO DAM" 20300.`

resetflg	**y** – Reset the sums of precipitation, interception evaporation, evaporation and sublimation to zero during the first week of October. This to allow the plotting of these with snow pillow and/or snow course data which is effectively a cumulative precipitation until the snow melts.

Flag	Description and Valid Values
divertflg	Enable water diversions **y** – Use diversion flow data (default) **g** – Generate lake St. Joseph diversion flow – special case for Winnipeg River only
pafflg	**y** – Generate Precipitation Adjustment Factors (PAF)
fliflg	**y** – Update routing data on-the-fly with **_fli.r2c* file which can be generated at the end of a run with *tbcflg* = **y** or generated with *FLI.exe*
lakeflg	**Y –** Use lake evaporation model for lakes with depth larger than 1 m.
iceflg	**Y –** Use the degree-day method to calculate flow reduction value due to ice formation

Notes:

- Flags that are set in the first event and always used throughout a multiple event run are: *snwflg*, *wetflg*, *trcflg*, *sedflg*, *frcflg*, *routeflg*, *modelflg*, *resinflg*, *deltat_report*, *divertflg*, *pafflg, lakeflg, iceflg*
- Flags that can optionally be set to run in all events with 'a' are: *kenueflg*, *grdflg*, *ntrlflg*, *smrflg*
- The basin*.* files are used for all events and will not replce the files listed in the first event except the ****_shd.r2c file, which can be replaced in any event by setting the shdflg = 'y'.

1.3.7.3 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 can also be chained using *resume.txt*, *soil_init.r2c* and *flow_init.r2c* files removing any limit on the length of a simulation. Please see Chapter 5 *Model Initialization* for more information on model initialization. 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 (only the end of the event file is shown):

```
# …
: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.

See Section 1.4 *WATFLOOD Tutorial* below.

TRICK: To check that all files for a long model run are properly set up so the whole sequence will execute set IOPT = 99 in the parameter file. This will run ONLY the first few time steps in the model before going to the next event and will quickly run through all the input files. If the model ends "normally" it will probably run all the events in a long simulation.

1.3.7.4 Creating Event Files

The old event files have old event names that are not compatible with the Green Kenue formats. Instead of editing all the old event 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.exe*, *TMP.exe*, *SNW.exe*, *MOIST.exe*, *SPL.exe*, etc. Each application has its own need for certain files associated with a given event. All required files for all programs (except *BSN.exe*) 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 (highlighted in yellow).

Please note that new keywords in the event file will not be recognized by the other, older executables like *SPL.exe*, *RAGMET.exe*, etc.

```
C:\spl\gr10k>make_evt
C:\spl\gr10k>make_evt
 ********************************************************
 *                                                      *
 *                  WATFLOOD (TM)                       *
 *                                                      *
 *         Program make_evt    Jun. 23 2015             *
 *                                                      *
 *                   Version 9.9a                       *
 *                                                      *
 *           (c) N. Kouwen, 1972-2015                   *
 *                                                      *
 ********************************************************

 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:
12

 No. of months per event file (1 or 12)
 If you are going to run long sequences - e.g. 40 years
 use 12 months per event - i.e. yearly events
 If you do not, you will have many many files.
 Use 12 month events unless you actually
 need month-long events for some reason
```

```
1
 type in start of event - eg. yyyy mm dd hh
 please stick with this convention so radar files work
1993 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

  will you be disaggregating precipitation? y/n
y
 what is your disaggregation rate mm/hr ?
1
 What reporting time step would you like in files?
 This should not be shorted than the str file Dt
1

  will you be using reservoir/lake inflow files? y/n
n
  will you be using wetland coupling? y/n
y

  will you be using diversions? y/n
  Note: diversion data needed for this option
n

  will you be running lake evaporation? y/n
  Note: diversion data needed for this option
n

  will you be using ice factors? y/n
  Note: diversion data needed for this option
n


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

gr10k
                      if names correspond
 WARNING:
 Existing evt files may be overwritten
                      if names correspond
 Hit Ctrl C to abort
Hit enter to continue


 recent change(s):
 8/12/2011 - `ensimflg` has been replaced by `kenueflg`
 in the new evt file
 Pre-existing programs will not accept `kenueflg` &
```

```
 will produce an error
 Please update all executables
 New exec`s will recognize ensimflg & kenueflg
 so there is no need to edit your data files

Hit enter to continue

 event\19930101.evt                                           ... created
 event\19930201.evt                                           ... created
 event\19930301.evt                                           ... created
 event\19930401.evt                                           ... created
 event\19930501.evt                                           ... created
 event\19930601.evt                                           ... created
 event\19930701.evt                                           ... created
 event\19930801.evt                                           ... created
 event\19930901.evt                                           ... created
 event\19931001.evt                                           ... created
 event\19931101.evt                                           ... created
 event\19931201.evt                                           ... created
 A file called events\events_to_follow.txt
 has been written
 This list can be used in the first event file
 of a connected set of events

 ********************************************************
 *                                                      *
 *                  WATFLOOD (TM)                       *
 *                                                      *
 *         Program make_evt   Jun. 23, 2015             *
 *                                                      *
 *                   Version 9.9a                       *
 *                                                      *
 *           (c) N. Kouwen, 1972-2015                   *
 *                                                      *
 ********************************************************

 Please see file evt_info.txt for information re: this run
Normal ending
```

C:\spl\gr10k>

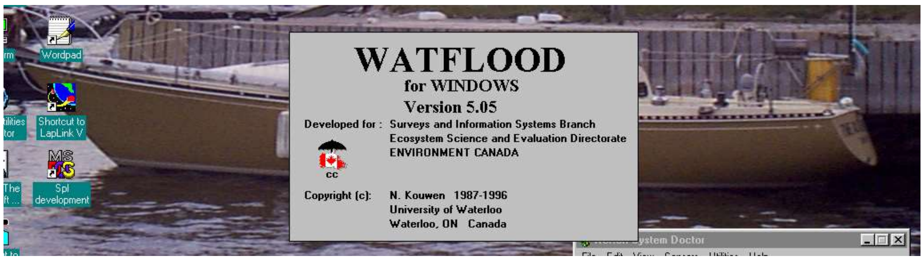
1.4 WATFLOOD Tutorial

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 so files can be edited in Excel™ for those users avoiding editors.



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.)

For a complete list of DOS commands, open a CMD window and launch the *help* command:

```
help
```

To get a list of extensions for a command (e.g. the *dir* command) run:

```
help dir
```

and so on.

To make life easier, batch files can be set up in the *c:\watflood* directory. Since this directory is in your path (if you have followed the instructions in Section 1.3), a batch file becomes a command.

Example: here is how to do a backup in DOS with a bat file in the *watflood* directory for say *C:\watflood\mack*. Create a *backup.bat* file with the following entrees and then use the command *backup* while in the *watflood* directory. This will create a new directory o the backup disk y: if it doesn't yet excist and then copy or update all entrees (copy only newer files)

```
mkdir y:\spl\mrb22
xcopy /s /d /y mrb22\*.*              y:\spl\mrb22\*.*
xcopy /s /d /y mrb22\basin\*.*        y:\spl\mrb22\basin\*.*
xcopy /s /d /y mrb22\data\*.*         y:\spl\mrb22\data\*.*
xcopy /s /d /y mrb22\diver\*.*        y:\spl\mrb22\diver\*.*
xcopy /s /d /y mrb22\drain\*.*        y:\spl\mrb22\drain\*.*
xcopy /s /d /y mrb22\dsnow\*.*        y:\spl\mrb22\dsnow\*.*
xcopy /s /d /y mrb22\event\*.*        y:\spl\mrb22\event\*.*
xcopy /s /d /y mrb22\kristof\*.*      y:\spl\mrb22\kristof\*.*
xcopy /s /d /y mrb22\level\*.*        y:\spl\mrb22\level\*.*
xcopy /s /d /y mrb22\moist\*.*        y:\spl\mrb22\moist\*.*
xcopy /s /d /y mrb22\MRBHM\*.*        y:\spl\mrb22\MRBHM\*.*
xcopy /s /d /y mrb22\radcl\*.*        y:\spl\mrb22\radcl\*.*
```

```
xcopy /s /d /y mrb22\raing\*.*         y:\spl\mrb22\raing\*.*
xcopy /s /d /y mrb22\reports\*.*       y:\spl\mrb22\reports\*.*
xcopy /s /d /y mrb22\resrl\*.*         y:\spl\mrb22\resrl\*.*
xcopy /s /d /y mrb22\results\*.*       y:\spl\mrb22\results\*.*
xcopy /s /d /y mrb22\snow1\*.*         y:\spl\mrb22\snow1\*.*
xcopy /s /d /y mrb22\strfw\*.*         y:\spl\mrb22\strfw\*.*
xcopy /s /d /y mrb22\tempg\*.*         y:\spl\mrb22\tempg\*.*
xcopy /s /d /y mrb22\tempr\*.*         y:\spl\mrb22\tempr\*.*
xcopy /s /d /y mrb22\screen shots\*.*  y:\spl\mrb22\screen shots\*.*
rem
```

1.4.3 Use Existing Event

For this tutorial, it is 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).

Example #2, create a *ce.bat* file in *c:\watflood* with the following content:

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

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

`c:`	Will put you on the C: drive
`cd spl\gr10k`	Will make *C:\spl\gr10k* your working directory
`ce 1993.evt`	Will make 1993.evt your active event file

- ce is a bat file with the command copy %1 event.evt
- %1 is a wildcard – 1993.evt is inserted for %1

If a ****.*bat* file is in the path, the command will be found and executed no matter what is your current working directory. The event file has the names of all input files needed for a particular simulation.

1.4.4 Create New Event [inactive]

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 precipitation, 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*.

Assuming you want to work in *c:\watflood*, create the *c:\watflood* directory and unzip the file *gr10kdata.zip* into it. The Grand River demonstration dataset is in c*:\watflood\gr10k*, event file name is *930103.evt.*

1.4.6 Editing Files

There are no templates for editing the WATFLOOD files but all input files can be viewed graphically in Green Kenue. 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 <u>should</u> be possible to edit these files in a spreadsheet.

All WATFLOOD files are described in detail in Chapters 3 to 14.

1.4.7 Initiating Snow Accounting

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 Snow Cover Depletion Curve (SDC) is no longer used but the data is included in the parameter file. The next two files **_swe.r2c* and **_tem.r2c* are the gridded initial snow water equivalent (swe) and the temperature (tem) files. The **_tem.r2c* file is normally in time steps of 4 hours or shorter to preserve the diurnal temperature variation. 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 known hour.

If only daily min & max temperatures are available, the program *TMP.exe* will make use of a sinusoidal expression to create a temperature file with 4 hour time steps.

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* file the *crseflg* flag can be set to '**y**' and the SWE would be updated for April 1, 1993. The computed value in the model would be discarded.

NEW March/14

For forecasting applications the SWE can be updated on any day of the simulation if the *crseflg*=**u**. For instance, in the *event\20140315.evt* file the *crseflg* flag can be set to '**u**' for the event that covers this data and the program will check each day of the simulation if there is an update SWE file. If the *snow1/20140315_swe.r2c* file exists, the SWE would be updated for Mar 15, 2014 on the fly. 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 (Table 1.2).

Table 1.2. Precipitation and temperature scaling factors.

Item (variable name in code)	**Purpose**

`:rainconvfactor 1.00` (conv)	This is to convert data units for say inches to mm or tenths of mm to mm for this event only.
`:eventprecipscalefactor 1.00` (scale)	Scale the precipitation, for current event only. if(scale.eq.0.0) scale=1.0
`:precipscalefactor 0.00` (readscale,scaleall)	Will scale all the precipitation in all the events in a run if *precipscalefactor* > 0. Read in the first event of a run only. Overrides *eventprecipscalefactor*.
`:eventsnowscalefactor 0.00` (scalesnw)	Scale snow precipitation when temp < 0ºC in current event only. If (scalesnw.eq.0.0) scalesnw=1.0
`:snowscalefactor0.00` (readscalesnw,scaleallsnw)	Will scale all snow precipitation in all events when temp<0ºC if *snowscalefactor* > 0.0 Overrides *eventsnowscalefactor*.
`:eventtempscalefactor 0.00` (scaletem)	Will adjust temperatures in current event if set ≠ 0.0 NEW Overrides *tempscalefactor*
`:tempscalefactor 0.00` (readscaletemp,scalealltem)	Will adjust temperatures in all events if set ≠ 0.0 in the first event..

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.

Table 1.3. WATFLOOD programs.

Task	Program and Purpose	Input/Output File(s)
Create bsnm_*shd.r2c* file	*BSN.exe* Converts the raw data in the *bsnm.map* file to a watershed file *bsnm_shd.r2c* readable by *SPL.exe*	*Bsnm.map* *Bsn_responses.txt* *Class_combine.csv*
Read CAPPI	*RADMET.exe* Converts the radar data file to a CHARM compatible format. This program has to be adapted for each radar source.	**.scn* **.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.	**.rad* **_met.r2c*

Task	Program and Purpose	Input/Output File(s)
Distribute Rainfall	*RAGMET.exe* This program will distribute gauge rainfall using a distance weighting technique. Can be used when no radar or gridded numerical weather data is available at all or you want to ignore such data. *RAGMET.exe* will use coordinates in the the *bsnm.pdl* file to set the extent of the gridded precip.	*BSNM.pdl* **.rag* **_met.r2c*
Distribute Snow Course	*SNW.exe* This entry will distribute snow course data with a distance weighting technique. *SNW.exe* will use coordinates in the the *BSNM_shd.r2c* file to set the extent of the gridded swe data	*BSNM_shd.r2c* **_crs.pt2* **_swe.r2c*
Distribute Initial Soil Moisture	*MOIST.exe* This entry will distribute initial soil moisture data with a distance weighting technique. *MOIST.exe* will use coordinates in the the *BSNM_shd.r2c* file to set the extent of the gridded soil moisture data	*BSNM_shd.r2c* **_psm.pt2* **_gsm.r2c*
Distribute Temperature	*TMP.exe* Will convert point temperatures to gridded temperature fields. *TMP.exe* will use coordinates in the the *bsnm.pdl* file to set the extent of the gridded temperature.	*BSNM.pdl* **_tag.tb0* **_tem.r2c*
Run SPLD (debug)	*SPLD.exe* Model executable compiled for maximum error diagnostics in Visual Fortran 6.	See section 1.3.4 Files listed in *outfiles.txt*
Run SPL (speed)	*SPL.exe* Same as above but compiled for speed and a minimum of error diagnostics.	See section 1.3.4 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.exe* program is executed while in the *c:\spl\bsnm\results* 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 SPL will have to be executed. Alternatively, *RAGMET.exe, TMP.exe & SPL*.exe will also be a complete sequence (assuming of course that all other files listed as minimum requirements exist – see Section 1.3.4. Distributing the snow course and soild moisture data is an optional activity, depending on whether initial data exists.

Notes:

- *RADMET.exe* and *CALMET.exe* are not usable now – nor converted to using the Green Kenue file formats.
- 32 bit versions have *"32"* attached to the names; 64 bit versions have *"64"* attached to the names – names as given on http://www.watflood.ca

1.5.1 Read CAPPI (*RADMET.exe*) [inactive]

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.exe*) [inactive]

CALMET will combine a radar rainfall file with rain gauge data using the Brandes radar rain gauge adjustment algorithm (Section **Error! Reference source not found.**). 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.exe*)

RAGMET.exe converts point precipitation data to gridded data using a distance weighting method to each grid in the domain. Inputs to *RAGMET.exe* are *basin\BSNM.pdl* and the point precipitation data file *raing*_rag.tb0*. Output gridded precipitation file produced by *RAGMET.exe* is *radcl*_met.r2c.* The input and output files names are obtained by reading the event file. For details please see Chapter 6 *Rainfall Data Processing*.

Note: The extent of the precipitation grid is determined by the values given in the *BSNM.pdl* file. The domain for the precipitation files can be larger than the domain of the *BSNM_shd.r2c* file.

1.5.4 Distribute Snow Course Data (*SNW.exe*)

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*_crs.pt2* and the output file is *snow1*_swe.r2c*. The event file is used to get these file names. The point data file *snow1*_crs.pt2* is based on snow course data. For details please see Section 5.1 *Initial Snow Cover*.

Note: The extent of the output gridded snow water equivalent (SWE) files (**_swe.r2c*) files is the same as the size of the domain in the *BSNM_shd.r2c* file.

1.5.5 Distribute Soil Moisture Data (*MOIST.exe*)

Initial soil moisture 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*_psm.pt2* and the output file is *moist*_gsm.r2c*. The event file is used to get these file names. For details please see Section 5.2 *Initial Soil Moisture*.

Note: The extent of the output gridded soil moisture files (**_gsm.r2c*) files is the same as the size of the domain in the *BSNM_shd.r2c* file.

1.5.6 Distribute Temperature Data (*TMP.exe*)

Temperature data are required only if the snowmelt or evaporation routines are invoked. *TMP.exe* converts point temperature data to gridded data using a distance weighting method to each grid in the domain. Inputs to *TMP.exe* are *basin\BSNM.pdl* and the point temperature data file *tempg*_tag.tb0*. Output gridded temperature file produced by *TMP.exe* is *tempr*_tem.r2c.* The input and output files names are obtained by reading the event file. For details please see Chapter 7 *Temperature Data*.

Note: The extent of the temperature grid is determined by the values given in the *BSNM.pdl* file. The domain for the temperature files can be larger than the domain of the *BSNM_shd.r2c* file.

Note: WATFLOOD started its life an an event model – e.g. a 5 day hydrograph for a rainfall event so originally there was no need for snow or temperature data. As WATFLOOD evolved, more data was needed but the option of running WATFLOOD as an event model remains – although this feature has not been tested for a long time as most applications tend to have long spinup requirements (a year say) or the model is run for long time periods as for climate change scenario testing.

1.5.7 Run CHARM (SPL)

There are two versions of CHARM: *SPLX.exe* and *SPLD.exe*. They are the same except that *SPLD.exe* is compiled to run in the debug mode. It will provide error messages pointing to problems in the code. *SPLD.exe* is slow in execution. *SPLX.exe* is compiled for maximum execution speed but provides no debugging information. 64 bit versions have *"64"* added to the names. If a problem such as division by zero or exceeding array dimensions occurs when running *SPLX.exe*, run *SPLD.exe* with the same data set, record the error message and send it to kouwen@uwaterloo.ca. In debug mode the error is pinpointed.

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 initial soil moisture values used for the simulation are the values in the *moist*_psm.pt2* file. If this file is not found, 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 is intended for short duration forecasts with no spinup period. The soil moisture is optimized 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. CHARM 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

Commented [AN1]: The modes described here seem to be a carryover from an older GUI-based app. What is the relevance of these modes now?

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 100 parameters can be optimized. The method is further described in Chapter 4 *Model Parameters and* Optimization.

1.5.12 Debug Mode (iopt= 0,1,2,…,99)

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 debug files are sent to the *results* directory. Routing variables are sent to *rte.txt*, reservoir information to *res.txt*, optimization data to *opt.txt*, and runoff to *rff##.txt*. The *##* in *rff##.txt* refers to the order of the land cover class. A more detailed explanation of the output file is given in Chapter 11 *Output* Files.

When the program is run in the Debug mode, a debug level is specified in parameter IOPT in the *basin\BSNM_par.csv* 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##.txt* files. A value higher than 2 is used for program development only. For optimization, the debug level is set to 0. To check if all files required to run the entire sequence of events set *iopt=99*

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 Stage Hydrographs (STGPLT) [provisional]

When appropriate information is provided through the basin\bsnm.str file, stage hydrographs can be plotted and damage elevations shown on the plot.

Example of an expanded stage hydrograph:

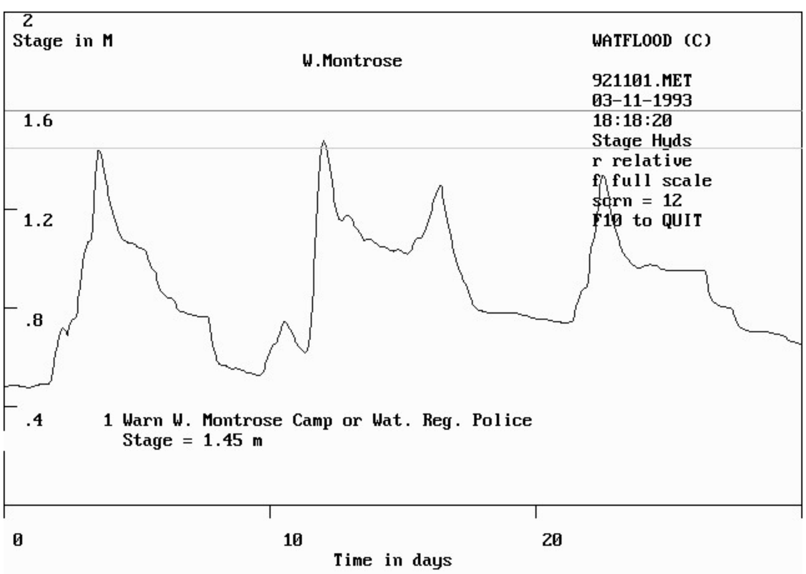


Figure 1.3. Stage hydrograph for a selected location on the Grand River.

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.

1.5.16 Flow Animation in Green Kenue

When the model is executed there is an option to create a *watflood.wfo* file with various state variables that can then animated in Green Kenue. The grids shown correspond to the computational units in the watershed. In the figure below, the flows in the main stem and tributaries of the Grand River (Ontario) are colour coded to the flows a point in time. This 2-D plot can show the progression of the flood wave downstream.

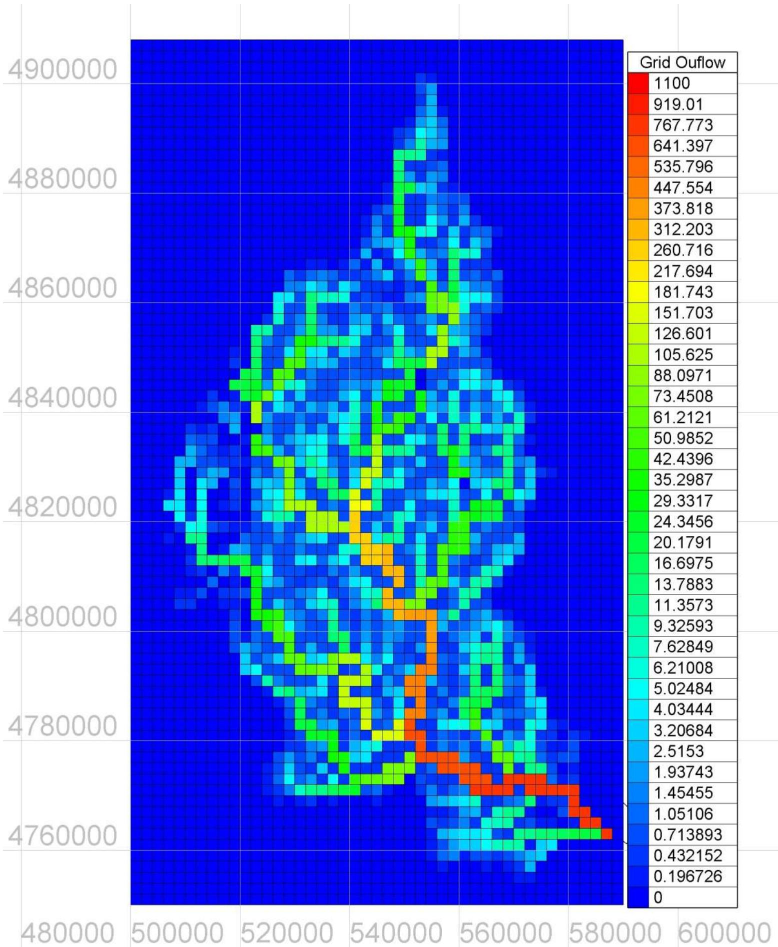


Figure 1.4. 2-dimensional representation of the flows in the main stem and tributaries of the Grand River.

1.6 Setting Up a New Event

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, CHARM 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 CHARM

The first entry in the PAR file sets the debug level for SPL. As the value of *iopt* is raised from 0 to 5, more state variables in the model are printed in the various files in the results directory. There are separate files for various parts of the program. The *rff##.txt* files are for the runoff subroutine, the *rte.txt* is for the routing subroutine and the *res.txt* refers to the reservoir and lake routing 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. In addition, state variable values can be written to the *results\watflood.wfo* file and viewed and animated in Green Kenue.

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 SPL, not much useful information is printed out (the operative word is "useful" here). When this happens, run *SPLD.exe* and the source of the error may become clear.

1.7.1 Common Problems

Table 1.4 summarizes common problems when executing WATFLOOD programs and how to troubleshoot them.

Table 1.4. Common WATFLOOD errors and troubleshooting.

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-protected 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 for Green Kenue by specifying 24 hour time increments and/or fewer variables.
Read errors	Check the *spl.txt* file to see how far the program was able to read the data. Use IOPT=1 in the parameter 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 it is useful to send all the files in an event causing the problem.
-ve storage errors	Slopes are too steep for Manning's n or Manning's n is too low for steep slopes. Also, check overbank Manning's n – it could be too low. Coefficients change in the reservoir release files from one event to the next – if grid is in a lake or reservoir. Minimum time step in the parameter file is too long.
Frac = 0 (or a very small value.	Occasionally, Green Kenue creates a map file with frac = 0 for grids in the watershed. The map file has to be edited to have reasonable values. Small values of frac for larger drainage areas can give problems with routing.

Example 1: program crash. Rerun 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  CHARM                    1122   CHARM.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 **_str.tb0* file:

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

All you need is:

