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:
Aug. 16, 2023

Copyright (C) by N. Kouwen, 1986 – 2022
(This manual may be reproduced whole or in part providing acknowledgements are given.)
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

WATFLOOD/CHARM is free software: you can redistribute it and/or modify it under the terms of the GNU Lesser General Public License as published by the Free Software Foundation, either version 3 of the License, or any later version.

WATFLOOD is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for more details.

DISCLAIMER

The WATFLOOD/CHARM software is furnished by N. Kouwen and the University of Waterloo and is accepted and used by the recipient upon the express understanding that N. Kouwen and the University of Waterloo make no warranties, either express or implied, concerning the accuracy, completeness, reliability, usability, performance, or fitness for any particular purpose or the information contained in this manual, to the software described in this manual, and to other material supplied in connection therewith. The material is provided "as is". The entire risk as to its quality and performance is with the user.

The forecasts produced by the WATFLOOD/CHARM software are for information and discussion purposes only and are not to be relied upon in any particular situation without the express written consent of N. Kouwen or the University of Waterloo.
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

## 1 WATFLOOD / CHARM USER’S MANUAL .......................................................... 1-13

### 1.1 Introduction ........................................................................................................... 1-13

### 1.2 Approach ..................................................................................................................... 1-13

### 1.3 Getting Started .......................................................................................................... 1-16

#### 1.3.1 Overview .............................................................................................................. 1-16

#### 1.3.2 Installation ............................................................................................................ 1-17

##### 1.3.2.1 Windows ............................................................................................................. 1-17

##### 1.3.2.2 DOS ...................................................................................................................... 1-17

##### 1.3.2.2.1 Windows 10 ........................................................................................................ 1-17

##### 1.3.2.2.2 Windows XP & 7 ................................................................................................ 1-17

#### 1.3.3 File Structure in WATFLOOD ............................................................................. 1-18

#### 1.3.4 Minimum File Requirements ............................................................................... 1-19

#### 1.3.5 File Naming Convention ..................................................................................... 1-20

#### 1.3.6 Green Kenue Compatibility ............................................................................... 1-21

#### 1.3.7 Event Configuration File .................................................................................... 1-21

##### 1.3.7.1 Example of an Event File .................................................................................... 1-22

##### 1.3.7.2 Meaning of the Flags in the Event File ................................................................. 1-24

##### 1.3.7.3 Multiple Events for Continuous Modelling (Chaining) ........................................ 1-27

##### 1.3.7.4 Creating Event Files ............................................................................................ 1-28

### 1.4 WATFLOOD Tutorial ............................................................................................ 1-30

#### 1.4.1 WATFLOOD for WINDOWS – Sadly, it’s Gone ..................................................... 1-30

#### 1.4.2 DOS (Disk Operating System) ............................................................................. 1-31

#### 1.4.3 Use Existing Event ............................................................................................... 1-32

#### 1.4.4 Create New Event ............................................................................................... 1-32

#### 1.4.5 Demonstration ..................................................................................................... 1-32

#### 1.4.6 Editing Files ......................................................................................................... 1-33

#### 1.4.7 Initiating Snow Accounting .................................................................................. 1-33

#### 1.4.8 Scale Factors ....................................................................................................... 1-33

### 1.5 WATFLOOD Programs – File Requirements ...................................................... 1-34

#### 1.5.1 Read CAPPI ([RADMET.exe] [inactive]) ............................................................... 1-34

#### 1.5.2 Adjust (or Calibrate) Radar Data ([CALMET.exe] [inactive]) .................................. 1-34

#### 1.5.3 Distribute Rainfall Data ([RAGMET.exe] [inactive]) ............................................. 1-34

#### 1.5.4 Distribute Snow Course Data ([SNW.exe]) ........................................................... 1-34

#### 1.5.5 Distribute Soil Moisture Data ([MOIST.exe]) ......................................................... 1-34

#### 1.5.6 Distribute Temperature Data ([TMP.exe]) ............................................................ 1-34

#### 1.5.7 Run CHARM (SPL) .............................................................................................. 1-34

#### 1.5.8 Single Event Mode ............................................................................................... 1-34
1. WATFLOOD / CHARM User’s Manual

1.5.9 Forecast without Optimization Mode ................................. 1-38
1.5.10 Forecast with Optimization Mode ................................. 1-38
1.5.11 Model Calibration Mode .............................................. 1-38
1.5.12 Debug Mode (iopt=0,1,2,...,99) ................................. 1-38
1.5.13 Forecast Mode without RADAR Image Scaling .............. 1-39
1.5.14 Forecast Mode with RADAR Image Scaling .................. 1-39
1.5.15 Stage Hydrographs (STGPLT) [provisional] ............... 1-39
1.5.16 Flow Animation in Green Kenue ................................. 1-40

1.6 Setting Up a New Event ..................................................... 1-41

1.7 Debugging CHARM .......................................................... 1-43
1.7.1 Common Problems ....................................................... 1-44

1.8 Output Files ................................................................. 1-47

1.9 Do’s and Don’ts ............................................................. 1-49
1.9.1 Do’s ................................................................. 1-49
1.9.2 Don’ts ............................................................. 1-50

1.10 Known Problems .......................................................... 1-51
1.11 Help (free for students – others: not so much) ................... 1-51

2 HYDROLOGICAL MODEL ................................................ 2-1

2.1 Introduction ................................................................. 2-1

2.2 Modeling Aspects .......................................................... 2-1
2.2.1 Surface Storage ......................................................... 2-2
2.2.2 Infiltration ............................................................... 2-3
2.2.3 Initial Soil Moisture ................................................... 2-4

2.3 Potential Evapotranspiration ............................................ 2-5
2.3.1 Priestley-Taylor Equation .......................................... 2-6
2.3.2 Hargreaves Equation ................................................ 2-7

2.4 Actual Evapotranspiration ................................................ 2-8
2.4.1 Soil Moisture Coefficient ............................................ 2-9
2.4.2 Soil Temperature Coefficient ...................................... 2-9
2.4.3 Forest Vegetation Coefficient (FTALL) ...................... 2-10
2.4.4 Calculating AET from PET – Land Cover Classes ........ 2-10
2.4.5 Calculating AET – Water Class (Lakes) ....................... 2-11

2.5 Interception ................................................................. 2-11

2.6 Interflow ................................................................. 2-13

2.7 UZ to LZ Drainage (or Groundwater Recharge) ................. 2-14

2.8 Overland Flow ............................................................. 2-15
1. WATFLOOD / CHARM User’s Manual

2. Base Flow ................................................................................................................. 2-15
2.10 Total Runoff ........................................................................................................... 2-16
2.11 Routing Model ....................................................................................................... 2-16
  2.11.1 Main Channel Flow .......................................................................................... 2-17
  2.11.2 Channel Flow and Overbank Flow .................................................................. 2-18
  2.11.3 Lake Effect on Routing .................................................................................... 2-18
  2.11.4 Bankfull Area – Drainage Area Relationship .................................................. 2-18
2.12 Wetland Routing (Bank Storage Model) ................................................................. 2-20
  2.12.1 Wetlands – Fens and Bogs .............................................................................. 2-21
2.13 Lake Routing .......................................................................................................... 2-21
  2.13.1 Reservoirs and Large Lakes .......................................................................... 2-21
  2.13.2 Instream Lakes (Numerous) [Revised Feb. 2018] ........................................... 2-22
2.15 Snowmelt Model .................................................................................................... 2-26
  2.15.1 Temperature Index Model .............................................................................. 2-26
  2.15.2 Radiation-Temperature Index Algorithm ......................................................... 2-28

3 WATERSHED DATA REQUIREMENTS .................................................................... 3-1
3.1 Georeferencing Requirements ................................................................................. 3-1
3.2 Setting Up a New Watershed .................................................................................. 3-1
  3.2.1 Mandatory Files (Summary) ............................................................................ 3-1
  3.2.2 Steps to Set Up a New Watershed ..................................................................... 3-2
  3.2.3 Watershed Data .................................................................................................. 3-3
3.3 Basin File ................................................................................................................. 3-5
  3.3.1 Entering Watershed Coordinates ..................................................................... 3-5
    3.3.1.1 Impervious area ............................................................................................. 3-7
    3.3.2 Data Separators (Headings) ............................................................................ 3-7
3.4 Map File Data Fields ............................................................................................... 3-7
  3.4.1 River Invert Elevation (ELV) ............................................................................. 3-7
  3.4.2 Grid Drainage Area (FRACT) ............................................................................ 3-8
  3.4.3 Drainage Direction (S) ...................................................................................... 3-8
  3.4.4 River Classification (IBN) ................................................................................ 3-9
  3.4.5 Contour Density (IROUGH) ............................................................................. 3-9
  3.4.6 Channel Density (ICHNL) ................................................................................ 3-10
  3.4.7 Routing Reach Number (IREACH) ................................................................. 3-11
  3.4.8 Land Cover Classes (IAK) .............................................................................. 3-11
3.5 Converting the map file to a shd file [new heading] .............................................. 3-14
  3.5.1 Wetlands – Splitting Bogs and Fens ................................................................ 3-14
3.5.2 Combining and Reordering Classes ................................................................. 3-15
3.5.3 Non-Contributing Areas ....................................................................................... 3-17
3.5.4 Fetch (8 Directions) [new] ....................................................................................... 3-19
3.5.5 Basin File (BSNM_shd.r2c) for UTM Coordinates ............................................. 3-20
3.5.6 Basin File (SHD) for UTM Coordinates (OLD FORMAT) .................................. 3-27
3.5.7 Basin File for Geographical Coordinates (LATLONG) ....................................... 3-30
3.6 Setting up Sub-watersheds [new] ............................................................................. 3-31
3.6.1 Creating a Sub-watershed (SUBBSNM_shd.r2c) [new] ........................................ 3-31
3.6.2 Creating Reduced Domain Precipitation and Temperature Files [new] ............. 3-32
3.7 Additional Required Files ......................................................................................... 3-33
3.7.1 BSNM.pdl File for UTM Coordinates ................................................................ 3-33
3.7.1.1 Example of a *.pdl File Created by BSN.exe ............................................. 3-33
3.7.1.2 Example of a User Modified *.pdl File .................................................. 3-34
3.8 Additional Optional Files [new 2012] ..................................................................... 3-35
3.8.1 Stage Hydrographs ............................................................................................ 3-35
3.8.2 Storage-Discharge Curves for Lakes and Reservoirs ........................................ 3-35
3.8.3 Initial Lake Levels [new 2015] ............................................................................ 3-36
3.8.4 Reservoir Operating Rules (NEW 2017) ............................................................ 3-38
3.8.5 Recorded Lake Levels ....................................................................................... 3-40
3.8.6 SWE updating .................................................................................................... 3-41
3.8.7 Parameter Files ................................................................................................. 3-42
3.8.8 calmet.par File [not supported] ....................................................................... 3-42
3.8.9 Mean and Max Grid Elevations for Lapse Rate Applications [new] ................. 3-43
3.9 Watershed Data Summary ....................................................................................... 3-43
4 MODEL PARAMETERS AND OPTIMIZATION ................................................................. 4-1
4.1 Parameter File ........................................................................................................ 4-1
4.2 General Parameters in the Parameter File ............................................................. 4-9
4.2.1 Example of Global Parameters ......................................................................... 4-11
4.2.2 River and Basin Parameters ............................................................................. 4-12
4.2.3 Hydrological (Surface) Parameters ................................................................. 4-12
4.2.4 Snowmelt Parameters ..................................................................................... 4-14
4.2.5 Monthly ET Data ............................................................................................ 4-14
4.2.6 Interception Parameters .................................................................................. 4-15
4.3 Monthly Climate Normals ..................................................................................... 4-15
4.4 Snow Cover Depletion Curve (SDC) ................................................................. 4-15
4.5 Optimization ......................................................................................................... 4-16
4.5.1 Hints for Successful Optimization ................................................................. 4-17
5.1 Initial Snow Cover .............................................................. 5-1
  5.1.1 Point Snow Water Equivalent Files (*_crs.pt2) .................. 5-1
  5.1.2 Gridded Snow Water Equivalent Files (*_swe.r2c) ............ 5-3

5.2 Initial Soil Moisture ........................................................... 5-4
  5.2.1 Point Soil Moisture Files (*_psm.pt2) ............................... 5-4

5.3 Optimization – Dynamically Dimensioned Search (DDS) ....... 4-21
  5.3.1 Specifying Parameters for Optimization ......................... 4-21
  5.3.2 Watflood_batch.bat ..................................................... 4-24
  5.3.3 Function_out.txt (Objective Function) .......................... 4-25
  5.3.4 Mean Observed Flows .................................................. 4-26
  5.3.5 DDS Process .............................................................. 4-26
  5.3.6 Monitoring a DDS Run ................................................ 4-28
  5.3.7 Speeding up DDS ....................................................... 4-29
  5.3.8 Analysis of Multiple Trials ........................................... 4-30
  5.3.9 Analysis of Multiple Trials – Part 2 ............................... 4-30
  5.3.10 Analysis of Multiple Trials – Part 3 .............................. 4-30

5.4 Ostrich (NEW 2022) ........................................................... 4-31
  5.4.1 Ost-CHARM.bat ......................................................... 4-32
  5.4.2 Resr\yyyyymmdd_reltb0.csv ........................................... 4-33
  5.4.3 Resr\yyyyymmdd_reltb0.tpl ........................................... 4-33
  5.4.4 Ostin.txt ................................................................. 4-33
  5.4.5 Ostrich error function .................................................. 4-34
  5.4.6 OstrichMPI - //processing (new 2022-05-15) .................. 4-34
  5.4.7 OstrichMPI setup files ............................................... 4-35
  5.4.8 go.bat ...................................................................... 4-35
  5.4.9 Example bsnm_par.csv file ......................................... 4-35
  5.4.10 Example of corresponding bsnm_par.tpl file ................. 4-36
  5.4.11 Example of the ostin.txt file ...................................... 4-36
  5.4.12 Example ost-watflood.bat ......................................... 4-39

5.5 Optimization Hints .......................................................... 4-40
  5.5.1 Pattern Search [currently not operational] ......................... 4-42
  5.5.2 Optimization for the BOREAS Southern Study Area (SSA) .... 4-43

5.6 Troubleshooting .............................................................. 4-46

5.7 Parameter Sensitivity Analysis (beta version) ....................... 4-49

5. MODEL INITIALIZATION .................................................. 5-1
1. WATFLOOD / CHARM User’s Manual

| 5.2.2 | Gridded Soil Moisture File (*_gsm.r2c) | 5-5 |
| 5.3 | Initial Channel Storage | 5-6 |
| 5.4 | Initial Lower Zone Storage | 5-7 |
| 5.5 | Model Initialization using ‘Resume’ | 5-7 |
| 5.6 | State Variable Updating ‘on the Fly’ | 5-8 |
| 5.6.1 | SWE Updating | 5-8 |
| 5.6.2 | Flow Updating | 5-8 |

6  RAINFALL DATA PROCESSING ................................................................. 6-1

| 6.1 | Introduction | 6-1 |
| 6.1.1 | Rain Gauge Data File (*_RAG.tb0) | 6-2 |
| 6.1.2 | Distribution of Gauge Precipitation | 6-4 |
| 6.1.3 | Modified Distribution of Precipitation | 6-4 |
| 6.1.4 | Precipitation Lapse Rate (RLAPSE) | 6-5 |
| 6.2 | Disaggregation of Rainfall (smrflg=y) | 6-6 |
| 6.3 | Precipitation Data (*_met.r2c) - Input to SPL | 6-6 |
| 6.4 | Climatic Precipitation Data [NEW] | 6-8 |

7  TEMPERATURE DATA................................................................................. 7-1

| 7.1 | Example of Point Temperature File: | 7-1 |
| 7.2 | Modified Distribution of Temperature | 7-2 |
| 7.3 | Temperature Lapse Rate (TLAPSE) [new] | 7-3 |
| 7.4 | Example of a Gridded Temperature File temp\*_tem.r2c | 7-3 |
| 7.5 | Daily Temperature Differences (for ET calculations) [new] | 7-4 |
| 7.6 | Climatic Temperature data Data [NEW] | 7-5 |

8  FLOW DATA............................................................................................ 8-1

| 8.1 | Streamflow Files | 8-1 |
| 8.1.1 | Example Streamflow File | 8-1 |
| 8.1.2 | Observed Stage Input [under construction] | 8-3 |
| 8.1.3 | Flow Station Area Check | 8-4 |
| 8.2 | Reservoir Release Files | 8-4 |
| 8.2.1 | Natural Lake and Uncontrolled Reservoirs | 8-6 |
| 8.2.2 | Initial Reservoir Levels | 8-7 |
| 8.2.3 | Natural Flows | 8-8 |
| 8.2.4 | Correcting Reservoir Releases [NEW] | 8-9 |
| 8.3 | Reservoir/Lake Routing with Target Water levels | 8-9 |
8.4 Reservoir Inflow Files
8.5 Diversions

9 WIND SPEED AND DIRECTION DATA
9.1 Example of Point Wind Speed File
9.2 Example of Point Wind Direction File
9.3 Example of Gridded Wind Speed File
9.4 Example of Gridded Wind Direction File

10 RADIATION DATA

11 OUTPUT FILES
11.1 Plotting Hydrographs (Observed versus Computed)
11.2 Spl.txt File - IOPT=1
11.2.1 File Names from the Event File
11.2.2 Land Cover by Sub-basin
11.2.3 Information on Flags
11.2.4 Reservoir Locations and Operating Rules
11.2.5 Information for Each Grid
11.2.6 Summary for Grids
11.2.7 Cumulative Statistics for Each Event
11.2.8 Repeated for Each Event
11.3 rff*.txt Files
11.4 outfiles.txt File
11.5 dds\dds_log.txt, precip.txt File

12 WATROUTE
12.1 How to Use WATROUTE
12.2 Runoff, Recharge, and Leakage File Creation with WATFLOOD
12.3 Recharge Files for MODFLOW
12.4 WATROUTE Output
12.5 Combining WATFLOOD Runoff and MODFLOW Leakage

13 INTERFACING WITH GREEN KENUE
13.1 How to Debug with Green Kenue

14 WATFLOOD OPTIONS
14.1 Precipitation Adjustment File (PAF)
TRADEMARKS

WATFLOOD is a registered trademark of N. Kouwen.

IBM is a registered trademark of International Business Machines Inc.

Intel is a registered trademark of Intel Corporation.

MS is a registered trademark of Microsoft Corporation.

GRAPHER is a registered trademark of Golden Software.

Use of the above terms will not be further acknowledged further in this manual.

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 Shieau 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 Souls. 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.
August 16, 2023
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 km² 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 of the area is grassed and the remaining 1/3 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 (Terstiep 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 Levesly 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 km² 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 1.2 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.
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.

Figure 1.2 - Schematic of the GRU pixel grouping model and channel routing scheme.
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 1.3.3.

**NOTE:** When extracting files in Windows, usually a new folder is created and files do not end up with the same path. You may (will) need to move files to get them in the path as given in Section 1.3.3.

**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
```
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**: snow\19930101_crs.pt2
- **griddedinitsnowweq**: snow\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
g10k 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.