```
:Projection             CARTESIAN
```

And leave out the other two lines.

Example 2: \ 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. Forward slashed are required in UNIX. When the file names are as highlighted above, the name is truncated at the forward slash.

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 *SPL.exe* the *outfiles.new* file is created that lists the default *SPL* output file set. You can edit this file and rename it to outfiles.txt to send the files anywhere you would like but you need to make sure the specified directories are created first. Most common WATFLOOD output files are described in Table 1.5.

Table 1.5. WATFLOOD output files.

Default File Name	File Description
results/error.r2s	Gridded streamflow error for each sub-basin
results/error.xyz	Gridded streamflow error for each sub-basin
results/evap.txt	Evaporation data echo and variable tracking
results/evapsep.txt	
results/evt_means.csv	Mean observed and computed flow by event
results/gridflow.r2c	Grid outflow in Green Kenue format – set kenueflg = 'y'
results/lake_sd.txt	Lake information (levels etc.)
results/leakage.dat	Gridded recharge in hourly timestep (for MODFLOW say)
results/min_max_lake_elevations	Minimum & maximum lake/reservoir levels & range
results/opt.txt	Optimization tracking file
results/peaks.txt	Event peaks – observed and computed
results/pic.txt	Mapper – flow animation (under repair)
results/qdwpr.txt	Reach inflows in DWOPER format
results/res.txt	Reservoir data echo and variable tracking
results/resin.txt	Reservoir inflows if known
results/rff##.txt	State variables land cover class ## – hourly time step (set IOPT=1 in parameter file)
results/rff.txt	Useless file
results/rte.txt	River routing data echo and variable tracking
results/sed.csv	Sediment data echo and variable tracking
results/snw.csv	Snow data echo and variable tracking
results/snw.txt	Snow data echo and variable tracking
results/snwdebug.txt	Snow data echo and variable tracking
results/spl.csv	Observed and computed flows for plotting programs (Grapher, Excel)
results/spl.plt	Observed and computed flows for *SPLPLT.exe*
results/spl.txt	Data echo mostly
results/spl_dly.csv	Observed and computed daily streamflows (if hourly input is used)
results/spl_mly.csv	Observed and computed monthly streamflows (if shorted dt is used)
results/stg.plt	Observed and computed stage for *STGPLT.exe*
results/strout.1	Computed .str files – can be used to compare new vs. old runs
results/swe.r2c	Gridded SWE – set kenueflg = 'y'

Default File Name	File Description
results/tracer.csv	Various streamflow components depending on choice of tracer
results/tracer_debug.csv	Tracer variable tracking
results/tracerMB.csv	Tracer variable tracking
results/tracerWET.csv	Wetland tracer variable tracking
results/tracerWETMB.csv	Tracer variable tracking
results/volumes.txt	Event volumes – observed and computed
results/watbal1.csv	Water balance at program initiation
results/watbal2.csv	Water balance at program termination
results/watflood.wfo	SPL output for Green Kenue input
results/wetland.csv	Wetland data echo and variable tracking
scratch5	
scratch6	
spl_info.txt	Program warnings and errors

1.9 Do's and Dont's

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 and drainage directions can be adjusted for each grid to get matching areas at reported watershed areas.
- When adjusting flow paths, when you change a drainage direction for a grid, make sure the new receiving grid has a lower elevation. Turn on: "Show Cell Labels" when the elevation and drainage directions are shown in the Green Kenue view.
- 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 hydrographs that do not represent reality. This can be

avoided by entering a minimum slope when executing the *BSN.exe* program. A minimum slope of 0.001 works quite well. You can also extract river flow profiles in Green Kenue.

- **Use yearly events for long simulations**.
- If your precipitation data is daily use *RAGMET.exe* to disaggregate the daily amounts. Set the smearflg = y in the event file.
- If your temperature is daily max and min, create a **_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. A WATFLOOD program *ECmet.exe* can be used to read standard Env. Canada meteorological files to create tb0 files with a deltat=4 hours.
- If your flow data is daily, do create **_str.tb0* files with 24 hour increments. *SPL.exe* will automatically calculate daily means for comparisons.
- In Canada, it is preferable to use lat-long coordinates to enable use of the Green Kenue data base of the Canada Water Survey drainage layer. It is also (much) better if your study region crosses UTM zones.
- When using lat-long coordinates, to have roughly square grids, your E-W grid size must be approximately 1.5 times your N-S grid size in the southern part of the country. This varies with latitude of course. It works out to a factor of 2 for the Mackenzie river.
- For the map file, make sure you leave blank rows and columns outside the boundaries of the watershed outline. (Green Kenue will do this automatically but if you set your own origin, extent & delta's you need to ensure you do this also).
- When setting up a new map file, locate your origin and chose your DeltaX and DeltaY such that the WATFLOOD grid lines coincide with major lat-long grid lines (or you will go batty looking at the 2-D graphics in Green Kenue).
- The drainage path, by following the drainage directions from grid-to-grid, MUST pass through the lake or reservoir outlet and it is best to ensure that drainage directions point into the lake except at the outlet. I.e. the reservoir outlet must be in a cell that drains all of the waterbody.
- Check the computed lake levels to ensure they are not continually increasing or decreasing over time. An accumulation or loss of water in lakes can seriously distort the runoff amounts at downstream gauging stations. Level data is in the *lake_sd.csv* file.

1.9.2 Dont's

- Do not make the grid size too small. It just wastes time and probably does not give better results. With current computers 3-4000 grid cells should be the maximum resulting in approx.. 3 min per year-long simulation with tracers turned off.
- 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 in Green Kenue to obtain the land cover percentages for WATFLOOD – use GeoTiff's. Convert polygons to a GeoTIFF (polygons within polygons result in double counting of the land cover class).
- **Do not divide daily precipitation into 24 equal amounts**. Just enter the DeltaT in the header, enter the data at that time increment and let *RAGMET.exe* disaggregate.

Note:

The frame numbers in the **.r2c* files are no longer used to indicate the time of the frame. The time stamp is used to match the data to the model clock.

1.10 Known Problems

In WATFLOOD, the DeltaT values are required in hours. In Green Kenue, the time interval is in seconds. This results in the wrong x-axis labels in Green Kenue when plotting time series. This does not apply to the *watflood.wfo* file which is compatible with Green Kenue. This problem would have been fixed long ago except for the problems it would create with 1000's of old WATFLOOD files.

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

You can get help by sending details of the problem to Nick Kouwen (kouwen@uwaterloo.ca)

Please send the set of files that give you grief, but leave out the gridded precipitation and temperature files which can be re-generated (unless they are from weather models).

2 HYDROLOGICAL MODEL

2.1 Introduction

The model CHARM 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 CHARM, 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 CHARM input format; BSN may be used to assemble and create a 'basin file' for CHARM.

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 Figure 2.1 are described below.

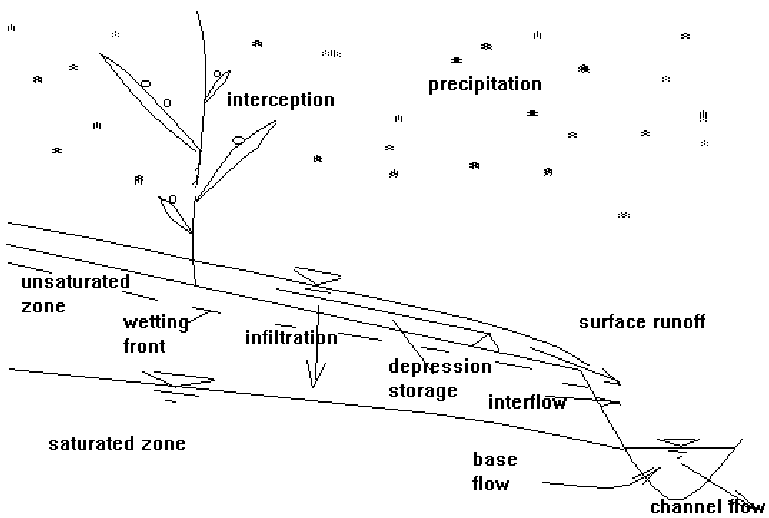


Figure 2.1. Schematic of the runoff algorithm.

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

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

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)
Impervious urban areas	1.25
Pervious urban areas	3.0
Smooth cultivated land	1.3 - 3.0
Good pasture	5.0
Forest litter	8.0

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 hydrological 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:

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

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
	=	detention storage

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 ~10 mm/hr to ~ 100 mm/hr.

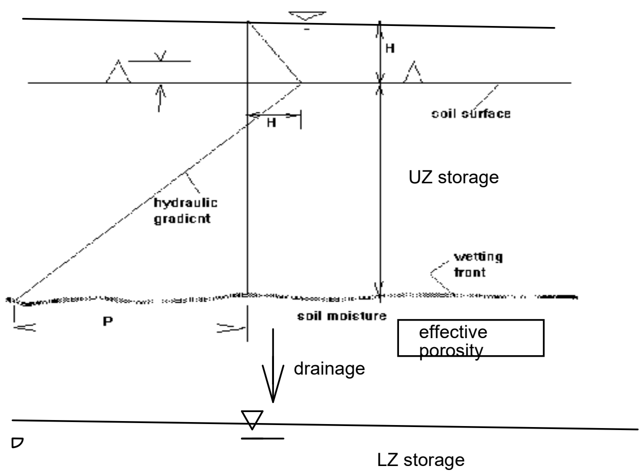


Figure 2.2. Schematic of the infiltration process.

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:

$$Pot = 250 \log (K/3600) + 100 \quad (2.3)$$

where:

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

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:

$$m_O = API/100 \quad (2.4)$$

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

$$APIi = k\,(API_{i-1}) + P_i \quad (2.5)$$

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 cell according to:

$$m_O\,(t+t) = A5 * m_O\,(t) + P_i/100 \quad (2.6)$$

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. This has the effect of gradually reducing the capillary potential of the soil which in turn also reduces the infiltration rate over time as it rains.

2.3 Potential Evapotranspiration

By 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 also required for the snow melt simulation so in the vast majority of current

watflood applications temperature data is used and the Hargreaves method has provided good results. There is no recnet ecperience with the Priestly-Tailor method.

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:

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

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 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:

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

2.3.2 Hargreaves Equation

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

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

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 measurements of temperature in degrees Celsius. 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:

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

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):

$$R_a = 15.392 \cdot d_r (w_s \cdot \sin\phi \cdot \sin\delta + \cos\phi \cdot \cos\delta \cdot \sin w_s) \tag{2.11}$$

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

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

δ is the solar declination (radians) defined by:

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

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

$$\mathrm{w_s} = \arccos(-\tan\phi \cdot \tan\delta) \quad (2.14)$$

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 (${}_t$), an approximation of the ratio of $s(T_a)$ to the sum of $s(T_a)$ and by using the temperature (T), and a reduction in the driving gradient when the vapour pressure deficit is small (C_t).

NEW (Jan. 2014)

A revised Hargreaves and Samani (1985) method has become available and is coded in CHARM. The new method requires the use of the daily difference between the min and max temperatures. These are calculated by *TMP.exe* and written to the file *tempr*_dif.r2c* for use in CHARM. To use the 1982 version set *flgevp2=2* in the *bsnm_par.csv* file. To use the revised 1985 version, set *flgevp2=4*

The only difference in the model is that δ_t is the difference between the daily min and max temperature for each day of the simulation. I.e. it is different for each day instead of relying on average values. This is now the preferred method.

2.4 Actual Evapotranspiration

By T. Neff.

2.4.1 Soil Moisture Coefficient

Up to three coefficients have been applied to reduce the calculated potential evapotranspiration (PET) to the actual evapotranspiration (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:

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

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).

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

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.

$$PWP = FFCAP \times FULL \qquad (2.17)$$

$$SAT = SPORE \times FULL \qquad (2.18)$$

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 minimum-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##.txt* files to plot cumulative precipitation 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 model parameter file if a simulation is not started on Jan. 1. On Jan 1 the value of TTON is reset to zero for continuous runs.

2.4.3 Forest Vegetation Coefficient (FTALL)

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.

$$FTALL = 0.70 \quad \text{for Tall Vegetation}$$

$$FTALL = 1.00 \quad \text{for Short Vegetation}$$

Although FTALL can be optimized, it was not intended by the originators of the method that this should be done. To optimize for volume of runoff, most attention should be paid to the values of the sublimation rate and the interception capacity.

2.4.4 Calculating AET from PET – Land Cover 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,

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

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

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

For lakes with a depth greater than 1 m, FTALL is used as a multiplier on the potential evaporation PET and lakeflg = y in the first event file.

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*.

Brass (1990) repproduced a table from Gray (1973) yielding somewhat greated values for maximum interception *h*. The value increases with precipitation. The table below gives values for .25, 10 and 25 mm of rainfall and can be used as a guide to settingthe maximum values in the parameter file (NK).

Vegetation	Maximum interception mm		
	for .25 mm pcp	for 10 mm	for 25 mm
orchards	1.05	2.80	5.50
Ash forest	0.55	2.30	5.00
Beech forest	1.05	2.80	5.50
Oak forest	1.30	3.05	5.75
maple forest	1.05	2.80	5.50
willow schrubs	0.60	4.50	10.50
hemlock & pine woods	1.75	4.41	6.25
Crops -veggies	0.54	2.00	4.25
grass	0.07	0.46	1.06
Forage	0.28	1.25	2.75
grains	0.14	0.63	1.38
corn	0.76	1.05	1.50

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,

$$\mathrm{IET} = \mathrm{FPET} \cdot \mathrm{PET} \tag{2.21}$$

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:

$$\mathrm{V} = \mathrm{F} \cdot \mathrm{X2} \tag{2.22}$$

and

$$\mathrm{X2} = \mathrm{h} + \mathrm{IET} = \mathrm{h} + \mathrm{FPET} \cdot \mathrm{PET} \tag{2.23}$$

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:

$$\text{fraction} = e^{-P_i / X2} \tag{2.24}$$

and

$$V = X2 \cdot e^{-P_i / X2} \tag{2.25}$$

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,

$$X2 = h + FPET \cdot PET \qquad \text{if } PET \leq h \tag{2.26}$$

or

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

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

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

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:

$$DUZ = REC * (UZS - RETN) * S_i \tag{2.29}$$

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
Si = 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 45º slope).*** DUZ is calculated simultaneously with UZ to LZ drainage (see below). Reasonable values for REC are approximately 0.5 - 5. An initial value of 1.0 is a good start for optimization.

The relative value of REC and DRNG (ak2 and ak2fs in the par file) will determine the split between interflow and drainage to the lower zone. DRNG is covered in the next section.

Interflow is assumed to be Darcian flow so proportional to the gradient. Figure 2.3 shows how the internal slope of a grid is related to the contour density within that grid. The greater the number of contours in a grid, the steeper the slope, and the quicker the overland flow and interflow. When the map file is created in Green Kenue, the number of contours along a straight line in a grid are counted and entered into the map file. *BSN.exe* converts this to an overland slope.

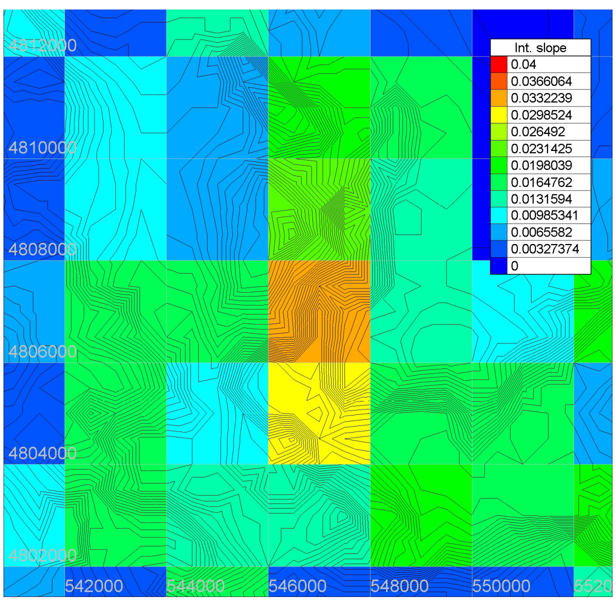


Figure 2.3. Internal slope – based on contour density

2.7 UZ to LZ Drainage (or Groundwater Recharge)

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

$$DRNG = AK2 * (UZS - RETN) \quad (2.30)$$

and is calculated simultaneously to the interflow. If the combined interflow and drainage depths exceed the available upper zone storage, the amounts are prorated according to the amounts calculated. AK2 is an intermediate zone (IZ) resistance 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 part of the water balance (i.e. the IZ has no water content) 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:

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

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 cell 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 cellary 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 CHARM, Equations 2.1 to 2.27 are used separately for each land class in each computational cell.

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-cell is found by prorating it to the total basin area. A groundwater depletion function is used to gradually diminish the base flow. Groundwater is replenished by drainage of the UZS (Eq. 2.30).

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

where:

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

There is only one LZS for each grid. All classes except water and hydraulically coupled wetlands (fens) contribute to the same LZS. The LZ discharge is to a fen if present, otherwise to the water body.

For short term flood forecasting (say a few days), 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. However, for long-term simulation, this parameter takes on added significance and low (winter) flows especially are significantly affected by LZF and PWR. These values should be optimized with longer periods that have dry and wet periods. Past calibrations indicate values of LZF = 10^{-6} to 10^{-4} and PWR = 2.0 to 3.0 but values may end up outside these ranges.

Dry weather flows are sensitive to the initial base flow. For this reason, it is helpful 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. Usually a one year spinup period is sufficient to enter the 2^{nd} year with good LZ values.

2.10 Total Runoff

The total inflow to the river system is found by adding the surface runoff from both pervious and impervious areas, the interflow, and the base flow. These flows are all added to the channel flow from upstream 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:

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

where

$I_{1,2}$	=	inflow to the reach consisting of overland flow, interflow, baseflow, and channel flow from all contributing upstream basin cells 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 (q_{in}) added or removed by hydrologic processes during the current time step:

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

where I, Q, and q_{in} are in cubic meters per second.

The lateral flow (q_{in}) is the sum of interflow (q_{int}), overland flow (q_1), baseflow (q_{lz}), precipitation falling on the stream (q_{stream}), less evaporation (q_{loss}):

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

Most river cross sections are rectangular with flat bottoms and near vertical sides. 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. Two values for Manning'n are required in the par file: r1n for the overbank and r2n for the channel roughness. The values should reflect published values for various river types but values slightly higher than these have been found to work well.

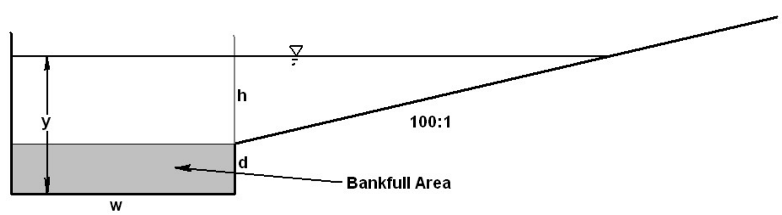


Figure 2.4. Representative river cross section.

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:

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

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

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

This formula works for the main channel flow only.

2.11.2 Channel Flow and 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:

$$\text{overbank area} = wh + 100h^2 \tag{2.38}$$

Solve for h using the quadratic equation:

$$h = \frac{-1 + \sqrt{1 + 4 * 100 * \text{overbank area}}}{2 * 100} \tag{2.39}$$

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

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 reservoir release files (see Section **Error! Reference source not found.**). But sometimes, there are too many small lakes to account for them all separately and for these, the parameter *Rlake* can be used to modify Manning's n. This will simply slow down the discharge due to the extra storage provided by many small lakes. Rlake can be optimized. This correction is activated be setting *a2* > 0 in the par file. For *a2* < 0, the correction will not be made. Please see Section 2.13 also.

2.11.4 Bankfull Area – Drainage Area Relationship

A requirement for running CHARM 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 (Figure 2.5). This relation is used to determine if the flow exceeds the channel's capacity at any point at any time.

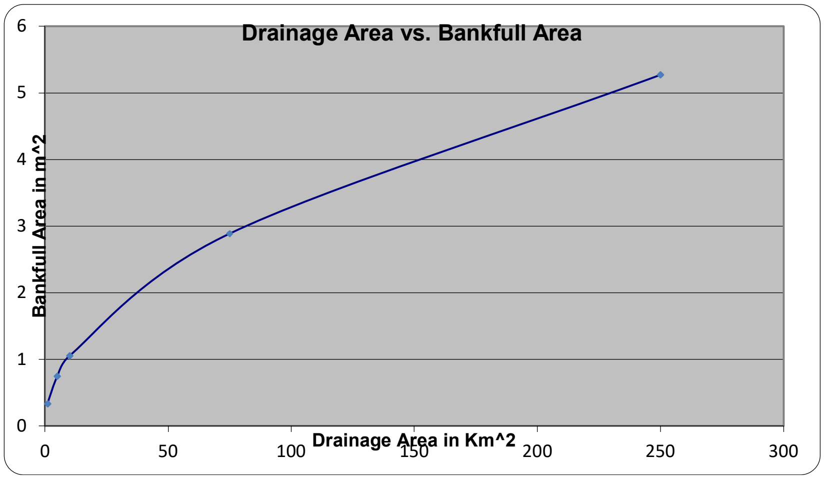


Figure 2.5. Example of bankfull area as a function of drainage area.

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

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

Example for Fig. 2.5:

DA	BF
km^2	m^2
5	0.8
10	1.1
50	2.3
100	3.2
150	3.9
200	4.6
250	5.1
300	5.8

For these data using the power function in EXCEL:

$$\text{bankfull area} = 0.0+0.3647BF^{0.4773} \qquad R^2=-.9989$$

Avoid entering values DA = 0 and BF = 0 as EXCEL cannot fit to these data. The aa2, aa3 and aa4 parameters can be specified for each river class in the model parameter file. In this example, aa2 = 0.0 but can have a value if before fitting the data a value is subtracted from each measured bankfull value.

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 = lateral wetland outflow in cubic meters per second
kcond = hydraulic conductivity in meters per second
hwet = height of water in the wetland in meters
hcha = 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 2.6 graphically illustrates the hydrologic interaction of the wetland and the channel:

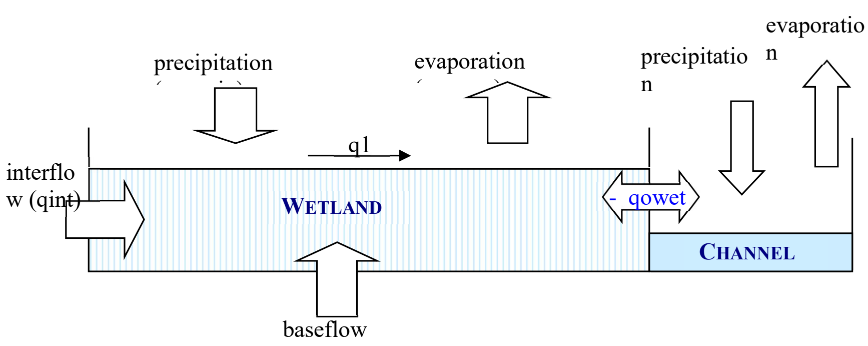


Figure 2.6. Hydrologic interaction between the wetland and the channel.

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):

$$q_{in} = q_{in} + q_{stream} - q_{loss} + qo_{wet} \qquad (2.45)$$

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 model parameter 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* event flag. 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 3.5 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. See Section 3.4.7 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 reservoir release (*resrl*_rel.tb0*); see Section **Error! Reference source not found.** for details.

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

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

or a polynomial like

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

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 represents the data of the storage-discharge curve reasonably well. An example input file is shown in Section **Error! Reference source not found.**.

For controlled reservoirs, the releases must be entered in the *resrl*_rel.tb0* file. The controlled reservoirs are indicated by b1 and b2 = 0.0 in the header of that file.

NOTES:

- 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. OR, if you do, be sure to put in the proper number of lines for that event. (number of hours/deltat).
- 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.
- Lake coefficients can be adjusted by trial and error to give a reasonable range of water levels. Local knowledge of water levels can be useful. Generally values for b1 range from 1.0E-12 to 1.0E-10 but could be outside this range. 1.0E-11 is a good starting point.

2.13.2 Instream Lakes (Numerous) (Revised Feb. 2018)

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. There are two methods to include the hydrograph attenuation characteristics:

1. Manning's n is modified for that grid according to the formula:

   R2n = MAX (r2n(i) ; r2n(i) * (water_area(i) / channel_area(i)) * rlake(j)) (2.48a)

   for water_area(n) > channel_area(n) where rlake(j) is a coefficient specified for reach j 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 reaches with many lakes. One or two small lakes do not have much of an effect. i = grid # j = channel class #

Note: Manning's n correction can be used in conjunction with wetland routing

2. **Pond routing**: This is done in the same manner as lake routing with the storage discharge function of Eq. 2.48. For this case, the exponent b2 is fixed at 1.75 and the coefficient b2 = rlake

For both cases rlake can be optimized. The pond routing is the revised method and is more physically realistic. The first method is kept to keep calibrated models intact. However, for new work, the pond routing should be used.

Note: It a hydrograph is delayed too much at a downstream location, check "rlake". Try a larger value.

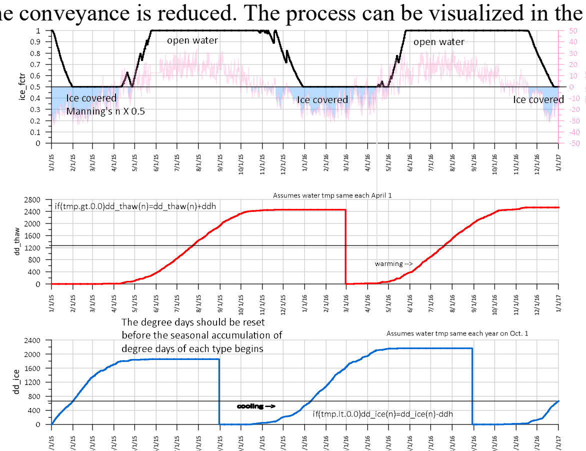
Pond routing is automatically implemented when:

1. the land cover map gives a water surface area that is greater than the water surface area calculated from the Bankfull Area vs. Drainage Area and width-to-depth relationships and
2. 0.0 < rlake < 1.0E-04 Values in the range 1.0E-10 to 1.0E-08 work in one known application. For the manning n correction, values for rlake should be nearer to 1.0
3. And **water area > wetland area**

   Note: pond routing and wetland routing can not be used in the same grid. (Up for revision)

2.13.3 Ice Factors

Ice on rivers (and lake outlets) can reduce the flow temporarily while the ice cover forms and release extra flow while it melts or breaks up. Using the ice flag in the event file y/n the Manning's n coefficient can be raised by a factor of 2. The degree days are accumulated from the onset of frost or the initial warming in the spring: dd_ice for freezeup and dd_thaw for breakup. The ice_factor is the amount by which the conveyance is reduced. The process can be visualized in the plot below:



2.14 Lake evaporation model (New 2017)

By Tegan Holmes, Univ. of Manitoba

The lake evaporation algorithm is activated by setting lakeflg = y in the event file and the lake depth > 1 m in the initial lake level file level\yyyymmdd_ill.pt2 file. Otherwise, the potential evaporation multiplied by fpet for the water class is used to compute lake evaporation.

The optional lake evaporation model is based on the Priestley-Taylor combination model, with heat storage flux from the lake included in the estimation. The evaporation rate is updated on a daily time step. The Priestley-Taylor equation is a simplified form of the Penman (1948) equation, which combines the mass transfer method and the energy budget method. The PTC approach simplifies Penman (1948) by assuming that the air over a water body will become saturated, while an empirical constant (α_{PT}) is used to account for the difference in the assumed equilibrium rate and the true rate of evaporation. The PTC model can be used to accurately estimate evaporation from lakes if heat storage flux from a lake is included (McJannet et al., 2013). Daily evaporation (mm day^{-1}) is calculated as:

$$E = \alpha_{PT} \frac{\Delta}{\Delta + \gamma} \frac{Q^* - J_{w_{max}}}{\lambda_v \rho_w} \times 86.4$$

where α_{PT} is the Priestley-Taylor evaporation coefficient (a value of 1.28 is used), Δ is the slope of the temperature-vapor pressure gradient (Pa °C^{-1}), $Q^*$is net radiation flux (W m^{-2}), $J_{w_{max}}$ is net lake heat storage flux (W m^{-2}), ρ_w is the density of water (kg m^3), and λ_v is the latent heat of vaporisation (MJ kg^{-1}). The values of Δ, γ, λ_v, P_{atm}, and ρ_w are calculated according to Dingman (2002), while Q^* and $J_{w_{max}}$ are estimated empirically.

Net radiation Q^* (W m^{-2}) is the sum of net longwave radiation and net shortwave, and in the calculation of evaporation is limited to positive net fluxes:

$$Q^* = L_n + S_n$$

$$Q^* = \begin{cases} Q^*, Q^* > 0 \\ 0, Q^* < 0 \end{cases}$$

Net shortwave radiation S_n (W m^{-2}) is calculated as (Annandale et al., 2002):

$$S_n = \tau K_{ET}(1 - \alpha)$$

where the atmospheric transmittance, τ, is defined as (Annandale et al., 2002):

$$\tau = 0.16(1 + 0.000027z)\sqrt{T_{a_{max}} - T_{a_{min}}}$$

where z is elevation (m above sea level) and α is the water surface albedo, interpolated based on latitude on a monthly basis from Table 5 of Cogley (1979) during ice free periods, and set to 0.8 during ice-on periods (Spence et al., 2013). $T_{a_{max}}$ and $T_{a_{min}}$ are the maximum and minimum daily air temperature.

K_{ET} is extraterrestrial shortwave radiation at the top of the atmosphere:

$$K_{ET} = \frac{I_{sc}}{\pi} E_0[\cos^{-1}(-\tan\delta \tan\Lambda) \sin\Lambda \sin\delta + \cos\Lambda \cos\delta \sin(\cos^{-1}(\tan\delta \tan\Lambda))]$$

where I_{sc} is the solar constant, 1367 W m^{-2}, Λ is latitude of the lake (radians), E_0 is the eccentricity correction factor, and δ is the sun's declination (radians), the latter two functions of the day of the year.

Net longwave radiation L_n (W m^{-2}) is calculated as the difference between incoming longwave radiation and outgoing longwave radiation (Dingman, 2002):

$$L_n = \sigma(T_a + 273.16)^4[1 - 0.261exp(-0.00077T_a^2)] - 0.98\sigma(T_w + 273.16)^4$$

where σ is the Stefan Boltzmann constant ($5.67x10^{-8}$ W m^{-2} K^{-4}), T_a (°C) is the mean daily air temperature, T_w is the average daily water temperature and ε is the emissivity of the surface, set to 0.98 as per Spence et al. (2013).

The lake water temperature estimation method is a generalisation of the model developed by Kettle et al. (2004). This estimation method applies an exponential smoothing function to air temperature to approximate the integrated response of lake water temperature to meteorological forcing, in combination with solar and lake depth effects:

$$T_{w_t} = 0.620lnD + 0.979f\left(T_{a,t}\right) + (0.0126 - 0.0059lnD)\left((0.75 + 0.00002z)K_{ET}\right)$$

$f\left(T_{a,t}\right)$ is a smoothed air temperature value:

$$f\left(T_{a,t}\right) = \alpha T_{a,t} + (1-\alpha)f\left(T_{a,t-1}\right)$$

where the smoothing parameter, α, is equal to:

$$\alpha = \frac{1}{6.7 - 0.829lnD}$$

The ice cover temperature is set at -0.5°C, this value is the lower limit of the water temperature.

Finally, the heat flux is calculated using solar radiation, air temperature, and the temperature difference between air and water, as:

$$J_w = -23 + 0.232K_{ET} + 28.2(T_a - T_w) - 2.1T_a$$

The maximum possible heat flux ($J_{w\,max}$, W m^{-2}) is limited by the amount of heat stored in the lake ($\sum J_w$):

$$J_{w_{max}} = \begin{cases} J_{w,t}, & -J_{w,t} < \sum J_w \\ -\sum J_w, & -J_{w,t} > \sum J_w \end{cases}$$

where heat storage is:

$$\sum J_w = \begin{cases} \sum J_w + J_{w,t}, & \sum J_w + J_{w,t} > 0 \\ 0, & \sum J_w + J_{w,t} < 0 \end{cases}$$

Heat storage ($\sum J_w$), rather than the estimated water temperature, is used to limit evaporation due to the potential for incomplete ice cover.

The lake evaporation method can be used for reservoirs by setting the lakeflg in the event file to y. The average lake depth must be set in the lake level file. The lake evaporation model is only used for lakes with an average depth greater than 1 m.

References this section:

Annandale, J., Jovanovic, N., Benadé, N., Allen, R., 2002. Software for missing data error analysis of Penman-Monteith reference evapotranspiration. Irrig. Sci. 21, 57–67.

Cogley, J.G., 1979. The albedo of water as a function of latitude. Mon. Weather Rev. 107, 775–781.

Dingman, S.L., 2002. Physical Hydrology, 2nd ed. Prentice Hall, Upper Saddle River, NJ.

Kettle, H., Thompson, R., Anderson, N.J., Livingstone, D.M., 2004. Empirical modeling of summer lake surface temperatures in southwest Greenland. Limnol. Oceanogr. 49, 271–282.

McJannet, D.L., Cook, F.J., Burn, S., 2013. Comparison of techniques for estimating evaporation from an irrigation water storage. Water Resour. Res. 49, 1415–1428.

Penman, H.L., 1948. Natural evaporation from open water, bare soil and grass, in: Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences. The Royal Society, pp. 120–145.

Priestley, C.H.S., Taylor, R.J., 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Mon. Weather Rev. 100, 81–92.

Spence, C., Blanken, P.D., Lenters, J.D., Hedstrom, N., 2013. The Importance of Spring and Autumn Atmospheric Conditions for the Evaporation Regime of Lake Superior. J. Hydrometeorol. 14, 1647–1658.

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/CHARM 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:

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

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 (^0C), and T_{base} is the temperature at which the snow begins to melt (^0C).

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 °C during a time step, is expressed as:

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

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.ºC/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:

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

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 $3.97\cdot10^{-07}$ 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 CHARM 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 CHARM 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 available 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 meteorological 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 Georeferencing 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 georeferenced data is originally entered in Green Kenuem. The map file is then transformed into the "watershed file" *basin\BSNM_shd.r2c* using the *BSN.exe* program.

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 *BSNM.map* file manually or with the use of Green Kenue, MAPMAKER 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*, etc. Table 3.1 summarizes the files required in the *BSNM\basin* directory.

Table 3.1. Minimum required files for running CHARM. All file paths are relative to the main basin directory.

File name	Purpose
basin\BSNM.map	Map file – contains all the watershed data in a gridded format. Created manually or by Green Kenue
basin\BSNM_shd.r2c	Basin file – produced from the map file using the *BSN.exe* utility. Contains watershed characteristics in a gridded format as used by WATFLOOD (*SPL.exe*). Some data from the map file are transformed, e.g. elevations are converted to slopes.
basin\BSNM_par.csv	Parameter file – contains the WATFLOOD model parameters.
basin\evap.dat	A table of climatic monthly evaporation. Can be used in lieu of calculating ET based on temperature and/or radiation data
basin\BSNM.pdl	Has the coordinates for the precipitation, snow course and temperature stations and has the grid specifications for the *_met, r2c and *_tmp.r2c files. Also 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).
*Radcl*_met.r2c*	Gridded precipitation file – created by *RAGMET.exe*
*Tempr/*_tem.r2c*	Gridded temperature file – created by *TMP.exe*

3.2.2 Steps to Set Up a New Watershed

1. Give the watershed a shortened name that identifies it, e.g. *gr10k* used for the Grand River tutorial dataset. This name replaces the *BSNM* placeholder in all file paths in this manual.
2. Create new folders (directories):

   \watflood\BSNM
   \watflood\BSNM\basin (required)
   \watflood\BSNM\bsflw
   \watflood\BSNM\evapo
   \watflood\BSNM\event (required)
   \watflood\BSNM\lkage
   \watflood\BSNM\moist (required)
   \watflood\BSNM\radar
   \watflood\BSNM\radcl (required)

\watflood\BSNM\raduc
\watflood\BSNM\raing
\watflood\BSNM\snow1 (required)
\watflood\BSNM\strfw (required)
\watflood\BSNM\tempg
\watflood\BSNM\tempr (required)
\watflood\BSNM\rchrg
\watflood\BSNM\resrl

The watflood directory can be placed anywhere but sould be made part of your path so all executables can be located in this directory.

3. The following files have to be created and placed in the *\watflood\BSNM\basin* subdirectory. Once these files are in place, everything else is automatic. See also example data files for details.

    a. Map file (*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 cells. 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.

       While it is still possible to create a map file manually, the Green Kenue has now completely automated the process. To create the .MAP file manually, draw the watershed on the grid as in the example in Figure 3.1. Then 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. Instructions 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 is not completely automatic!) please see Chapter 18. This Chapter presents a step-by-step set of instruction to set up a new watershed.

    b. Basin file (*BSNM_shd.r2c*) – 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 basin description file to be read by *SPL.exe*.

    c. parameter file *BSNM_par.csv)* – The set up and content of the parameter file is described in detail in Chapter 4

3.2.3 Watershed Data

Commented [AN2]: Some repetition with previous sections. Ideally reconcile all in one place.

Two watershed files are used to organize all the watershed data required by WATFLOOD. The first is the map file (*BSNM.map*), it retains the layout of the map and imagery from which the data is derived.

The second is the basin file (*BSNM_shd.r2c*), which is a condensation of the map file data into a format that preserves all the information but reduces the memory requirements of the programs. Basin file uses the 2D rectangular cell grid (r2c) format of Green Kenue. Figure 3.1 below shows an example of a watershed map (Grand River in Ontario, Canada).

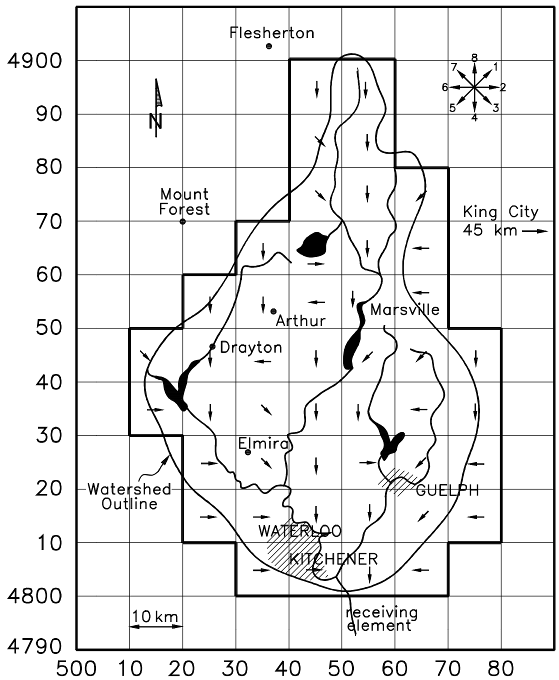


Figure 3.1. Example watershed map showing UTM coordinates in km, basin outline, reservoirs, rain gauge stations, grid size and drainage directions. NOTE: UTM coordinates must be entered in meters.

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 cell may be, but does not have to be, within this border.
3. Each grid is referenced in its bottom left corner.
4. The example grid extent is 500,000 – 590,000 in the east-west direction and 4,790,000 – 4,910,000 in the north-south direction.

3.3 Basin File

A WATFLOOD watershed map can be created automatically using Green Kenue. This methodology is fully described in its manual. Chapter 18 is a tutorial for a 2-day workshop showing the step-by-step process. Chapter 13 shows the use of Green Kenue as a post processor. It also shows the Green Kenue map for the Grand River watershed shown in Figure 3.1.

The watershed map can also be created manually and this actually serves as a good training exercise leading to a better understanding of the model.

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 the *BSNM_shd.r2c* 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 metadata 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.

The header of the *BSNM.map* file uses a free text format with keywords (prefixed by ':') followed by space-separated values.

Table 3.2 documents the keywords accepted in a map file, and Table 3.3 provides examples of headers for the three coordinate systems.

Table 3.2. Map file header keywords.

Keyword	Description
CoordSys	Coordinate system – should be one of: *Cartesian*, *UTM*, *LATLONG*. The same coordinate system must be used in all input files for a given watershed.
Datum, **Zone**	Geodetic datum and projection zone – these depend on the coordinate system: • For Cartesian coordinate system *Datum* and *Zone* are not allowed • For UTM, *Datum* and *Zone* are required • For LATLONG, *Datum* is required and *Zone* is not allowed
xOrigin, yOrigin	X and Y coordinates of the bottom left corner
xCount, yCount	Number of cells in the X and Y dimensions
xDelta, yDelta	Cell size in the units of the specified coordinate system in the X and Y dimensions
ContourInterval	Contour interval in meters – usually equals to 1 when automatic procedures are employed, otherwise as on the map used.
ImperviousArea	Used when land cover classification yields "urban area" but only a percentage of urban area is impervious. The value given is the percent 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. Please see **Section 3.3.1.1 Impervious area**
ClassCount	Number of land cover classes in the watershed .
ElevConversion	Conversion factor to apply to the elevation values. Should be 1 if elevations are in S.I. Units (meters), or 0.305 for Imperial Units (feet). Default is 1.0 (if zero is entered).

Table 3.3. Examples of map file headers.

Coordinate System	Example

Cartesian	`: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`

UTM	`: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`

LATLONG	`#`
	`:Projection LatLong`
	`:Ellipsoid GRS80`
	`#`
	`#`
	`:xOrigin -140.800000`
	`:yOrigin 51.800000`
	`#`
	`:xCount 98`
	`:yCount 86`
	`:xDelta 0.400000`
	`:yDelta 0.200000`
	`#`

	:contourInterval 1.000000 :imperviousArea 0 :classCount 40 :elevConversion 1.000000 #--- ------- :endHeader

3.3.1.1 Impervious area

Normally, impervious areas can be split into two parts that are the same for the whole domain. But for some areas where the housing density may vary considerable across the domain, more flexibility is needed.

The impervious areas can be split differentially by sub-watersheds corresponding to channel classes with a file called **SubBasinImpPc.txt** in the **basin** directory. The percentage of impervious area moved to class 1 will be done according to the values listed in this file.

Example file:

```
RiverClass  ImpPercent
        1       65
        2       65
        3       65
        4       65
        5       65
        6       65
        7       65
```

3.3.2 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.

3.4 Map File Data Fields

3.4.1 River Invert Elevation (ELV)

The elevations of the cells refer to the elevation of the main channel in the grid cell at its midpoint between the cell 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 cells surrounding the basin. Only one cell is used as the receiving square (ELV = 850). More receiving cells are possible but they must all have the same elevation. This is automatic if the receiving cells are all in the same water body but if this is not the case, dummy receiving-cells must be used. That is, there will have to be at least two cells outside the watershed: one with the proper elevation and the second with an elevation common to all watershed outlets. (no longer a requirement)

Care should be taken that successive downstream cells have lower stream bottom elevations. If this rule is violated, negative slopes result with dire consequences in CHARM. Also, the contributing areas to each streamflow gauge will be wrong. These points can be checked in the *new_format.shd* output file produced by *BSN.exe* (no longer used by CHARM but useful to locate these problems). 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.exe* output file *new_shd.r2c* (used by CHARM) can be checked using Green Kenue.

It is quite helpful, and really essential, to produce a square grid outline of the watershed (Figure 3.1) to aid with the coding. Below is an example of the river invert elevation block of the map file (values are aligned for ease of reading; this neat alignment is not a requirement for the map file).

```
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
```

3.4.2 Grid Drainage Area (FRAC)

The drainage area of the basin cannot be closely matched if only full rectangular border cells are used. There is a provision in CHARM to accept partial cells. An example of the required data is shown below. The data is the percentage of each cell FRAC within the basin. The 0's denote the blank rows outside the watershed. It is possible to adjust sub-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 specified as percent 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 areas in the top data line are 10 and 60 km^2.

3.4.3 Drainage Direction (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 cell, use the predominant drainage direction. A 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
```

3.4.4 River Classification (IBN)

IBN is a classification of the grid cell 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. Each class can be given different main channel and flood plain Manning's n parameter as R2n and R1n respectively. Similarly, LZF, PWR, mndr, aa2, aa3, aa4, theta, widep, kcond, pool, and rlake 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
```

3.4.5 Contour Density (IROUGH)

The surface slope of each cell is calculated by:

$$slope = \frac{\#of\ contours\ \times contour\ \text{int}\,erval}{grid\ length} X100 \qquad (3.1)$$

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 (Figure 3.2). The contours can go up or down continuously or can go up and then down or vice 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. For the example below, the contour density is 14.

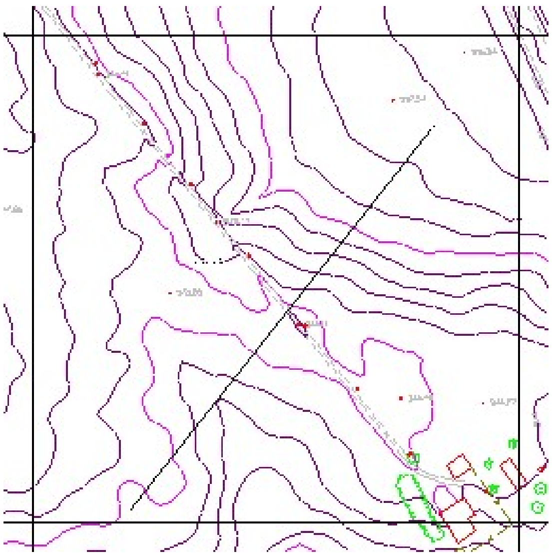


Figure 3.2. Contour density.

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
```

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.

Green Kenue does this count automatically.

3.4.6 Channel Density (ICHNL)

Channel density is the number of channels traversing the cell. This refers to main channels. If there are 2, 3, or up to 5 equally sized channels traversing the cells, 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 by increasing Manning's n a little to account for the lower efficiency of multiple streams. Upstream (headwater cells) are given a value of 5. Cells within the basin must have a value from 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
```

3.4.7 Routing Reach Number (IREACH)

Reach numbers need to assigned to all cells where routing other than channel routing is to be used. For all lakes and reservoirs reaches numbers need to be assigned. Simply, lakes and reservoirs are numbered from 1 to the number of lakes and reservoirs. The number will correspond to the lake rule specified in the *_rel.tb0 file – see Section **Error! Reference source not found.**

In some situations, the user may wish to route flows outside the CHARM model with another model, 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 cells where channel inflows are desired as output in a separated file. In this case, the reaches where external routing is required need to placed ahead of the reservoirs or lakes with rules. The output will be in a tb0 formatted file. A block of zeros is required where there is no external routing. (The is a custom application of the model. At time of writing there is just one such application which is hard-coded in the model. Please contact NK to extend this option to other locations)

See Section 2.13 *Lake* Routing for details of the lake/reservoir routing proceedure. Section **Error! Reference source not found.** explains how to set up the optional *_rel.tb0 file.

```
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 (Fig. 3.1) there are three reservoirs. The numbers 1 to 3 correspond to the reservoir locations in the *resrl*_rel.tb0* 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.

3.4.8 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). This feature is there because in some imagery what is classified as urban or developed is a mix of pervious and impervious areas and should thus be split. On other imagery, impervious and pervious are separate classes.

Any number of land cover classes can be specified (classcount). 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. **Water and impervious are always to be present in the file even if there is no area reported in the land cover map.**

Example of ordering land cover classes:

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

Important notes:

- **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).
- In 2006 when all files were changed to Green Kenue 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.
- Repeat: The last 4 classes – if present – must be in this order:
  glaciers
  wetlands
  water
  impervious
- **The keywords must be as shown!!**

```
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.
```

Notes:

- At this point the bankfull capacities in m^3/s of the stream in each cell can be entered. If no data is provided, a value is assumed for the purpose of doing the animation. **This capability is currently an undocumented feature.**
- Without this data, the bankfull cross-sectional area is calculated for each grid using Eqn. 2.41

3.5 Converting the map file to a shd file (new heading)

The map file contains measurable data such as an elevation for each grid. However, the model requires channel slope for routing purposes. The program BSN64x.exe reads the map file and makes all the necessary calculations needed by the model e.g. channel slope derived from grid elevations.

3.5.1 Wetlands – Splitting Bogs and Fens

As mentioned in Section 2.12.1 *Wetlands – Fens* and Bogs, wetlands can be either coupled or uncoupled from the flow routing as specified by the *wetflg* event flag. Usually a split of approximately 15-20% coupled wetlands (the balance remaining uncoupled) 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 grids as 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 *bsnm_shd.r2c* file (i.e. one more than in the map file). They will both be called 'wetland'. The last one, before the 'water' class will be the coupled wetland class if wetflg = 'y' in the parameter file.

The last 5 classes – if present – must be in this order which they will be if properly set in the *bsnm.map* file:

glaciers
wetlands
wetlands
water
impervious

Notes (important):

- The parameter file and snow depletion curve file need to be edited to ensure that the number of classes are the same as in the basin file.
- The hydrological parameters for both wetlands should be the same. If they are not so in the par file, the parameters for the coupled wetland will be set equal in CHARM.

3.5.2 Combining and Reordering Classes

Often land cover maps in GEOTIFF 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*.

(Please delete the old *class_combine.txt* making sure the data is transferred to the *class_combine.csv* first. The *class_combine.csv* file is more user-friendly than the *class_combine.txt* file, e.g. could be edited in Excel.)

Below is an example of a *class_combine.csv* file as edited in Excel:

The third column is the class order as in the map file and the 4^{th} column has the order of the output basin file – that is, class numbers in column 3 are mapped to those in column 4, performing class aggregation and reordering in the process.

class_combine_version	2					
description	GeoBase	Rank	ParFile#	ParFileClass	max_%		
nodata	0	1	9	water	0		
shadow	12	2	9	barren	26		
water	20	3	14	water			
barren/non-vegetated	30	4	9	barren	0		
snow_ice	31	5	12	glacier	93		
rock_rubble	32	6	9	barren	73		
exposed_land	33	7	9	barren	79		
developed	34	8	9	barren	6		
sparsely_vegetated_bedrock	35	9	15	impervious	0		
sparsely_vegetated_till-collovium	36	10	9	barren	0		
bare_soil_with_cryptogam_crust_-_frost_boils	37	11	9	barren	1		
Bryoids	40	12	10	Bryoids	61		
Shrubland	50	13	8	mixed	92		
Shrub-Tall	51	14	8	mixed	65		
Shrub-Low	52	15	10	Bryoids	85	1	grass
Prostratedwarfshrub	53	16	10	Bryoids	0	2	crops
wetland	80	17	13	wetland	4	3	shadow
wetland-treed	81	18	11	wetland_treed	86	4	conf_sparse
wetland-shrub	82	19	13	wetland	75	5	conif_open
wetland-herb	83	20	13	wetland	51	6	dec_dense
Herb	100	21	13	wetland	75	7	mixed/dec_dense
tussockgaminoidtundra	101	22	13	wetland	11	8	mixed_open_sparse
wetsedge	102	23	13	wetland	0	9	barren
moisttodrynon-tussockgraminoid/dwarfshrubtundra	103	24	13	wetland	0	10	byroids_lowshrubs
drygraminoidprostratedwarfshrubtundra	104	25	13	wetland	0	11	wetland_treed
grassland	110	26	1	grass	14	12	glacier/ice
class120_0%	120	27	1	grass	0	13	wetland
cultivatedagriculturalland	121	28	2	crops	72	14	water
annualcropland	122	29	2	crops	59	15	impervious
coniferousforest	210	30	5	conif dense	78		
coniferousdense	211	31	5	conif dense	94		
coniferousopen	212	32	4	conif_sparse	89		
coniferoussparse	213	33	4	conif_sparse	70		
Broadleaf	220	34	6	decid_dense	51		
broadleafdense	221	35	6	decid_dense	83		
broadleafopen	222	36	6	decid_dense	59		
broadleafsparse	223	37	8	decid_open	16		
mixedwooddense	231	38	7	mixed_dense	30		
mixedwoodopen	232	39	8	mixed_open	64		
mixedwoodsparse	233	40	8	mixed_open	25		

3.5.3 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 non-contributing areas (NCA) data and the methods cannot 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 on its own. The non-contributing area will then be completely ignored in the model.
2. OR: Each of first three land cover classes can be split into separate land covers. For instance, if the first three land cover files in the basin (*BSNM_shd.r2c*) file are crops pasture and grass, these can be split into four classes e.g. *crops*, *nca_crops*, *pasture, nca_pasture, 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 class can be made much larger thus allowing runoff only 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 but still contribute in very wet years by setting higher runoff thresholds (eg. retention and depression storage).

Notes:

- If using the 2nd approach, you will need to make extra classes in the parameter file as needed.

The following is an example of the first few lines and 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             Green Kenue
: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 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 and 0 points in each WATFLOOD cell and calculates the fraction of a cell that is not contributing and multiplies that by the original cell area. The cell areas can be subsequently viewed by loading the *BSNM_shd.r2c* file into Green Kenue.

The following steps could be used to make the *nca.r2s* file:

1. In a GIS:
   a. Convert data layer (e.g. a shapefile) to raster, e.g.resolution 100 m = 0.0009 degrees
   b. Use "spatial analysis tools" to reclass:
      i. Data (non-contributing) => 0 and
      ii. Nodata (contributing) =>1
   c. Convert from raster to ASCII format
2. In Green Kenue: Load the ASCII file, assign the projection and ellipsoid (and zone if UTM) and save it as *nca.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
…
```

3.5.4 Fetch (8 Directions) [new]

A lake evaporation model is under development by Trish Stadnyk and her students at the University of Manitoba. To accommodate this model, the fetch for each grid in a lake is required for 8 possible wind directions. Eight fields of data have been added to the *BSNM_shd.r2c* file between the reach numbers and the land cover classes. The fetch is automatically calculated by *BSN.exe* for each grid marked as a reach. You will see these listed in attribute list in the *bsnm_sgd.r2c* file as highlighted below:

```
: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 FetchNE
:AttributeName 14 FetchE
:AttributeName 15 FetchSE
:AttributeName 16 FetchS
:AttributeName 17 FetchSW
:AttributeName 18 FetchW
:AttributeName 19 FetchNW
:AttributeName 20 FetchN
:AttributeName 21 Bare
:AttributeName 22 forest
:AttributeName 23 crops
:AttributeName 24 wetland
:AttributeName 25 water
:AttributeName 26 impervious
```

Note: Sadly, in the new lake evaporation model, wind is not required nor used but for the time being, fetch is left in the map & shd files in case it's needed in the future.

3.5.5 Basin File (*BSNM_shd.r2c*) for UTM Coordinates

The watershed data as read by the model (*SPL.exe*) is created by *BSN.exe*, which reads information obtained from maps (manually or using Green Kenue, MAPMAKER or TOPAZ).

Example run with *BSN.exe* with user responses are highlighted in yellow (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 =na
 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

```
Green Kenue 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
```

This basin file for CHARM 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.**

CHARM reads only this watershed file. The older formats are no longer supported. However, *BSN.exe* does produce the old format as shown in sections 3.5.6 and 3.5.7 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         ← note: fetch is missing
: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
```

3.5.6 Basin File (.SHD) for UTM Coordinates (OLD FORMAT)

For the time being, the previous format created by *BSN.exe* (*new_format.shd*) will be kept as well as the new Green Kenue R2C format (*BSNM_shd.r2c*). It can be used for information only. It is useful to look at the data when Green Kenue is not available to the user or to look at the raw data in column format.

The basin file for CHARM 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 cell ***47*** is outside the watershed. If there are more than 1 receiving cells, they must be the last rows in the new_format.shd file. The new_format.shd file is only used for the HYPE input format and for information
- 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 (frac) of 0.0 to ensure that no computations are carried out for that cell and must all have the same elevation..

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

```
  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. Impervious fraction first. Water last.

This example of the basin file is the required format for CHARM. The proper format is automatically created by the program *BSN.exe*. Note that the last six columns in each row should add up to 1.0 to preserve the proper drainage area of each cell. Thus for cell 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). CHARM 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:

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 cell number that has the gauge:

   Suppose that the gauge is at the outlet of cell # 46. The computed drainage area at that location is found in the fourth column for cell 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
…
```

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 in Green Kenue 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.

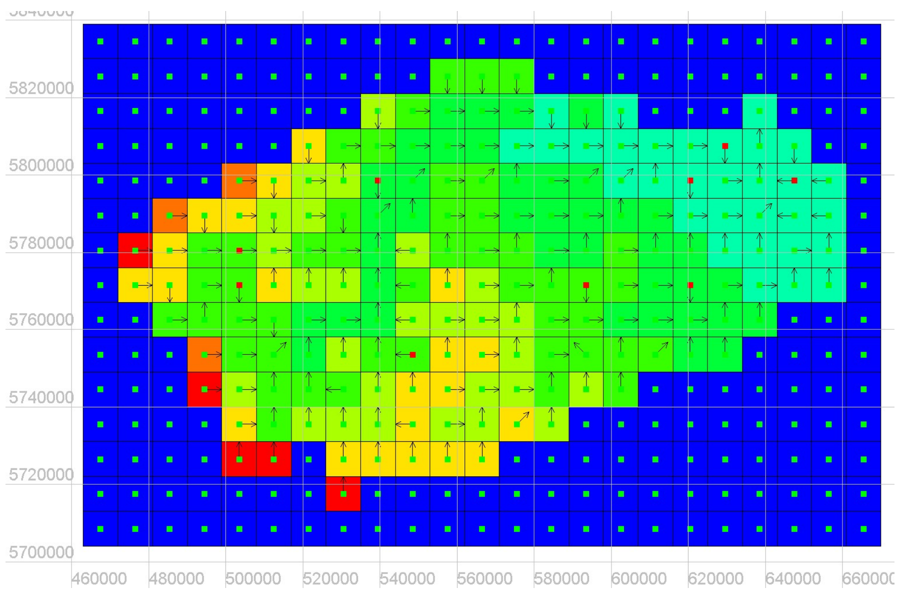


Figure 3.3. Debugging the map file with Green Kenue.

3.5.7 Basin File for Geographical Coordinates (LATLONG)

When the *BSN.exe* program reads a file for geographical coordinates, the header for the bsnm_shd.r2c file is as follows:

Commented [AN3]: Is this section out of date?

```
########################################
:FileType r2c  ASCII  EnSim 1.0
#
# DataType               2D Rect Cell
#
:Application             WATFLOOD
:Version                 10
:WrittenBy          nk
:CreationDate       2016-04-06  10:49
#
#---------------------------------------
:SourceFileName     mrb22_v12.map
:NominalGridSize_AL    22167.572
:ContourInterval          1.000
:ImperviousArea           1.000
:ClassCount                  16
:NumRiverClasses              6
:ElevConversion           1.000
:TotalNumOfGrids           3958
:numGridsInBasin           3957
:DebugGridNo               1979
#
#effective nca %           0.00000
#center deltaX  km        22.05108
#center deltaY  km        22.28468
```

```
#
:Projection         LATLONG
:Ellipsoid          GRS80
#
:xOrigin                 -140.80000
:yOrigin                   51.80000
#
:AttributeName 1 Rank
.
.  etc.
.
:AttributeName 36 impervious
#
:xCount                      98
:yCount                      86
:xDelta                   0.40000
:yDelta                   0.20000
#
:EndHeader
```

3.6 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, you may wish to optimize on just one sub-watershed to concentrate on one dominant land or river class.

Once you set up a sub-watershed, the same *rag, tag, str and rel* files as those for the whole watershed can be used (without deleting locations outside the subwatershed). Flow stations outside the sub-watersheds will just be ignored.

3.6.1 Creating a Sub-watershed (*SUBBSNM_shd.r2c*) [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. The following steps are required:

1. Set up a new watershed folder complete with all the sub-folders as in Section 0.
2. Copy *BSNM\basin\BSNM.map* to the new *SUBBSNM\basin* folder.
3. Delete the old *bsn_responses.txt* file in the new directory.
4. Run *BSN.exe* and enter the rank of the last sub-watershed grid(s) you want to model – usually grids with a flow gauge. You need to enter only the rank of the 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 Green Kenue and overlaying the *flow_station.xyz* file.
5. Rename *new.pdl* to *SUBBSNM.pdl* and *new_shd.r2c* to *SUBBSNM_shd.r2c*.
6. Edit the event files and replace *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 *SUBBSNM.pdl* file. (*RAGMET.exe* and *TMP.exe* 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.exe* and *SNW.exe* use the *SUBBSNM_shd.r2c* 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 *SPL.exe* and edit the *outfiles.new* file for the next run or copy the *outfiles.txt* file from another watershed before executing *SPL*.
11. Enjoy!

Note:

1. 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 simply be ignored.
3. You can even remove upstream sub-basins by specifying the appropriate nodes but then flow needs to be "nudged" at the upstream points to have the proper inflow to the downstream part of the watershed. (nudging is where observed flows are inserted into the outflow of a particular cell that contains a flow station with data).

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

Example *bsn_responses.txt* file:

```
version_#                     4
map_file_name                 bsnm.map
par_file_name                 na
initial                       nk
no_outlets_&_locations        1
534                                    ← **
no_inlets_&_locations         0
wetland_split_%                 35.0000000
split_type_1~2                1
min_allowed_slope                0.00100
adjust_frac_y|n               n
nca_choice_1|2                0
%_to_use(choice_1)               0.0000000
nca_classes(1-3)(choice_2)    0
create_max|mean.r2c_y~n       y
```

** This is the rank of the new outlet location in the original `whole`watershed file

3.6.2 Creating Reduced Domain Precipitation and Temperature Files [new]

If point precipitation 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, but only because it takes more time to read larger files..

Reducing the domain of the **_met.r2c* and **_tem.r2c* files can be easily accomplished by creating sub-directories in the *radcl* and *tempr* directories: *radcl\new_grid* and *tempr\new_grid*, and executing *SPL.exe*. The new files will be automatically created if these subdirectories exist. Next, backup the original files and copy these new **_met.r2c* and **_tem.r2c* files to the *radcl* and *tempr* directories respectively. They are then ready for use.

3.7 Additional Required Files

3.7.1 *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.exe* and *TMP.exe***. 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 “spaghetti plots”.

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

3.7.1.1 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.

3.7.1.2 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
```

3.8 Additional Optional Files [new 2012]

3.8.1 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:

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

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 and 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.

3.8.2 Storage-Discharge Curves for Lakes and Reservoirs

Lake storage-discharge curve for routing through natural lakes are entered in the *resrl*_rel.tb0* files. The first two entrees b_1 and b_2 after the lake outlet (reservoir outlet) coordinates are used in the simple power function:

$$\text{outflow} = b_1 \text{storage}^{b_2} \quad (3.3)$$

Values for $b_1 = 10^{-13}$ and $b_2 = 1.75$ are reasonable first trial values but b_1 can vary from 10^{-16} to 10^{-11}. The value of b_1 depends on the relative size of the lake to the watershed contributing to the lake. The initial storage of a lake is automaticall determined by a backward calculation from the initial flow at a downstream station or it is read from the **_ill.pt2* file

The third, fourth and fifth entrees – b_3, b_4, and b_5 – are used if the best fit is a polynomial. See Section **Error! Reference source not found.** for more details and an examle.

3.8.3 Initial Lake Levels [new 2015]

The *_ill_pt2 file can be used to initialize lake or reservoir levels as well as provide the model with the sill level and depth for each lake. The coordinates for the lakes must match the coordinates in the **_rel.tb0* file. The lake depth is used in the lake evaporation model.

Figure 3.4 shows the nomenclature for lakes and reservoirs. CHARM will calculate the invert elevation from the Initial Lake elsevation and the depth. A check is made to make sure that the listed depth is larger than the InitialLake elevation – Datum.

A larger depth can be used to ensure that lake storage does not become negative. Negative lake storage will destroy the tracer and isotope models.

Note: The depth in the *_ill.pt2 file is the depth of the dead storage only – i.e. datum – invert. In the program, the depth of the live storage is added during the initialization of the program.

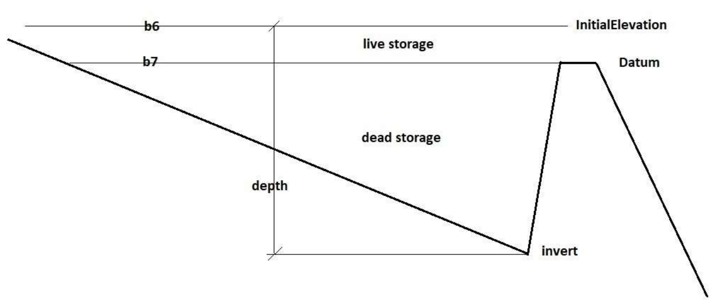


Figure 3.4 – Reservoir/Lake definition diagram

New 2017 – Reversoir "rules"

Safe max. lake level and a value for minimum releases for each lake or reservoir. These values are used in the reservoir "rules" option in CHARM – next section.

```
########################################
:FileType pt2  ASCII  EnSim 1.0
#
# DataType               EnSim PT2 Set
#
:Application             WATFLOOD
:Version                 2.1.23
:WrittenBy          NK
:CreationDate       2015-04-03  18:26
#
#---------------------------------------
:SourceFile                   flow_data
#
:Name
#
:Projection         LATLONG
:Ellipsoid          WGS84
#
 :SampleTime        1985/01/01  00:00:00.0
#
:AttributeName 1     StationName
:AttributeType 1     text
:AttributeName 2     InitialElevation
:AttributeType 2     float
:AttributeName 3     Datum
:AttributeType 3     float
:AttributeName 4     Depth
:AttributeType 4     float
:AttributeName 5     Safe_max
:AttributeType 5     float
:AttributeName 6     Qmin
:AttributeType 6     float
:endHeader
553309 4842575      BELWOOD      417.5  410.5    10 424.5    8
522939 4835772      CONESTOGO    387    373.5    10 393.5    8
557495 4802660      SHADES       287    284.9     5 289.71  .2
547958 4867847      LUTHER       481    480.6     3 482.2   .2
534751 4813601      LAUREL       342.5  339.2     6 343.5   .2
535189 4830041      WOOLWICH     362.7  358       3 365.2   .2
559131 4827107      GUELPH       346.5  342.8     8 350.0    4
```

Normally, only the first 4 attributes (name, elevation, datum and depth) are used. If reservoir operating rules are used (next section) then all columns are needed.

3.8.4 Reservoir Operating Rules (NEW 2017)

Reservoir target water levels can be read by CHARM and used to determine reservoir outflows. For example, the GRCA in Ontario publishes charts like the following:

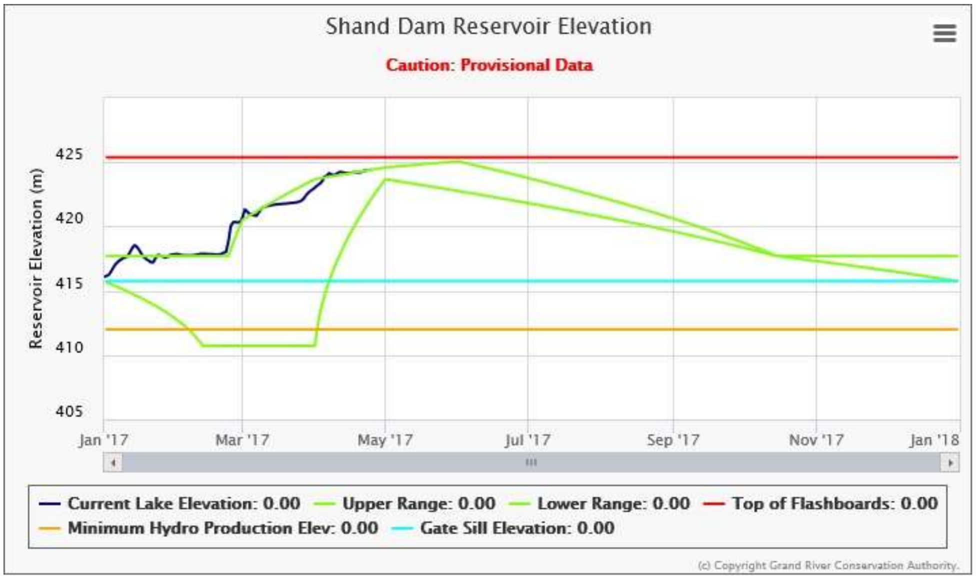


Figure 3.5 – Example reservoir rule curves
https://apps.grandriver.ca/waterdata/kiwischarts/hk_shand.aspx

The target water level elevations and other data can be picked off a figure like this and coded as rules for the WATFLOOD system with a **resrl\rules.pt5** file. The first entrees for a pt5 format file are shown below for 2 reservoirs on the Grand River in Ontario. A data line is required for each day of the year. The date stamp is ignored. Each reservoir has two columns of data: low target and high target. These need only be specified for break points in the curve – CHARM will interpolate for the intervening periods. If a **resrl\rules.pt5** file is present, these rules will be used – no flag is needed.

Notes:

1. The example data below is for only 2 locations. The example data set on **watflood.ca** has the rules for all seven GRCA reservoirs. Note that the "point" locations are needed for each column. CHARM output of reservoir levels can be found in results\res_levels.csv
2. Current code will attempt to follow the upper target levels when its slope is +ve (upwards in time). This because operators tend to try to ensure the reservoirs will be full at the end of the melt. In Fig. 3.5, the upper target level is constant Jan. – Mar. This period was coded with a very slight upward slope to keep the reservevel at its max as in Fig. 3.6. For a constant or -ve slope upper target level, the code will try for the midpoint between upper & lower target levels.

3. The order of the lakes or the number of lakes in the yyyymmdd_rel.tb0 and the rules.tb0 files does not need to match.
4. For example: https://pcacdn.azureedge.net/-/media/lhn-nhs/on/trentsevern/WET4/info/PDF/Fev-02-Feb/2018,-d-,02,-d-,02,-d-,kawartha.pdf?la=en&modified=20180202154537&hash=7D4FB2F65E6B4F4BA1F0F38C0307A3676ED79A09

```
#########################################################################
:FileType ts5 ASCII EnSim 1.0
# Canadian Hydraulics Centre/National Research Council (c) 1998-2007
# DataType Type 5 Time Series
#
:Application WATFLOOD
:Version 3.1.33
:WrittenBy NK
:CreationDate 2015-08-12
#
#-----------------------------------------------------------------------
#
:AttributeName 1_low
:AttributeUnits m
:AttributeName 1_high
:AttributeUnits m
:AttributeName 2_low
:AttributeUnits m
:AttributeName 2_high
:AttributeUnits m
:BeginLine 14
:Point    553309.0       4842575.
:Point    553309.0       4842575.
:Point    522939.0       4835772.
:Point    522939.0       4835772.
:EndLine
#       1 BELWOOD     regulated
#       2 CONESTOGO   regulated
:Targetlevels
:EndHeader
2015-01-01   00:00.0    415.70    417.79    373.60    384.29
2015-01-02   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-01-03   00:00.0      -1.0      -1.0      -1.0      -1.0
.
.
2015-02-07   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-02-08   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-02-09   00:00.0    410.50      -1.0    373.60      -1.0
2015-02-10   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-02-11   00:00.0      -1.0      -1.0      -1.0      -1.0
.
.
.015-02-21   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-02-22   00:00.0      -1.0    417.80      -1.0    384.30
2015-02-23   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-02-24   00:00.0      -1.0      -1.0      -1.0      -1.0
.
.
2015-12-29   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-12-30   00:00.0      -1.0      -1.0      -1.0      -1.0
2015-12-31   00:00.0    415.70    417.80    373.60    384.30
```

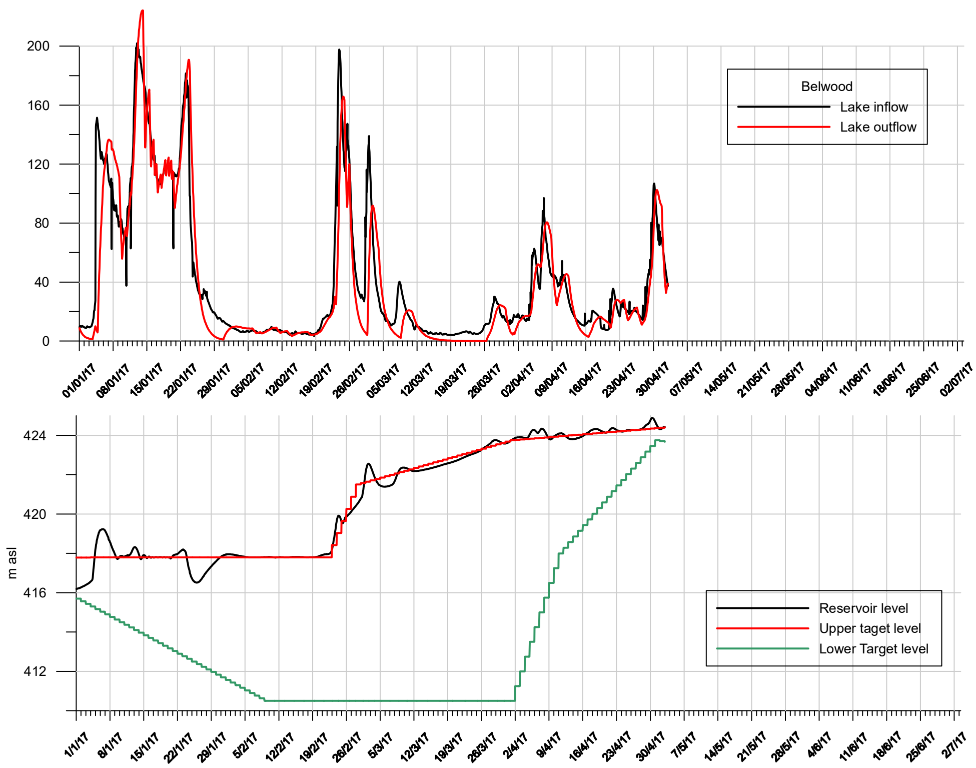


Figure 3.6 Example CHARM output for lake routing using lake rules.

3.8.5 Recorded Lake Levels

If recorded lake levels are present, they will be read in by CHARM and the file *levels.txt* will be created in the *results* directory. The *levels.txt* file will have paired columns of observed and computed levels so they can be directly compared.

The recorded lake levels can then be compaired. (Currently not used for automatic calibration but they can be used for manually fitting the coefficients for lake routing.

Example recorded lake level file:

```
########################################
:FileType tb0   ASCII  EnSim 1.0
#
# DataType                Time Series
#
:Application              EnSimHydrologic
:Version                  2.1.23
:WrittenBy           EC_lvl.exe
:CreationDate        2016-04-02   00:01
```

```
#
#--------------------------------------
:SourceFile                   level_data
#
:Name               level
#
:Projection         LATLONG
:Ellipsoid          WGS84
#
:StartDate          1990/01/01
:StartTime          00:00:00.0
#
:AttributeUnits            1.0000000
:DeltaT               24
:RoutingDeltaT         1
#
:ColumnMetaData
   :ColumnUnits             m          m          m          m       more
   :ColumnType            float      float      float      float    columns
   :ColumnName          07BJ006    07EF002    07EF003    07JA001
   :ColumnLocationX    -115.7720  -123.7480  -122.7320  -115.1710
   :ColumnLocationY      55.3057    56.0500    56.1056    55.9141
:EndColumnMetaData
:endHeader
                         576.475     31.191     31.181   -999.000
                         576.474     31.154     31.139   -999.000
                         576.481     31.086     31.086   -999.000
                         576.476     31.031     31.039   -999.000
.
.
.   more lines
```

Missing data -999.000

3.8.6 SWE updating

During the snow melt modelling period additional data in the form of snow course data may become available. This can be entered into the model on-the-fly so that the computed swe state will be replaced by the observed snow course data. The data is read from a file *_swe.r2c if the file is present for the day being modelled and the crseflg = u (for update). If the crseflg = y, the swe will only be updated on the first day of an event (in a possible string of chained events).

First create a **_crs.pt2* file with the swe for each land cover class at each snow course.
Example:

```
################################################
:FileType pt2 ASCII EnSim 1.0
#
# DataType                EnSim PT2 Set
#
:Application              EnSimHydrologic
:Version                  2.1.23
:WrittenBy                NK
:CreationDate             Fri, Jul 14, 1506 08:0
#
#-----------------------------------------------
#
:Name  Point Snow Water Equivalent
#
:Projection  CARTESIAN
```

```
#
:SampleTime   1993/01/15 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
:AttributeName 8 Class7
:AttributeType 8 float
:AttributeName 9 Class8
:AttributeType 9 float
:AttributeName 10 Class9
:AttributeType 10 float
:AttributeName 11 Class10
:AttributeType 11 float
:EndHeader
1426312        12057826         minden      111.8  111.8 .......8 more columns
1397780        12085225         NorwayPt    84     84
1418688        12021902         cboconk     132    132
1426088        11996493         Cameron     142    142
1483583        12066590         Bancroft    116    116
1458835        12121937         Whitney     137    137
1422509.2      12123621.7       OuseL       -1     -1
1400937        12111463         Kiwanis     103    103
1407704        11993149         Woodvill    146    146
```

This file is for 1993 01 15 so use the command snw64 20130115 in the working directory to create a snowc\20130115*_swe.r2c* file.

3.8.7 Parameter Files

The makeup of the parameter file (*basin\BSNM_par.csv*) is described in detail in Chapter 4.

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

3.8.8 *calmet.par* File [not supported]

This file is used only for radar calibration using the *CALMET.exe* program. Please refer to Section **Error! Reference source not found.**.

3.8.9 Mean and Max Grid Elevations for Lapse Rate Applications [new]

In mountainous terrain the use of lapse rates for temperature and precipitation is 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 makes 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 (ELV) and is propagated into the basin (*basin\BSNM_shd.r2c*) file (Elev). However, this channel elevation may not be the most desirable to use for the calculation of the grid's temperature and precipitation amounts. 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 affected by the higher elevations.

For this purpose, a file called *dem.r2s* can be created by saving the DEM in Green Kenue as an R2S (Green Kenue 2D Scalar Rectangular Grid format) file in the *basin* directory. Be sure to assign a **Projection** and **Ellipsoid** to the DEM in Green Kenue before saving the file or you will have to edit the R2S file to add it. *BSN.exe* will look for this file and if found, it will create two files called *elv_means.r2*c and *elv_max.r2c*, containing the mean and maximum elevations within each model cell.

If these files are present in the *basin* directory, the temperature and precipitation adjustments using the lapse rates TLAPSE and RLAPSE respectively will be based on the mean and max grid elevations respectively. *RAGMET.exe* will look for *elv_max.r2c*, and if found, will use these highest grid elevations instead of the channel elevations (Elev) stored in the basin (*BSNM_shd.r2c*) file. Similarly, if *elv_means.r2c* is found, *TMP.exe* will use these average grid elevations in place of the channel elevations in the basin file.

See Sections 6.1.4 and 7.3 for the precipitation and temperature lapse rate discussions.

3.9 Watershed Data Summary

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

Change to the *BSNM* directory and run *MAKE_EVT.exe*. Enter the appropriate data. Sometimes it takes a couple of tries to get started – you cannot correct the data if it has been entered incorrectly. This will create a sets of files in the *event* directory: a number of annual or monthly event files **.evt*. Please see Section 1.3.7.4 for details.

The *event.evt* file is always the default file. Once you have created the event file, you can run any event by copying the **.evt* file into the *event.evt* file and adding chained event names as needed at the bottom of the event.evt file. This makes the **.evt* file the active event file.

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

Commented [AN4]: STOPPED HERE for this chapter: possibly need to restructure subsections for more clarity

… add tables too

The parameter file contains most of the parameters used in CHARM. There are others in the program, which are not likely to ever need changing. 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 of CHARM and the coupler to DDS.

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 free format – i.e. **blanks between entries**. **Keywords have to be exact.**

Notes:

The impervious class is now like any other – it needs all parameters.

The par file should be edited in Excel and saved as a CSV file.

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 the output file *results\parfile.csv* to the parameter 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 – difficult to read:

```
…
#,,,,,,,,,,,,,,,
: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,,,,,,,,,
…
```

Important program revision **[New]**

Commented [AN5]: Would be useful to have some other general guidelines on the format of the par file: use of comments (#), blank lines

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
…
# Global parameters are entered in this section
…
:EndGlobalParameters
```

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

The following programs read the parameter file: *SPL.exe*, *RAGMET.exe*, *TMP.exe* and *DDS_WFLD_REV4.exe*. All these programs work in unison and should be updated together.

Part 1 – for normal runs. New sections are highlighted. (To get this nicely formatted file, run *SPL.exe* and edit *results/parfile.csv*

```
: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 disaggrdation
:a13,              0.000,# rain/snow temperature
: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
#
: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
#
: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
#
: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
```

NEW – used by RAGMET.exe and TMP.exe

```
: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
#
```

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 Parameter 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-date 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. For optimization, most 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.

Inactive stuff:
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 the Green Kenue 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	0	# 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.

*** NEW – use lat = 0 to trigger use of lat based solar angles and temperature differences

4.2.2 River and Basin Parameters

The following 11 lines are dimensioned for river classes. The river roughness and groundwater classes are grouped together. In the case where a river class cannot be associated with a groundwater class, you would have two river classes with the same river roughness but different groundwater 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 cell is set in the fourth field (ibn) in the *bsnm.map* file under the heading 'river class'. 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 *bsnm_shd.r2c* file.

4.2.3 Hydrological (Surface) Parameters

The following 11 lines are hydrological parameters for each of the land cover classes. 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.

The parameter names are listed and are defined as follows (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_rate	# sublimation rate mm/day
: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 and sublime_rate 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.

These are only used if the evaporation model in CHARM is not to be used. Used when *flgevp2 = 1*

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. It is not possible to optimize the interception capacity for each month for each land cover type. In the *results\parfile.csv* file, the values in the table have been multiplied by fratio so here the values in the table are the actual values.