```plaintext
#
:filetype .evt
:fileversionno 9.9
:year 1993
:month 01
:day 01
:hour 0
#
:snwflg y
:sedflg n
:mapflg y
:smflg y
:vapflg n
:tbcflg n
:resinflg n
:resflg n
:contflg n
:routeflg n
:crseflg n
:kenueflg n
:picflg n
:wetflg y
:modelflg n
:shdflg n
:trcflg n
:frcflg n
:infflg n
:hdrflg n
:igrdflg n
:nudgeflg n
:setflg n
```
1. WATFLOOD / CHARM User's Manual | 1-23

_REALFLOW/divertflg                    n
_REALFLOW/pafflg                       n
_REALFLOW/fliflg                       n
_REALFLOW/lakeflg                      n
_REALFLOW/iceflg                       n
# _REALFLOW/intsoilmoisture              0.25 0.25 0.25 0.25 0.25
# _REALFLOW/rainconvfactor                1.00
# _REALFLOW/reventprecipscalefactor       1.00
# _REALFLOW/precipscalefactor              0.00
# _REALFLOW/reventsnowscalefactor          0.00
# _REALFLOW/snowscalefactor               0.00
# _REALFLOW/reventtempscalefactor          0.00
# _REALFLOW/tempscalefactor               0.00
# _REALFLOW/disaggregate                  1.00
# _REALFLOW/hoursraindata                  744
# _REALFLOW/hoursflowdata                  744
# _REALFLOW/deltat_report                  1
# _REALFLOW/basinfilename                basin\gr10k_shd.r2c
# _REALFLOW/parfilename                  basin\gr10k_par.csv
# _REALFLOW/channelparfile               basin\gr10k_ch_par.r2c
# _REALFLOW/pointdatalocations           basin\gr10k.pdl
# _REALFLOW/snowcoverdepletioncurve      basin\gr10k.sdc
# _REALFLOW/waterqualitydatafile         basin\gr10k.wqd
# _REALFLOW/pointsoilmoisture            moist\19930101_psm.pt2
# _REALFLOW/pointprecip                   raing\19930101_rag.tb0
# _REALFLOW/pointtemps                    tempg\19930101_tag.tb0
# _REALFLOW/pointnetradiation            tempr\19930101_tem.r2c
# _REALFLOW/pointshortwave               winds\19930101_spd.r2c
# _REALFLOW/pointlongwave                winds\19930101_dir.tb0
# _REALFLOW/pointatmpressure             winds\19930101_spd.r2c
# _REALFLOW/pointatmpressure             winds\19930101_spd.r2c
# _REALFLOW/pointstmpression              winds\19930101_spd.r2c
# _REALFLOW/pointdrain                   drain\19930101_drn.tb0
# _REALFLOW/pointdsnow                   dsnow\19930101_dsn.tb0
# _REALFLOW/streamflowdatafile           strfw\19930101_str.tb0
# _REALFLOW/reservoirreleasefile          resrl\19930101_rel.tb0
# _REALFLOW/reservoirinflowfile           resrl\19930101_rin.tb0
# _REALFLOW/diversionflowfile             diver\19930101_div.tb0
# _REALFLOW/observedlakelevel            level\19930101_lvl.tb0
# _REALFLOW/snowcoursefile               snow1\19930101_crs.pt2
# _REALFLOW/initlakelevel                level\19930101_lill.pt2
# _REALFLOW/observedlakelevel            level\19930101_lvl.tb0
# _REALFLOW/radarfile                    raduc\19930101.rad
# _REALFLOW/rawradarfile                 radar\19930101.scn
# _REALFLOW/clutterfile                 radar\19930101.clt
# _REALFLOW/griddedinitnetradiation      tempr\19930101_tem.r2c
# _REALFLOW/griddedinitsoilmoisture      moist\19930101_gsm.r2c
# _REALFLOW/griddedinitlszs               moist\19930101_gsm.r2c
# _REALFLOW/griddedrainfile              radcl\19930101_met.r2c
# _REALFLOW/appendedsoilmoisture         moist\19930101_gsm.r2c
# _REALFLOW/griddedsnowfile               radcl\19930101_mat.r2c
# _REALFLOW/griddedtemperaturefile       tempr\19930101_tem.r2c
# _REALFLOW/griddeddailydifference       tempr\19930101_dif.r2c
# _REALFLOW/griddeddrainage               tempr\19930101_dif.r2c
# _REALFLOW/griddedhumidity               humid\19930101_hum.r2c
# _REALFLOW/griddedwindspd                winds\19930101_spd.r2c


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>
<thead>
<tr>
<th>Flag</th>
<th>Description and Valid Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>snwflg</code></td>
<td>y – Snowmelt routines will be used</td>
</tr>
<tr>
<td><code>sedflg</code></td>
<td>y – Sediment production and routing routines will be used</td>
</tr>
<tr>
<td><code>vapflg</code></td>
<td>y – Evaporation turned on (need temperature files)</td>
</tr>
</tbody>
</table>
| `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 `smrflg` entries will be ignored and `smrflg` 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.                                                                                      |
<table>
<thead>
<tr>
<th>Flag</th>
<th>Description and Valid Values</th>
</tr>
</thead>
</table>
| **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 L2S 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:  
  | \$\{bsnm\}runof\*_rff.r2c  
  | \$\{bsnm\}rchrg\*_rch.r2c  
  | \$\{bsnm\}lkage\*_lkg.r2c  
  | \$\{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 \$\{bsnm\}results\watflood.wfo file for Green Kenue |
| **picflg** | y – Create \$\{bsnm\}results\pic.txt file for flow animation with MAPPER.exe |
| **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 & interflow only  
  I – Run WATROUTE for surface and groundwater leakage routing  
  r – Run WATROUTE for surface to channel and recharge 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 |
### Flag Description and Valid Values

<table>
<thead>
<tr>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>trcflg</td>
<td><strong>y</strong> – Use the tracer module. This flag is set in event.evt and used for all subsequent events.</td>
</tr>
<tr>
<td>frcflg</td>
<td><strong>y</strong> – Use fractionization module (under development). This flag is set in event.evt and used for all subsequent events.</td>
</tr>
<tr>
<td>initflg</td>
<td><strong>y</strong> – Write flow_init.r2c file for WATROUTE (Initial flow for each grid), write lzs_init.r2c file for WATROUTE (Initial LZS for each grid)</td>
</tr>
<tr>
<td>hdrflg</td>
<td><strong>Y</strong> – Write column headers on spl.csv, resin.csv &amp; evapsep.txt files</td>
</tr>
<tr>
<td>grdflg</td>
<td><strong>y</strong> – Write r2c files for flow, SWE &amp; evaporative loss: gridflow.r2c, swe.r2c and evap.r2c respectively</td>
</tr>
<tr>
<td>ntrflg</td>
<td>Use ‘natural flows’ instead of the specified reservoir releases <strong>y</strong> – If the reservoir release file for the first event has coefficients for <strong>ALL</strong> 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 ntrflg = <strong>y</strong>. If ntrflg ≠ <strong>y</strong> in a subsequent event, the coefficients will be reset to the coefficients in that event. <strong>a</strong> – The subsequent ntrflg entries will be ignored and ntrflg is set to <strong>y</strong> for the whole run.</td>
</tr>
<tr>
<td>nudgeflg</td>
<td>'Nudge' the model: replace computed flows with the observed flows <strong>a</strong> – All computed flows for all events in this run will be replaced by observed flows at all flow stations. <strong>1</strong> – 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 <strong>n</strong> 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 srt file e.g. -113.838 50.760 1 058L024 &quot;HIGHWOOD RIVER NEAR THE MOUTH&quot; 3950. -113.435 50.823 2 058M002 &quot;BOW RIVER BELOW CARSELAND DAM&quot; 15701. -112.542 50.750 1 058M004 &quot;BOW RIVER BELOW BASSANO DAM&quot; 20300.</td>
</tr>
<tr>
<td>resetflg</td>
<td><strong>y</strong> – 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.</td>
</tr>
<tr>
<td>divertflg</td>
<td>Enable water diversions <strong>y</strong> – Use diversion flow data (default) <strong>g</strong> – Generate lake St. Joseph diversion flow – special case for Winnipeg River only</td>
</tr>
<tr>
<td>paflg</td>
<td><strong>y</strong> – Generate Precipitation Adjustment Factors (PAF)</td>
</tr>
<tr>
<td>fliflg</td>
<td><strong>y</strong> – Update routing data on-the-fly with*_fli.r2c file which can be generated at the end of a run with tbcflg = <strong>y</strong> or generated with FLI.exe</td>
</tr>
<tr>
<td>lakeflg</td>
<td><strong>Y</strong> – Use lake evaporation model for lakes with depth larger than 1 m.</td>
</tr>
</tbody>
</table>
1. WATFLOOD / CHARM User’s Manual

Flag | Description and Valid Values
---|---

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, ntrflg, smrflg

- The basin*.** files are used for all events and will not replace 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 shorter 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
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:\sp1gr10k>

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 entries and then use the command `backup` while in the `watflood` directory. This will create a new directory on the backup disk `y:` if it doesn’t yet exist and then copy or update all entries (copy only newer files)

```
mkdir y:\spl\mrbb22
xcopy /s /d /y mrbb22\*.* y:\spl\mrbb22\*.*
xcopy /s /d /y mrbb22\basin\*.* y:\spl\mrbb22\basin\*.*
xcopy /s /d /y mrbb22\data\*.* y:\spl\mrbb22\data\*.*
xcopy /s /d /y mrbb22\drain\*.* y:\spl\mrbb22\drain\*.*
xcopy /s /d /y mrbb22\event\*.* y:\spl\mrbb22\event\*.*
xcopy /s /d /y mrbb22\kristof\*.* y:\spl\mrbb22\kristof\*.*
xcopy /s /d /y mrbb22\level\*.* y:\spl\mrbb22\level\*.*
xcopy /s /d /y mrbb22\moist\*.* y:\spl\mrbb22\moist\*.*
xcopy /s /d /y mrbb22\MRBHM\*.* y:\spl\mrbb22\MRBHM\*.*
xcopy /s /d /y mrbb22\radcl\*.* y:\spl\mrbb22\radcl\*.*
xcopy /s /d /y mrbb22\raing\*.* y:\spl\mrbb22\raing\*.*
```
xcopy /s /d /y mrb22\reports\*.*  y:\spl\mrb22\reports\*.*
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 *should* 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* 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 *snow/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).
### 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>
<thead>
<tr>
<th>Task</th>
<th>Program and Purpose</th>
<th>Input/Output File(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create bsnm_shd.r2c file</td>
<td>BSN.exe Converts the raw data in the bsnm.map file to a watershed file bsnm_shd.r2c readable by SPL.exe</td>
<td>Bsnm.map Bsn_responses.txt Class_combine.csv</td>
</tr>
<tr>
<td>Read CAPP</td>
<td>RADMET.exe Converts the radar data file to a CHARM compatible format. This program has to be adapted for each radar source.</td>
<td>*.scn *.rad</td>
</tr>
<tr>
<td>Calibrate Radar</td>
<td>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.</td>
<td>*.rad *.met.r2c</td>
</tr>
<tr>
<td>Task</td>
<td>Program and Purpose</td>
<td>Input/Output File(s)</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Distribute Rainfall</td>
<td>RAGMET.exe</td>
<td>BSNM.pdl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*.rag</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*_met.r2c</td>
</tr>
<tr>
<td>Distribute Snow Course</td>
<td>SNW.exe</td>
<td>BSNM_shd.r2c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*_crs.pt2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*_swe.r2c</td>
</tr>
<tr>
<td>Distribute Initial Soil Moisture</td>
<td>MOIST.exe</td>
<td>BSNM_shd.r2c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*_psm.pt2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*_gsm.r2c</td>
</tr>
<tr>
<td>Distribute Temperature</td>
<td>TMP.exe</td>
<td>BSNM.pdl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*_tag.tb0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*_tem.r2c</td>
</tr>
<tr>
<td>Run SPLD (debug)</td>
<td>SPLD.exe</td>
<td>See section 1.3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Files listed in outfiles.txt</td>
</tr>
<tr>
<td>Run SPL (speed)</td>
<td>SPL.exe</td>
<td>See section 1.3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Files listed in outfiles.txt</td>
</tr>
<tr>
<td>Calculate Statistics</td>
<td>STATS.exe</td>
<td>results\spl.csv</td>
</tr>
<tr>
<td></td>
<td></td>
<td>results\stats.txt</td>
</tr>
</tbody>
</table>

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 entries 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 soil moisture data is an optional activity, depending on whether initial data exists.

Notes:
1. WATFLOOD / CHARM User’s Manual

- 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 \snp\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 `temp\*_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. *SPLX.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

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 `i-opt=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:

![Stage Hydrograph](image)

*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/basin/basnam.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.
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.**
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
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>
<thead>
<tr>
<th>Problem</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>File Errors</strong></td>
<td></td>
</tr>
<tr>
<td>Visual FORTRAN does not seem to like tabs in the data files.</td>
<td>Replace tabs with blanks.</td>
</tr>
<tr>
<td>Sometimes old output files are write-protected and the program cannot write to a file. The error message is obscure.</td>
<td>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.</td>
</tr>
<tr>
<td>Disk full errors. Usually obvious.</td>
<td>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.</td>
</tr>
<tr>
<td>Read errors</td>
<td>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.</td>
</tr>
<tr>
<td><strong>Computing Errors</strong></td>
<td></td>
</tr>
<tr>
<td>When executing SPLX.exe with the result of say division by zero or floating point overflow.</td>
<td>Run the debug program SPLD.exe to determine the line of code where the error occurred. E-mail the details to <a href="mailto:kouwen@uwaterloo.ca">kouwen@uwaterloo.ca</a> and hope that the error can be located. Most often it is useful to send all the files in an event causing the problem.</td>
</tr>
<tr>
<td>-ve storage errors</td>
<td>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.</td>
</tr>
<tr>
<td>Frac = 0 (or a very small value.)</td>
<td>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.</td>
</tr>
</tbody>
</table>
### Example 1: program crash. Rerun with `SPLD.exe` and get:

```plaintext
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
```

<table>
<thead>
<tr>
<th>Image</th>
<th>PC</th>
<th>Routine</th>
<th>Line</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>spld.exe</td>
<td>006490B9</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00648F17</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>spld.exe</td>
<td>006480F4</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00648529</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00636783</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00635FFD</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>spld.exe</td>
<td>004129C4</td>
<td>EF_MODULE_mp_PARs</td>
<td>870</td>
<td>EF_Module.f</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00415A7D</td>
<td>EF_MODULE_mp_PARs</td>
<td>1424</td>
<td>EF_Module.f</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00415CBC</td>
<td>EF_MODULE_mp_PARs</td>
<td>1471</td>
<td>EF_Module.f</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00519B68</td>
<td>READ_FLOW_EF</td>
<td>107</td>
<td>read_flow_ef.f</td>
</tr>
<tr>
<td>spld.exe</td>
<td>0058B5D5</td>
<td>SUB</td>
<td>197</td>
<td>sub.f</td>
</tr>
<tr>
<td>spld.exe</td>
<td>004BFA9C</td>
<td>OPTIONS</td>
<td>186</td>
<td>options.f</td>
</tr>
<tr>
<td>spld.exe</td>
<td>0058A809</td>
<td>CHARM</td>
<td>1122</td>
<td>CHARM.f</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00675449</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>spld.exe</td>
<td>00665064</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>kernel32.dll</td>
<td>7C817067</td>
<td>Unknown</td>
<td>Unknown Unknown</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

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

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

All you need is:

```plaintext
: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        *
*  debug level 1 ynynnnnnnnnnnnn  strfw *
*  channel type 0 123456789012345678  resrl *
*                                     snowl *
*                                        watflood(tm) *
*                                       resrl *
*                                        radcl *
*   copyright (c) by n kouwen 1985-2008  temp *
*   university of waterloo, canada     *
*   debug level   1 ynynnnnnnnnnnnn  strfw *
*   channel type 0 123456789012345678  resrl *
*                                        snowl *
*                                        watflood(tm) *
*                                        resrl *
*                                        radcl *
*   copyright (c) by n kouwen 1985-2008  temp *
*   university of waterloo, canada     *
*------------------------------------------------*
```

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 outfile.new file is created that lists the default SPL output file set. You can edit this file and rename it to outfile.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.

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

- 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 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.
2. 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):

$$D_s = S_d(1 - e^{-kP_e})$$  \hspace{2cm} (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.

<table>
<thead>
<tr>
<th>Type of Surface</th>
<th>Detention (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impervious urban areas</td>
<td>1.25</td>
</tr>
<tr>
<td>Pervious urban areas</td>
<td>3.0</td>
</tr>
<tr>
<td>Smooth cultivated land</td>
<td>1.3 - 3.0</td>
</tr>
<tr>
<td>Good pasture</td>
<td>5.0</td>
</tr>
<tr>
<td>Forest litter</td>
<td>8.0</td>
</tr>
</tbody>
</table>

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:

\[
\frac{dF}{dt} = K \left[ l + \frac{(m - m_0)(\text{Pot} + D_1)}{F} \right]
\]

(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
- \( \text{Pot} \): capillary potential at the wetting front in mm
- \( D_1 \): depth of water on the soil surface
- \( D_1 \): 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.

\[ \text{Pot} = 250 \log \left( \frac{K}{3600} \right) + 100 \]  

where:
- \( \text{Pot} \) = the capillary potential in mm
- \( K \) = hydraulic conductivity in mm/hr.

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:

\[ \text{Pot} = 250 \log \left( \frac{K}{3600} \right) + 100 \]  

\[ (2.3) \]

The potential head calculated by Eq. 2.3 compares very well with values reported by Rawls and Brakensick (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:
### 2. Hydrological Model

<table>
<thead>
<tr>
<th>UZ</th>
<th>Upper zone storage (saturated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IZ</td>
<td>Intermediate zone storage (unsaturated)</td>
</tr>
<tr>
<td>LZ</td>
<td>Lower zone storage (saturated)</td>
</tr>
</tbody>
</table>

The initial moisture $m_0$ 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 $m_0$ is related to the antecedent precipitation index by:

$$m_0 = \text{API}/100$$  \hspace{1cm} (2.4)

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

$$\text{API}_i = k \left( \text{API}_{i-1} \right) + P_i$$  \hspace{1cm} (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:

$$m_0 (t+t) = A5 \cdot m_0 (t) + P_i/100$$  \hspace{1cm} (2.6)

where $A5$ is an optimized parameter (approximate value is 0.985 -0.998 on an hourly basis). When the temperature $< 0$ °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 recent experience with the Priestly-Taylor 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\textsubscript{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\textsubscript{eq} by a factor (α) equal to 1.26:

\[
PET = \alpha \frac{s(T_a)}{s(T_a) + \gamma} \left( K_n + L_n \right) \frac{1}{\rho_w \lambda_v} \tag{2.7}
\]

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, \(\gamma\) is the psychrometric constant, \(\rho_w\) is the mass density of water, and \(\lambda_v\) is the latent heat of vaporization. Although the value of \(\alpha\) 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 \(\alpha\), ranging up to 1.74, have been recommended for estimating potential evapotranspiration in more arid regions (ASCE, 1990).

The \(\alpha\) 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 \(\alpha\) 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:

\[ \text{PET} = 0.05 \cdot \text{PET} + 0.95 \cdot \text{PET} \cdot \frac{1 - \text{alb}}{1 - \text{albe}}. \]  

(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:

\[ \text{PET} = 0.0075 \cdot R_a \cdot C_t \cdot \delta_t \cdot T_{\text{avg,d}} \]  

(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 (\(w_a\)), \(\delta_t\) is the difference between the mean monthly maximum and mean monthly minimum temperatures (\(^\circ\)F) \{mxmn in the monthly_climate_normals.txt file\}, and \(T_{\text{avg,d}}\) is the mean temperature (\(^\circ\)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:

\[ C_t = 0.035 \left(100 - w_a\right)^{0.5} \quad w_a \geq 54% \]

\[ C_t = 0.125 \quad w_a < 54% \]  

(2.10)

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

\[ R_a = 15.392 \cdot d_r \left( w_a \cdot \sin \phi \cdot \sin \delta + \cos \phi \cdot \cos \delta \cdot \sin \omega \right) \]  

(2.11)

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

\[ d_r = 1 + 0.033 \cdot \cos \left( \frac{2\pi \cdot J}{365} \right) \]  

(2.12)
\[ \delta = 0.4093 \cdot \sin \left( \frac{2\pi \cdot J}{365} - 1.405 \right) \] (2.13)

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

\[ w_s = \arccos \left( -\tan \phi \cdot \tan \delta \right) \] (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 (\( \Delta \)), an approximation of the ratio of \( s(T_a) \) to the sum of \( s(T_a) \) and \( s(T) \) 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 \( \delta_t \) 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. Hydrological Model

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:

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

(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).

\[ FULL = \frac{RETN}{FCAP} \]  

(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.

\[ PWP = FFCAP \times FULL \]  

(2.17)

\[ SAT = SPORE \times FULL \]  

(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
2. Hydrological Model

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:

\[
FPET2 = \frac{\text{TTO} - \text{TTOMIN}}{\text{Temp}^3} \times 0.02 \times \text{FPET2} < 1.0
\]

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.

\[
\text{FTALL} = 0.70 \quad \text{for Tall Vegetation}
\]
\[
\text{FTALL} = 1.00 \quad \text{for Short Vegetation}
\]

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,

\[
\begin{align*}
AET &= PET & \text{if } PET < IET, \\
AET &= (PET - IET) \cdot UZSI \cdot FPET2 \cdot FTALL \cdot ETP & \text{if } PET > IET, \\
AET &= PET \cdot UZSI \cdot FPET2 \cdot FTALL \cdot ETP & \text{if } IET = 0, \\
AET &= PET & \text{for water (rivers / lakes)}
\end{align*}
\]

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

\[
AET = FPET \cdot PET
\]

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/m² (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) reproduced a table from Gray (1973) yielding somewhat greater 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 setting the maximum values in the parameter file (NK).
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,

\[ \text{IET} = \text{FPET} \cdot \text{PET} \]  

(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 (\( X_2 \)) of the maximum storage and the interception evaporation, in mm:

\[ V = F \cdot X_2 \]  

(2.22)

and

\[ X_2 = h + \text{IET} = h + \text{FPET} \cdot \text{PET} \]  

(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:

\[
\text{fraction} = e^{-P_i/X_2} \quad (2.24)
\]

and

\[
V = X_2 \cdot e^{-P_i/X_2} \quad (2.25)
\]

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,

\[
X_2 = h + FPET \cdot PET \quad \text{if } PET \leq h
\]

or

\[
X_2 = h + FPET \cdot h \quad \text{if } PET > h
\]

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:

\[
\text{Throughfall} = \text{Precipitation} - (V_i - V_{i+1}) - PET
\]

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:

\[
DUZ = \text{REC} \ast (\text{UZS}-\text{RETN}) \ast S_i
\]

where:

- $DUZ$ = is the depth of upper zone storage released as interflow in mm
- $\text{REC}$ = a dimensionless coefficient (optimized)
2. Hydrological Model

\[ UZS = \text{water accumulation in the upper zone region in mm} \]
\[ RETN = \text{retention} \]
\[ Si = \text{internal slope (land surface slope)} \]

REC is a coefficient, which cannot be predicted, and is therefore estimated through optimization. Values of REC are expressed as the depletion fraction per hour of the UZ storage that is drained off each hour when the internal slope (overland slope) is 1.0 (i.e. a 45° 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.

![Internal slope – based on contour density](image)

**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:
2. Hydrological Model

\[ \text{DRNG} = \text{AK2} \times (\text{UZS} - \text{RETN}) \]  \hspace{1cm} \text{(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 \( m_0 \) 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:

\[ Q_r = \frac{(D_1 - D_s)^{1.67} S^{0.5} A}{R^3} \] \hspace{1cm} \text{(2.31)}

where:
- \( Q_r \) = channel inflow in m\(^3\)/s
- \( D_1 \) = surface storage in mm
- \( D_s \) = depression storage capacity in mm (optimized)
- \( A \) = the area of the basin cell in m\(^2\)
- \( R \) = combined roughness and channel length parameter (optimized)

The \( R \) 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 \( R \) 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, \( R \) 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).

\[ Q_{LZ} = \text{LZF} \times \text{LZS} \times \text{PWR} \] \hspace{1cm} \text{(2.32)}

where:
2. Hydrological Model

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 2nd 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:

\[
\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{\Delta t}
\]  

(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$^3$
- $\Delta t$ = 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:

\[
I = Q + q_{in}
\]  

(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 \( q_{loss} \):

\[
q_{in} = q + q_{int} + q_{1} + q_{lz} - q_{stream} - q_{loss}
\]  

(2.35)

Most river cross sections are rectangular with flat bottoms and near vertical sides. The width-depth ratio \texttt{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: \texttt{r1n} for the overbank and \texttt{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.

\[\text{Figure 2.4. Representative river cross section.}\]

\[\text{2.11.1 Main Channel Flow}\]

The following notation is used:

\[
\begin{align*}
  y & = \text{depth of flow} = d+h \\
  w & = \text{main channel width} \\
  A & = \text{Main channel cross sectional area of the flow} \\
  R & = \text{hydraulic radius main channel} \\
  \text{Over} & = \text{overbank area (not shaded)}
\end{align*}
\]

Start with Manning’s formula:
2. Hydrological Model

\[ Q = \frac{1}{n} AR^{\frac{1}{2}} S^{\frac{1}{2}} \]  
(2.36)

\[ A = wy \quad \text{Assume: } R = y \quad \text{so } R = A/w \]

\[ Q = \frac{1}{n} \frac{1}{w_{ave}} A^{1.667} S^{0.5} \]  
(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:

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

Solve for \( h \) using the quadratic equation:

\[ h = \frac{-1 + \sqrt{1 + 4 \times 100 \times \text{overbank area}}}{2 \times 100} \]  
(2.39)

\[ Q = \frac{1}{n} \frac{1}{w_{\text{ave}}} A^{1.667} S^{0.5} + 0.17 \frac{1}{n_{oh}} \left( \text{over} - h \times w \right)^{3.33} S^{0.5} \]  
(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 \( R_{lake} \) 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. \( R_{lake} \) can be optimized. This correction is activated by setting \( a^2 > 0 \) in the par file. For \( a^2 < 0 \), 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.
Two equations can be used to calculate the bankfull cross sectional area. The original WATFLOOD equation is:

\[
\text{Bankfull area} = a_2 + a_3 \times (\text{drainage area})^{a_4}
\]

(2.41)

Example for Fig. 2.5:

<table>
<thead>
<tr>
<th>DA (km(^2))</th>
<th>BF (m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>10</td>
<td>1.1</td>
</tr>
<tr>
<td>50</td>
<td>2.3</td>
</tr>
<tr>
<td>100</td>
<td>3.2</td>
</tr>
<tr>
<td>150</td>
<td>3.9</td>
</tr>
<tr>
<td>200</td>
<td>4.6</td>
</tr>
<tr>
<td>250</td>
<td>5.1</td>
</tr>
<tr>
<td>300</td>
<td>5.8</td>
</tr>
</tbody>
</table>

For these data using the power function in EXCEL:

\[
\text{bankfull area} = 0.0 + 0.3647 \times BF^{0.4773} \quad R^2 = -0.9989
\]

Avoid entering values DA = 0 and BF = 0 as EXCEL cannot fit to these data. The \(a_2\), \(a_3\) and \(a_4\) parameters can be specified for each river class in the model parameter file. In this example, \(a_2 = 0.0\) 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):

\[
q_{owet} = \frac{k_{cond}}{2} (h_{wet}^2 - h_{cha}^2)
\]  

(2.43)

where:

- \(q_{owet}\) = lateral wetland outflow in cubic meters per second
- \(k_{cond}\) = hydraulic conductivity in meters per second
- \(h_{wet}\) = height of water in the wetland in meters
- \(h_{cha}\) = 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, \(q_{owet}\) 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:

During wetland-storage routing, the lateral inflow \(q_{in}\) contributing to total channel inflow \((I)\) from equation 2.40 is reduced to the sum of streamflow \((q_{stream})\) and wetland outflow \((q_{owet})\), less the evaporation losses \((q_{loss})\):

\[
q_{in} = q_{in} + q_{stream} - q_{loss} + q_{owet}
\]  

(2.45)
If water is moving from the channel into the wetland, \( q_{\text{owet}} \) will be negative and will therefore reduce the total channel inflow \( I \). The lateral interflow \( q_{\text{int}} \), overland flow \( q_1 \), and baseflow \( q_{\text{lz}} \) instead contribute to the wetland inflow \( q_{\text{iwet}} \), and not the channel inflow \( q_{\text{in}} \):

\[
q_{\text{iwet}} = q_{\text{int}} + q_1 + q_{\text{lz}} - q_{\text{sw}}
\]

where all flows are in cubic meters per second.

The flow contribution from precipitation \( q_{\text{swrain}} \) is calculated in the wetland runoff routine and is added directly onto the wetland surface, and \( q_{\text{swevp}} \) is the evaporation loss off of the wetland surface from the wetland evaporation routine.

The wetland outflows \( q_{\text{owet}} (1,2) \) contribute to the inflows \( I_1 \) and \( I_2 \) of equation 2.33. \( q_{\text{owet}} \) 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 \((k_{\text{cond}})\), and the channel width to depth ratio \((\text{widep})\). The wetland width is calculated by \( \text{BSN.exe} \) by taking the fraction of the grid composed of wetlands \((\text{FRAC}_{\text{wet}})\) 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 \( k_{\text{cond}} \) are entered in the model parameter file.

To use the wetland or bank storage function, the wetland flag \((\text{wetflg})\) 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 \( \text{wetfld} \) 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 \( \text{BSN.exe} \), 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 \( \text{BSNM.map} \) file. Once
Hydrological Model

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

\[
\text{Outflow} = b_1 \text{ Storage} \quad b_2
\]  

(2.47)

or a polynomial like

\[
\text{Outflow} = b_1 \text{ Storage} + b_2 \text{ Storage}^2 + b_3 \text{ Storage}^3 + b_4 \text{ Storage}^4 + b_5 \text{ Storage}^5
\]  

(2.48)

must be used. If \( b_3, b_4 \) and \( b_5 = 0.0 \), a power function with coefficients \( b_1 \) and \( b_2 \) is assumed. If \( b_3 \) or \( b_4 \) or \( b_5 \neq 0.0 \), a polynomial is assumed. For the latter, \( b_3 \) must have a value although \( b_4 \) and/or \( b_5 \) 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 \( b_1 \) and \( b_2 = 0.0 \) 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 \( b_1-b_5 \) 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 \( b_1 \) 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:

\[
R2n = \text{MAX} ( r2n(i) ; r2n(i) * (\text{water_area}(i) / \text{channel_area}(i)) * rlake(j) )
\]  

(2.48a)

for \( \text{water_area}(n) > \text{channel_area}(n) \) where \( rlake(j) \) is a coefficient specified for reach \( j \) in the parameter file and \( \text{channel_area} \) 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
Hydrological Model

Timing of hydrographs downstream from reaches with many lakes. One or two small lakes do not have much of an effect. \( i = \text{grid} \# \quad j = \text{channel class} \# \)

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 \( b_2 \) is fixed at 1.75 and the coefficient \( b_2 = r_{\text{lake}} \)

For both cases \( r_{\text{lake}} \) 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. \( 0.0 < r_{\text{lake}} < 1.0 \times 10^{-4} \quad \text{Values in the range } 1.0 \times 10^{-10} \text{ to } 1.0 \times 10^{-8} \text{ work in one known application. For the manning } n \text{ correction, values for } r_{\text{lake}} \text{ should be nearer to } 1.0 \)
3. \( \text{And water area} > \text{wetland area} \)

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: \( d_\text{d_ice} \) for freezeup and \( d_\text{d_thaw} \) 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\yyyyymmd_duill.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 (αPT) 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:

\[ E = \alpha_{PT} \frac{\Delta}{\Delta + \gamma} \left( Q^* - J_{w\max} \right) \times 86.4 \]

where \( \alpha_{PT} \) is the Priestley-Taylor evaporation coefficient (a value of 1.28 is used), \( \Delta \) 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), \( \rho_w \) is the density of water (kg m⁻³), and \( \lambda_v \) is the latent heat of vaporisation (MJ kg⁻¹). The values of \( \Delta, \gamma, \lambda_v, P_{atm}, \) and \( \rho_w \) 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, \( \tau \), is defined as (Annandale et al., 2002):

\[ \tau = 0.16 \left( 1 + 0.000027z \right) \sqrt{T_{max} - T_{min}} \]

where \( z \) is elevation (m above sea level) and \( \alpha \) 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). \( T_{max} \) and \( T_{min} \) 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, \( \Lambda \) is latitude of the lake (radians), \( E_0 \) is the eccentricity correction factor, and \( \delta \) 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):

\[ L_n = \sigma (T_w + 273.16)^4 \left[ 1 - 0.261 \exp(-0.00077 T_w^2) \right] - 0.98 \sigma (T_w + 273.16)^4 \]
where $\sigma$ is the Stefan Boltzmann constant ($5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$), $T_a$ (°C) is the mean daily air temperature, $T_w$ is the average daily water temperature and $\varepsilon$ 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:

$$ T_w(t) = 0.620 \ln D + 0.979 f(T_{a,t}) + (0.75 + (0.00002z)K_{ET})f(T_{a,t}) $$

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

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

where the smoothing parameter, $\alpha$, is equal to:

$$ \alpha = \frac{1}{6.7 - 0.829 \ln D} $$

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:

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

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

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

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:


2. Hydrological Model


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 area 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:

\[ M = MF \left( T_a - T_{base} \right) \]  

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

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

\[ \Delta H_s = NMF(\text{ATI} - T_a) - \frac{S_i T_a}{160} \]  

(2.36)
where $\Delta H_s$ is the change in heat deficit (mm of water equivalent), NMF is the negative melt factor – rate of change in heat deficit based on air temperature per unit time (mm.$^o$C/day), ATI is the antecedent temperature index, and $S_f$ is the amount of snow fallen per unit time represented as snow water equivalent (SWE) in mm.

The first portion of Eq. 2-36 accounts for the difference between the snow pack surface temperature and the overlying air temperature converted to mm of water equivalent using the negative melt factor (NMF). In the NWSRFS model (Anderson, 1973), the value of the negative melt factor increased through the ablation period based on a sine curve function having a typical maximum value of 0.500 mm.hr$^{-1}$.C$^{-1}$.

In WATFLOOD, the negative melt factor does not vary through the ablation period and its value is set in the parameter file for each vegetation class. Donald (1992) found that values of 0.200 mm.hr$^{-1}$.C$^{-1}$ produced reasonable results. The latter portion of Eq. 2-36 represents the change in heat resulting from the addition of new snow assuming that the temperature of the snow is equal to the air temperature (where $T_a$ is less than or equal to 0 $^o$C). If the air temperature is greater than 0 $^o$C, the change in heat ($\Delta \theta_s$) is assumed to equal zero and the heat deficit is reduced by the maximum probable melt as calculated in Eq. 2-35 (i.e., snow pack is warmed by the amount of maximum probable melt).

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

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

where $T(x, t)$ is the temperature at some depth "x" at time "t" ($^o$C), $T_o$ is the altered surface temperature ($^o$C), $T_i$ is the original surface temperature ($^o$C), $\alpha$ is the thermal diffusivity (m$^2$/s) ($\alpha = k/\rho c$ which gives a value of $3.97 \times 10^{-7}$ for typical $k$ value listed below), $k$ is the thermal conductivity (W$^2$$^o$C$^{-1}$) (common value for snow is 0.25 for a density of 300 kg.m$^{-3}$), and $c$ is the specific heat of snow (KJ$^2$kg$^{-1}$.$^o$C$^{-1}$) (assume that it can be approximated by $c_{\text{ice}} = 2.1$ KJ$^2$kg$^{-1}$.$^o$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.

$$ATI_2 = ATI_1 + \text{tipm}(T_a - ATI_1)$$

where $ATI_1$ is the Antecedent Temperature Index at time "t-1" ($^o$C) and $ATI_2$ is the Antecedent Temperature Index at time "t" ($^o$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):

\[
M = MF \left( T_a - T_{\text{base}} \right) + r_m \cdot R \tag{2.39}
\]

where \( M \) is snowmelt depth (mm), \( MF \) is the melt factor, rate of melt per degree per unit time (mm.\(^\circ\)C.\(^{-1}\).hr\(^{-1}\)), \( T_a \) is the average air temperature over the time unit (\(^\circ\)C), \( T_{\text{base}} \) is the base temperature at which the snow will begin to melt (\(^\circ\)C), \( r_m \) 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.
3. Watershed Data Requirements

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

<table>
<thead>
<tr>
<th>File name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>basin\BSNM.map</td>
<td>Map file – contains all the watershed data in a gridded format. Created manually or by Green Kenue</td>
</tr>
<tr>
<td>basin\BSNM_shd.r2c</td>
<td>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.</td>
</tr>
<tr>
<td>basin\BSNM_par.csv</td>
<td>Parameter file – contains the WATFLOOD model parameters.</td>
</tr>
<tr>
<td>basin\evap.dat</td>
<td>A table of climatic monthly evaporation. Can be used in lieu of calculating ET based on temperature and/or radiation data.</td>
</tr>
<tr>
<td>basin\BSNM.pdl</td>
<td>Has the coordinates for the precipitation, snow course and temperature stations and has the grid specifications for the *_met, r2c and *_temp.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).</td>
</tr>
<tr>
<td>RADC*_met.r2c</td>
<td>Gridded precipitation file – created by RAGMET.exe</td>
</tr>
<tr>
<td>Tempr/*_tem.r2c</td>
<td>Gridded temperature file – created by TMP.exe</td>
</tr>
</tbody>
</table>

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` (required)
   - `watflood\BSNM\basin` (required)
   - `watflood\BSNM\bsflw` (required)
   - `watflood\BSNM\evapo` (required)
   - `watflood\BSNM\event` (required)
   - `watflood\BSNM\kage` (required)
   - `watflood\BSNM\moist` (required)
   - `watflood\BSNM\radar` (required)
   - `watflood\BSNM\radcl` (required)
3. Watershed Data Requirements

The watflood directory can be placed anywhere but should 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 instructions 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 setup and content of the parameter file is described in detail in Chapter 4

3.2.3 Watershed Data

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.
3. Watershed Data Requirements

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.](image)

**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. Watershed Data Requirements

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>
<thead>
<tr>
<th>Keyword</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoordSys</td>
<td>Coordinate system – should be one of: Cartesian, UTM, LATLONG. The same coordinate system must be used in all input files for a given watershed.</td>
</tr>
<tr>
<td>Datum, Zone</td>
<td>Geodetic datum and projection zone – these depend on the coordinate system:</td>
</tr>
<tr>
<td></td>
<td>• For Cartesian coordinate system Datum and Zone are not allowed</td>
</tr>
<tr>
<td></td>
<td>• For UTM, Datum and Zone are required</td>
</tr>
<tr>
<td></td>
<td>• For LATLONG, Datum is required and Zone is not allowed</td>
</tr>
<tr>
<td>xOrigin, yOrigin</td>
<td>X and Y coordinates of the bottom left corner</td>
</tr>
<tr>
<td>xCount, yCount</td>
<td>Number of cells in the X and Y dimensions</td>
</tr>
<tr>
<td>xDelta, yDelta</td>
<td>Cell size in the units of the specified coordinate system in the X and Y dimensions</td>
</tr>
<tr>
<td>ContourInterval</td>
<td>Contour interval in meters – usually equals to 1 when automatic procedures are employed, otherwise as on the map used.</td>
</tr>
<tr>
<td>ImperviousArea</td>
<td>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</td>
</tr>
</tbody>
</table>
3. Watershed Data Requirements

| **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).

**Section 3.3.1.1 Impervious area**

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

---

**Table 3.3. Examples of map file headers.**

<table>
<thead>
<tr>
<th>Coordinate System</th>
<th>Example</th>
</tr>
</thead>
</table>
| Cartesian         | ```
:CoordSys        Cartesian
#
:xOrigin          500000.000
:yOrigin          4790000.000
#
:xCount           9
:yCount           12
:xDelta           10000.000
:yDelta           10000.000
#
:contourInterval  30.500
:imperviousArea   33
:classList         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
:classList         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
``` |
3. Watershed Data Requirements