4.3 Monthly Climate Normals

At one time this table was part of the par file but now a separate file called *basin/monthly_climate_normals.txt* It is still used if *flgevp2 = 2* in the par file.

```
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:

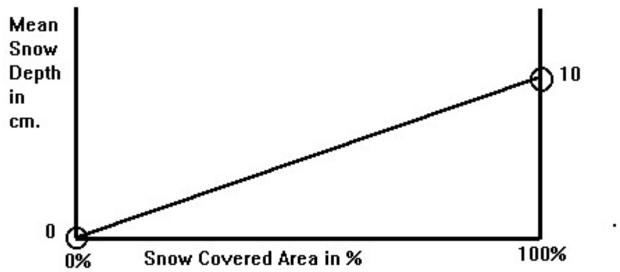


Figure 4.1. Snow depth vs. snow covered area.

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, in the par file in the section *:snowparameters*.

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

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 CHARM executable *SPL.exe*. The DDS method is external and required two additional executables namely *DDS_p.exe* and *DDS_wfld_rev5.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

BEEP: *SPL.exe* will produce two short beeps when finished. To turn these annoying beeps off when optimizing, create a file called beep.txt in the working directory and have the word **off** on the first line as the first 3 characters.

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 Green Kenue. In Green Kenue, plot the cumulative 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.
- *temp3* is a soil temperature coefficient that will advance or delay the rate of ET so you get about the right amount of ET in the early summer & fall. See Section 2.4.2

Commented [AN6]: tempa2 and tempa3 are not explained here or in the basin file

- Adjust pwr and lzf so the low flow recession curves have the same slope on a plot of Log(flow) vs. time.
- Adjust fratio (along with the interception capacities for each month and the retention (retn) to adjust the evapotranspiration for each land cover class. Use the file *results\precip.txt* to make plots of error vs. class fraction as shown below.

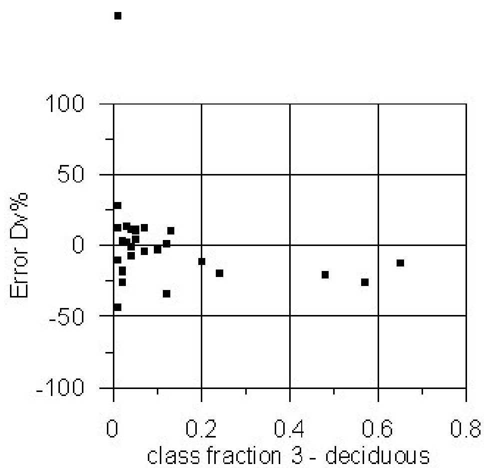


Figure 4.2. Volumetric error vs. class fraction.

You can create a figure like Fig. 4.2 for each land cover class based on data in the precip.txt file. The error Dv% is plotted against the Class Fraction, in this case col. q in *results\precip.txt*. Each point is based on one sub-watershed. Fig. 4.2 indicates that class 3 tends to under estimate flow, i.e. too much loss for deciduous forests in this case. This can be too much sublimation or too much ET. For sub-watersheds with a small fraction of deciduous forest, the errors average out to zero but for watersheds with large fractions, the errors increase.

Once you have reasonable results, you can tweak the parameters automatically. Always make sure the processes are reasonable: use the rff*nn* plots and Green Kenue animations & time series of the state variables to ensure they are realistic. You can also use the tracer option (Section 14.4) to plot the base flow hydrograph as well as the observed and computed hydrographs.

d) Perform the Pattern Search or the Dynamically Dimensioned Search (DDS) 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 in the par file need to be defined for optimization:

```
:OptimizationSwitches
:numa,         0,# PS optimization 1=yes 0=no
:nper,         1,# opt 1=delta 0=absolute
:kc,           5,# no of times delta halved
:maxn,      2001,# max no of trials
:ddsflg,       0,# 0=single run  1=DDS
:errflg,       5,# 1=wMSE 2=SSE 3=wSSE 4=VOL
:EndOptimizationSwitches
```

NUMA is used as a flag for the Pattern Search (PS) 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. Itis 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. (1/10th 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*_str.tb0* 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 4th 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).

Shortcut: if there is jusr -1 in the first str file the values in the 1st file will be used through out.

4.5.3 Optimization – Dynamically Dimensioned Search (DDS)

4.5.3.1 Specifying Parameters for Optimization

The following values need in the par file 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 *SPL.exe* for the DDS search. It disables all non-essential output and ensures the objective function value is written in the DDS directory
errflg = 1-8: stipulates 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:

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)
1000	!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.

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 SPL.exe.*

For DDS, the parameter values for each evaluation are decided by *DDS_p.exe* and are passed to *SPL.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 *SPL.exe* (evaluations) to compute the sum of squared errors. These sets of parameters from *DDS_p.exe* are converted from the *variables_in.txt* file written by *DDSP_p.exe* to a new WATFLOOD par file that can be read by *SPL.exe*.

The function of each of the executables is:

- *DDS_p.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 SPL.exe
- SPL.exe is the WATFLOOD/CHARM model
- *DDS_WFLD_rev4.exe* is the coupler between *DDS_p.exe and SPL.exe* – i.e. it converts the DDS_p parameter file format to WATFLOOD parameter file format and vice versa.

Note: All programs need to be updated at the same time to ensure that the parsers will be able to read updated list of keywords in various files – especially the event file.

4.5.3.2 Watflood_batch.bat

```
DDS_WFLD_rev3.exe
cd ..
SPL64.exe
cd dds
```

With radius of influence and smoothing distance also being optimized:

```
DDS_WFLD_rev4.exe
cd ..
ragmet64x.exe
tmp64x.exe
SPL64.exe
cd dds
```

The *bsnm_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_p.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_rev5.exe*, then moves up one directory level to the watershed working directory (where *SPL.exe* is normally executed), runs *SPL.exe* (which spews out a new value of the objective function) and then goes back to the *DDS* directory to do some more work itself. If *DDS_p_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_p.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)

DDS_p.exe is the active program and shells out to runs two batch files

a *watflood_batch.bat* -> runs the coupler & SPL

b *save best .bat* -> takes best files to now and saves them in the dds\best directory

DDS_p.exe reads the objective function written by SPL.exe in *function_out.txt*

4.5.3.3 Function_out.txt (Objective Function)

example:

```
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 **errflg.**

Eight objective functions are available.

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

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

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 $= sw_l = \frac{\acute{O}_l}{\sum_{l=1}^{no}\acute{O}_l}$

2. Sum of squared errors (SSE):

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

3. Sum of squared errors weighted with mean flow:

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

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:

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

7. Nash Efficiency (to be minimized)**

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

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

**Note: There is an added penalty if the volume is off by more than the value of a3 given in the Global Parameter section of the par file. E.g. if a4 = 0.03, the penaty is applied when Dv > 3%. A3 is a multiplier e=e-a3*(Dv(ii)-a4)*(Dv(ii)-a4) where ii is the flow station number.

4.5.3.4 Mean Observed Flows

For the Nash efficiency calculation, the mean observed flows are required before SPL is executed. This file is written at the conclusion of each SPL run. If the number of stations is changed, you will get an error message to that effect. Simply delete the file and run SPL to get a new mean_observed.txt file with the current flow & reservoir inflow data.

4.5.3.5 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:

Edit the dds_init file to have the proper values in lines 3, 5 & 6. You need only the first 15 lines to start.

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) *DDS_WFLD_rev5.exe*

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 – a very nasty process as there is no metadata in this file)

(The initial values and limits are set in an initial par file that could be called *basin\bsnm_start_par.csv*

Initially, 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.

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.csv* file should now be rewritten and be the same as before. If this works then:

Edit the *variables_in.txt* file to have -999.0 again.

Now run DDS_p 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. For 4000 cells it may take 2-3 weeks for a single DDS run on a fast PC.

- a DDS shells out and runs *watflood_batch.bat*
  - i This runs the coupler which I have called *DDS_WFLD_ver5.exe* This creates the
    - 1 *dds_init.txt* file and
    - 2 *variables_in.txt* file and a new
    - 3 basin|\bsnm_par.csv file
  - ii And hey, it runs SPL which writes *function_out.txt*
- b Back in DDS_p,
  - i it ingests the value of the objective function *function_out.txt*
  - 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\bsnm_par.csv* 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 SPL with the new par file and writes *function_out.txt*
- d Back to b.

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\SPL64.exe ..\SPL64.exe
del dds_log.txt
del pre-emption_value.txt
dds_wfld_rev5
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\SPL64.exe ..\SPL64.exe
del dds_log.txt
del pre-emption_value.txt
dds_wfld_rev5
```

- 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.

4.5.3.6 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* directory a file called *dds_log.txt* file shows the SSE value after 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:

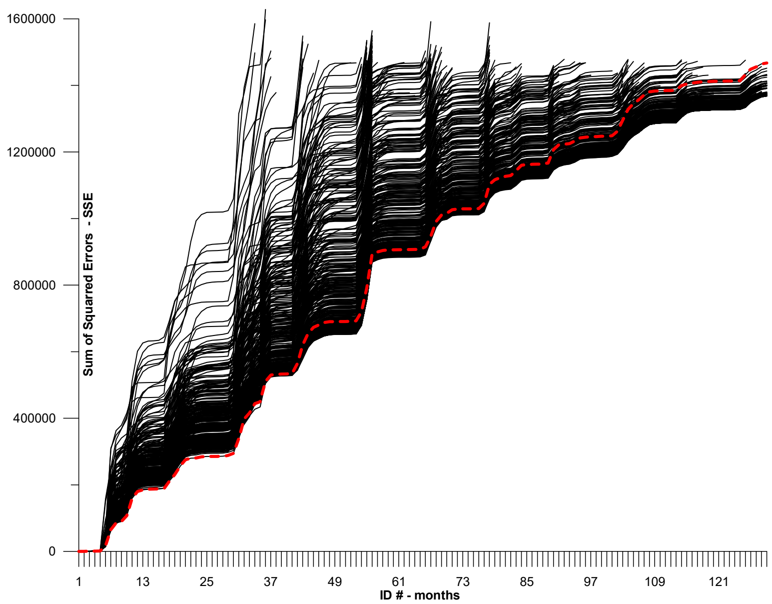


Figure 4.3. Each line is the SSE of an evaluation. Red line = 1st evaluation. Lines to the left of the red line are for evaluations terminated early with pre-emption.

4.5.3.7 Speeding up DDS

To use DDS it is recommended to do at least 3 trials each with 1000 evaluations of the objective functions = SPL runs. You can make multiple simultaneous DDS runs by setting up multiple identical watershed derectories e.g. *\gr10k_1 \gr10k_2* etc. Just give each run a different seed value in line 7 of the *DDS_init.txt* file. You can do these runs on different computers or as I do, on a 12 cpu computer with 4 SSD's. I then do each DDS trial on a different disk. My experience has shown that running multiple DDS runs on one hard drive can lead to its early failure.

4.5.3.8 Analysis of Multiple Trials

Three trials of DDS usually suffices to indicate some insistency 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.

4.5.3.9 Analysis of Multiple Trials – Part 2

A program called *PAR_C.exe* can read any number of par files and compare the values of those parameters that are flagged for optimization. Simply make a list of the par files you want to compare:

```
d:\spl\wpegr\dds\best\wpegr_par.csv
g:\spl\wpegr\dds\best\wpegr_par.csv
m:\spl\wpegr\dds\best\wpegr_par.csv
n:\spl\wpegr\dds\best\wpegr_par.csv
```

and run the program. The output will be in the working directory and looks like this:

```
sublim_rate:
  1   crops_1        0.020    0.033    0.033    0.035
  2   grass_2        0.010    0.001    0.042    0.014
  3   decid_3        0.009    0.001    0.015    0.001
  4   decid_4        0.023    0.017    0.031    0.040
  5   decid_5        0.028    0.036    0.005    0.015
  6   conif_6        0.011    0.006    0.011    0.003
  7   everg_7        0.015    0.028    0.032    0.012
  8   mixed_8        0.002    0.007    0.040    0.015
  9   mixed_9        0.019    0.023    0.010    0.023
 10   mixed_10       0.041    0.013    0.021    0.024
 11   mixed_11       0.018    0.004    0.006    0.006
 12   tr_rck_12      0.001    0.004    0.010    0.002
 13   burns_13       0.032    0.042    0.001    0.017
 14   fr_cut_14      0.011    0.032    0.027    0.007
 15   bogs_15        0.024    0.027    0.018    0.026
 16   bogs_16        0.001    0.005    0.001    0.001
 17   openbog17      0.020    0.024    0.033    0.018
 18   wetland        0.017    0.036    0.003    0.037
 19   wetland        0.017    0.036    0.003    0.037
 20   water          0.000    0.000    0.000    0.000
 21   imper_21       0.021    0.021    0.021    0.021
```

The values are not shown for the parameters that were not optimized. I.e., the table above shows the optimized sublimation rate for 21 land cover classes resulting from 4 DDS trials.

Ideally, all values in one line are close in value but the column with the least number of outliers should be favoured.

4.5.3.10 Analysis of Multiple Trials – Part 3

Another method to evaluate DDS outcomes is to enter the best Nash efficiency (first 4 columns) and the least volumetric error (column 6 – 9) for each station of interest and count the number of best values in each column. This example is for the Mackenzie River watershed using only the main rivers for the choice of the best parameter set. Trial #3 has the best record for Nash efficiency with 15 best-in-class but the values did not have a large range. For this application, I deemed the volumetric error to be most important and here trial #4 scored best. So this was the choice in this case: best volume without giving up much fit in the timing of the hydrographs. These values can be found in the *results\precip.txt* file.

Nash	efficiency				Volumetric	error				
Trial 1	2	3	4		1	2	3	4		
0.38	0.4	0.43	0.41		-13.97	-19.15	-19.71	-20.2	3	07AE001
0.35	0.43	0.44	0.44		4.45	-1.03	-0.36	-2.27	10	07BE001
0.29	0.35	0.37	0.34		-4.78	-9.31	-9.27	-9.9	17	07DA001
-0.04	-0.01	0.03	-0.01		-12.24	-16.49	-16.75	-17.04	22	07DD001
1	1	1	1		0.31	0.31	0.3	0.29	33	07EF001
0.83	0.83	0.84	0.84		2.42	2.59	2.31	2.09	34	07FA004
0.87	0.87	0.87	0.87		0.05	0.28	-0.17	-0.49	42	07FD002
0.69	0.7	0.71	0.7		6.36	6.6	6.03	5.34	43	07FD003
0.28	0.27	0.3	0.29		6.49	6.85	6.29	5.86	46	07FD010
0.56	0.61	0.61	0.6		7.23	5.86	5.77	4.99	55	07HF001
0.54	0.57	0.58	0.56		0.09	-1.21	-1.36	-1.85	59	07KC001
0.56	0.57	0.56	0.57		-6.93	-7.55	-8.05	-8.31	64	07NB001
0.75	0.76	0.75	0.74		-3.35	-2.62	-3.44	-3.69	88	10ED002
0.39	0.43	0.43	0.43		-9.83	-7.32	-8.62	-8.01	90	10FB001
0	0.04	0.05	0.05		1.13	4.18	3.21	2.88	92	10FB006
0.68	0.69	0.69	0.68		-4.91	-2.71	-3.75	-3.75	95	10GC001
0.65	0.66	0.67	0.65		-9.37	-6.44	-7.32	-7.29	103	10KA001
0.68	0.7	0.7	0.69		-8.07	-5.19	-5.76	-5.97	109	10LC014
1	6	15	6		5	4	2	7		

4.5.4 Ostrich (NEW 2022)

OSTRICH, developed by L. Shawn Matott, is a model-independent multi-algorithm paralell-friendly optimization and parameter estimation tool that implements numerous model-independent optmization and calibration (parameter estimation) algorithms.

This section describes a simple application still using DDS to optimize lake routing coefficients which has not been possible with the stand-alone DDS as the WATFLOOD-DDS coupler does not have these variables included.

To obtain a value for the objective function in CHARM, set the ddsflg in the par file = 1

Only four files need to be set up to run Ostrich in the Ostrich working directory. Note the additional file name extensions

1. Ost-CHARM.bat
2. yyyymmdd_rel.tb0.csv
3. yyyymmdd_rel.tb0.tpl
4. ostin.txt

Once these 4 files are set up, run Ostrich in the Ostrich directory

4.5.4.1 Ost-CHARM.bat

In this example we are optimzing the coefficients in the resrl\yyyymmdd_rel.tbo file. Ostrich will operate on only one file so if you are running a number of events, with each iteration the newly generated file will be called yyyymmdd_rel.tb0.csv.

```
copy 20150101_rel.tb0.csv     ..\resrl\20150101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\20160101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\20170101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\20180101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\20190101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\20200101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\20210101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\20220101_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\regl_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\glb_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\climate_rel.tb0
copy 20150101_rel.tb0.csv     ..\resrl\geps16_rel.tb0
cd ..
charm64x
cd Ostrich
copy ..\dds\function_out.txt  function_out.csv
Rem Now Ostrich does its thing . . .
```

4.5.4.2 Resrl\yyyymmdd_rel.tb0.csv

This file is identical to the yyyymmdd_rel.tb0 file but just has the .csv extension added.

```
########################################
:FileType tb0  ASCII  EnSim 1.0
#
# DataType               Time Series
#
:Application             WATFLOOD
:Version                 2.1.23
:WrittenBy          ECrel.exe
:CreationDate       2021-10-20  16:22
#
#---------------------------------------
:SourceFile                   WSC flow_data
#
:Name               ReservoirReleases
#
:Projection         LatLong
#
```

```
:StartDate          2015/01/01
:StartTime          00:00:00.0
#
:DeltaT               24
#
:ColumnMetaData
   :ColumnUnits              m3/s        m3/s        m3/s        m3/s        m3/s
   :ColumnType              float       float       float       float       float
   :ColumnName            Muskoka     Lrossea       DummL      3MileL     Skeleto
   :ColumnLocationX      -79.6780    -79.5760    -79.5050    -79.5160    -79.4990
   :ColumnLocationY       45.0220     45.1180     45.2440     45.1790     45.2250
   :coeff1             0.5000E-10  0.4000E-11  0.2000E-10  0.1000E-10  0.1000E-11
   :coeff2             0.1750E+01  0.1750E+01  0.1750E+01  0.1750E+01  0.1750E+01
   :coeff3             0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
   :coeff4             0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
   :coeff5             0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

4.5.4.3 Resrl\yyyymmdd_rel.tb0.tpl

This file is identical to the yyyymmdd_rel.tb0 file but has the coefficients replaced by names in stead of values as highlighted. The vaues in the yyymmdd_rel.tb0.csv file are matched up with the names in yyymmdd_rel.tb0.tpl file in the ostin.txt file as in Section 4.5.4.4

Header as above

```
:ColumnMetaData
   :ColumnUnits              m3/s        m3/s        m3/s        m3/s        m3/s
   :ColumnType              float       float       float       float       float
   :ColumnName            Muskoka     Lrossea       DummL      3MileL     Skeleto
   :ColumnLocationX      -79.6780    -79.5760    -79.5050    -79.5160    -79.4990
   :ColumnLocationY       45.0220     45.1180     45.2440     45.1790     45.2250
   :coeff1                Muskoka     Lrossea       DummL      3MileL     Skeleto
   :coeff2             0.1750E+01  0.1750E+01  0.1750E+01  0.1750E+01  0.1750E+01
   :coeff3             0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
   :coeff4             0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
   :coeff5             0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
:EndColumnMetaData
:endHeader
```

4.5.4.4 Ostin.txt

```
ProgramType  DDS
ObjectiveFunction  GCOP
ModelExecutable  ost-CHARM.bat
PreserveBestModel save_best.bat
# Randomsed control added
RandomSeed 795912532


BeginFilePairs
#
20150101_rel.tb0.tpl;  20150101_rel.tb0.csv
EndFilePairs

BeginParams
#Parameter Specification
#Dropped in from Calibration Parameters.xls
xMuskoka     5.00E-11   2.50E-11      10.00E-11     none   none   none
xLrossea     4.00E-12   2.00E-12       8.00E-12     none   none   none
xDummL       2.00E-11   1.00E-11       4.00E-11     none   none   none
x3MileL      1.00E-11   0.50E-11       2.00E-11     none   none   none
xSkeleto     1.00E-12   0.50E-12       2.00E-12     none   none   none
xMaryL       5.00E-09   2.50E-09      10.00E-09     none   none   none
xLFairy      5.00E-10   2.50E-10      10.00E-10     none   none   none
xDeerhur     2.00E-11   1.00E-11       4.00E-11     none   none   none
xLofBays     5.00E-11   2.50E-11      10.00E-11     none   none   none
xKawagam     5.00E-11   2.50E-11      10.00E-11     none   none   none
xOxtonqu     1.00E-10   0.50E-10       2.00E-10     none   none   none
xSmokeL      1.00E-10   0.50E-10       2.00E-10     none   none   none
xTeaL        1.00E-10   0.50E-10       2.00E-10     none   none   none
```

```
xTepeeL      1.00E-11    0.50E-11       2.00E-11     none    none    none
EndParams

BeginGCOP
CostFunction NSE_NEG
EndGCOP

BeginResponseVars
#name   filename                                                          keyword        line    col
       token   augmented?
NSE_NEG function_out.csv ;             OST_NULL       0              1     ','                yes
# remember to have a dds folder & have dds flg on in the event file
EndResponseVars

BeginDDS
PerturbationValue 0.20
MaxIterations 1000
UseRandomParamValues
EndDDS
```

4.5.4.5 Ostrich error function

CHARM will write the objective function value to the dds dorectory. In the Ost-CHARM.bat file the value is copied to the ostrich working directory with

copy ..\dds\function_out.txt function_out.csv

Any of the usual CHARM objective criteria can be used. The Kling-Gupta efficiency (KGE) is now available.

4.5.5 OstrichMPI - //processing (new 2022-05-15)

OSTRICH, developed by L. Shawn Matott, is a model-independent multi-algorithm paralell-friendly optimization and parameter estimation tool that implements numerous model-independent optmization and calibration (parameter estimation) algorithms.

This section describes an application using DDS to optimize CHARM model

First thing: download the Ostric Manual at OSTRICH Optimization Software Toolkit (uwaterloo.ca)
Her you fine the following statement and a link to download the manual:

> OSTRICH supports MPI-based **parallel processing** on both Windows and Linux machines! The parallel version of OSTRICH is called OstrichMPI and can be launched using mpirun or mpiexec. The **Windows** version now uses MS-MPI, which must be installed separately. **Linux** users should use the launcher of a separate package like openmpi, mpich, mvapich2, intel-mpi, or platform mpi.

Do:

- Install MS-MPI (see highlight above)
- Download & install OstrichMPI in your path: Click hhere to download the user manual, demos, source code, and executables for Windows and Linux

Copy msvcr120.dll (2016 version) to you path – available on the WATFLOOD ftp

4.5.5.1 OstrichMPI setup files

First create a working directory – e.g. **Ostrich_bsnm** (replace bsnm with your watershed name)

Only six additional files need to be set up to run Ostrich in the Ostrich working directory. Note the additional file name extensions

1. go.bat
2. bsnm_par.csv
3. bsnm_tpl.csv
4. ostin.txt
5. ost-watflood.bat
6. save_best.bat

Once these 6 files are set up, run Ostrich in the Ostrich_bsnm directory. Your directory structure should look like this:

**\Ostrich_bsnm\bsnm\basin*.*
****\Ostrich_bsnm\bsnm\DDS*.*   <<<<<< add this dir!**
**\Ostrich_bsnm\bsnm\debug*.*
**\Ostrich_bsnm\bsnm\basin*.*
Etc. – all the dir's to run CHARM for the watershed
**\Ostrich_bsnm\go.bat
**\Ostrich_bsnm\bsnm_par.csv
**\Ostrich_bsnm\bsnm_par.tpl
**\Ostrich_bsnm\ostin.txt

4.5.5.2 go.bat

This bat file will start off an OstrichMPI run. All old CHARM output is deleted so it won't cause an error by accidentally being open or locked. The number of cpu's to be used is specified here with "n".

```
rem @echo off
rem get rid of all the old CHARM output in case it's read-only
cd bsnm
del /F /Q  debug\*.*
del /F /Q  results\*.*
cd ..
REM mpiexec,  ostrichMPI .exe  &  msvcr120.dll (2016) must be in your path
REM # = number of cpu's to engage: 1 or 2 less than the no of cpu's in your PC
mpiexec -n #-debug 1 OstrichMPI.exe
```

4.5.5.3 Example bsnm_par.csv file

For this example we will only optimize 4 paramters:

flz(1), pwr(1),r2n(1) & rlake(1) for river class # 1

```
:RoutingParameters
:RiverClasses,           1
:RiverClassName,  Default     ,
:flz,                 0.486E-05,# lower_zone_coefficient
:pwr,                  2.25    ,# lower_zone_exponent
:r1n,                 0.300E-01,# overbank_Manning`s_n
:r2n,                 0.310E-01,# channel_Manning`s_n
:mndr,                 1.00    ,# meander_channel_length_multiplier
:aa2,                  1.10    ,# channel_area_intercept=min_channel_xsect_area
:aa3,                 0.430E-01,# channel_area_coefficient
:aa4,                  1.00    ,# channel_area_exponent
:theta,               0.696    ,# wetland_or_bank_porosity
:widep,                30.0    ,# channel_width_to_depth_ratio
:kcond,               0.534    ,# wetland\bank_lateral_conductivity
:pool,                 0.00    ,# average_area_of_zero_flow_pools
:rlake,               0.110E-07,# in_channel_lake_retardation_coefficient
:EndRoutingParameters
```

4.5.5.4 Example of corresponding bsnm_tpl.csv file

```
:RoutingParameters
:RiverClasses,           1
:RiverClassName,  Default     ,
:flz,                 flz_1    ,# lower_zone_coefficient
:pwr,                 pwr_1    ,# lower_zone_exponent
:r1n,                 0.300E-01,# overbank_Manning`s_n
:r2n,                 r2n_1    ,# channel_Manning`s_n
:mndr,                 1.00    ,# meander_channel_length_multiplier
:aa2,                  1.10    ,# channel_area_intercept=min_channel_xsect_area
:aa3,                 0.430E-01,# channel_area_coefficient
:aa4,                  1.00    ,# channel_area_exponent
:theta,               0.696    ,# wetland_or_bank_porosity
:widep,                30.0    ,# channel_width_to_depth_ratio
:kcond,               0.534    ,# wetland\bank_lateral_conductivity
:pool,                 0.00    ,# average_area_of_zero_flow_pools
:rlake,               rlake_1  ,# in_channel_lake_retardation_coefficient
```

Notes:

- The other lines in the csv & tpl files are identical – only one section is shown here
- the 2 files both have to be csv files so it's best to edit the files in Excel as csv files. Then save the tpl file as a bsnm_par_tpl.csv file and then rename it to bsnm_par.tpl
- The formats of the files have to be the same – same # lines and entries.
- Be sure that the 2 *.par.csv (in the ostrich working directory & the bsnm directory) & the *_par.tpl files have the same Optimization switches. If they are different, the initial evaluation will be wrong! e.g.:

```
: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,1,# 0=single run  1=DDS ,,,,,,,,,,,
:errflg,3,# 1=wMSE 2=SSE 3=wSSE 4=VOL ,,,,,,,,,,,
:EndOptimizationSwitches,,,,,,,,,,,,,
```

4.5.5.5 Example of the ostin.txt file

This is boiler plate text from the Ostrich manual with highlighted substitutions for a run with CHARM

```
#Configuration File for Ostrich Program
#--------------Section1---------------
ProgramType ParallelDDS
#ProgramType  ParaPADDS

#--------------Section2----------------
ObjectiveFunction GCOP
ModelExecutable  ost-watflood.bat
PreserveBestModel save_best.bat
ModelSubdir   proc
#CheckSensitivities yes
#extractSeed  200

#--------------Section3----------------
BeginFilePairs
bsnm_tpl.csv ;bsnm_par.csv
EndFilePairs

#--------------Section4----------------
BeginExtraFiles
#calStats-IRP.r
#statsStationNumbers.txt
#statsPar.txt
#iteration.txt
EndExtraFiles

#--------------Section5----------------
BeginExtraDirs
bsnm
EndExtraDirs

#--------------Section6-----------------
BeginParams
#name             init    lower        upper transformations   format
flz_1    0.486E-05 1.0000000E-07 1.0000000E-04 none none none free
pwr_1     2.25     2.00          3.50          none none none free
r2n_1    0.310E-01 0.025         0.050         none none none free
rlake_1  0.110E-07 1.0000000E-09 1.0000000E-06 none none none free
EndParams

#BeginTiedParams
#EndTiedParams

#--------------Section7-----------------
#BeginInitParams
#EndInitParams

#--------------Section8-----------------
BeginResponseVars
#name filename ; keyword  line col token
KGE objfun.txt ; OST_NULL 0 1 ' '

EndResponseVars

#--------------Section9-----------------
BeginConstraints
EndConstraints

#--------------Section10----------------
BeginTiedRespVars
```

```
#name np pname type type_data
NegKGE 1 KGE wsum -1
EndTiedRespVars

#--------------Section11----------------
BeginGCOP
CostFunction NegKGE
#CostFunction ABSPBIAS
#CostFunction NegNSE
PenaltyFunction APM
EndGCOP

#-------------Section12-DDS-------------
BeginParallelDDSAlg
MaxIterations       15
PerturbationValue 0.2
EndParallelDDSAlg

#------------Section12-PADDS------------
#BeginParaPADDS
#MaxIterations   1500
#PerturbationValue 0.2
#SelectionMetric  EstimatedHyperVolumeContribution
#EndParaPADDS
```

4.5.5.6 Making an ostin.txt file

Creating an ostin.txt file tends to be a painful process when optimizing a large number of parameters in different parts of the *par.csv file. The help in this effort, a program called **MAKE_OST_INIT.exe** will read the basin*_par.csv file and create certain parts of the *.tpl and ostin.txt files. Simply flag the parameters in the par file beginning at
`:HydrologicalParLimits`
that need to be optimized and set the limits in the bottom part of the *_par.csv file. Next run MAKE_OST_INPUT in the watershed working directory. The program will read the event file to get the name of the *.par.csv file. The output file will be called Ostrich_input_info.txt

Example file with selected lines for the ostin.txt file. This is **NOT** a complete ostin.txt file – just a part of it with some example lines.

```
#name            init      lower      upper          transformations format
fmadjust       0.343000      0.100000       1.00000     none  none  none  free
fmalow         0.995000      0.300000       1.00000     none  none  none  free
fmahigh         1.00200       1.00000       2.00000     none  none  none  free
rainsnow        4.00000       0.00000       5.00000     none  none  none  free
flz_Defau      0.486000E-05  0.100000E-07  0.100000E-03 none  none  none  free
pwr_Defau       2.25000       2.00000       3.50000     none  none  none  free
r2n_Defau      0.350000E-01  0.100000E-01  0.500000E-01 none  none  none  free
theta_Defau    0.696000      0.300000      0.700000     none  none  none  free
sdcd_wetla      100.000       10.0000       100.000     none  none  none  free
sdcd_water      1.00000       10.0000       100.000     none  none  none  free
sdcd_imper      100.000       10.0000       100.000     none  none  none  free
 IMPORTANT: remove the line with the 2nd wetland if there are 2
```

Stuff for the *_tpl.csv file: these lines replace the corresponding lines in the *.par.csv file. The *.tpl.csv and the *.par.csv file will be identical except for the lines produced by make_Ost_init.exe

```
:fmadjust,&fmadjust
:fmalow,fmalow
:fmahigh,fmahigh
```

```
:gladjust,  0.0000000E+00
:rlapse,  3.6000001E-04
:tlapse, -4.0710000E-03
:rainsnowtemp,rainsnow
:radiusinflce,   125.0000
:smoothdist,   1.338000
:a5,  0.9850000

:flz,          flz_Defau    ,
:pwr,          pwr_Defau    ,
:r2n,          r2n_Defau    ,
:theta,        theta_Defau  ,
:kcond,        kcond_Defau  ,
:rlake,        rlake_Defau  ,

:rec,          0.197000     ,rec_crops    ,rec_conif    ,rec_decid    ,rec_mixed    ,rec_regen
,0.703000E-01 ,0.110000     ,rec_wetla    ,0.520000E-01 ,0.100000     ,0.900000     ,
:ak,            25.0000     ,ak_crops     ,ak_conif     ,ak_decid     ,ak_mixed     ,ak_regen     ,
1.75000     , 42.2000     ,ak_wetla     , 42.1000     ,-.100000     ,0.100000E-01 ,
:akfs,          25.0000     ,akfs_crops   ,akfs_conif   ,akfs_decid   ,akfs_mixed   ,akfs_regen   ,
15.9000     , 26.2000     ,akfs_wetla   , 45.6000     ,-.100000     ,0.100000E-01 ,
.
.
```

4.5.5.7 Example ost-watflood.bat

```
REM CHARM is run in the proc**\bsnm dir
Rem note: this file is copied to the proc** dir.
cd bsnm

REM Copy input files created by Ostrich
copy ..\BSNM_par.csv  basin\BSNM_par.csv /y

Rem run CHARM:
charm64x.exe

rem  copy the objective function value to the proc** dir so Ostrich can find it
copy function_out.txt    ..\objfun.txt

REM Return to the ostrich working directory proc**
cd ..
```

Important: To obtain a value for the objective function in CHARM, set the ddsflg in the par file = 1

4.5.5.8 Example save_best.bat

```
@echo off
@TITLE SAVE BEST SOLUTION

REM Create Subdirectory to save best solution
REM if not exist best mkdir best

REM copy the files for the best solution to the best
REM subdirectory

copy Trent\results\spl.csv          ..\best\spl.csv
copy Trent\results\stats.txt        ..\best\stats.txt
copy Trent\results\precip.txt       ..\best\precip.txt
copy Trent\results\parfile.csv      ..\best\SRB_par.csv
```

4.5.6 Optimization Hints

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.
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!!!!*

1. 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 effect 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, otherwise the snow would melt too rapidly.
2. In mountainous terrain especially, but also on regions with lower relief, the lapse rates for precipitation and temperatures should also be optimized unless you have these values from other sources. I have found that even in regions with elevation differences of 200 m or more orographic effects can be seen, especially if the observations are made in the low areas and then distributed to the higher elevations. If glaciers are present, the glacier adjustment factor should also be optimized.
3. The radius of influence & smoothing distance can be done in conjunction with 4.
4. 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. Normal retention values are in the 50 – 100 mm range. 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. Interception capacities in the 1 – 4 mm range are normal.
5. 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.

6. 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 using the Pattern Serach 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.

4.5.7 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.

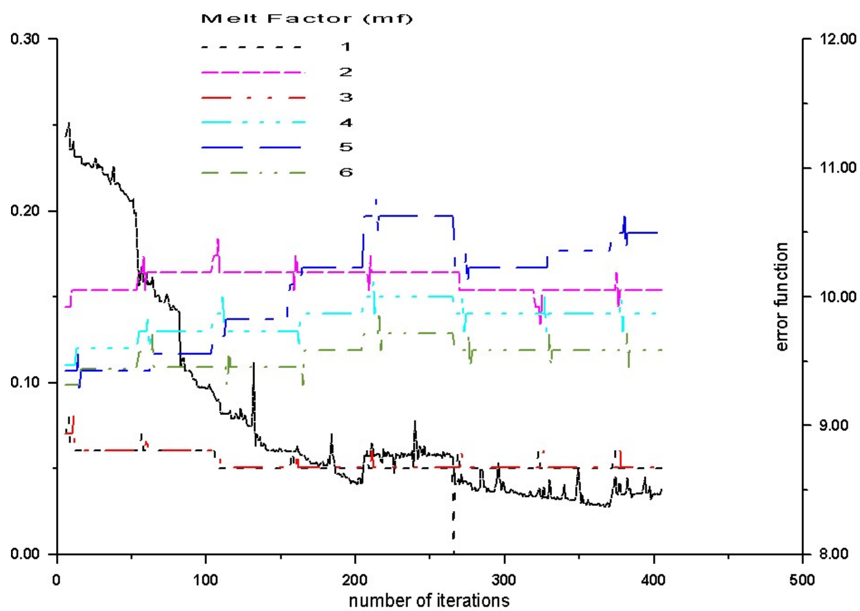
Before starting an optimization run, the upper and lower portion of the parameter file should be synchronized. This is done by setting all delta values except one to a –ve number and setting the parameter value whose delta is +ve to the same value in both the top and the lower part of the parameter file. 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.