| :contourInterval | 1.000000 |
| :imperviousArea  | 0         |
| :classCount      | 40        |
| :elevConversion  | 1.000000  |

#-----------------------------

endHeader

3.3.1 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 considerably 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:

<table>
<thead>
<tr>
<th>RiverClass</th>
<th>ImpPercent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>65</td>
</tr>
<tr>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>6</td>
<td>65</td>
</tr>
<tr>
<td>7</td>
<td>65</td>
</tr>
</tbody>
</table>

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).

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

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.

<table>
<thead>
<tr>
<th>Drainage Area (FRAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 10 60 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 20 100 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 72 120 72 0 0</td>
</tr>
<tr>
<td>0 0 68 100 100 91 50 0 0</td>
</tr>
<tr>
<td>0 10 90 118 165 35 31 110 0</td>
</tr>
<tr>
<td>0 0 19 85 85 22 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Drainage direction (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>
3. Watershed Data Requirements

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.

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

\[
slope = \frac{\text{# of contours} \times \text{contour interval}}{\text{grid length}} \times 100
\]  \hspace{1cm} (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.
There are 14 contours crossing the line in this example.

The line length = grid length.

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.
3. Watershed Data Requirements

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 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 be 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. (This 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 procedure. 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 0 0 0 0
0 0 0 0 0 1 0 0 0
0 0 0 0 0 1 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 resr1*_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!!**
<table>
<thead>
<tr>
<th>forest class = 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>34 27 25 23 18 28 22 19 29</td>
</tr>
<tr>
<td>26 24 25 27 22 31 19 20 23</td>
</tr>
<tr>
<td>27 26 24 26 24 21 20 19 11</td>
</tr>
<tr>
<td>24 20 20 18 26 23 16 14 19</td>
</tr>
<tr>
<td>16 9 15 8 9 11 15 25 27</td>
</tr>
<tr>
<td>9 14 11 10 14 20 27 24 29</td>
</tr>
<tr>
<td>9 6 6 9 11 18 20 23 17</td>
</tr>
<tr>
<td>3 4 6 8 13 13 14 29 25</td>
</tr>
<tr>
<td>14 10 16 13 12 13 16 28 34</td>
</tr>
<tr>
<td>9 12 10 9 11 10 26 27 25</td>
</tr>
<tr>
<td>9 4 4 11 13 21 17 19 15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>all vegetation class = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>34 64 64 68 72 65 74 70 43</td>
</tr>
<tr>
<td>66 67 67 64 64 76 63 62</td>
</tr>
<tr>
<td>68 67 70 71 71 75 73 72 75</td>
</tr>
<tr>
<td>80 67 70 63 62 75 73 66 68</td>
</tr>
<tr>
<td>71 71 76 77 42 72 74 58 46</td>
</tr>
<tr>
<td>80 86 80 85 84 79 74 56 53</td>
</tr>
<tr>
<td>87 81 84 85 79 62 58 56 60</td>
</tr>
<tr>
<td>90 89 84 85 79 73 68 63 63</td>
</tr>
<tr>
<td>93 92 89 86 78 73 61 52 63</td>
</tr>
<tr>
<td>79 86 78 63 62 76 61 55 51</td>
</tr>
<tr>
<td>79 83 81 77 59 49 55 51 62</td>
</tr>
<tr>
<td>87 92 91 79 75 63 73 67 64</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>wetland class = n-1 (= 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 6 7 3 5 4 2 3 20</td>
</tr>
<tr>
<td>5 5 6 4 2 2 3 11 4</td>
</tr>
<tr>
<td>3 4 3 1 2 1 3 5 4</td>
</tr>
<tr>
<td>2 7 4 6 10 1 1 7 7</td>
</tr>
<tr>
<td>1 5 3 17 7 6 7 14</td>
</tr>
<tr>
<td>1 0 2 2 2 4 6 9 7</td>
</tr>
<tr>
<td>0 1 2 1 2 8 9 11 3</td>
</tr>
<tr>
<td>0 0 2 1 4 4 8 5 2</td>
</tr>
<tr>
<td>0 0 0 1 2 1 4 8 2</td>
</tr>
<tr>
<td>4 0 2 2 2 3 4 3</td>
</tr>
<tr>
<td>0 0 1 0 2 2 4 10 2</td>
</tr>
<tr>
<td>0 0 0 1 2 3 3 3 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>water class = n (= 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 1 2 3 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 1 1 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 0 1 0 0 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impervious Area (= 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 1 1 1 1 0 6 6</td>
</tr>
<tr>
<td>1 2 0 0 1 1 0 4 8</td>
</tr>
<tr>
<td>0 1 0 0 1 1 2 8</td>
</tr>
<tr>
<td>0 2 1 2 5 1 1 0 4</td>
</tr>
<tr>
<td>0 1 1 2 3 3 11 7</td>
</tr>
<tr>
<td>1 2 1 1 2 2 2 6 8</td>
</tr>
<tr>
<td>1 0 1 0 1 4 3 6 5</td>
</tr>
<tr>
<td>0 2 3 1 3 1 2 5 15</td>
</tr>
<tr>
<td>1 1 2 3 2 9 14 7 6</td>
</tr>
<tr>
<td>1 1 1 18 19 6 15 8 9</td>
</tr>
</tbody>
</table>
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
- 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 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 4th 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.
### Watershed Data Requirements

<table>
<thead>
<tr>
<th>class Combine Version</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>description</td>
<td>GeoBase</td>
</tr>
<tr>
<td>nodata</td>
<td>0</td>
</tr>
<tr>
<td>shadow</td>
<td>12</td>
</tr>
<tr>
<td>water</td>
<td>20</td>
</tr>
<tr>
<td>barren/non-vegetated</td>
<td>30</td>
</tr>
<tr>
<td>snow_ice</td>
<td>31</td>
</tr>
<tr>
<td>rock_rubble</td>
<td>32</td>
</tr>
<tr>
<td>exposed_land</td>
<td>33</td>
</tr>
<tr>
<td>developed</td>
<td>34</td>
</tr>
<tr>
<td>sparsely_vegetated_bedrock</td>
<td>35</td>
</tr>
<tr>
<td>sparsely_vegetated_till-colluvium</td>
<td>36</td>
</tr>
<tr>
<td>bare_soil_with_cryptogam_crust_-frost_balls</td>
<td>37</td>
</tr>
<tr>
<td>Bryoids</td>
<td>40</td>
</tr>
<tr>
<td>Shrubland</td>
<td>50</td>
</tr>
<tr>
<td>Shrub-Tall</td>
<td>51</td>
</tr>
<tr>
<td>Shrub-Low</td>
<td>52</td>
</tr>
<tr>
<td>Prostratedwarfshrub</td>
<td>53</td>
</tr>
<tr>
<td>wetland</td>
<td>80</td>
</tr>
<tr>
<td>wetland-treed</td>
<td>81</td>
</tr>
<tr>
<td>wetland-shrub</td>
<td>82</td>
</tr>
<tr>
<td>wetland-herb</td>
<td>83</td>
</tr>
<tr>
<td>Herb</td>
<td>100</td>
</tr>
<tr>
<td>tussockgraminoidtundra</td>
<td>101</td>
</tr>
<tr>
<td>wetedge</td>
<td>102</td>
</tr>
<tr>
<td>moisttidiodyntussockgraminoid/dwarfshrub</td>
<td>103</td>
</tr>
<tr>
<td>drygraminoidprostratedwarfshrub</td>
<td>104</td>
</tr>
<tr>
<td>grassland</td>
<td>110</td>
</tr>
<tr>
<td>class 120_0%</td>
<td>120</td>
</tr>
<tr>
<td>cultivatedagriculturalland</td>
<td>121</td>
</tr>
<tr>
<td>annualcropand</td>
<td>122</td>
</tr>
<tr>
<td>coniferousforest</td>
<td>210</td>
</tr>
<tr>
<td>coniferousdense</td>
<td>211</td>
</tr>
<tr>
<td>coniferousopen</td>
<td>212</td>
</tr>
<tr>
<td>coniferousssparsel</td>
<td>213</td>
</tr>
<tr>
<td>Broadleaf</td>
<td>220</td>
</tr>
<tr>
<td>broadleafdense</td>
<td>221</td>
</tr>
<tr>
<td>broadleafopen</td>
<td>222</td>
</tr>
<tr>
<td>broadleafsparsel</td>
<td>223</td>
</tr>
<tr>
<td>mixedwooddense</td>
<td>231</td>
</tr>
<tr>
<td>mixedwoodopen</td>
<td>232</td>
</tr>
<tr>
<td>mixedwoodsparsel</td>
<td>233</td>
</tr>
</tbody>
</table>
3. Watershed Data Requirements

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 . . .
```

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

September 2016
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 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:

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
eastlimt -103.3742
yorigin_nca 48.81422
northlimt 54.48063

counting pixels
3. Watershed Data Requirements

calculating the nca on each cell
writing the nca.xyz file
nca.xyz written
done computing non contributing areas
Would you like to split any classes into
classifying 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:

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. Watershed Data Requirements

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!!!!
3. Watershed Data Requirements

There can only be one (1) outlet with this option
e.g. example: 6639 Hit Return to use whole dataset

<<OPTIONAL

Green Kenue compatible free format map file expected

:CoordSys UTM
:CoordSys UTM
:Zone 17

#----------------------------------
:iXOrigin 500000.0
:iYOrigin 4790000.
:iXCount
:iYCount
:iXDelta
:iYDelta
:iContourInterval
:iImperviousArea
:iClassCount
:iElevConversion
#----------------------------------
:endHeader

Computed nominal grid size = 10000.00
please check above numbers & hit enter to continue

Enter the split: % of wetland coupled to channel
only if you have two identical sets of wetland
land cover 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
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 system - e.g. 0.0001
Min accepted value = 0.0000001
Max value accepted is 1.0 (45 degrees!)

0.0001
No of river classes found in the map file = 5
This should match the number specified in the par file

Bare
forest
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 profi01.dat
finished writing river01.dat
finished writing profi02.dat
finished writing river02.dat
finished writing profi03.dat
finished writing river03.dat
finished writing profi04.dat
finished writing river04.dat
finished writing profi05.dat
finished writing river05.dat
finished writing profi06.dat
finished writing river06.dat
finished writing profi07.dat
finished writing river07.dat
finished writing profi08.dat
finished writing river08.dat
finished writing profi09.dat
finished writing river09.dat
finished writing profi10.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
```
### Watershed Data Requirements

#### WATFLOOD/CHARM – Canadian Hydrological And Routing Model

**September 2016**

#### #
```
<table>
<thead>
<tr>
<th>xOrigin</th>
<th>yOrigin</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>500000.00000</td>
<td>4790000.00000</td>
<td></td>
</tr>
</tbody>
</table>
```

#### AttributeName
- Rank
- Date
- DA
- Bankfull
- ChnlSlope
- Elev
- ChnlLength
- IAK
- IntSlope
- Chnl
- Reach
- GridArea
- Bare
- forest
- crops
- wetland
- water
- impervious

#### #
```
xOrigin| yOrigin| xCount| yCount| xDelta| yDelta| EndHeader
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10000</td>
<td>10000</td>
<td>0000000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>23</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>0000000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>18</td>
<td>0000000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>33</td>
<td>0000000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>22</td>
<td>0000000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0000000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0000000</td>
</tr>
</tbody>
</table>

0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 |
0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 | 0000000.0000000E+00 |
```

#### Note: fetch is missing
### Watershed Data Requirements

<table>
<thead>
<tr>
<th>Month</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>September</td>
<td>2016</td>
</tr>
</tbody>
</table>

```
<table>
<thead>
<tr>
<th>Week</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>Week</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
```

---

**WATFLOOD/CHARM – Canadian Hydrological And Routing Model**

September 2016
### 3. Watershed Data Requirements

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 3, 2016</td>
<td></td>
</tr>
</tbody>
</table>
3. Watershed Data Requirements | 3-27

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 distance 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 .SHD file.