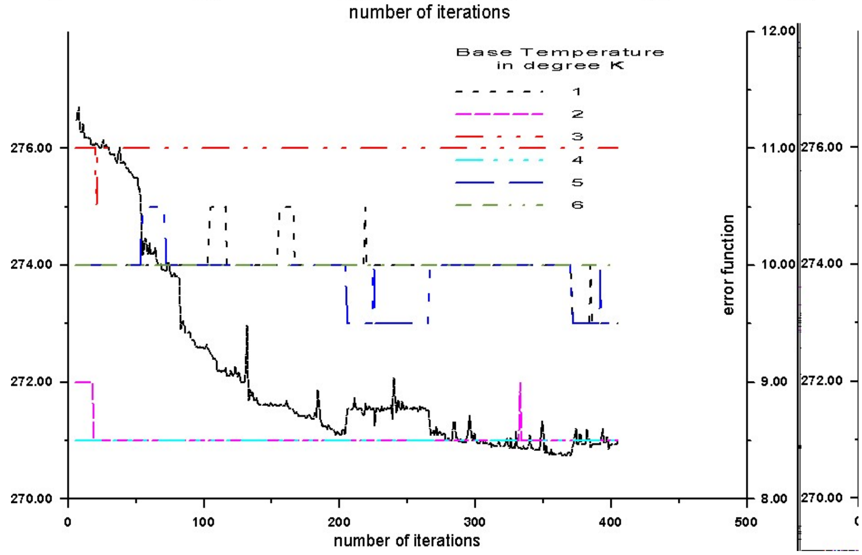
Once you have selected your parameters to be optimized, set the limits and the intervals, start the program. Often an optimization run can takes days if not weeks, depending on the size of the watershed and the duration of the simulation. Usually a two or three year run will do nicely if the run covers 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

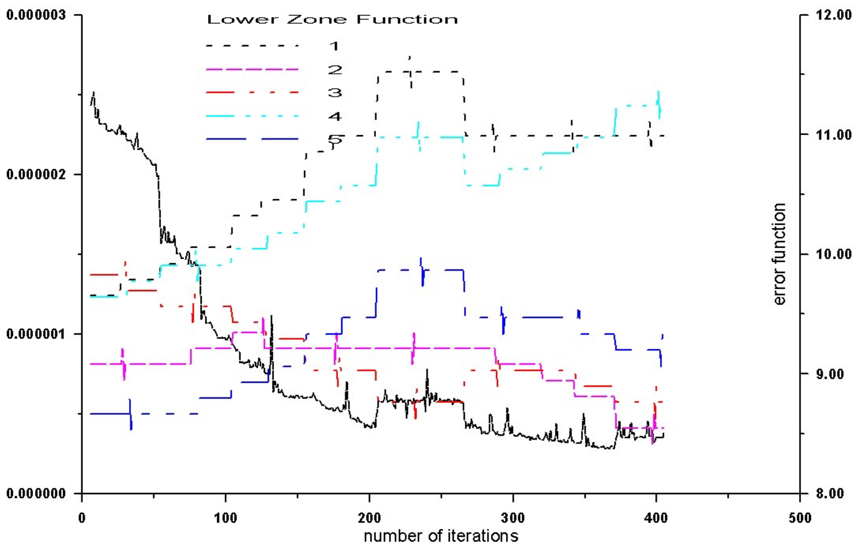
With luck, you will see the dramatic kind of reduction in the error that is shown in these plots. After about 200 evaluations, the error is still being reduced but at a much slower rate. In this example, the melt factor MF has hit a lower constraint of 0.05 for classes 1 and 3. Similarly, some of the 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}.

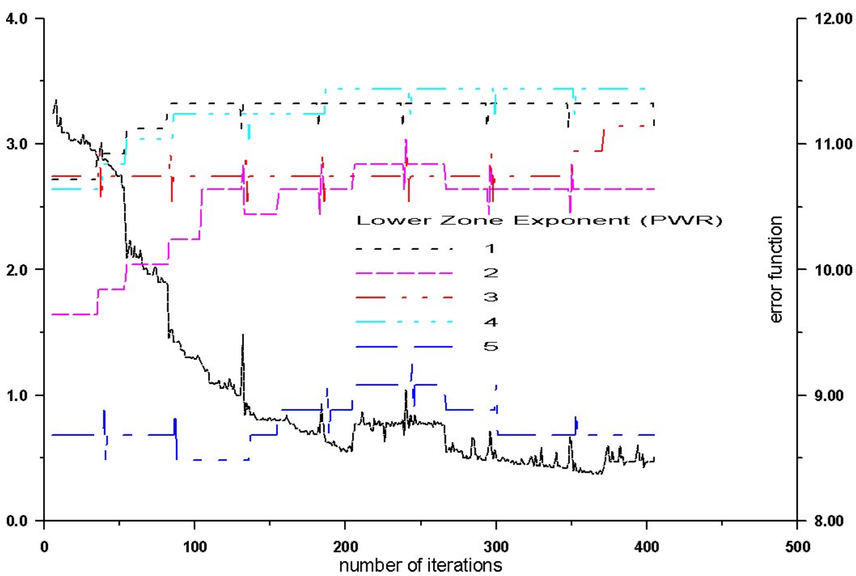
At you own discretion, other parameters can be included in the optimization. There are no hard and fast rules for doing this work but this approach works in this case. The basic presumption is that the initial parameter set is reasonable. The GRU method to some extent precluded a problem that many people 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.

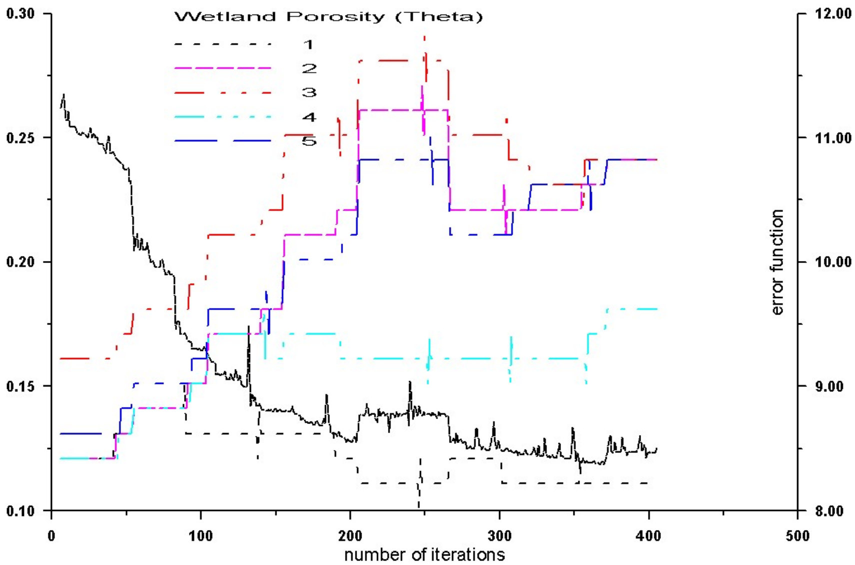
4.5.7.1 Optimization for the BOREAS Southern Study Area (SSA)

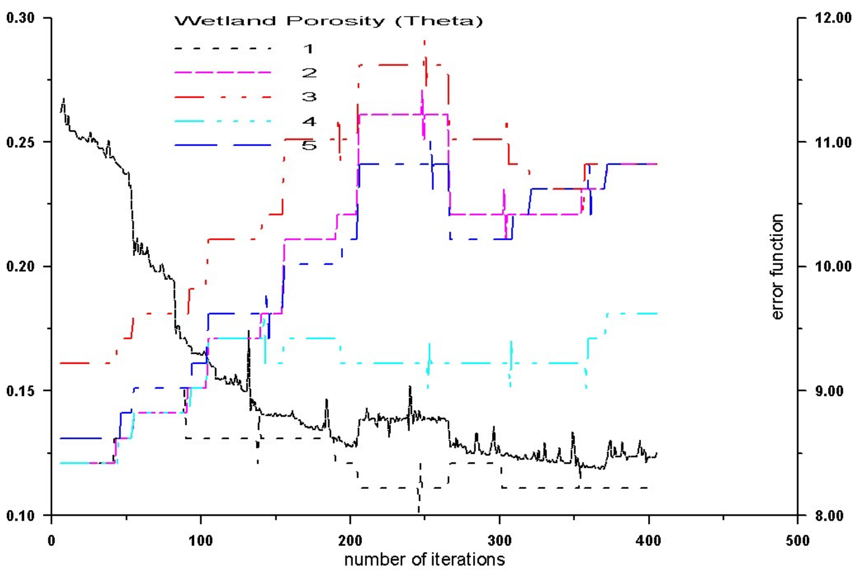





Lower Zone Function
1
2
3
4
5
0.000003
0.000002
0.000001
0.000000
12.00
11.00
10.00
9.00
8.00
error function
0
100
200
300
400
500
number of iterations


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


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
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

4.5.8 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 1000 evaluations for 3 trials is recommended by the author of the method (Brian Tolson). (Each trial produces a parameter set). For a run on say 3000 grids for a 10 year calibration period this can take several weeks. Brian suggests 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 4.5.4, 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 vice versa.

4.6 Troubleshooting

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:

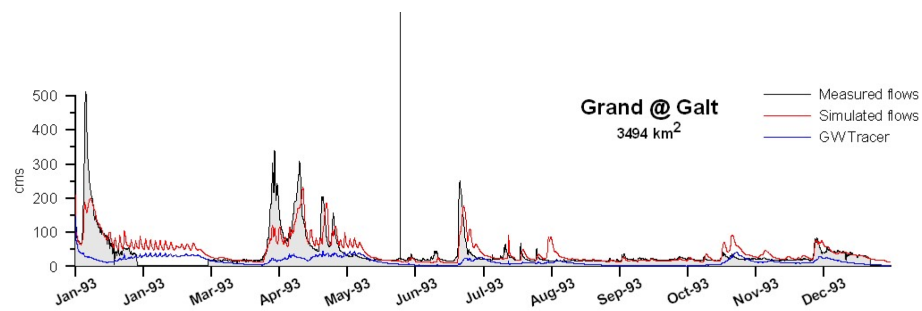


Figure 4.4. Problem hydrograph.

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 Green Kenue (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.

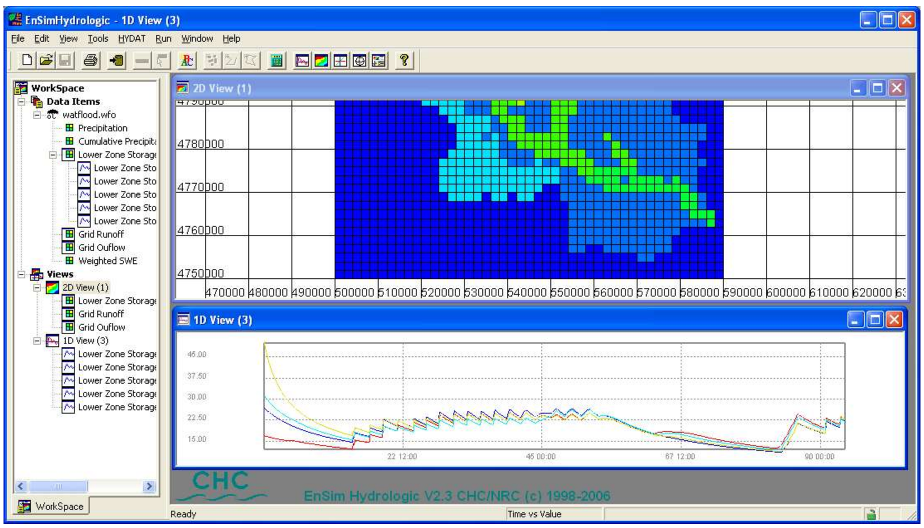


Figure 4.5. Diagnostics in Green Kenue.

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 0ºC 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.

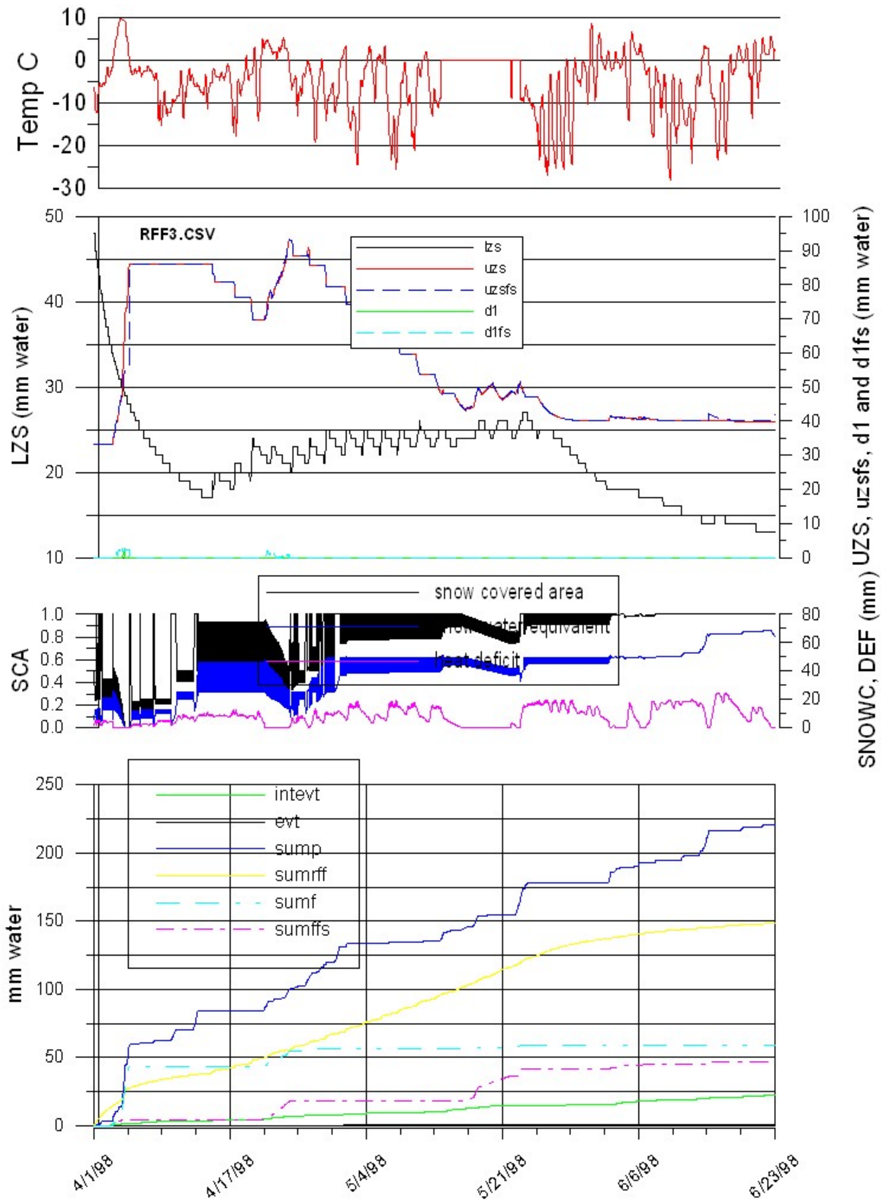


Figure 4.6. Diagnostic tool: plot of state variable for one land cover class.

4.7 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 error criterion 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 *SPL.exe* has to execute is 12 * (# optimizable flow parameters) + 24 *(# optimizable hydrological parameters). For a large 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 choose 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 basin file as specified in the event file (typically *basin\BSNM_shd.r2c*).

5.1.1 Point Snow Water Equivalent Files (**_crs.pt2*)

Data on snow water equivalent (SWE) at point locations in or near the basin (typically snow courses) is stored in the *snow1*_crs.pt2* files. These files use the ASCII Point Set (PT2) format of Green Kenue which allows storing point data with multiple attributes.

Optional: **snw64.exe** can be run with an argument e.g. **snw64 20180219** With this argument, the yyyymmdd_crs.pt2 file in the event file will be ignored and the file snow1\20180319_crs.pt2 will be used to produce the snow1\20180319_swe.r2c file. Then, if the crseflg in the event file is set to **u,** the swe in the model will be replaced by the value in the r2c file for the given date.

The file header contains metadata including information on the coordinate system, time of SWE observation, unit conversion factor, initial heat deficit and data columns (Table 5.1). In the example below there are 2 snow courses and 6 land cover classes. There is a line of data for each snow gauge location. Data lines start with the easting and northing of the gauge location, followed by point attributes: station name and SWE value for each land cover class. Missing data is denoted by a negative number.

Table 5.1. Point snow water equivalent file header keywords.

Keyword	Description
CoordSys	Coordinate system – should be one of: *Cartesian*, *UTM*, *LATLONG*. The same coordinate system must be used in all input files for a given watershed.
Datum, **Zone**	Geodetic datum and projection zone – these depend on the coordinate system: • For Cartesian coordinate system *Datum* and *Zone* are not allowed • For UTM, *Datum* and *Zone* are required • For LATLONG, *Datum* is required and *Zone* is not allowed
SampleTime	Date/time of SWE observation.
UnitConversion	Conversion factor to apply to the SWE values. Should be 1 if SWE are in mm of water. Can be used to convert any measurement (e.g. SWE in inches or snow depth) to mm of snow water equivalent.

InitHeatDeficit	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°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.
AttributeName, **AttributeType**	Name and data type of each attribute field (i.e. any data column following the point coordinates).

```
########################################################################
:FileType pt2 ASCII Green Kenue 1.0
#
# DataType                Green Kenue PT2 Set
#
:Application              Green Kenue
: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 RadiusInfluence                NEW
:AttributeType 2 float                          NEW
:AttributeName 3 Class1
:AttributeType 3 float
:AttributeName 4 Class2
:AttributeType 4 float
:AttributeName 5 Class3
:AttributeType 5 float
:AttributeName 6 Class4
:AttributeType 6 float
:AttributeName 7 Class5
:AttributeType 7 float
:AttributeName 8 Class6
:AttributeType 8 float
:EndHeader
556000.0 4799000.0 "Cambridge" 100.0 1.0 3.0 20.0 1.0 0.0 3.0
547000.0 4932000.0 "Wormwood"  100.0 20.0 3.0 1.0 1.0 3.0 0.0
```

Notes:

- The program *SNW.exe* will read the snow course data and create the gridded snow water equivalent file (*snow1*_swe.r2c*).
- If there is only 1 swe value for all classes, only class1 needs to be entered. snw.exe will insert the same value to the other classes

- Afer distributing the swe, open the snow1\yyyymmdd_swe.r2c file in Green Kenue and ensure that all wateshed grids have values. It the rad. of Inf. is too small,outlining areas may not be covered.

5.1.2 Gridded Snow Water Equivalent Files (*_swe.r2c*)

The following data is based on the snow course values listed for the UTM coordinates in Section 5.1.1. Gridded snow cover files (*snow1*_swe.r2c*) are created when the program *SNW.exe* is run to distribute the snow. The grid information is obtained from the basin file as specified in the event file (typically *BSNM_shd.r2c*) to ensure that the SWE grid matches the basin file.

SNW.exe reads point SWE files (*snow1*_crs.pt2*) and generates gridded SWE data in the Green Kenue ASCII 2D Rectangular Cell Grid (R2C) format. The gridded SWE files are named *snow1*_swe.r2c* and can be loaded into Green Kenue where SWE data can be viewed for each land cover class.

Notes:

1. Unlike the gridded precipitation (*radcl*_met.r2c*) and temperature (*tempr*_tem.r2c*) time series files (see Sections 6.3 and 7.4) which are multi-frame, a SWE gridded data file contains data for a single point in time (single-frame *.r2c file). Hence, data lines for each land cover class are not separated by frame headers; instead they run together (see example below).
2. Data lines within each land cover segment are arranged from south to north, and data values in each line proceed from west to east. Therefore, the first value within each land cover segment corresponds to the SW corner of the model grid.

```
########################################
:FileType r2c  ASCII Green Kenue 1.0
#
# DataType               2D Rect Cell
#
:Application            Green Kenue
: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      # start of class 1 data
   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      # start of class 2 data
   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
# …
```

5.2 Initial Soil Moisture

The initial soil moisture data can be 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 file *moist*_psm.pt2* and create the gridded soil moisture file *moist*_gsm.r2c* for all land cover classes.

Helpful Hint:

- If retention values (RETN) in the parameter file are large (say 150-200 mm) and you are in a dry climate, you may not have any flow in the first year if you set your initial soil moisture in the *moist*_psm.pt2* file too low. Values around 0.25 are usually a good start. If you find that your initial flows are too high, you can lower this.

5.2.1 Point Soil Moisture Files (*_psm.pt2)

The point soil moisture files (*moist*_psm.pt2*) use the same Green Kenue ASCII Point Set (PT2) format as the SWE point data; please refer to Section 5.1.1 for description of the metadata keywords in the file header.

Data values represent the fraction of the soil volume that is filled with water, and should, therefore, range approximately from 0 to 0.35, where the maximum value is the porosity of the soil. The *UnitConversion* keyword can be used to convert any measurement to the fraction of soil water present.

Like in the SWE point file, each line of data corresponds to a location with soil moisture data, and the data lines contain location easting and northing, followed by the location name and the soil moisture values for each land cover class. The initial soil moisture can be obtained using the API method as described in Section 2.2.3. Listing below provides a sample point soil moisture class.

```
########################################################################
:FileType pt2 ASCIIGreen Kenue 1.0
#
# DataType               Green Kenue PT2 Set
#
:Application             Green Kenue
: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 Gridded Soil Moisture File (**_gsm.r2c*)

The following example is based on the initial soil moisture values listed for the UTM coordinates in Section 5.2.1 above. This file is created when the program *MOIST.exe* is run to distribute the initial soil moisture. The grid information is obtained from the basin file *basin\BSNM_shd.r2c* as specified in the event file. *MOIST.exe* generates gridded soil moisture data files *moist*_gsm.r2c* which are in the Green Kenue ASCII 2D rectangular cell grid (r2c) format and can be opened by Green Kenue where the soil moisture data can be viewed for each land cover class.

Notes:

1. Unlike the gridded precipitation (*radcl*_met.r2c*) and temperature (*tempr*_tem.r2c*) time series files (see Sections 6.3 and 7.4) which are multi-frame, a soil moisture gridded data file contains data for a single point in time (single-frame *.r2c file). Hence, data lines for each land cover class are not separated by frame headers; instead they run together (see example below).

2. Data lines within each land cover segment are arranged from south to north, and data values in each line proceed from west to east. Therefore, the first value within each land cover segment corresponds to the SW corner of the model grid.

```
: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      # start of class 1 data
  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      # start of class 2 data
  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
# …
```

5.3 Initial Channel Storage

The initial flow conditions in the drainage network are computed by pro-rating the initial flow given in the **_str.tb0* streamflow file (see Section 8.1) according to the relative values of the drainage areas of a grid and the flow station. A multi-pass procedure is used to obtain 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 basin file.

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

5.4 Initial Lower Zone Storage

The initial lower zone storage is computed based on the initial flow in each grid assuming that all flow is base and/or groundwater flow. The LZF and PWR parameters are used to derive the initial lower zone storage. It is also possible to read a **_lzs.r2c* file to initialize the lower zone storage. Because the initial LZS is based on the initial flow, it is important that the initiation is done during dry weather flow xonditions. If this is not possible, an adequated spinup period is necessary.

5.5 Model Initialization using 'Resume'

A model run can be initialized with the values of the state variables saved at the end of a previous run. To save the end state of a model run, set the event flag *tbcflg* **= y** in the last chained event file of the model run. With this flag ('to be continued') four files are written in the working directory: *resume.txt*, *flow_init.r2c*, *lake_level_init.pt2* and *soil_init.r2c*.

Generally, the way model resuming works is that everything is initialized as usual using whatever information is available for a normal initialization as described above. If the resume flag is set (*resumflg* = **y)** in the first event file (*event\event.evt*), the resume files *resume.txt*, *soil_init.r2c*, *flow_init.r2c* and *lake_level_init.pt2* are read and all previous data are over written. So whatever is in the *soil_init.r2c* and *flow_init.r2c* files overwrites previously initialized state variables including SWE (snowc) and gridded soil moisture (uzs). The *resume.txt* file contains data that is not readily written as a Green Kenue format file.

Lake levels are initialized based on values in the file *lake_level_init.pt2*. This file also contains the datum for each lake, namely the elevation of the sill of a weir or invert of a natural outlet. If this file is not present when *resumflg* **= y**, the program is aborted. The lake storage and discharge in the *flow_init.r2c* file will be overwritten by values based on the lake levels in the *lake_level_init.pt2* file.

If the values in the *lake_level_init.pt2* file are left unaltered from the same run that created the *flow_init.r2c* file, the lake storage and outflow from *flow_init.r2c* will not be altered. But they can be – the values of the lake levels in the *lake_level_init.pt2* file can be edited to reflect observed rather than the computed values at the end of the previous model run. The lake storage and outflow will then be based on this updated lake level and the rating curve in the lake/reservoir release file *resrl*_rel.tb0* (see Section **Error! Reference source not found.**).

5.6 State Variable Updating 'on the Fly'

5.6.1 SWE Updating

The snow water equivalent (SWE) can be updated 'on the fly' on any day of the model run by setting the flag *crsflg* = **u** in the event file. The model will then check for each day simulated if there exists a file *snow1*_swe.r2c* for this date, and if found it will read the file and replace the computed SWE with the values in the file (for each land cover of course).

snw64.exe can be run with an argument e.g. **snw64 20180219** With this argument, the yyyymmdd_crs.pt2 file in the event file will be ignored and the file snow1\20180319_crs.pt2 will be used to produce the snow1\20180319_swe.r2c file.

Data external to WATFLOOD (e.g. based on remotely sensed data) could also be used to update the model swe. The user will need to create the r2c file in this case.

5.6.2 Flow Updating

All state variables can be updated using the *flow_init.r2c* file, but only at the beginning of each event if the flag *fliflg* = **y** in the event file. The *flow_init.r2c* file can be created in two ways: at the end of a run using the flag *tbcflg* = **y** in the last event file (see Section 5.5 above), or using the program *FLI.exe*.

These features may be useful for forecasting applications where the model's hydrological state variables are carried forward from the spinup period, but routing state variables need to be re-initialized.

6 RAINFALL DATA PROCESSING

Commented [AN7]: Stopped here

Originally, gauge rainfall amounts are primarily used as a basis for adjusting radar rainfall measurements and to fill in missing radar rainfall measurements. More recently, most applications have used either observed point precipitation or some form of numerical weather data: re-analysis (CaPA), forecast or climate change weather simulations.

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

calmet 10 or ragmet 10

6.1 Introduction

A number of precipitation 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 precip gauge data
&_MET.r2c	\RADCL	Distributed precip gauge data or adjusted radar data

CHARM uses the **_MET.r2c* file as the precipitation input file for the hydrological simulation. The MET file can be created from rain gauge information alone using *RAGMET.exe*, 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.exe* 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. Usually some custom coding is required for these applications.

6.1.1 Rain Gauge Data File (*_RAG.tb0)

The rain gauge data file *_rag.tb0* is used by the program RAGMET to create a georeferenced rainfall data file *_met.r2c* for CHARM. 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 Green Kenue 1.0
#
# DataType               Green Kenue Table
#
:Application             Green Kenue
: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.

*elevations are required if the precipitation is to be adjusted for elevation using the precip lapse rate (rlapse) in the par file .

The coordinate system is UTM, LATLONG or Cartesian. All lines in this header are **required** eventhough data may not excist for some entries. 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.

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 width 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. 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

6.1.2 Distribution of Gauge Precipitation

RAGMET.exe is for distribution of gauge rainfall. Rainfall amounts for each cell 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 cell 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) unless lapse rates are used to correct for elevation influences. The precip lapse rate can be optimized with DDS.
RAGMET.exe will read the **_rag.tb0* file and create a **_met.r2c* file. The **_met.r2c* can be loaded into Green Kenue and animated. Timeseries of precipitatin can be extracted also.

Caution: Each time *RAGMET.exe* is executed, the existing *_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.

6.1.3 Modified Distribution of Precipitation

This section is identical to Section 7.2 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. Also, if all stations are included in the distribution, if there is precip anywhere, all cells will have some precipitation.

NEW

To overcome these problems, two coefficients can be used by *RAGMET.exe*. These are read from basin\bsnm_par.csv in the appropriate line – e.g.:

: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 affected. It is best to try different values until the cumulative precipitation field for the complete simulation period looks acceptably smooth.

For optimization:

- Set the radius of influence **<u>just</u>** 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 these in loading the cumulative precipitation in a wfo file into Green Kenue

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

6.1.4 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 *_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 cell

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.

A good starting value for rlapse is 0.0003

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 *_met.r2c* file in hourly amounts until the total amount is used. If the rate = 1 mm and 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 in the *_rag.tb0* 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 (*_met.r2c) - Input to SPL

The *_met.r2c* file for an event over the Grand River Watershed follows:

The Green Kenue format file called *_met.r2c* is produced by RAGMET.exe and can be loaded into Green Kenue where it can be animated and time series extracted for each grid. The watershed dimensions are taken from the *bsnm.pdl* file.

Hours with no data are simply missing frames. Zero precipitation is assumed when a frame is missing.

NOTE: Frames are numbered consecutively. The time stamp is read by CHARM and used by Green Kenue to do the animation. CHARM will read the next timestamp and when this time is reached in the model, the data is read and processed.

```
########################################
:FileType r2c  ASCII Green Kenue 1.0
#
# DataType               2D Rect Cell
#
:Application             Green Kenue
: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 Climatic Precipitation Data (NEW)

RAGMET upon completion of creating the *_met.r2c files will create an additional file in the model directory called **climate_pcp.r2c**

This file will have a daily time step and have the mean precipitation of each grid for each day processed. E.G., if RAGMET is run for say 1981 to 2015, a total of 35 years, each frame, covering one day, in the r2c file will have the mean precipitation on each grid for the 35 years.

If a “climate.evt” is created with flow, reservoir releases and temperatures, and the climate event is added to the bottom of the event file, CHARM will run this event for a period of 90 days after the end of the normal run.

Since this data are on a daily time step, the data will need to be disaggregated with the DA.exe program.

7 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 CHARM version, temperatures can be ingested at various time increments – e.g. hourly or in 3,4 or 6 hour time steps.

Since climate data is generally collected or predicted at specific point locations, this data needs to be converted into a grid format. CHARM 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 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

7.1 Example of Point Temperature File:

FLN = tempr\yymmdd_tag.tb0

```
########################################
:FileType tb0  ASCII Green Kenue 1.0
#
# DataType              Green Kenue Table
#
:Application            Green Kenue
: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. 6.1.1

Notes:

- Missing data should be entered as –99.9 (or anything less than -99.0, e.g. -999.0).
- 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

7.2 Modified Distribution of Temperature

This section is identical to section 6.1.3 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 stations.

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 distance (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 temperature field will be affected. It is best to try different values until the temperature field looks acceptably smooth.

Set the radius of influence **just** large enough so the whole watershed will have temperatures assigned. Set the smoothing distance**just** large enough to get a nice looking interpolation between stations. (Check this in loading the precipitation field in a wfo file into Green Kenue)

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

7.3 Temperature Lapse Rate (TLAPSE) [new]

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. A good starting value is -.005

7.4 Example of a Gridded Temperature File tempr*_tem.r2c

The TMP.exe program produces a Green Kenue format r2c file with a file name *_*tem.r2c* This file can be loaded in Green Kenue 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.

Hours with no data are simply missing frames. The last temperature read is used until a new frame with data is encountered.

NOTE: Frames are numbered consecutively. The time stamp is read by CHARM and used by Green Kenue to do the animation. CHARM will read the next timestamp and when this time is reached in the model, the data is read and processed.

```
########################################
:FileType r2c  ASCII Green Kenue 1.0
#
# DataType               2D Rect Cell
#
:Application             Green Kenue
: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.
```

7.5 Daily Temperature Differences (for ET calculations) [new]

A new feature (Jan. 2014) is the use of daily temperature differences (between the min & max temperature) for the 1985 version of the Hargreaves and Samani ET model (Hargreaves and Samani, 1985). A file is generated by TMP.exe at the same time as the **_tem.r2c* file and named as specified in the event file **_dif.r2x*:

```
:griddedtemperaturefile        tempr\19810101_tem.r2c
:griddeddailydifference        tempr\19810101_dif.r2c
```

There is one frame for each day as in the example below.

```
#####################################
:FileType r2c  ASCII  EnSim 1.0
#
# DataType               2D Rect Cell
#
:Application             WATFLOOD
:Version                 2.1.23
:WrittenBy          tmp.exe
:Weight used                       2
:CreationDate       2014-01-25  21:38
#
#----------------------------------------
#
```

```
:Name                Gridded Temprature Differences
#
:Projection          UTM
:Ellipsoid           GRS80
:Zone                        17
#
:xOrigin                  500000.0000
:yOrigin                 4790000.0000
#
:SourceFile                    tempg\19930101_tag.tb0
#
:AttributeName 1     dailyTemperatureDifferences
:AttributeUnits      degreeCelcius
#
:xCount                             9
:yCount                            12
:xDelta                    10000.0000
:yDelta                    10000.0000
#
#
:endHeader
:Frame         1          1   "1993/1/1 01:00:00.000"
   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.7   6.7   6.8   6.7   6.7
   6.7   6.7   6.7   6.8   6.7   6.8   6.7   6.8   6.7
   6.7   6.7   6.7   6.7   6.7   6.8   6.7   6.7   6.7
   6.7   6.7   6.7   6.8   6.7   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.8   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7
   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7   6.7
:EndFrame
:Frame         2          2   "1993/1/2 01:00:00.000"
   4.1   4.1   4.1   4.1   4.1   4.1   4.1   4.1   4.1
   4.1   4.1   4.1   4.1   4.1   4.1   4.1   4.1   4.1
   4.1   4.1   4.1   4.1   4.1   4.1   4.2   4.1   4.1
   4.1   4.1   4.1   4.2   4.1   4.1   4.2   4.1   4.1
   4.1   4.1   4.1   4.1   4.1   4.1   4.1   4.1   4.1
.
Etc.
```

7.6 Climatic Temperature data Data (NEW)

TMP.exe upon completion of creating the *_tem.r2c files will create an additional file in the tempr directory called **climate_tmp.r2c**

This file will have time step equal to the usual tem file (usually 4 hours) and have the mean temperature of each grid for time step processed. E.G., if TMP is run for say 1981 to 2015, a total of

35 years, each frame, covering one time step, in the r2c file will have the mean temperature on each grid for the 35 years.

If a "climate.evt" is created with flow, reservoir releases and temperatures, and the climate event is added to the bottom of the event file, CHARM will run this event for a period of 90 days after the end of the normal run.

8 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 *_str.tb0 file.

Reservoir release files (*_rel.tb0*) are also required if reaches (lakes & reservoirs) have been designated in the map & shd files. The rel files do not need data if the coefficients of the lake outlet are specified. See Section 8.2.

8.1 Streamflow Files

8.1.1 Example Streamflow File

The *_str.tb0* file contains recorded flows at various sites in the watershed in Green Kenue format. This file can be loaded into Green Kenue 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 if the observations are levels instead of flow.

The next line of data in the *_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 Green Kenue 1.0
#
# DataType               Green Kenue Table
#
:Application             Green Kenue
: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
:WFruntime                nnnn   ***
#
: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
                           .
                           .
```

***** OPTIONAL LINE: If this line is inserted model will run nnnn hours this event regardles of file length**

The coefficients can be used for applications where only stage data is available which can be converted to flows using a polinomial function. (Section 0)

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 <u>not</u> 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 and/or setting nudgeflg = 1 in the event file.
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 1.3.7. 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. 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. This will nudge all the flows for the designated flow stations for **all** events in this run.

Notes:
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

The duration of the str file can be shortened with a comment card:
#WFruntime   nnnn
Placed before
:ColumnMetaData
Where nnnn is the number of hours to run this event

8.1.2 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 cells (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.

8.1.3 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, C 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 into Green Kenue 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.

8.2 Reservoir Release Files

The *resrl*_rel.tb0 file* has the reservoir locations and releases.

If this file does not exist, the no of reservoirs is assumed to be 0 and there should be no reaches marked in the*_shd.r2c file.

If there are no reservoirs, do not have a *_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`) For SPL, the event length is not known until the program has read to the end of the streamflow files. For WATROUTE, the event length is not known until the program has read to the end of the runoff files.

Example resrl*_rel.tb0 file:

```
########################################
:FileType tb0  ASCII Green Kenue 1.0
#
# DataType              Green Kenue Table
#
:Application            Green Kenue
: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 the reservoir/lake locations are in the outlet cell of each lake respectively.

Notes:

- CHARM accepts 24 hour data: 1 line of data for each day with the deltat set = 24. Do not have 23 lines with -1.0 for the 'missing' data for this case
- The value is assumed to be the release at the beginning of the time step.
- The *_*REL.tb0* file has the reservoir locations and releases.

8.2.1 Natural Lake and Uncontrolled Reservoirs

The 5 coefficients give the operating rulefor each lake or uncontrolled reservoir– see Section 3.8.2. The operating rule has to be programmed for each individual reservoir but five parameters are reserved for this purpose. Controlled reservoirs where the discharge is known can use a table of the releases in m^3/s. 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 ignored.

Below is an example for Tabacco Creek for a watershed with many farm ponds. An Excel spreadsheet can be used to fit polynomials or power functions to each of the storage-discharge curves.

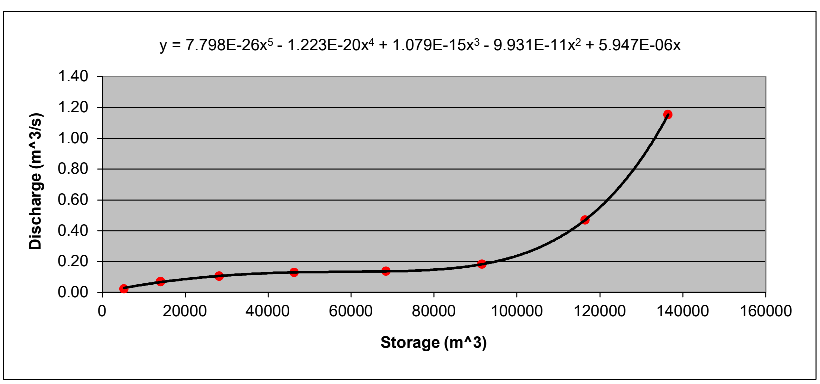


Figure 8.1 Example of a storage-discharge curve (Subbasin 55 below). (Please note that the order of the terms is reversed below)

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 polynomial is used, it must be a 3, 4 or 5 parameter polynomial. It is **important** that the polynomial be monotonically increasing and the it does not dip down after the last point. For this reason, the coefficient for the highest order term must be positive and the function should be plotted to ensure is is monotonically 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 monotonically 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 than the default in Excel – 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**

8.2.2 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 *results\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 2.13

The elevation-storage function is:

$$Elevation = coeff3(datum) + coeff4*storage^{coeff5}$$

Notes:

- The datum is the elevation of the reservoir when the discharge = 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
```

8.2.3 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 *_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.

8.2.4 Correcting Reservoir Releases NEW

Situations arise where reservoir releases can be in error due to incorrect rating curves. This can happen at generating stations where rating curves may be based on theoretical calculations without verification or outflows are based on mass balance calculations. Such problems may be found when plotting lake elevations over a prolonged period that make no sense – eg. a continuously rising or falling rservoir level – sometimes one following the other – while being reasonably sure that the reservoir inflows are reasonable.

Reservoir releases can be adjusted on a year-by-year basis by adding a table with correction factors to the **resrl** directory. An example file with the file name is **resrl\reservoir_fudge_factors.csv** is shown below. Note that the first year MUST coincide with the first year of the simulation. A check is made in CHARM to ensure this is the case.

Sta_No	1	2	3	4	5	6
Sta_name	Skunk_falls	Shiny_Rapids	Beaver_GS	HiHo_GS	Moonshine	TranquilLake
YEAR	regulated	weir	regulated	regulated	regulated	weir
2002	1	1	0.95	1.05	1	1
2003	1	1	0.95	1.05	1	1
2004	1.2	1	1.255	1.25	1	1
2005	1.2	1	1.255	1.25	1.6	1
2006	1.2	1	1.255	1.15	1.6	1
2007	1	1	1	1.15	1.2	1
2008	0.85	1	0.9	0.9	1.2	1
2009	0.85	1	0.9	0.9	1.2	1
2010	1	1	1.1	1	1.2	1
2011	1	1	1.1	1	1.2	1
2012	1	1	1.1	1	1.1	1
2013	1	1	1.1	1	1.1	1
2014	1	1	1.1	1	1.1	1

8.3 Reservoir/Lake Routing with Target Water levels

CHARM has an option to read in target upper an lower water levels for lakes and reservoirs and route the inflows to meet the targets. A separate file is needed to accomplish this. In addition, special rules can be added to for instance meet minimum flow downstream or add emergency rules for flood flows. These latter actions can be added to the model through custom coding in a special section of the model.

Below is an example of a reservoir operating rule that can be entered into CHARM by way of a file. Please contact NK. There is a small charge for this addon.

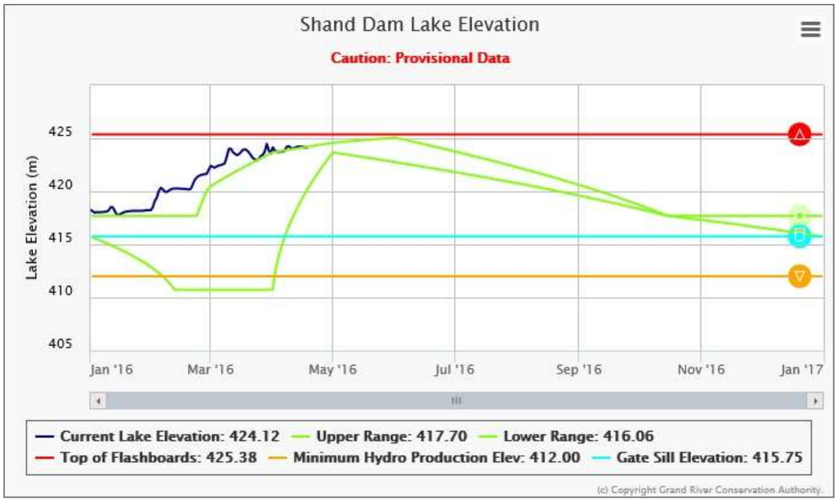


Figure 8.2. Example operating rule – GRCA (https://apps.grandriver.ca/waterdata/kiwischarts/hk_shand.aspx).

8.4 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 a resrl*_ .rin file must exist for all events. This flag is set in event.evt (first event file) and used for all subsequent events.
- The time increment in the *resin.csv* file is the same as the interval in the input **_res.tb0* file.

The following is an example of a reservoir inflow file *_rin.tb0

```
########################################
:FileType tb0  ASCII  EnSim 1.0
#
# DataType               Time Series
#
:Application             EnSimHydrologic
:Version                 2.1.23
:WrittenBy          mh_write_lakeinflow_tb0.f=MH6.exe
:CreationDate       2013-09-12  09:36
#
#---------------------------------------
:SourceFile                   lake_inflow_data
#
```

```
:Name               lakeInflows
#
:Projection         LATLONG
:Ellipsoid          WGS84
#
:StartDate          1985/01/01
:StartTime          00:00:00.0
#
:DeltaT               24
#
:ColumnMetaData
   :ColumnUnits              cms          cms          cms
   :ColumnType             float        float        float
   :ColumnName        L_o_t_Woods  Lac_Seul     L_St_Joseph
   :ColumnLocationX      -94.5131     -93.1990     -90.2010
   :ColumnLocationY       49.7844      50.6333      51.1000
   :Value1                      1            1            1
:EndColumnMetaData
:endHeader
                          300.900      140.300       33.100
                          227.300      190.300       32.300
                          240.300      226.800      139.800
                          233.200      224.000      140.500
                           89.500      224.600       87.200
Etc.
```

8.5 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*_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).
5. The value of value1 is the drainage area above the diversion. Enter this if the area is to be added to the receiving grid. This allows the proper runoff depth to be calculated for downstream stations..

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.
- If the value of the flow diversion is always the same, all you have to do is have a `*_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 `*_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 *_div.tb0 file is not present, the diversion code will just be bypassed.

9 WIND SPEED AND DIRECTION DATA

Commented [AN8]: Why grayed out?

Wind speed and direction data are required for each grid for the lake evaporation model.

Since climate data is generally collected or predicted at specific point locations, this data also needs to be converted into a grid format as **SPL** reads only gridded data. The example files below show the wind speed and direction data in point and gridded formats. The program **WIND.exe** converts point wind speed and direction time series to gridded wind speed and direction time series.

The default weighting for distributing the data is distance squared. I.e. the default weight parameter is 2. However, if you want the distribution of wind speed and direction to be more like Thiessen poligons, you can make the weight = 10 by issuing the command:

wind64x 10

The distribution of wind speed and direction is carried out in a number of steps:

1. Wind speed and wind direction are read from separate files winds*_spd.tb0 and windd*_dir.r2c respectively. The station names and coordinates in both files need to be matched.
2. The wind vector is disaggregated into x (east) and y (north) components at each station (with data).
3. The x and y windspeed components are distributed separately using distance weighting giving and x and y component of wind at each grid point.
4. For each grid point, the x and y components are combined into a vector of speed and direction.
5. Separate files for gridded wind speed and wind direction are written winds*_spd.r2c and windd*_dir.r2c respectively.

Note:
In the point data files, wind direction is entered as a clockwise azimuth with north = 0 degrees, east = 90 degrees etc.
In the gridded wind direction files, the data is written in terms of 8 directions with increments of 45 degrees: 337.5° → 22.5° = 8 (N), 22.5° → 67.5° = 1 (NE), 67.5° → 112.5° = 2 (E) etc.

9.1 Example of Point Wind Speed File

FLN = winds*_spd.tb0

```
########################################
:FileType tb0  ASCII  EnSim 1.0
#
# DataType                Time Series
```

```
#
:Application             WATFLOOD
:Version                 1
:WrittenBy          mkwnd
:CreationDate       2013-12-09  07:44
#
#---------------------------------------
:SourceFile                   EC wind speed & direction
#
:Name                          WindSpeed
#
:Projection         LatLong
:Ellipsoid          WGS84
#
:StartDate          1990/01/01
:StartTime          00:00:00.0
#
:DeltaT               1
#
:ColumnMetaData
   :ColumnUnits             m/sec        m/sec        m/sec    etc.
   :ColumnType               float        float        float
   :ColumnName       5040131      5030203      5010480
   :ColumnLocationX      -99.9000     -97.0219     -99.9519
   :ColumnLocationY       51.7500      52.3597      49.9100
:EndColumnMetaData
:endHeader
                           -1.000        9.000       -1.000
                           -1.000        7.000       -1.000
                           -1.000        9.000       -1.000
                           -1.000       11.000       -1.000
                           -1.000       15.000        6.000
                           -1.000       22.000        7.000
                           -1.000       26.000        9.000
                           -1.000       26.000        9.000
                           -1.000       28.000       26.000
ect.
```

9.2 Example of Point Wind Direction File

FLN = windd*_dir.tb0

```
########################################
:FileType tb0  ASCII  EnSim 1.0
#
# DataType               Time Series
#
:Application             WATFLOOD
:Version                 1
:WrittenBy          mkwnd
:CreationDate       2013-12-09  07:44
#
#---------------------------------------

etc.
:SourceFile                   EC wind speed & direction
#
:Name                   WindDirection
#
:Projection         LatLong
:Ellipsoid          WGS84
#
:StartDate          1990/01/01
:StartTime          00:00:00.0
#
:DeltaT                1
#
:ColumnMetaData
   :ColumnUnits           degreesdegreesdegrees     etc.
   :ColumnType              float         float         float
   :ColumnName       5040131      5030203      5010480
   :ColumnLocationX      -99.9000     -97.0219     -99.9519
   :ColumnLocationY       51.7500      52.3597      49.9100
:EndColumnMetaData
:endHeader
                           -1.000      150.000       -1.000
                           -1.000      150.000       -1.000
                           -1.000      150.000       -1.000
                           -1.000      140.000       -1.000
                           -1.000      150.000       80.000
                           -1.000      150.000       90.000
                           -1.000      150.000       60.000
                           -1.000      150.000      300.000
                           -1.000      140.000      220.000
                           -1.000      160.000      240.000
                           -1.000      160.000      220.000
```

etc.

9.3 Example of Gridded Wind Speed File

FLN = winds*_spd.r2c

```
########################################
:FileType r2c  ASCII  EnSim 1.0
#
# DataType               2D Rect Cell
#
:Application             WATFLOOD
:Version                 2.1.23
:WrittenBy          wind.exe
:Weight used                       2
:CreationDate       2015-01-09  12:44
#
#---------------------------------------
#
:Name               WindSpeed
#
:Projection         LatLong
:Ellipsoid          WGS84
#
:xOrigin                  -104.8220
:yOrigin                    49.4120
#
:SourceFile                   winds\19900101_spd.tb0
#
:AttributeName 1    wind_speed
:AttributeUnits     m/s
#
:xCount                          86
:yCount                          57
:xDelta                      0.1500
:yDelta                      0.1000
#
#
#                                              -1.0000000
#radius of influence  km                      243.6560059
#smoothing distance   km                       44.9729996
#
:endHeader
:Frame         1         1   "1990/1/1  4:00:00.000"
   1.00   1.00   1.00   1.00   1.00   5.86   5.92   6.01   6.13
6.28   etc
   1.00   1.00   1.00   1.00   5.65   5.68   5.74   5.83   5.96
5.35
   1.00   1.00   1.00   5.47   5.45   5.47   5.53   5.63   5.78
4.74
```

```
   1.00   4.17   4.17   4.18   4.20   4.25   4.33   4.44   5.00
4.67
   4.09   4.07   4.05   4.05   4.06   4.09   4.17   3.99   3.87
4.00
   4.00   3.97   3.94   3.91   3.90   3.92   3.75   3.85   3.78
3.94

ect.
```

9.4 Example of Gridded Wind Direction File

FLN = windd*_dir.tb0

```
########################################
:FileType r2c  ASCII  EnSim 1.0
#
# DataType               2D Rect Cell
#
:Application             WATFLOOD
:Version                 2.1.23
:WrittenBy          wind.exe
:Weight used                       2
:CreationDate       2015-01-09  12:44
#
#---------------------------------------
#
:Name               WindDirection
#
:Projection         LatLong
:Ellipsoid          WGS84
#
:xOrigin                   -104.8220
:yOrigin                     49.4120
#
:SourceFile                   winds\19900101_dir.tb0
#
:AttributeName 1    wind_direction
:AttributeUnits     na
#
:xCount                           86
:yCount                           57
:xDelta                       0.1500
:yDelta                       0.1000
#
#
#                                                 -1.0000000
#radius of influence  km                         243.6560059
#smoothing distance   km                          44.9729996
#
:endHeader
:Frame         1         1   "1990/1/1  4:00:00.000"
    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.   etc.
    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
    4.    4.    4.    4.    4.    4.    4.    4.    4.    4.
etc.
```

NOTE: Wind direction is used in 8 compas points. NE = 1, E = 2, SE = 3, S = 4, SW = 5, W = 6, NW = 7 and N = 8 (the same as the drainage directions in the map file)

The wind distribution pre-processor **WINDxx.exe** creates a 2 dimensional wind field for the each time step. Below is and example of wind directions. The example clearly shows a counter clockwise flow field centered near Dauphin, Manitoba.

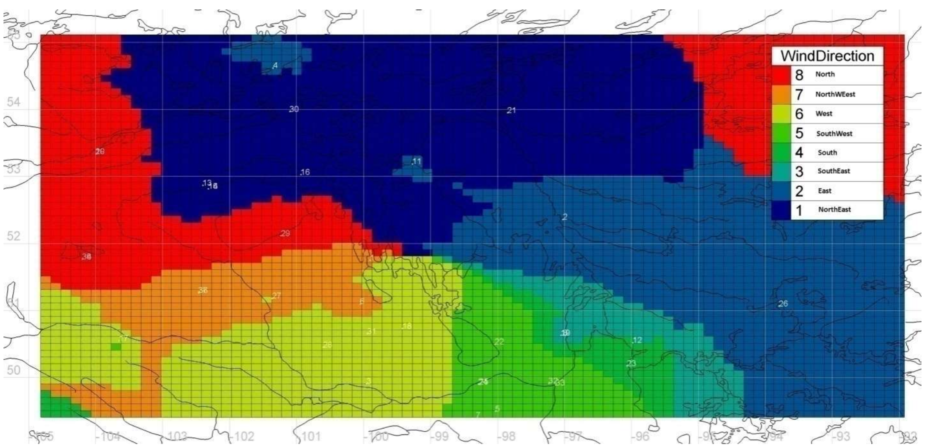


Figure 9.1 – Wind directions for the Interlake region in Manitoba, Jan. 8, 1990.

10 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

11 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 11.2 for details and examples.

Many output files are used for program development and in general, the higher the value of IOPT (debug level) 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 11.4) will be written with these default names. 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 as 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.

Commented [AN9]: Why not just use different directories?

Just be sure that the directories exist for the files, as SPL does not make directories on-the-fly.

results\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 cell, the runoff at each streamflow gauge station and the errors. ***spl.csv*** is the files for hydrograph plotsand 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.

The output file *flow_station_locations* in the working directory lists the plotting positions for each of the columns in the *spl.csv* file. (Very handy)

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 but can be sent elsewhere with the *outfiles.txt* file in the working directory:

Table 11.1. ..

File Name		Purpose
Class_distribution.txt		The percent of each land cover above each flow gauge (inclyding all sub-basins).
Error.r2c	**	An r2c file for showing a 2D plot of flow error in Green Kenue
Evap.txt		For program development – output from s/r AET.f
Evt_means.csv		Mean flows for each event: observed & computed.
Gridflow.r2c		An r2c file for showing grid outflow in Green Kenue. This can also be done with the *watflood.wfo* file
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.
Mrb_master_inflow.tb0		Reach inflows that can be used directly as input to the 1D hydraulic model Flow1D. These reaches can also be lakes or reservoirs.
Nash_eff.r2c		An r2c file for showing a 2D plot of Nash efficience in Green Kenue
Opt.txt		Parameter values and errors are written for each iteration when optimizing
Peaks.txt		Not used
Pic.txt		Gridded bankfull index values used by the mapper.exe program to do the watershed animation
Precip.txt		Diagnostic file with a quick check for volumetric error (Dv) and a table that allows plots of Dv vs. land cover fractions. See Section 4.5.1
Res.txt		Reservoir information when running with IOPT >0
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.
Rff(1-class#)	**	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. Written for the debug grid as specified in *bsnm_shd.r2c*
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.
Sed.csv		Sediment routine output. Sediment concentration graphs. (Not for general use).
Snw.csv		Snow debug file for debug grid and class
Snw.txt		Diagnostic data for the melt routines
Snw1.txt		Diagnostic file for melt routines with IOPT>0

Snowdebug.txt		Write swe at designated snow courses
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 time, observed, computed, observed, computed,........... for stations 1, 2, 3, ... respectively. the file *flow_station_location.xyz* has the column code for plotting programs.
Spl.tb0	*	Pairs of observed/computed streamflow for use in Green Kenue (same data as spl.csv below)
Spl_dly.csv		A file with daily flows created when the input hydrograph has time steps less than 24 hours.
Spl_mly.csv		A file with monthly flows observed & computed
Stg.plt		Computed streamflow used by stgplt.exe (DOS) to plot stage hydrographs
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.
Temp_junk.txt		As the name implies. Used for program development.
Volumes.txt		Not used
Watbal(1 & 2)		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. This does not work for cels with lakes or wetlands at this time.
Watflood.wfo	**	File read by Green Kenue Hydrologic for displaying results. Use the wfo_spec.txt file to specify the time step and which elementcell should be included. Please see Chapter 13
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.

11.1 Plotting Hydrographs (Observed versus 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 *flow_station_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 inexpensive 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.

11.2 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.

11.2.1 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
```

11.2.2 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 above each flow gauge location (including sub-basins). This is very helpful for optimizing the parameters as the dominant class in the sub watershed should yield the greatest sensitivity in the hydrograph.

11.2.3 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 <<<<<<<
```

11.2.4 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
```

11.2.5 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
```

11.2.6 Summary for Grids

```
  final soil moisture for each cell 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 cell 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
```

11.2.7 Cumulative 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.
```

11.2.8 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.

11.3 rff*.txt Files

For iopt > 1 in the par file and for the debug grid # specified in the *_shd.r2c file, *rff*.txt* files are written for each land cover class. The *results\rff*.txt* files 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 files can be imported to Excel or Grapher for plotting the time series. One file is written for each land cover class. The headings of the columns are shown in the table on the next table below. For land covers with no area in that grid, only the header is written.

Table 11.2. …

Variable	**Units**	**Variable description**
Time	hours	
intevt	mm	cumulative interception evaporation
evt	mm	cumulative 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 (groundwater)**

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	ºC	temperature in degree Celcius
Tempvmin	ºC	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**

11.4 outfiles.txt File

This file is a list of all output files created by the SPL.exe program. It can be edited and used to redirect the output to any desired drive and directory. This can be useful 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 SPL.exe program will look for this file and use it if it exists.

The *FOR.nnn* 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
not_in_use
results\rte.txt
results\pic.txt
results\snw.txt
not_in_use
results\stg.plt
results\spl.csv
results\swe.r2c
results\snw.csv
results\strout.1
results\snwdebug.txt
results\watflood.wfo
results\nash_eff.r2c
results\error.r2c
results\wetland.csv
results\sed.csv
mrbhm\mrb_master_inflows.tb0
results\spl_dly.csv
results\gridflow.r2c
results\resin.csv
results\evap.txt
results\evt_means.csv
results\peaks.txt
results\volumes.txt
results\spl_mly.csv
results\leakage.dat
results\lake_sd.csv
results\rff01.txt
results\rff02.txt
results\rff03.txt
.
.
results\rff29.txt
results\rff30.txt
results\tracer.csv
results\tracerMB.csv
results\tracer_debug.csv
results\tracerWET.csv
results\tracerWETMB.csv
results\evapsep.txt
results\watbal1.csv
results\watbal2.csv
warnings.txt
scratch5
results\evap.r2c
results\parfile.csv
results\precip.txt
results\stats.txt
results\domain_precip.txt
```

11.5 dds\dds_log.txt *precip.txt* File

The file results\precip.txt can be used for manual parameter fitting of those parameters affecting loss: fratio (interception multiplier), retn (soil retention), fpet(water) and sublim_rate (sublimation rate).

Colum name	Description
Station No	Sequential gauge number
Location	Station name
Area	Drainage area

Precip	Average upstream precip
o/ro	Observed runoff during recorded streamflow period
c/ro	Modelled runoff during recorded streamflow period – can be compared
c/ro(t)	Total modelled runoff for entire simulation period – can not be compared
Dv%	Volumetric error for observed flow period
Nash E	Nash –Sutcliffe efficiency for period of observed flow period
Qp/m	Max. observed peak flow
Qp/c	Max. computed peak flow
WS_A	Actual drainage area (can be supplied in `basin\flow_station_info.txt)`
Spl_A	Model drainage area
%Diff	% difference between model & actual drainage area
Class fractions	Fractions of each land cover class (total ~ 1.00)

12 WATROUTE

WATROUTE is a gridded routing model made up of a subset of CHARM. 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** but this is not supported. (I has not been updated since 2006 but may still work).

To run WATROUTE one or two of the three files are required as input and need 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 data sets in Green Kenue r2c format as shown below.

In addition, a *flow_init.r2c* file is required in the working directory to initialize all streamflow and LZ state variables. This file can be generated by executing CHARM with the routeflg= y or with FLOWINI.exe**.** To initialize the WATROUTE program, initial flows in the **_str.tb0* file are required for FLOWINIT.exe.

The **_rff.r2c* 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/r2c* file is the recharge from the upper zone to the lower zone in mm

The **_lkg.r2c* file is the leakage (lower zone discharge) to the stream in mm.

These files can be used in various combinations:

- **_rff,r2c* alone – has all river inflow – use modelflg = i
- *_rff.r2c + lkg.r2c – input is runoff _ LZ discharge (leakage) – recharge has been routed in host model – use modelflg - l
- **_rff.r2c* + **_rch.r2c* - input is runoff + recharge; LZ routing by WATROUTE – use modelflg = r

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 12.2

Similarly, RUNOF.exe will create these files.

The parameter file is the same for WATROUTE and SPL if SPL is used as the executable. 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 **use by WATROUTE (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 Green Kenue 1.0
#
# DataType               2D Rect Cell
#
:Application            Green Kenue
: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 Green Kenue 1.0
#
# DataType               2D Rect Cell
#
:Application            Green Kenue
: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 Green Kenue 1.0
#
# DataType               2D Rect Cell
#
:Application            Green Kenue
: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 Green Kenue 1.0
#
# DataType               2D Rect Cell
#
:Application            Green Kenue
: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
```

12.1 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: (a little repetition here & there)

Routing option l: Route surface, interflow and groundwater (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
```

12.2 Runoff, Recharge, and Leakage 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 in Green Kenue

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\*_rff.r2c
:griddedrecharge              rchrg\*_rch.r2c
:griddedleakage               lkage\*_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 CHARM 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.r2c* 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.r2c* 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_r2c* 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.

Please see Section 1.3.7.2 for a complete list of flags.

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

#
```

12.3 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
.
```

12.4 WATROUTE Output [new]

Instead of a results\spl.csv file, WATROUTE will write results\wrt.csv

This allows a comparison of the **spl.csv** produced by the hydrological model and whe **wrt.csv** file which is produced by WATROUTE. For the modelflg = ‘r’ or ‘l’, the results should be very close.

12.5 Combining WATFLOOD Runoff and MODFLOW Leakage

Under construction

13 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 from Green Kenue. 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 for Green Kenue (hr)
8784 End Reporting Time for Green Kenue (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
```

**** *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.*

The above file is file used for the example in Section 13.1. 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. SPL.exe will use this file if present and if the Green Kenue 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 for Green Kenue (hr)
 8784 End Reporting Time for Green Kenue (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 for Green Kenue 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, the Green Kenue flag in the event file must be set to a (for all).

13.1 How to Debug with Green Kenue

Figure 11.1 shows how Green Kenue 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 into Green Kenue. 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.

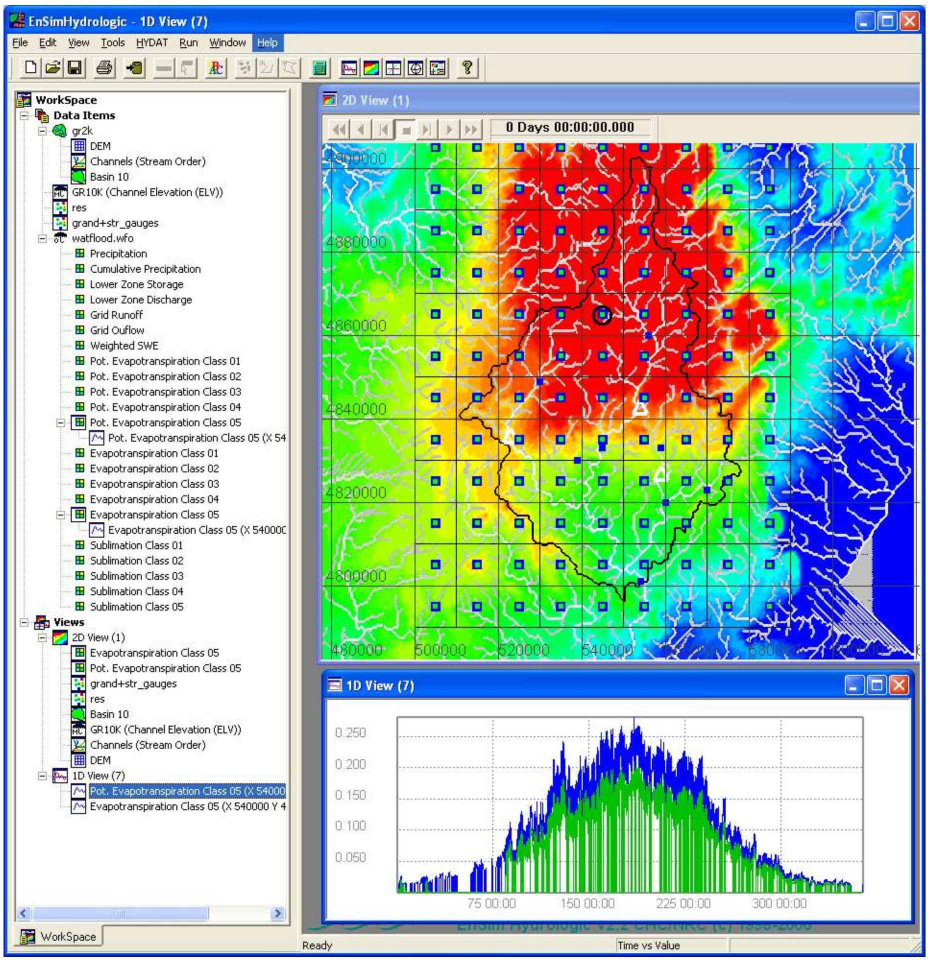


Figure 13.1. Example Green Kenue[1)] interface for debugging.

[1)]Green Kenue Hydrologic is available from NRC. Please see watflood.ca for the link.

Anoter example is to compare runs. Figure 11.2 shows three runs made with different programs. Green Kenue 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 synchronizing 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.

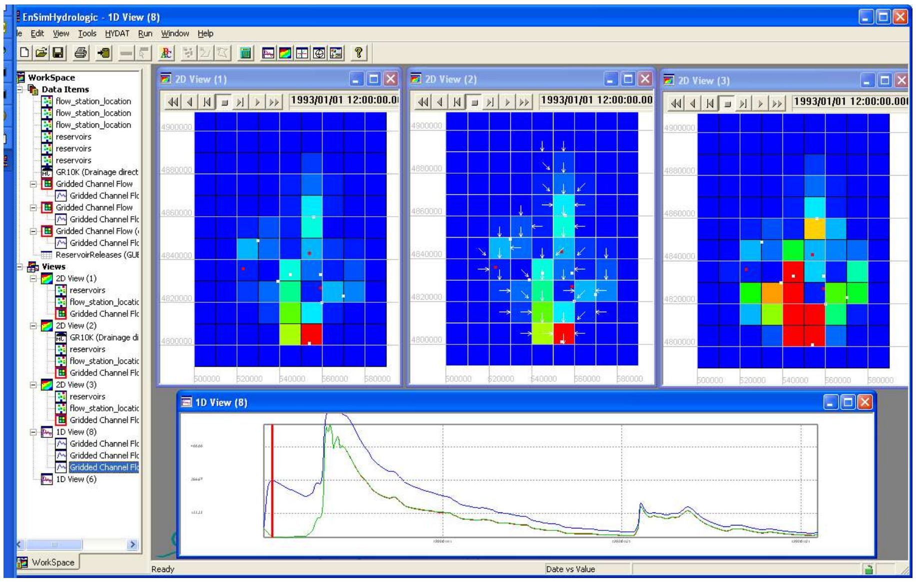


Figure 13.2. Looking for differences with Green Kenue.

14 WATFLOOD OPTIONS

14.1 Precipitation Adjustment File (PAF) [undergoing revision]

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 precipitation measurements are at low elevations and you want to adjust the higher elevations by some height dependent factor.

To use this feature, set pafflg = y in the *event\event.evt* file

When you run the SPL.exe program, two files called *newerror.txt* in the working directory and *results\error.r2c* are created. An example of the newerror.txt file for the Grand River is below.

```
        1 Errors in %.Runtime 07:58:40  2013-08-07
 :xcount           9
 :ycount          12
     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.    14.    14.     0.     0.     0.
     0.     0.     0.     0.    14.    14.     0.     0.     0.
     0.     0.     0.     0.    14.    14.    14.     0.     0.
     0.     0.     0.    94.    14.    14.    14.     0.     0.
     0.     0.     5.    94.    94.   -18.   -18.     0.     0.
     0.     5.     5.    94.   -18.   -18.   -37.     2.     0.
     0.     5.     5.     5.   -18.   -37.   -37.     2.     0.
     0.     0.     5.     5.     5.    27.    27.     2.     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.
    2 Errors in %.Runtime 07:58:44  2013-08-07
 :xcount           9
 :ycount          12
     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     2.     2.     0.     0.     0.
     0.     0.     0.     0.     2.     2.     0.     0.     0.
     0.     0.     0.     0.     2.     2.     2.     0.     0.
     0.     0.     0.    12.     2.     2.     2.     0.     0.
     0.     0.     5.    12.    12.   -14.   -14.     0.     0.
     0.     5.     5.    12.   -14.   -14.   -11.     1.     0.
     0.     5.     5.     5.   -14.   -11.   -11.     1.     0.
     0.     0.     5.     5.     5.    21.    21.     1.     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 Errors in %.Runtime 07:58:47  2013-08-07
 :xcount           9
 :ycount          12
     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     1.     1.     0.     0.     0.
.
.
.
```

.
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. -0. 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 SPL.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 for values that are erroneous such as for sub-basisn that have no data for the period of the run such as a flow station that may be in a lake. These could have errors of -100%. (You should take that flow station out of the str files!). You could replace the erroneous value by the value from the next downstream station.
4. Run SPL.exe This creates a *newpaf.txt* file. You can stop this run with ^C as soon as the file is written if you only want a new PAF file based on the last *error.txt* file.
5. Run FILL.exe It reads the *newpaf.txt* file and spits out a *fill.txt* file. This program fills in blank areas and smoothes the boundaries of sub-basins.
6. Copy the *fill.txt* file to *paf.txt* if it looks ok. (It looks ok when the PAF's look ok)
7. Run SPL.exe for the last time with the *paf.txt* file.

Note:

SPL.exe will first look for a *paf.r2s* file. If it does not exist, it will look for an *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.

14.2 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
.
.
.
.
```

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.

14.3 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.

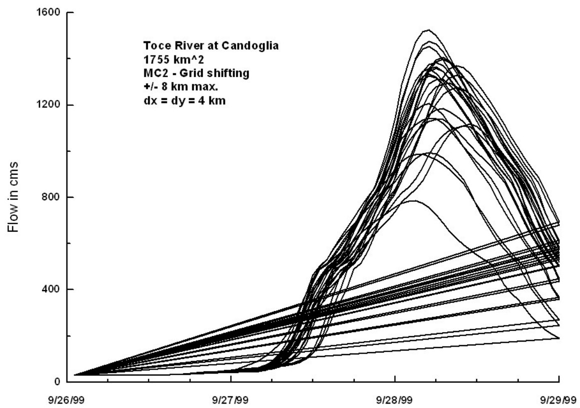


Figure 12.1 – Example of a grid shifting exercise during MAP

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 grid points in all directions in steps of 4 grid points. In other words, SPL will be executed 25 times.

14.4 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)
```

14.5 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

SPL.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.

15 CONVERSION TO GREEN KENUE FORMATS (TRANSLATE)

This Chapter explains the steps required to convert old WATFLOOD files to the Green Kenue formats. The old Formats are no longer supported.

Examples are taken from various watersheds.

- Version 10 and higher will only read the Green Kenue format files tb0, pt2 and r2c
- The file naming convention is ***_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 Green Kenue formats. **trns.exe** will use the same event file as SPL.exe simple converting all the files in a run to the new formats.

Steps to convert files to Green Kenue formats:

15.1 Step 1

BACK UP ALL FILES before you begin!!!!!
Run SPL.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

15.2 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-Green Kenue format), load it into Green Kenue and save it as bsnm_ef.map. This will update the format to the Green Kenue 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**

15.3 Step 3

Run **trns.exe** the same way you would run **SPL.exe** for one event or a set of events.
This converts the str, rel, rin, met, and tem files to the Green Kenue 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 SPL.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 new Green Kenue 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 new Green Kenue 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 new Green Kenue compatible file formats

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 opening fln(537): resrl/dummy_rel.tb0         ---

 Closed unit          537  Filename =   resrl/dummy_rel.tb0
Green Kenue 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 new Green Kenue compatible file formats

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

 opening fln(536): strfw/900901_str.tb0        ---

 Closed unit          536  Filename =   strfw/900901_str.tb0
Green Kenue 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
Green Kenue compatible r2c file format written

 Closed unit          515  Filename =   tempr/900901_tem.r2c
Green Kenue compatible r2c file format written

  In .par file, temp3 set too low
  Results in underestimated evaporation
  Please see manual section 2.4.2
```

15.4 Step 4

Rename all files to the new *_???.??? formats using a batch command if the names are not in the * 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 *_???.??? 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

15.5 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 the Green Kenue 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 1.3.7.3

15.6 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*_crs.pt2** file:
Note: the impervious class is now the last class (11)

```
#########################################################################
:FileType pt2 ASCIIGreen Kenue 1.0
#
# DataType               Green Kenue PT2 Set
#
:Application             Green Kenue
: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*_psm.pt2** file:

```
#########################################################################
:FileType pt2 ASCIIGreen Kenue 1.0
#
# DataType               Green Kenue PT2 Set
#
:Application             Green Kenue
: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.

15.7 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.

15.8 Step 8

You should now have all the files necessary to run SPL version 10. All the files should be viewable in Green Kenue. 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.

16 PROGRAM REVISIONS

16.1 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 simout/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
!     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 for ensim
!                  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
!     rev. 9.1.08  Jan.  17/02  - fixed rev. 9.1.04
!     rev. 9.1.09  Jan.  21/02  - fixed reservoir release timing in CHARM see8.99l
!     rev. 9.1.10  Jan.  29/02  - flow nudging added for nopt(1)=2
!     rev. 9.1.11  Feb.  07/02  - fixed bug in reservoir routing
!     rev. 9.1.12  Mar.  15/02  - added xdelta and ydelta for ensim
!     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 simout\error.r2s file for ENSIM_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  - Added ensim1flg - if ensimflg='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 to ENSIM 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
!     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: ENSIM 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 chaeck 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 scale 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
!     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
!      rev. 9.5.50  Jan.  05/09  - NK: read evap data for reaches only
!      rev. 9.5.51  Jan.  13/09  - NK: added reading *_ill.pt2 for all lakes
!      rev. 9.5.52  Jan.  20/09  - NK: added reading *_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 classcount 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
!     rev. 9.7.20  Jan.  31/11  - NK: Moved open statement for rdpar to rdpar/f
!     rev. 9.7.21. Mar.  07/11  - NK: Fixed delta_reort for longer periods in lst
!     rev. 9.7.22. Mar.  07/11  - NK: Changed diversion code: give/route take/rerout
!     rev. 9.7.23  Mar.  18/11  - NK: Revamped auto hydrograph fitting with precip icase=-2
!     rev. 9.7.24  Apr.  20/11  - NK: Added diverflg to indicate if a diversion is in grid
!     rev. 9.7.25  Apr.  28/11  - NK: Fixed daily flows
!     rev. 9.7.27  May.  26/11  - NK: Add lake_ice_factor
!     rev. 9.7.28  Jun.  14/11  - NK: Add degree_day for lake_ice_factor  dd_ice
!     rev. 9.7.29  Jul.  07/11  - NK: Add sublim_rate to set sublimation rate/day to par file
!     rev. 9.7.30  Jul.  13/11  - NK: imax > ycount & jmax > xcount also imin > 1 jnim > 1
!     rev. 9.8.00  Jul.  14/11  - NK: ntype+1 replaced by classcount (plus all derivatives)
!     rev. 9.8.01  Jul.  21/11  - NK: added ragmet optimization to dds setup
!     rev. 9.8.02  Jul.  26/11  - NK: reactivated meander length
!     rev. 9.8.02  Aug.  02/11  - NK: added lake level tb0 file
!     rev. 9.8.03  Aug.  08/11  - NK: check no of mean observed flows in file are ok
!     rev. 9.8.04  Sep.  02/11  - NK: Fix bug in write)par_10 when reading old par file
!     rev. 9.8.05  Oct.  18/11  - NK: New read_par_parser subroutine
!     rev. 9.8.06  Nov.  08/11  - NK: Added check for `water` class name
!     rev. 9.8.07  Oct.  10/11  - NK: area_check - removed unused stations
!     rev. 9.8.08  Nov.  18/11  - NK: added fratio for interception hight optimization
!     rev. 9.8.09  Nov.  22/11  - NK: nopt(l)=0 for area_error(l) > 10%
!     rev. 9.8.10  Dec.  06/11  - NK: Added message for FP overflow in route
!     rev. 9.8.11  Dec.  06/11  - NK: removed 30 char limit on find filetype
!     rev. 9.8.12  Dec.  07/11  - NK: removed 30 char limit on find filetype
!     rev. 9.8.12  Dec.  08/11  - NK: recognize kenueflg in the event file
!     rev. 9.8.13  Jan.  17/12  - NK: modifications to read_r2c for single frame data
!     rev. 9.8.14  Jan.  27/12  - NK: dds_penalty added for swe not to zero in summer
!     rev. 9.8.15  Mar.  12/12  - NK: write error.txt for every dds evaluation
!     rev. 9.8.16  Mar.  21/12  - NK: reinstate reservoir inflow error for dds
!     rev. 9.8.17  Apr.  24/12  - NK: Moved dds flags to top of par file
!     rev. 9.8.18  Apr.  26/12  - NK: Added in-basin check in tracer4
!     rev. 9.8.19  May.  10/12  - NK: Added check on mising init flow for lakes
!     rev. 9.8.20  MAy.  15/12  - NK: fixed lake area in flowinit9.5.34
!     rev. 9.8.21  Jun.  18/12  - NK: Added swe observed date & report
!     rev. 9.8.22  Jul.  17/12  - NK: Added resetflg to reset cumm. precip Sept.1
!     rev. 9.8.23  Aug.  03/12  - NK: Added resinid1flg to use resinflg for id=1
!     rev. 9.8.24  Aug.  07/12  - NK: Added reading *_lvl.tb0 for lake levels
!     rev. 9.8.25  Sep.  26/12  - NK: Added warning for resumflg=y and ID > 1
!     rev. 9.8.26  Sep.  26/12  - NK: Added error check on # chained files for id>1'
```

```
!     rev. 9.8.27  Sep.  27/12  - NK: changed action on resumflg='s' - keep tbcflg='y'
!     rev. 9.8.28  Oct.  12/12  - NK: fixed heat deficit reset for resume
!     rev. 9.8.29  Oct.  15/12  - NK: added wetland_flag to speed up route.f
!     rev. 9.8.30  Oct.  16/12  - NK: remove p(i,j)=0.0 from precip_adjust
!     rev. 9.8.31  Oct.  16/12  - NK: continue rff files for contflg = y
!     rev. 9.8.32  Oct.  19/12  - NK: Fixed format for resin.csv in lst.f
!     rev. 9.8.33  Oct.  23/12  - NK: Deleted header for rff files with resumflg = y
!     rev. 9.8.34  Oct.  23/12  - NK: Added sums to the resume.txt file
!     rev. 9.8.35  Oct.  23/12  - NK: Fixed bug in read_soilinit_ef
!     rev. 9.8.36  Oct.  23/12  - NK: added fields to rff files
!     rev. 9.8.37  Oct.  27/12  - NK: added section to read_flow_ef to check # columns = no
!     rev. 9.8.38  Nov.  13/12  - NK: changed name level_plotting.xyz > level_station_location.xyz
!     rev. 9.8.39  Nov.  26/12  - NK: added check for flow stations in lakes
!     rev. 9.8.40  Jan.  14/13  - NK: convert interception cap: h(,)*fratio()
!     rev. 9.8.41  Jan.  28/13  - NK: fixed bug in lst for level print statement
!     rev. 9.8.42  Jan.  31/13  - NK: fixed bug in read_resvin: nopti int conversion
!     rev. 9.8.43  Jan.  31/13  - NK: fixed bug in lst.f : undefined output for iopt=99
!     rev. 9.8.44  Jan.  31/13  - NK: fixed bug in sub.f : uninitialized course_calc(n,j)
!     rev. 9.8.45  Jan.  31/13  - NK: disabled some writes for iopt = 99
!     rev. 9.8.46  Feb.  04/13  - NK: Fixed some write formats in lst,stats,watbal
!     rev. 9.8.47  Feb.  04/13  - NK: Headers added for spl & resin csv files
!     rev. 9.8.48  Feb.  12/13  - NK: Replaced spl.plt with spl.tb0 file
!     rev. 9.8.49  Feb.  20/13  - NK: Added n=municipal & irrigation withdrawals
!     rev. 9.8.50  Feb.  27/13  - NK: Initialize store1&2() for zero lake outflow
!     rev. 9.8.51  Mar.  11/13  - NK: Link skiphours in s/r stats to valuel in the str file
!     rev. 9.8.52  Mar.  20/13  - NK: deleted a pause for dds runs in route
!     rev. 9.8.53  Mar.  20/13  - NK: Add Lake St. Joseph diversion algorithm to REROUT.f
!     rev. 9.8.54  Apr.  02/13  - NK: deltat conversion seconds to hours
!     rev. 9.8.55  Apr.  10/13  - NK: fixed pause for dds runs in route
!     rev. 9.8.56  Apr.  10/13  - NK: Added check in rerout for -ve storage due to evaporation
!     rev. 9.8.57  Apr.  12/13  - NK: Added lakeEflg to stop lake evaporation whan levels very low
!     rev. 9.8.58  Apr.  12/13  - NK: REvised Family Lake (WPEGR) O/R in rerout
!     rev. 9.8.59  May   14/13  - NK: REmoved psmear & punused from the program
!     rev. 9.8.60  May   14/13  - NK: fixed ice factor for whole x-section
!     rev. 9.8.61  May   22/13  - NK: Introduced flag1 to speed up runof6
!     rev. 9.8.62  May   22/13  - NK: Fixed bug in runof6: (classcount-3) to (classcount-2)
!     rev. 9.8.63  May   22/13  - NK: Fixed bug in s/r SUB.f argument list: "jan" missing
!     rev. 9.8.64  May   28/13  - NK: Undocumented debug file
!     rev. 9.8.65  May   28/13  - NK: Dimensioned firstpass_local()in REROUT
!     rev. 9.8.66  Jun   03/13  - NK: Added error_Dv.txt output in stats.f
!     rev. 9.8.67  Jun   06/13  - NK: Added allocation for flag1
!     rev. 9.8.68  Jun   17/13  - NK: Added dds_override file
!     rev. 9.8.69  Jun   17/13  - NK: Fixed bug in allocating clumnunits in SUB.f
!     rev. 9.8.70  Jun   17/13  - NK: for PAF: change error & PAF files to use GK formats
!     rev. 9.8.77  Jul   08/13  - NK: Made universal the use of wetland_flag(n)
!     rev. 9.8.78  Jul   16/13  - NK: Fixed divertflg to have the first event file value
!     rev. 9.8.79  Jul   19/13  - NK: Fixed wetland conditional screwed up with rev 9.8.77 in runof6
!     rev. 9.8.80  Aug   09/13  - NK: Added withdraw.r2c output file in route.f
!     rev. 9.8.81  Sep.  03/13  - NK: Add pafflg and update precip adjustment factors
PAF!***********************************************************************
!     rev. 9.8.82  Sep.  07/13  - NK: Bypass of hard-coded lake rules when coeff1=0
!     rev. 9.8.83  Sep.  10/13  - NK: Set classcount=0 for fli.exe program only
!     rev. 9.8.84  Sep.  15/13  - NK: Added fratio to list of equal values for bog & fen
!     rev. 9.8.85  Sep.  30/13  - NK: Fixed the water balance for Lake St. Jo so diversion is taken
care of
!     rev. 9.8.86  Oct.  16/13  - NK: Added version no to stats.txt output
!     rev. 9.8.87  Oct.  25/13  - NK: Added error message for mismatched resume file
!     rev. 9.8.88  Oct.  26/13  - NK: Fixed header writing sequence for spl.tb0
!     rev. 9.8.89  Oct.  27/13  - NK: Fixed undefined (NAN) problem in flowint
!     rev. 9.8.90  Oct.  30/13  - NK: Added fetch to the shd file
!     rev. 9.8.91  Oct.  30/13  - NK: Got rid of lzs_init.r2c - data is in flow_init.r2c already
!     rev. 9.8.92  Nov.  06/13  - NK: Changed output file swe.txt to swe.csv
!     rev. 9.8.93  Nov.  12/13  - NK: Added the routing initialization with *_fli.r2c
!     rev. 9.8.94  Nov.  20/13  - NK: Added check on interception capacity for water
!     rev. 9.8.95  Nov.  20/13  - NK: Changed unit 58 to 955 for spl.tb0
!     rev. 9.9.00  Dec.  08/13  - NK: Added Lake Evaporation model
!     rev. 9.9.01  Dec.  12/13  - NK: Added `pintwarning' in route added
!     rev. 9.9.02  Dec.  12/13  - NK: Changed format for origin in wfo code
!     rev. 9.9.03  Dec.  15/13  - NK: Change to gridded latitude for etharg
!     rev. 9.9.04  Dec.  17/13  - NK: Change over to gridded climate normals to diff
!     rev. 9.9.05  Jan.  02/14  - NK: Add check if in-basin in flowinit
!     rev. 9.9.06  Jan.  08/14  - NK: Add daily differences to Harfreaves ETHarg.f
!     rev. 9.9.07  Jan.  10/14  - NK: Overhaul of the frame numbers to EnSim specs
```

```
!     rev. 9.9.08  Jan.  10/14  - NK: Add check on diversion locations in read_divert'
!     rev. 9.9.09  Feb.  24/14  - NK: Fixed reading the time stame in r2c frame headers
!     rev. 9.9.10  Mar.  20/14  - NK: Update swe anytime a file is found
!     rev. 9.9.11  Mar.  20/14  - NK: Added lake_level_init.pt2 file for a resume
!     rev. 9.9.12  Apr.  04/14  - NK: Added min & max lake_level output file
!     rev. 9.9.13  Apr.  04/14  - NK: Fix water balance
!     rev. 9.9.14  Jun.  02/14  - NK: Fix water balance for water class
!     rev. 9.9.15  Jun.  02/14  - NK: Add lz to the water balance - it was missing
!     rev. 9.9.16  Jun.  06/14  - NK: Added location file for Root R. diversion
!     rev. 9.9.17  Jun.  07/14  - NK: Added check for allocation of outarray in Sub.f
!     rev. 9.9.18  Jun.  08/14  - NK: Fixed glacier_class check for wetlands
!     rev. 9.9.19  Jun.  11/14  - NK: Added a file for lat-long diversion locations for L. St. Jo
!     rev. 9.9.20  Jul.  15/14  - NK: Fix -ve lake storage when release data used
!     rev. 9.9.20  Jul.  24/14  - NK: Added dead storage for lakes "store_dead"
!     rev. 9.9.21  Jul.  27/14  - NK: Added allocation for outarray in sub
!     rev. 9.9.22  Jul.  29/14  - NK: Fixed basin no assignment in flowinit.f
!     rev. 9.9.23  Aug.  10/14  - NK: Uniform arguments for write_r2c
!     rev. 9.9.24  Aug.  20/14  - NK: Added monthly mean flow csv file spl_mly_nn.csv
!     rev. 9.9.25  Sep.  02/14  - NK: Finally fixed the error when nbasin=0
!     rev. 9.9.26  Sep.  16/14  - NK: Added precip adjust for forecast & fcstflg
!     rev. 9.9.27  Sep.  18/14  - NK: Added zero class bypass in intcept.f
!     rev. 9.9.28  Sep.  18/14  - NK: Added 'a' as option for ntrlflg & smrflg
!     rev. 9.9.29  Sep.  30/14  - NK: Remove unnecessary writes for watroute
!     rev. 9.9.30  Sep.  30/14  - NK: fixed allocation for qhyd_mly & qsyn_mly
!     rev. 9.9.31  Oct.  13/14  - NK: Changed flow initialization RE: zero init flows
!     rev. 9.9.33  Oct.  16/14  - NK: Added checks for files existing for a resume'
!     rev. 9.9.34  Oct.  17/14  - NK: Added re-compute of lake storage re: new lake levels
!     rev. 9.9.35  Oct.  20/14  - NK: Added keyword & file checks
!     rev. 9.9.36  Nov.  03/14  - NK: Revised error message for daily diff choices
!     rev. 9.9.37  Nov.  05/14  - NK: Added `newDataFlag` check to WATROUTE
!     rev. 9.9.38  Nov.  12/14  - NK: Added LKdepth to ill file
!     rev. 9.9.39  Nov.  14/14  - NK: Modifications for watroute
!     rev. 9.9.40  Nov.  19/14  - NK: Modified the 'a' option for ntrlflg
!     rev. 9.9.41  Nov.  20/14  - NK: Added check if diversion = in-basin
!     rev. 9.9.42  Nov.  26/14  - NK: Added error check if diversion does not exist
!     rev. 9.9.43  Nov.  26/14  - NK: Allocation for divertflg = 'g'
!     rev. 9.9.44  Nov.  28/14  - NK: Added dead storage to reservoirs
!     rev. 9.9.45  Dec.  03/14  - NK: Revamped read_pt2 for general use
!     rev. 9.9.46  Dec.  10/14  - NK: Added check on initial lake outflow
!     rev. 9.9.47  Dec.  24/14  - NK: Added lakeflg for lake evaporation option
!     rev. 9.9.48  Jan.  06/15  - NK: Added wetland cond. function for o/b flow
!     rev. 9.9.49  Jan.  06/15  - NK: Added courantflg
!     rev. 9.9.50  Jan.  07/15  - NK: Added zero - initial flow warning
!     rev. 9.9.51  Jan.  13/15  - NK: Added min channel area in flowinit
!     rev. 9.9.52  Jan.  14/15  - NK: Fixed bug for channel store < 0 for withdrawals
!     rev. 9.9.53  Jan.  18/15  - NK: Prevent mode switch during iteration in wetland routing
!     rev. 9.9.54  Jan.  19/15  - NK: Put par & shd file names for 1st event in the headers
!     rev. 9.9.55  Jan.  22/15  - NK: Added diversion upstream drainage area in div file
!     rev. 9.9.56  Feb.  04/15  - NK: Fixed missing initial rel data in read_resv
!     rev. 9.9.57  Feb.  08/15  - NK: Fixed resv inflow output resin & lake_sd
!     rev. 9.9.58  Feb.  13/15  - NK: Added time column to levels.txt
!     rev. 9.9.59  Mar.  06/15  - NK: In route: strloss option frcflg y/n
!     rev. 9.9.60  Mar.  06/15  - NK: In sub: fixed call write_r2c for close condition
!     rev. 9.9.61  Mar.  06/15  - NK: In route: restored hcha2(n)=store2(n)/chaarea(n)
!     rev. 9.9.62  Mar.  21/15  - NK: Change zone from character to integer
!     rev. 9.9.63  Apr.  06/15  - NK: Changed reas_resv to carry on with last known release(s)
!     rev. 9.9.64  Apr.  08/15  - NK: DDS bypass in sub for single runs
!     rev. 9.9.65  Apr.  03/15  - NK: Added rule s/r; resrl\rules.txt & ruleflg
!     rev. 9.9.66  Apr.  03/15  - NK: Added options to write_tb0 str files
!     rev. 9.9.67  Apr.  29/15  - NK: Deleted mid_file headers in with tbcflg=y
!     rev. 9.9.68  Apr.  29/15  - NK: Fixed tto reset with resume
!     rev. 9.9.69  Jun.  10/15  - NK: prevent write ro rff if there is no class area
!     rev. 9.9.70  Jun.  12/15  - NK: Add del_rain, and dSTRconc2  to the wfo file
!     rev. 9.9.71  Jun.  13/15  - NK: DDS obf function taken out of sub > s/r obj_fn
!     rev. 9.9.72  Jul.  21/15  - NK: Dave Newson additions to sub & process_rain
!     rev. 9.9.73  Aug.  31/15  - NK: Finshed rules s/r - ready for beta testing
!     rev. 9.9.74  Sep.  11/15  - NK: Added output to unit 53 in flowinit
!     rev. 9.9.75  Sep.  11/15  - NK: Added basin_no.r2c output to flowinit.f
!     rev. 9.9.76  Sep.  11/15  - NK: Added recorded isotope concentrations
!     rev. 9.9.77  Sep.  11/15  - NK: S/r read_ts5 created
!     rev. 9.9.78  Sep.  16/15  - NK: Fixed wcl in melt.f
!     rev. 10.1.01 Oct.  05/15  - NK: Isotope update: added 2H
!     rev. 10.1.02 Oct.  09/15  - NK: Fixed allocation for qhyd_mly & qsyn_mly
```

```
!     rev. 10.1.03 Oct.  09/15  - NK: Added units 81-83 for isotope output
!     rev. 10.1.04 Oct.  10/15  - NK: Added year_last variable for use in reading isotope data
!     rev. 10.1.05 Oct.  11/15  - NK: Iso RMS error
!     rev. 10.1.06 Nov.  19/15  - NK: Added area_check with can_discharge_sites.xyz
!     rev. 10.1.07 Dec.  02/15  - NK: Added ice_fctr(n) to route
!     rev. 10.1.08 Dec.  04/15  - NK: Added msg re: replacing "mean_observed_flows.txt"'
!     rev. 10.1.09 Dec.  07/15  - NK: Add blank line for missing data in the precip.txt file in lst.f
!     rev. 10.1.10 Dec.  09/15  - NK: Add blank line for missing data in the precip.txt file in lst.f
!     rev. 10.1.11 Dec.  11/15  - NK: Revised ice factor initialization and calculation
!     rev. 10.1.12 Dec.  12/15  - NK: Added Nash Efficiency nasheff.r2c file unit-66
!     REV. 10.1.13 Dec.  28/15  - NK: Rearranged the par file blocks & contents
!     REV. 10.1.14 Jan.  05/16  - NK: Added ice rules for Lakes Athabaska & Great Slave.
!     REV. 10.1.15 Jan.  08/16  - NK: Custom coding for Mackenzie River Basin Hydraulic Model
!     REV. 10.1.16 Jan.  11/16  - NK: Added subroutine ice_factor.f
!     REV. 10.1.17 Jan.  11/16  - NK: Added fpetLakeOverride factor
!     REV. 10.1.18 Jan.  15/16  - NK: Made opening of the master_inflow file optional with routeflg=q
!     REV. 10.1.19 Jan.  15/16  - NK: Fixed initialization of ice_factr - moved from lake_ice > runof6
!     REV. 10.1.20 Jan.  15/16  - NK: Fixed initialization of ice_factr - moved from lake_ice > runof6
!     REV. 10.1.21 Jan.  22/16  - NK: isotope updates
!     REV. 10.1.21 Jan.  23/16  - NK: Fixed lake init flow bug in flowinit
!     REV. 10.1.22 Jan.  25/16  - NK: Fixed flowinit for partial basins
!     REV. 10.1.23 Jan.  28/16  - NK: Added abort when water class not specified
!     REV. 10.1.24 Jan.  30/16  - NK: Added qUS1 & qUS2 for watbal
!     REV. 10.1.25 Feb.  21/16  - NK: Added nudge_flags.txt
!     REV. 10.1.26 Mar.  23/16  - NK: Fixed comment for spinup period
!     REV. 10.1.27 Apr.  19/16  - NK: Moved outfiles code in spl9 (below)
!     REV. 10.1.28 Apr.  26/16  - NK: Fixed first day of output for master_inflows file
!     REV. 10.1.29 May   04/16  - NK: Added parfile comments
!     REV. 10.1.30 May   08/16  - NK: Added smoothdist warning in read_par_parser
!     REV. 10.1.31 May   15/16  - NK: Revised output to precip.txt : include all str stations
!     REV. 10.1.32 May   18/16  - NK: Separate radinfl for precip & temperature
!     REV. 10.1.33 Jun   20/16  - NK: Change the time stamp in the watflood.wfo file
!     REV. 10.1.34 Jul   05/16  - NK: Added Obs. & Model mean flows to wfo file
!     REV. 10.1.35 Jul   07/16  - NK: Added simulation start time to the wfo file
!     REV. 10.1.36 Jul   12/16  - NK: Added results\LakeName.tb0
!     REV. 10.1.37 Jul   28/16  - NK: Added "Ellipsoid to the WFO header
!     REV. 10.1.38 Jul   28/16  - NK: Added noDataValue to WFO & tb0 files
!     REV. 10.1.39 Sep   16/16  - NK: Fixed stations outside the watershed for tb0
!     REV. 10.1.40 Oct   11/16  - NK: Fixed bug in read_divert for missing u/s DA
!     REV. 10.1.41 Oct   11/16  - NK: Added tb0flg to write lake_*.tb0 files
!     REV. 10.1.42 Oct   20/16  - NK: Reinstated read_ice_factor.f as default if present
!     REV. 10.1.43 Oct   21/16  - NK: lake_ice_facter changed from : to :,:
!     rev. 10.1.44 Oct.  22/16  - NK: Reworked icerivflg & icelakeflg
!     rev. 10.1.45 Oct.  26/16  - NK: Added allocation check for qdivert in rerout
!     rev. 10.1.46 Nov.  08/16  - TH: Changed B1 - 5 to real*8
!     rev. 10.1.47 Nov.  08/16  - TH: Major changes in the ISO part of AET.f
!     rev. 10.1.48 Nov.  08/16  - TH: addet fpet(ii_water) to the wetland evaporation
!     rev. 10.1.49 Nov.  08/16  - TH: Overhauled lake evaporation
!     rev. 10.1.50 Nov.  08/16  - TH: Overhauled lst for new isotope output
!     rev. 10.1.51 Nov.  08/16  - TH: removed unused isotope related calculations, merged two
!     rev. 10.1.51                TH: isotope related calc sections to reduce if statements
!     rev. 10.1.52 Nov.  08/16  - NK:
!     rev. 10.1.53 Nov.  09/16  - NK: Changed levels.txt to levels.csv
!     rev. 10.1.54 Nov.  25/16  - NK: Moved tdum under call timer in sub
!     rev. 10.1.55 Nov.  30/16  - NK: Fixed sumf & sumffs in runof6
!     rev. 10.1.56 Dec.  05/16  - NK: Fixed evt in AET.f to account for sca
!     rev. 10.1.57 Dec.  06/16  - NK: Added snwNN.txt files for iopt > 0
!     rev. 10.1.58 Dec.  06/16  - NK: corrected tdum > tdum1 for modelflg=i
!     rev. 10.1.59 Dec.  18/16  - NK: Fixed missing # channel correction chnl(1-5)
!     rev. 10.1.60 Jan.  03/17  - NK: Fixed conditional in route
!     rev. 10.1.61 Jan.  03/17  - NK: Changed results\peaks.txt to write peak flows
!     rev. 10.1.62 Jan.  08/17  - NK: Checkup on strloss effect on low flows
!     rev. 10.1.63 Jan.  25/17  - NK: Intel® Parallel Studio XE 2017 Update 1
!     rev. 10.1.64 Jan.  26/17  - NK: Added XML output file
!     rev. 10.1.65 Jan.  28/17  - NK: Fixed allocate lake_elv from read_flow
```

```
!     rev. 10.1.66 Jan.  28/17  - NK: Fixed leap year in timer
!     rev. 10.1.67 Feb.  18/17  - NK: Ignore start year in subsequent event files
!     rev. 10.1.68 Mar.  03/17  - NK: Made midnight 00 instead of 24
!     rev. 10.1.69 Mar.  03/17  - NK: Changed allocation for lvl_reach in read_lvl.f
!     rev. 10.1.70 Mar.  03/17  - NK: Added year_now2 etc. for converting Grib2 files
!     rev. 10.1.71 Mar.  14/17  - NK: Revised reading mean_observed_flows in sub
!     rev. 10.1.72 Mar.  20/17  - NK: Fixed bug in sub for error_flag = 4
!     rev. 10.1.73 Mar.  27/17  - NK: Advisory message set in precip.txt for iopt=0
!     rev. 10.1.74 Apr.  01/17  - NK: Changed timer to fix 1 day-off problem
!     rev. 10.1.75 Apr.  03/17  - NK: Fixed time & thr in runof6 arg list
!     rev. 10.1.76 Apr.  05/17  - NK: Reorganized the outfiles.* file
!     rev. 10.1.77 Apr.  17/17  - NK: Moved DDS err calcs to new dds_code s/r's
!     rev. 10.1.78 Apr.  17/17  - NK: New s/r dds_UZS to calculate low flow penalty
!     rev. 10.1.79 Apr.  18/17  - NK: Set trcflg=0 for all dds except errflg=10
!     rev. 10.1.80 Apr.  26/17  - NK: Fixed tracer turnoff for -ve resv. storage
!     rev. 10.1.81 May   05/17  - NK: Added snowg\yyyymmdd_swe.tb0 obs. swe
!     rev. 10.1.82 May   09/17  - NK: Added reservoir_fudge_factors.csv
!     rev. 10.1.83 May   09/17  - NK: Fixed lake evap bug - moved it outside lake-only loop
!     rev. 10.1.84 May   09/17  - NK: Put drng(n,ii)=drng(n,ii)*fraction back into runof6
!     rev. 10.1.85 May   17/17  - NK: Level_station_location.xyx for iopt > 0 only
!     rev. 10.1.86 May   17/17  - NK: Diversion_location.xyx for iopt > 0 only
!     rev. 10.1.87 May   18/17  - NK: Added DA to reservoir_location.xyz
!     rev. 10.1.88 May   23/17  - NK: Fixed Juliean_day problems for iso R/W
!     rev. 10.1.89 May   25/17  - NK: Added errflg = 11 for isotope DDS
!     rev. 10.1.90 Jul.  27/17  - NK: Added date_now for i/o files
!     rev. 10.1.91 May   25/17  - NK: Added errflg = 12 for isotope DDS
!     rev. 10.1.92 May   25/17  - NK: Changed to max 200 dds variables
!     rev. 10.1.92 Aug   12/17  - NK: delete store_dead in iso s/r's
!     rev. 10.1.93 Aug   17/17  - NK: allow year1 etc. to be passed for each event
!     rev. 10.1.94 Aug   29/17  - NK: Fixed col check bug in read_lvl
!     rev. 10.1.95 Sep   11/17  - NK: Fixed LKdepth bug in sub
!     rev. 10.1.96 Sep   11/17  - NK: Added variable lake depth calculation
!     rev. 10.1.97 Sep   11/17  - NK: Moved hdrflg action in runof6.f
!     rev. 10.1.98 Oct   04/17  - NK: Deal with -ve flows in route
!     rev. 10.1.99 Oct   08/17  - NK: Added error check for # sdc classes in Melt.f
!     rev. 10.2.01 Oct   08/17  - NK: Moved ruleflg from sub.f to spl.f
!     rev. 10.2.02 Oct   24/17  - NK: Fixed xml output file
!     rev. 10.2.03 Oct   28/17  - NK: Revert to old G format for lakeSD.csv
!     rev. 10.2.04 Oct   28/17  - NK: Change to one xml output file for computed flow
!     rev. 10.2.05 Oct   28/17  - NK: Killed off stats_info.txt for iopt.ge.1
!     rev. 10.2.06 Oct   28/17  - NK: wfo_spec.txt in working OR basin directory
!     rev. 10.2.07 Nov.  03/17  - NK: New rt_pond subroutine for channel pond routing
!     rev. 10.2.08 Nov.  04/17  - NK: New rt_channel & rt-_wetland subroutines
!     rev. 10.2.09 Nov.  04/17  - NK: Reinstated old Manning's n correction for legacy files
!     rev. 10.2.10 Nov.  04/17  - NK: Fixed XML file
!     rev. 10.2.11 Dec.  18/17  - NK: 4 files added for BLEND.exe
!     rev. 10.2.12 Dec.  30/17  - NK: Added frame headers to static r2c files incl. shd file
!     rev. 10.2.13 Jan.  31/18  - NK: Re-wrote rules.f to mimic stop log operations
!     rev. 10.2.14 Jan.  31/18  - NK: Ren. rules.f to rules_tl.f - for use with target levels
!     rev. 10.2.15 Feb.  05/18  - NK: Added 'results\monthly_peaks'
!     rev. 10.2.16 Feb.  14/18  - NK: Added bankfull flow calculation
```

17 BIBLIOGRAPHY

17.1 General References

Ambach, W. 1988. Interpretation of the positive degree-day factor by heat balance characteristics – West Greenland. Nordic Hydrology, 19: 217-224.

American Society of Civil Engineers. 1969. Design and Construction of Sanitary and Storm Sewers. Manuals and Reports of Engineering Practice, No. 37, New York.

American Society of Civil Engineers, Committee on Irrigation Water Requirements of the Irrigation and Drainage Division of the ASCE. 1990. Evapotranspiration and Irrigation Water Requirements: a Manual. 332 p.

Anderson, E.A. 1973. National Weather Service River Forecast System-Snow Accumulation and Ablation Model. National Oceanographic and Atmospheric Administration, Silver Springs, Md., Tech. Memo NWS_HYDRO-17.

Anderson, E.A. 1976. A Point Energy and Mass Balance Model of a Snow Cover, NOAA Technical Report, NWS-HYDRO-19, 150p.

Beven, K., R. Lamb, P. Qiunn, R. Romanowicz, and J. Freer. 1995. Computer Models of Watershed Hydrology. Singh, V.P. (ed.), Water Resources Publications, Colorado, Chapter 18, 627-668.

Black, T.A., D.T. Price, F.M. Kelliher, and P.M. Osberg. 1984. Effect of overstory removal on seasonal growth of a young Douglas-fir stand. 1983-84 Annual Report, E.P. 855, Research Branch, B.C. Ministry of Forests, Victoria, B.C.

Bras, R. 1990. Hydrology – An introduction to hydrologic science. Addison-Wesley. New York.

Browning, K.A. and C.G. Collier. 1989. Nowcasting of precipitation systems. Reviews of Geophysics, 27(3): 345-370.

Brutsaert, W., and H. Stricker. 1979. An advection-aridity approach to estimate actual regional evapotranspiration. Water Resources Research, 15(2): 443-450.

De Bruin, H.A.R., and J.Q. Keijman. 1979. The Priestley-Taylor evaporation model applied to a large, shallow lake in the Netherlands. J. of Applied Meteorology, 18: 898-903.

Donald, J.R. 1992. Snowcover depletion curves and satellite snowcover estimates for snowmelt runoff modelling. Ph.D. Thesis, University of Waterloo, ON, Canada, 232 p.

Duffie, J.A., and W.A. Beckman. 1980. Solar Engineering of Thermal Processes. Wiley, N.Y., pp. 1-109.

Giles, D.G., T.A. Black, and D.L. Spittlehouse. 1985. Determination of growing season soil water deficits on a forested slope using water balance analysis. Canadian Journal of Forest Resources, 15: 107-114.

Gray, D.M. 1973. Handbook on the Principles of Hydrology. National Research Council of Canada.

Green, W.H., and G.A. Ampt. 1911. Studies in soil physics. 1: Flow of air and water through soils. J. Agricultural Research, 4: 1-24.

Hamlin, L.P.B. 1996. Snowmelt Hydrologic Modelling of Northern Wetland Dominated River Basins. M.A.Sc. Thesis, University of Waterloo, Waterloo, ON. 213 p.

Hargraeves, G.H., and Z.A. Samani. 1982. Estimating potential evapotranspiration. ASCE, J. Irrigation and Drainage Division, 108(3): 225-230.

Hooke, R., and T.A. Jeeves. 1961. Direct search solution of numerical and statistical problems. J. Assoc. Comp. Mach., 8 (2): 212-229.

Huggins, L.F., and E.J. Monke. 1966. The mathematical simulation of the hydrology of small watersheds. Technical Report No. 1, Water Resources Center, Purdue University, LaFayette, Ind.

Kohler, M.A., and R.K. Linsley, Jr. 1951. Prediction of Runoff from Storm Rainfall. U.S. Weather Bureau, Research Paper 34.

Kouwen, N., and G. Garland. 1984. HYMO-BASIC Users Manual. Department of Civil Engineering, University of Waterloo, Waterloo, 88p.

Leavesley, G.H., and L.G. Stannard. 1995. The precipitation-runoff modelling system - PRMS. Computer Models of Watershed Hydrology. Singh, V.P. (ed.), Water Resources Publications, Colorado, Chapter 9, 281-310.

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1949. Applied Hydrology. McGraw - Hill Book Company, New York, N.Y.

Martinec, J. 1989. Hour-to-hour snowmelt rates and lysimeter outflow during an entire ablation period: Snow cover and glacier variations. Proc. of the Baltimore Symposium, Maryland, IAHS Publ. No. 193: 19-28.

Martinec, J., and M.R. de Quervain. 1975. The effect of snow displacement by avelanches on snowmelt and runoff. Proc. Snow and Ice Symposium, Moscow, IAHS Publ. No. 104:364-377.

McKillop, R., N. Kouwen and E.D. Soulis. 1999. "Modeling the Rainfall-Runoff Response of a Headwater Wetland", *Water Resources Research*, Am. Geophysical Union. Vol. 35, No. 4, 1165-1177.
McNaughton, K.G., and T.A. Black. 1973. A study of evapotranspiration from a Douglas-fir forest using the energy balance approach. Water Resources Research, 9(6): 1579-1590.

Mohan, S. 1991. Intercomparison of evapotranspiration estimates. Hydrological Sciences Journal, 36(5): 447-461.

Monro, J.C. 1971. Direct search optimization in mathematical modelling and a watershed application. NOAA Technical Memorandum, NWS-HYDRO-12, April.

Morton, F.I. 1983. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology, 66: 1-76.

Morton, F.I. 1983. Operational estimates of lake evaporation. Journal of Hydrology, 66: 77-100.

Munro, D.S. 1979. Daytime energy exchange and evaporation from a wooded swamp. Water Resources Research, 15(5): 1259-1265.

Philip, J.R. 1954. An infiltration equation with physical significance. Soil Science, 77(1): 153-157.

Ponce, M., 1990. Personal communication. Durango, Colorado.

Price, D.T. 1987. Some effects of variations in weather and soil water storage on canopy evapotranspiration and net photosynthesis of a young douglas-fir stand. Ph.D. Thesis, University of British Columbia, Vancouver, B.C.

Priestley, C.H.B., and R.J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review, 100(2): 81-92.

Rango, A. and J. Martinec. 1995. Revisiting the degree-day method for snowmelt computations. Water Resources Bulletin, AWRA, 31(4): 657-669.

Rawls, W.J., and D.L. Brakensiek. 1983. A procedure to predict Green and Ampt infiltration parameters. Advances in Infiltration, Proc. of the Nat. Conf. on Adv. in Infiltration, ASAE, Dec. 12-13, Chicago, pp. 102-112.

Refsgaard, J.C., and B. Storm. 1995. MIKE SHE. Computer Models of Watershed Hydrology. Singh, V.P. (ed.), Water Resources Publications, Colorado, Chapter 23, 809-846.

Rowe, L.K. 1983. Rainfall interception by an evergreen beech forest, Nelson, New Zealand. Journal of Hydrology, 66: 143-158.

Rutter, A.J., K.A. Kershaw, P.C. Robins, and A.J. Morton. 1971. A predictive model of rainfall interception in forests; 1. Derivation of the model from observations in a plantation of Corsican pine. Agricultural Meteorology, 9: 367-384.

Saeed, M. 1986. The estimation of evapotranspiration by some equations under hot and arid conditions. Transactions of the American Society of Agricultural Engineers, 29(2): 434-438.

Seglenieks, F.R. 1994. Application of Remote Sensing and Ground Measurements to Calibrate the Hydrologic Model WATFLOOD. M.A.Sc. Thesis, University of Waterloo, Waterloo, ON. 162 p.

Shuttleworth, W.J., and I.R. Calder. 1979. Has the Priestley-Taylor equation any relevance to the forest evaporation? Journal of Applied Meteorology, 18: 639-646.

Spittlehouse, D.L., and T.A. Black. 1981. A growing season water balance model applied to two Douglas-fir stands. Water Resources Research, 17: 1651-1656.

Stagnitti, F., J.Y. Parlange, and C.W. Rose. 1989. Hydrology of a small wet catchment. Hydrological Processes, 3: 137-150.

Stewart, J.B. 1977. Evaporation from the wet canopy of a pine forest. Water Resources Research, 13(6): 915-921.

Stewart, R.B., and W.R. Rouse. 1976. A simple method for determining the evaporation from shallow lakes and ponds. Water Resources Research, 12(4): 623-628.

Stewart, H.B., and A.S. Thom. 1973. Energy budgets in pine forest. Quarterly Journal of the Royal Meteorological Society, 99: 145-170.

Terstriep, M.L. and J.B. Stall. 1969. Urban Runoff by the Road Research Laboratory Method. ASCE, Hydraulics Division, 95(6): 1809-1834.

Tolson, B.A., and C.A. Shoemaker. 2007. Dynamically Dimensioned Search Algorithm for Computationally Efficient Watershed Model Calibration. Water Resources Research, 43(1).

Viessman, W, J.W. Knapp, G.L. Lewis, and T.E. Harbaugh. 1977. Introduction to Hydrology, Harper & Row, N.Y.

Wei, T.C., and J.L. McGuinnes. 1973. Reciprocal distances squared method: a computer technique for estimating areal precipitation. U.S. Department of Agriculture, ARS-NS-8, pp. 1-23.

17.2 Radar Related References

Brandes, E.A. 1975. Optimizing rainfall estimates with the aid of radar. J. Applied Meteorology, 14: 1339-1345.

Collier, C.G. 1987. Accuracy of real-time radar measurements. In: Collinge V. and C. Kirby (edts.), Weather Radar and Flood Forecasting, John Wiley & Sons, N.Y., pp. 71-95.

Collier, C.G., P.R. Larke, and B.R. May. 1983. A weather radar correction procedure for real-time estimation of surface rainfall. Quarterly Journal of the Meteorological Society, 109: 589-608.

Crozier, C.L. 1975. A C-Band meteorological radar system for quantitative measurements of cloud physics research. Meteorological Memoirs, No. 30, Atmospheric Environment Service, Canada.

Dalezios, N.R. 1982. Real-time radar rainfall measurements for hydrologic modeling. Ph. D. Thesis, Department of Civil Engineering, University of Waterloo, Ontario, Canada.

Dean, J.D., and W.M. Snyder. 1977. Temporally and areally distributed rainfall. ASCE, J. of Irrigation and Drainage Division, 103(2): 293-297.

Jones, D.M. 1956. Rainfall drop size distribution and radar reflectivity. Research Report No. 6, Illinios State Water Survey, Urbana, IL.

Krajewski, W.F., and M.D. Hudlow. 1983. Evaluation and application of a real-time method to estimate mean areal precipitation from rain gauge and radar data. Proceedings, Conference on Mitigation of Natural Hazards Through Real-Time Data Collection Systems and Hydrological Forecasting, Sacramento, California.

Marshall, J.S., and W.M. Palmer. 1948. The distribution of raindrops with size. Journal of Meteorology, 5:165-166.

Nemec, J. 1985. The use of radar in world meteorological organization hydrological projects in developing countries. Preprints, Weather Radar and Flood Warning Symposium, University of Lancaster, UK.

NWS. 1972. National Weather Service River Forecast System: Forecast Procedures. Tech. Mem. NWS HYDRO-14, National Weather Service, National Oceanographic and Atmospheric Administration, Silver Springs, MD.

USDA. 1968. Hydrology, Supplement A to Sect. 4, Engineering Handbook, US Department of Agriculture, Soil Conservation Service.

Wilson, J.W. 1976. Radar-rain gage precipitation measurements-a summary. Proceedings of First National Conference on Hydrometeorology, Fort Worth, TX, pp. 72-75.

18 WATFLOOD/GREEN KENUE WORKSHOP (2 DAYS)

This workshop was held at McMaster using the TRCA domain, Torornto, ON.
The watershed name used = **trca**
The DEM = **trca_dem.asc**
The land cover map = **TRCA_ALL_SOLRIS_LL.tif**
The theme file GK **C:\Program Files\CHC\GreenKenue64\Templates\GeoTIFF\trca.thm**

You can substitute these names with your own.

18.1 Installing WATFLOOD and Green Kenue

Copying stuff (you may use a different drive for executables & data)
Make folders
c:\watflood (all executables go here – see d. below)
c:\watflood\ trca
c:\watflood\ trca \\basin
c:\watflood\ trca \results
.
You can do this by copying the files from the CD

Files needed in the c:\watflood\Trca\data folder:

As on the cd

Files (on the CD) needed in the c:\watflood folder:
bsn***.exe
make_evt**.exe
moist**.exe
ragmet***.exe
snw**.exe
charm***.exe
ragmet***.exe
tmp***.exe
*** = 64x, 64d, 32x, 32d ** = 64, 32

Files needed in the c:\watflood\Trca\basin folder**:**
trca_par.csv
trca.sdc

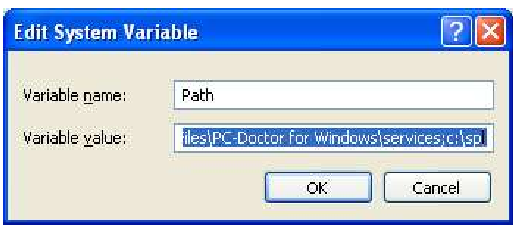
Copy the folders event, moist, radcl, resrl, snow1, strfw and tempr into the **watflood\trca** folder

Set the path:

WINDOWS 10

Right Click Start
Click on Settings
In the find a setting box type "path"
double-click "Path" and then click on the ***tiny*** fixed-width dialog and you get System Properties
Click on Environment Variables and in this window go to New…
The Browse Directory and select the C:\watflood directory - or what ever location you hve it at.

WINDOWS 7
Right click on **My Computer** and go to **Properties.** Clickon **Advanced** and go to **Environment Variables** and select Path under System variables. Click on **EDIT** and add ;**c:\watflood** to the end of the Path line and click OK:



In DOS:

Use the command:

set PATH=%PATH%;c:\watflood

or a complete path like:

set PATH=%PATH%;c:\Users*username*\Documants\watflood

18.2 Working with Green Kenue (GK)

GK may be downloaded from
https://www.nrc-cnrc.gc.ca/eng/solutions/advisory/green_kenue/download_green_kenue.html

18.2.1 Creating the Watershed File for WATFLOOD

1. Open Green Kenue & make it full screen.
    a. Import the **Goetiff** file 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 **thm** file in your Green Kenue directory (for me, its C:\Program Files\CHC\GreenKenue\Templates\GeoTIFF)
c. In the workspace, double click on the Geotiff item and,
    i. in the Classes tab, choose custom theme and select the **trca** from the list (it should appear if the file is in the right directory - you may have to restart Green Kenue).
    ii. Also check Show Legend and enlarge it in the view.
d. Import the DEM and drag into 2D view. Various formats are supported e.g. ArcINFO Grid (ASCII); DTED or CDED DEM; Surfer Grid. Or load GK supported files e.g. xyz, r2s. For the Don River: ArcINFO Grid (ASCII) **trca_dem.asc**
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 \watflood\trca – give it a name e.g. **trca** (KENUEWorkSpace)
g. Other GK tricks:
    i. Go to File → Base Maps → 1:1,000,000 →SubSub Drainage Basins DblClk
    ii. Go to File → Base Maps → 1:1,000,000 →Cities DblClk
    iii. Click on Cities and make characters **bold** & 16 pt.

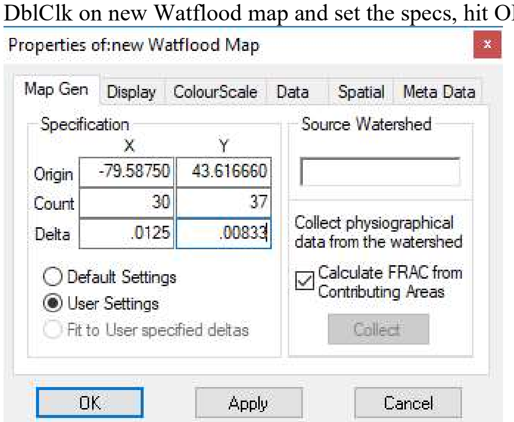
2. Creating a New Watershed Object. **P. 118 Green Kenue manual**.
    a. Remove the land cover map from the 2D view (just right click on the name and make it invisible)
    b. Assign projection attributes to DEM. Right click in **trca_dem** and set projection = LatLong & Ellipsoid = NAD83
    c. Set the colour scale for the DEM: double click on the file name & click on ColorScale
        i. Set min = 70 (lowest elevation at the river outlets)
        ii. Interval = 5
        iii. Levels = 80 (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 **\watflood\trca** as **trca.ews**
    d. Create a new watershed object:
        i. File → New → watershed ↵
        ii. Drag the **trca dem** 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 will now be 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 in the Display window, make the point size 1 and the line width 2. Apply & OK if you like it.
        vi. Bring in some features: Base Maps → 1:1,000,000 → Rivers and lakes and check to see that GK has properly delineated the rivers.
        vii. File → open Watflood\trca\strfw\WSC_data\FavHydatStations.PT2 This fle is produced by WSC HYDAT by selecting all the 02HC stations as Favourite Stations.
        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 \watflood\trca.ews (**KENUEW**ork**S**pace). Give the New Watershed a name trca.wsd

e. Delineate watershed(s) for the WATFLOOD model – one for each streamflow gauge
   i. Zoom in on the Don River outlet & Left click in the line segment, then right click & add basin. Call it Don and hit OK
   ii. Remove the default basin = basin 1 < important!
   iii. Save your workspace in \watflood\trca\trca.ews Answer yes to saving the new watershed object if asked.
   iv. Zoom in or out to have the watershed fill the view.
   v. Click on “Don” and change the colour to black.

3. Creating a new WATFLOOD map file **P. 155 Green Kenue Manual**

a. Generate map file spatial attributes
   i. File → New → Watflood Map
   ii. Drag the trca watershed object into the new Watflood map
   iii. DblClk on new Watflood map and set the specs, hit OK when done:



Note: This is very tricky. These numbers were chosen so the cells will be almost square and the cell boundaries coincide witht eh view grid. GK can do a default but it will make you dizzy eventually and the grids will not be square.

   iv. Right click on new Watflood map, click on Calculate Frac & hit collect data from watershed.
   v. Save the new_watflood file don.map: File → Save copy as ***trca*** → save (note: make a new folder “basin” and save trca.map in it.)
   vi. Drag **trca** into the 2D view & drag basins & channels & reservoir_location over top.
   vii. Right click on **trca.map** and click on spatial. Assign the projection (LatLong) and Ellipsoid (NAD83) (It doesn’t hurt to make a backup copy of the map file incase something goes wrong with the file in the next steps)
   viii. Right click in don (Channel Elevation)
      1. Make it transparent, show drainage directions & check Show Cell Labels. Drainage directions and cell elevations can be edited to change the flow path if rivers are not properly followed.

2. Click on the colour scale & make it the same as for the DEM: min = 70; Intvl = 5; levels = 80 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
3. 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:

x. Double click on **trca** & 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. 162 Green Kenue manual**.

xi. Dblclk on any grid and Edit Selected Cell. There you can see & edit any value assigned by GK

xii. Save the DEM in the **watflood\tca\basin** directory as an GK format r2s file for use later: click on DEM, then File → Save copy as **DEM** → save

xiii. Open the DEM.r2s file in GK and right click. In Spatial, Assign Projection = LatLong & Elipsoid = NAD83

xiv. Save DEM.r2s

b. Adding land cover information to the map file.

i. **Follow the directions in the Green Kenue manual in Section 2.4.4.5.2 Mapping Land Use Data to the Land Classes.** The **trca** land cover map is already in your workspace.

ii. Edit the class names in the properties dialogue box for the land cover map and save the theme with the name of your watershed. This will create a thm file called: (Done for you already)

C:\Program Files\CHC\GreenKenue64\Templates\GeoTIFF\trca.thm

```
# CLASSIFICATION THEME FILE
# Original name trca
# INDEX   COLOUR   TEXT
:CLASS 2 0xff004000 Rock-2
:CLASS 5 0xff0b0b0b class-5
:CLASS 6 0xff80ffff Beach-6
:CLASS 10 0xff80ffff Sand-10
:CLASS 20 0xffffff80 GrassPrairy-20
:CLASS 22 0xffffff80 GrassWoodland-22
:CLASS 27 0xff00ff00 ForestMixed-27
:CLASS 28 0xff408000 Coniferous-28
:CLASS 29 0xff00ff00 MixedForest-29
:CLASS 30 0xff808000 Deciduous-36
:CLASS 36 0xff747474 ForesPlantations-63
:CLASS 37 0xff808080 Hedgerows-37
:CLASS 42 0xff0000ff PavedRoads-42
:CLASS 43 0xff80ffff Quarries-43
:CLASS 44 0xff80ff80 Pervious-44
:CLASS 45 0xff0000ff Impervious-45
:CLASS 50 0xff004080 Swamp-50
:CLASS 55 0xff0080ff Fen-55
:CLASS 59 0xff004080 Bog-59
:CLASS 63 0xff004080 Marsh-63
```

```
:CLASS 66 0xffff0000 Water-66
:CLASS 99 0xffc0c0c0 Undifferentiated-99
:CLASS 127 0xffc080ff Class 127
```

iii. Collect the land cover data from the geoTIFF:
   1. Right click on the **trca.map** file and select **Map Land Use Data from GeoTIFF in the shortcut menu**
   2. Dblclk in **trca.map** and select **Meta Data;** then set the % impervious area IMPR if the "URBAN" class in the GeoTIFF includes both previous and impervious areas. Usually 33 is a good start but can be adjusted later if necessary – i.e. if there is not enough or too much runoff in the urban part of a watershed.

iv. Click onthe trca.map file and Save copy as **trca.map**

v. Save your workspace in **watflood\trca\trca.ews**

c. Create the watershed **basin\trca_shd.r2c** file
   i. Open a DOS window Run cmd
   ii. Go to whatever drive Watflood\trca is on dr:↵
   iii. Cd \watflood\trca\basin↵
   iv. Run the program bsn64x.exe: bsn64x ↵ **(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.

Interactions are highlighted

```
H:\watflood\TRCA\basin>bsn64x
 ********************************************************
 *                                                      *
 *                  WATFLOOD (TM)                       *
 *                                                      *
 *     Program BSN Version 10.9     Nov. 23, 2015       *
 *               Revised  Sep. 16, 2016                 *
 *                                                      *
 *           (c) N. Kouwen, 1972-2016                   *
 *                                                      *
 ********************************************************

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

 VERY IMPORTANT CHANGES:

 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

 Program = modified to allow for non-contributing areas
 The file nca.r2s is required - see WATFLOOD manual

 Program = modified to allow for mean & max grid elev`s
 The file dem.r2s is required - see WATFLOOD manual

Hit enter to continue - Ctrl C to abort


 bsn_responses.txt  NOT found
```

```
 Please create a new file by answering the following:
 Opened bsn_responses.txt

 Enter the basin (map) file name:
trca.map
 Enter the parameter (par) file name ONLY
 if you need a bsnm_par.r2c file for WATROUTE
 other wise, enter:    na
na

 Enter your name or initials
nk
 Once you have a shd file for the whole domain
 you can extract sub-watersheds to run on their own
 I.e. you can remove downstream grids from the modelling
 Load the shd file for the whole domain
 into GreenKenue and note the rank(s)
 of the location(s) where you would like an outlet -
 normally at streamflow locations but not necessarily so
 Enter the number of sub-watersheds
 (to NOT remove downstream gridsenter 0)
0

 Enter the outlet grid rank(s) you would
 like included in the simulation
 These should NOT be the receiving grids!!!!

 Please enter the rank of           0  outlet(s):

 example:  1482
 example:  1043
 example:  1899

 Similarly,
 Upstream watersheds can be removed from the modelling
 Enter the number of inlet grids
 To use the all upstream watershes enter 0
 OR enter the no of grids where upstream area is NOT
 to be modelled:
0

 Enter the inlet grid rank(s) you would
 like to use for the simulation
 These would normally be streamgage locations
 where you could add inflow to be routed downstream
 using either the str or div files

 Please enter the rank of           0  inlet(s)

  example:   482
  example:    43
  example:    99


 Enter the split: % of wetland coupled to channel
 only if you have two identical sets of wetland
 land cover grids as 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

  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
 Do you want to incorporate
```

```
 non-contributing areas (nca)   y/n?
 To incorporate nca`s an nca.r2s file is required

n
 non-contributing areas will not be incorporated
 in the shed file

 Do you want to create  new
 elev_means.r2c & elev_max.r2c files   y/n?
 To create these files, a dem.2rs file is required
 which can be created in GK by saving the dem
 as an r2s file

y

 A DEM file has been found
 so mean grid elevations will be calculated
 and written to a files: elev_means.r2c
 These mean elevations will be used for lapse rate
 adjustments to temperature & precip if left in
 the basin directory


 A new (Ver. 4) bsn_resonse.txt file will be created
 Any old file will be overwritted with:

version_#                     4
map_file_name                 trca.map
par_file_name                 na
initial                       nk
no_outlets_&_locations        0
no_inlets_&_locations         0
wetland_split_%                  0.0000000
split_type_1~2
min_allowed_slope                0.0001000
adjust_frac_y|n               n
nca_choice_1|2                0
%_to_use(choice_1)               0.0000000
nca_classes(1-3)(choice_2)    0
create_max|mean.r2c_y~n       y


 If you wish to keep the existing bsn_responses.txt,
 file, please move it now
 Waiting  .......  hit return to continue


 New bsn_response.txt file written
 bsnm_par.r2c not wanted for watroute

 Ensim compatible free format map file expected

:
 projection=LATLONG
 datum1=GRS80
 zone=unknown
 xorigin=  -79.58750
 yorigin=   43.61666
 xcount=          30
 ycount=          37
 xdelta=  1.2500000E-02
 ydelta=  8.3330004E-03
 cintv=   1.000000
 aimpr=  0.0000000E+00
 antype=   20.00000
 elvconv=   1.000000
 Number of classes now includes the impervious class
 Number of classes stipulated =           20
 Is this correct?

 Hit enter to continue

 before allocating area17
```

```
area17 allocated

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


A DEM file has been found
so mean grid elevations will be calculated
and written to a files: elev_means.r2c
These mean elevations will be used for lapse rate
adjustments to temperature & precip if left in
the basin directory

reading dem.r2s file
opened unit =          99  filename =dem.r2s
######################################################################
:FileType r2s  ASCII  EnSim 1.0
# National Research Council Canada (c) 1998-2014
# DataType                 2D Rect Scalar
#
:Application              GreenKenue
:Version                  3.4.27
:WrittenBy                Nick
:CreationDate             Sun, Nov 19, 2017 04:49 PM
#
#---------------------------------------------------------------------
:SourceFile   trca_dem_new.asc
#
#
:Projection LatLong
:Ellipsoid GRS80
#
:xOrigin -80.267500
:yOrigin 43.394167
#
:xCount 2139
:yCount 1000
:xDelta  0.000833333333
:yDelta  0.000833333333
:Angle 0.000000
#
:endHeader

Values found:
projection=LATLONG
datum1=GRS80
zone=           0
xorigin=  -80.26750
yorigin=   43.39417
xcount=        2139
ycount=        1000
xdelta=  8.3333335E-04
ydelta=  8.3333335E-04

last value read in filename1(1:40)

 1.2500000E-02  8.3333335E-04  8.3330004E-03  8.3333335E-04
no points in the dem.r2s file:         175
doing row         100 /        1000
doing row         200 /        1000
doing row         300 /        1000
doing row         400 /        1000
doing row         500 /        1000
doing row         600 /        1000
doing row         700 /        1000
doing row         800 /        1000
doing row         900 /        1000
doing row        1000 /        1000
calculating means
Done calculating mean elevations


Arrange grids for // computing y/n ?
```

```
n
 WARNING: missing blank edge(s) - crash possible
         30          37
 No of river classes found in the map file =            1
 This should match the number specified in the par file

 ntype=          19
 Gone to fetch
 reachcount=           0  in ftch
 Back from fetch

 Reading the class names as listed in the attribute list
 of the map file:
 map file class name:            1 Rock-2
 map file class name:            2 Beach-6
 map file class name:            3 GrassWoodland-22
 map file class name:            4 ForestMixed-27
 map file class name:            5 Coniferous-28
 map file class name:            6 MixedForest-29
 map file class name:            7 Deciduous-36
 map file class name:            8 ForesPlantations-63
 map file class name:            9 Hedgerows-37
 map file class name:           10 PavedRoads-42
 map file class name:           11 Quarries-43
 map file class name:           12 Pervious-44
 map file class name:           13 Impervious-45
 map file class name:           14 Swamp-50
 map file class name:           15 Fen-55
 map file class name:           16 Bog-59
 map file class name:           17 Marsh-63
 map file class name:           18 Water-66
 map file class name:           19 Undifferentiated-99
 map file class name:           20 Class
 Finished reading the class list in the map file
 please check this table carefully
 Make sure the numbers march up with the table in the
 class_combine.csv file
 Warning: / are read as commas so change to _
 ********************************************
waiting.....


 End of map file reached and classes combined

 Note:    impervious area > 0 in the header
          0 % of the impervious class (urban)
 has been subtracted from class          20
 and added to class 1
 Class 1 should be a land cover compatible with
 the pervious areas in urban areas (eg. grass)

  frame=            1  written to bsn_info
  frame=            2  written to bsn_info
.
.
.
  frame=           20  written to bsn_info
 A grid with 100% water has not been assigned
 a reach number. Program will crash if you try
 to use a resume file
Hit enter to continue but you have been warned

 grid,row,col           1          37           9
 grid,row,col           7          34           5
          2  grid(s) with 100% water has(ve)
  not been assigned
 a reach number(s). The water class has been changed
 99% and class 1 has been changed to 1%
Hit enter to continue but you have been warned AGAIN!

Class
 ios=          -1
```

```
  No bankfull values found
  Default assumed

 frac_2d(    2   19)=     0.000 - please check
   Basin # not coded @ grid #   453 @      2    19 elv= 70.995
# contours not coded @ grid #   453 @      2    19 elv= 70.995
# channels not coded @ grid #   453 @      2    19 elv= 70.995
       next grid = 0 @ grid #   453 @      2    19 elv= 70.995
Possible cause: wrong drainage direction
Errors OK if last receiving grid !!!!!!!!!!!!!


Please see new_format.shd file for -ve slope location
 receiving grid higher in grid    2   19  453 elv=    70.995

 These can be fatal errors  <<<<<<<<<<<<<<<<<<<<<<<<<<<
 Please correct the map file to elliminate these errors

Hit enter to continue

 ireach_2d_max=           0
:xCount                       30
:yCount                       37
 na,naa/         453         452
 2nd time
 No. of rows removed north side =       0
 No. of rows removed south side =       0
 No. of columns removed west side =       0
 No. of columns removed east side =       0

  frame=            1  written
  frame=            2  written
  frame=            4  written

 -ve slopes found
 You must fix the drainage directions &/or elevations
 to fix the problem. However, you can allow bsn.exe to
 set these as the min. slope
 Would you like to proceed this way
 and accept responsibility  y/n
y

 -ve slopes eliminated
  frame=            5  written
  frame=            6  written
  frame=            7  written
.
.
.
  frame=           38  written
# Undifferentiated-99
  frame=           39  written
# Class
  frame=           40  written
 new_shd.r2c written

 Closed unit           99  Filename=
 elv_means.r2c                                                   fr #
           1           1
 elv_means.r2c written
 Closed unit           99  Filename=
 elv_max.r2c                                                     fr #
           1           1
 elv_max.r2c written
 NCA class count           0
waiting

 wfo_spec.new  written
 new.pdl  written

 If you have gotten this far, you probably will have
 a good shd file - i.e. there will be a shd file
```

```
The rest of the program tends to work only if you have
a single watershed outlet



No. of errors found in the map file =           1
No. of errors found in the map file =           1
No. of errors found in the map file =           1

 ********* please check the bsn_info.txt file **********
 ********* please check the bsn_info.txt file **********
 ********* please check the bsn_info.txt file **********

Normal ending
```

d. Load the file **New_shd.r2c** into GK & have a look
e. Save as **trca_shd.r2c** in the **\watflood\basin** folder
f. Save your workspace
g. Check some of the data: Dblclk on any grid and then right click, then edit. You will see all the attributes for that grid.

4. Setup event for WATFLOOD
   i. Copy additional folders from the cd in Watflood\trca to Watflood\trca on your pc. (These are rainfall, temperature, initial snow and moisture and streamflow files as well as event files.
   ii. Copy & rename watflood\basin**wfo_spec.new** to watflood\trca**wfo_spec.txt** e.g. in DOS: in watflood\trca
   `copy basin\wfo_spec.new wfo_spec.txt`
   iii. Rename watflood\basin**pdl.new** to watflood\trca**pdl.txt** e.g. in DOS: in watflood\trca\basin
   `ren pdl.new pdl.txt`
   iv. Edit the watflood\trca\wfo_spec.txt file and set the reporting time step to 01. This file is formated so do not change the spacing!
   v. In a Windows window, change the properties of the files in **watflood\trca*** 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)
   vi. In a dos window in folder watflood\trca, change the event: copy event\yyyy.evt event\event.evt (yyyy will be announced)

5. **Other files needed to run CHARM:**
   a. Init. SWE – snow1\yyyymmdd_crs.pt2
   b. Init. soild moisture – moist\yyyymmdd_psm.pt2
   c. strfw\yyyymmdd_str.tb0
   d. Point precip – raing\yyyymmdd_rag.tb0
   e. Point Temp. – tempg\yyyymmdd_tag.tb0
   f. Reservoir releases (optional) – resrl\yyyymmdd_rel.tb0
   g. Parameter file – basin\trca_par.csv
      i.
      ii. Pre-processing: Distribute data from point form to gridded form :
         1. distribute snow **snw64** ↵
         2. distribute moisture **moist64** ↵
         3. distribute rainfall **ragmet64x** ↵
         4. distribute temperature **tmp64x** ↵

h. 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 in Green Kenue. Probably you would like:

```
  3.0 Version Number
  132 AttributeCount
6 ReportingTimeStep Hours
    0 Start Reporting Time for Green Kenue (hr)
    0 End Reporting Time for Green Kenue (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. Optional: You can edit the outfiles.new file & to change the path of the output files (use replace) and save as outfiles.txt

6. Run the model **charm64x** ↵ or if you did not set your path: **c:\.......\watflood\charm64x** ↵

7. **Editing the map file: add lakes**
   i. Make **new_shd** invisible
   ii. Open **trca.map** (if not present) in the basin folder and drag into 2D view
   iii. Make Reach Number the active layer and make display wireframe/monochrome black; check Show Cell Labels (check box, check bold & set text size = 16)
   iv. Get rid of the grid lines in the 2D View (uncheck the box)
   v. Make the DEM invisible (right click on DEM)
   vi. Make the land cover map visisble and zoom in on the G.R. Lord reservoir (just above the Downsview airport)
   vii. In 2D view be sure **trca.map** is the top layer over the land cover map.
   viii. Mark all grids that are part of the lake – it doesn't depend on how much of the grid is in the lake. Hold the shift key & Dblclk on each grid, then right click & Edit Selected Cell(s). Mark them as 1.
   ix. Fix the drainage directions so the arrows follow the lake. Elevations must decrease in the downstream direction. Make the view show Channel Elevation. Edit the drainage directions. We're lucky as the elevations don't need to be fixed!
   x. Obtain the reservoir outlet – must be inside the grid of the last reach numberd cell. -79.464E 43.771N
   xi. Save the **trca map** file
   xii. In the trca\basin folder, run bsn.exe as before & if ok, change the name of the file new_shd.r2c trca_shd.r2c
   xiii. Rename of the **res_rl** folder to **resrl**
   xiv. Run CHARM64x & look at results. Compare with previous run without lake(s).

18.3 Post-processing with Green Kenue

8. **Run 1 year of data for the TRCA**
   a. Debugging.
      i. In GK load the file **results\watflood.wfo**
      ii. Drag **Computed Grid Outflow** into the 2D view.
      iii. Right click on **Computed Grid Outflow** in the 2D view & activate "animate"
      iv. Double Click on **Computed Grid Outflow** -> colour scale and set NLOG & 80 levels & Apply
      v. Fix the colour scale
      vi. Check off **Legend; Dblclk on it and move off the work ara & enlarge.**
      vii. Drag **Observed Grid Outflow** into the 2D view and move the other layers back on top.
      viii. (Shows only at flow stations).
      ix. Drag the **trca.map** file into the 2D view and make it a wireframe with directions visible and change colour to monochrome black.

x. Extract some time series for points along the river going upstream from the grids with flow stations. First click on Computed grid Outflow in the workspace, then the grid.
xi. Do the dsame for observed flows.
xii. Open a 1D view and drag the observed & computed grid outflow time series for the downstream station into the 1D view
xiii. Fix the scale: hold left click & drag graph; use thumb wheel to zoom in and out
xiv. Synchronize animation: Clicklick on the 1D window, then **View** and then **SelectSync View** and select 2D view & hit **OK**
xv. Try the play, pause, rewind buttons in the animation toolbar
xvi. Animate to the peak flow time
xvii. Look for discontinuity in the flows caused by a flat spot in the river – these would have to be fixed.

b. Sensitivity
i. Edit the **basin\trca.par** file and double the R2n value
ii. Run the model: **CHARM64X** ↵
iii. In Green Kenue, 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 the lowest flow station
v. Note that you can see a bit of damping
vi. Delete the first watflood.wfo file from the data items

c. Looking at snow water equivalent
i. Edit the event\event.evt file and add the line:
:grdflg y
ii. Edit the c:\spl\trca\wfo_spec.txt file and make the reporting time step = 24 and the end reporting time for Green Kenue = 0
iii. Run the model **SPL**
iv. In Green Kenue, while it's running, open the 5 ts3 files in the snow1 folder
v. Open the file results\swe.r2c – let Green Kenue 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.)

d. Fixing the model
i. Edit the basin\trca.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 SPL
iii. Open Open the file results\swe.r2c – let Green Kenue translate it to a binary file (again)

iv. Repeat vii to ix above – you see an earlier melt now
v. Edit the basin\trca.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 SPL
      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 trca.par by new.par
      viii. Run SPL
      ix. Compare with previous watflood.wfo file

19 INDEX

G

H

I

K

L

M

N

O

P

V

W