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

```
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 km²
CH CAP = Bankfull cross-section area of river channel in m²
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 BSW.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 drained to cell 47.
Watershed Data Requirements

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.

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.
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:

```
########################################
:*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
```

Commented [AN3]: Is this section out of date?
3. Watershed Data Requirements

### 3.6 Setting up Sub-watersheds

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*)

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 1.3.3.
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 subdirectories in the radcl and temp directories: radcl\new_grid and temp\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 temp 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 site. 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

```plaintext
# :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
```

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

September 2016
3. Watershed Data Requirements

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               GR980
 :Zone                17
 #
 :xOrigin             5000000.000000
 :yOrigin             4790000.000000
 #
 :xCount              9
 :yCount              12
 :xDelta              10000.000000
 :yDelta              10000.000000
 #
 :NoPrecipStations    9
 #
 550000.  4850000.  GuelphColl
 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.  M.Montrose 0.000E+00 0.000E+00 0.000E+00 0.000E+00
 555000.  4860000.  Marsville 0.482E+02 0.256E+01 0.035E+00 0.226E+00
 570000.  4823000.  Eramosa  0.261E+02 0.176E+01 0.420E+00 0.250E+00
 530000.  4849000.  Grayton  0.345E+02 0.241E+01 0.000E+00 0.626E+00
 559000.  4830000.  Drayton  0.289E+02 0.200E+01 0.300E-01 0.330E+00
 539000.  4830000.  Elmira  0.000E+00 0.000E+00 0.000E+00 0.000E+00
 565000.  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
```
3. Watershed Data Requirements

<table>
<thead>
<tr>
<th>NoDamageSites</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>550000.</td>
<td>4800000.</td>
</tr>
<tr>
<td>540000.</td>
<td>4810000.</td>
</tr>
<tr>
<td>545000.</td>
<td>4833000.</td>
</tr>
<tr>
<td>530000.</td>
<td>4820000.</td>
</tr>
<tr>
<td>520000.</td>
<td>4840000.</td>
</tr>
</tbody>
</table>

|DamageDetails| | |
|Galt| 4 |
|573 3.3 | On shoulder Hwy. 24 |
|638 3.5 | Over Hwy. 24 |
|1550 5.8 | 1974 Flood |

|Bridgeport| 5 |
|335 2.85 | Warn Bingeman Park or Wat. Reg. Police |
|400 3.15 | Bingeman Park = Flooded |
|1370 5.5 | Issue advisory to Village |
|1700 6.0 | Evacuate residents |

|W.Montrose| 4 |
|106 1.45 | Warn W. Montrose Camp or Wat. Reg. Police |
|283 2.6 | Flooding of roads and houses |
|675 3.45 | 1974 Flood |

|St.Jacobs| 1 |
|566 3.0 | Channel Capacity |

|Drayton| 1 |
|255 2.9 | Channel Capacity |

|Hanlon| 1 |
|255 3.1 | Channel Capacity (Approx) |

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:

\[
\text{flow} = a_4 + a_1 (\text{stage} - a_3)^4
\]

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 entries \(b_1\) and \(b_2\) after the lake outlet (reservoir outlet) coordinates are used in the simple power function:

\[
\text{outflow} = b_1 \cdot \text{storage}^{b_2}
\]  

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 automatically 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 entries – \(b_3\), \(b_4\), and \(b_5\) – are used if the best fit is a polynomial. See Section Error! Reference source not found. for more details and an example.

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 InitialLake elevation 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](image)
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.

```
#---------------------------------------
: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 WOOLMICH 362.7 359 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 `resrules.pt5` file. The first entries 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 `resrules.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](https://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 reservoiv level 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. Watershed Data Requirements

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-nths/on/trentsevern/WET4/info/PDF/Fev-02-Feb/2018-d-02-d-02-d-kawartha.pdf?la=en&modified=20180202154537&hash=7D4FB2F6E6B4F4BA1F0F38C030 7A3676ED79A09

#########################################################################
#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
#AttributeName 1_high
#AttributeName 2_low
#AttributeName 2_high
#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
...
2015-02-21 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
3. Watershed Data Requirements

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 compared. (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
```

Figure 3.6 Example CHARM output for lake routing using lake rules.
3. Watershed Data Requirements

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:
```
#-----------------------------------------------
#Name  Point Snow Water Equivalent
#Projection  CARTESIAN
```
### Watershed Data Requirements

```
# SampleTime 1993/01/15 0:00:00.000
#
#: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
```

This file is for 1993 01 15 so use the command `snow64 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

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.r2c 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

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 coefficient,,,,,,,,,
:pwr,2.17,2.1,3.34,2.73,3.16,# lower zone exponent,,,,,,,,,
:rln,0.04,0.04,0.04,0.04,0.04,0.04, # overbank Manning’s n,,,,,,,,,
:rln,0.04,0.04,0.04,0.04,0.04,0.04, # channel Manning’s n,,,,,,,,,
:m ndr,1,1,1,1,1,1,1,# 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]

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:

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

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

: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)
4. Model Parameters and Optimization

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

September 2016

---

```plaintext
Evento: EndOptimizationSwitches
#
# :RoutingParameters
# :RiverClasses
:RiverClassName, upper_gr, conestoga, speed, eramosa, lower_gr,
Lflz, 0.100E+05, 0.100E+05, 0.271E-04, 0.156E-04, 0.208E-05, # lower zone coefficient
Lwrz, 0.100E+01, 0.200E+01, 0.200E+01, 0.200E+01, 0.200E+01, # overbank Manning's n
Lmndr, 1.00, 1.00, 1.00, 1.00, 1.00, # meander channel length multiplier
Larea, 0.100E+05, 0.100E+05, 0.271E-04, 0.156E-04, 0.209E-05, # lower zone coefficient
Lpwr, 3.20, 3.00, 2.00, 2.20, 2.60, # lower zone exponent
Lr1n, 0.200E-01, 0.200E-01, 0.200E-01, 0.200E-01, 0.200E-01, # channel Manning's n
Lr2n, 0.100E+01, 0.200E+01, 0.200E+01, 0.200E+01, 0.200E+01, # channel Manning's n
# :RoutingParameters
:EndRoutingParameters
#
# :HydrologicalParameters
:LandCoverClasses
:ClassName, bare_soil, forest, crops, water, impervious, # class name
:Lds, 1.00, 10.0, 2.00, 0.100E+10, 0.00, 1.00, # depression storage bare ground mm
:Ldsf, 1.00, 10.0, 2.00, 0.100E+10, 0.00, 1.00, # depression storage snow covered area mm
:Lrec, 1.00, 2.00, 2.00, 0.800, 0.100, 0.800, # interflow coefficient
:Lak, 2.94, 12.0, 3.00, 400, -0.100, 0.100E-10, # infiltration coefficient bare ground
:Lakf, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, # infiltration coefficient snow covered ground
# :HydrologicalParameters
: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
:uad, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000, # not used
:tilp, 0.100, 0.100, 0.100, 0.100, 0.100, 0.100, # coefficient for ati

---

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

September 2016
```
4. Model Parameters and Optimization

:rho, 0.333, 0.333, 0.333, 0.333, 0.333, 0.333, # snow density
:wcl, 0.035, 0.035, 0.035, 0.035, 0.035, 0.035, # fraction of swe as water in rip snow
:alb, 0.110, 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, 600.000, -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

: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

: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

:APILimits
:a5dlt, -0.100E-02
:a5low, 0.980
:a5hgh, 0.999

: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, # class name
:aklow, 0.400, 0.040, 0.004, 0.040, 0.040, 0.040, # class name
:akhgh, 50.000, 20.000, 0.050, 5.000, 5.000, 5.000, # class name
# infiltration coefficient snow covered ground
:akfslow, 0.004, 0.040, 0.044, 0.046, 0.046, 0.046,
:akfshgh, 0.500, 5.000, 5.000, 5.000, 5.000, 5.000,

# infiltration coefficient
:recdlow, -0.200E-01, -0.200E-01, -0.200E-01, -0.200E-01, -0.200E-01, -0.200E-01,
:recflow, 0.500E-03, 0.500E-03, 0.500E-03, 0.500E-03, 0.500E-03, 0.500E-03,
:recgh, 0.100, 0.100, 0.100, 0.100, 0.100, 0.100,

# overland flow roughness coeff bare ground
:r3dlow, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00,
:r3gh, 25.0, 10.0, 25.0, 10.0, 10.0, 10.0,

# 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,
:fratilow, 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
:ak2dlow, 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
:ak2fsdlow, 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,
4. Model Parameters and Optimization

:gladjustlow,          0.500
:gladjusthgh,           1.50
:EndGlobalSnowParLimits
#
:SnowParLimits
:ClassName       ,bare_soil   ,forest      ,crops       ,wetland     ,water       ,impervious  ,# class name
# melt factor mm/dc/hour
:fmldlt,             -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,  -0.500E-01,
:fmllow,              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
:baseedlt,           -0.200E-02,  -0.200E-02,  -0.200E-02,  -0.200E-02,  -0.200E-02,  -0.200E-02,
:baseelow,            -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 coefficient
:flzdlt,            -0.200E-01,  -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,   0.100E-06,
:flzhgh,             0.100E-03,   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,  -0.200E-01,
:pwrlow,             0.300    ,   0.300    ,   0.300    ,   0.300    ,   0.300    ,   0.300    ,
:pwrhgh,             4.00    ,    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,  -0.200E-01,
:r2nlow,             0.100E-01,   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    ,   0.100    ,
# wetland or bank porosity
:thetadlt,          -0.200E-01,  -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    ,   0.100    ,
:thetahgh,            0.600    ,   0.600    ,   0.600    ,   0.600    ,   0.600    ,   0.600    ,
# wetland/bank lateral conductivity
:kcondidlt,         -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,  -0.200E-01,
:kcondidlow,          0.900    ,   0.900    ,   0.900    ,   0.900    ,   0.900    ,   0.900    ,
:kcondidhgh,            3.00    ,    3.00    ,    3.00    ,    3.00    ,    3.00    ,    3.00    ,
# in channel lake retardation coefficient
:rlakedlt,          -0.100    ,  -0.100    ,  -0.100    ,  -0.100    ,  -0.100    ,  -0.100    ,
:rlakelow,               0.00    ,   0.00    ,   0.00    ,   0.00    ,   0.00    ,   0.00    ,
:rlakehgh,               3.00    ,    3.00    ,    3.00    ,    3.00    ,    3.00    ,    3.00    ,
:EndRoutingParLimits
#
:GlobalParLimits
# precip isep rate
:rlapsedlt,         0.100
:rlapseslow,          0.100
4. Model Parameters and Optimization

```
# temperature lapse rate
ttlapsehgh, 1.00
# radius of influence
radinfldlt, 1.00
radinflow, 0.00
radinflgh, 400.
# smoothing distance
smoothdisdlt, 1.00
smoothdislow, 0.00
smoothdisgh, 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 rffn.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. The WATFLOOD menu. When NUMA > 0, IOPT is set to 0 and the Green Keneu flag is set to off. I.e. all debug and visualization output is suppressed to help speed the optimization run. 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

> 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 a 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

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

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

\[
\text{Ch} = \begin{cases} 
1 & \text{for main channel} \\
0.9 & \text{for first channel} \\
0.7 & \text{for second channel} \\
0.6 & \text{for third channel} \\
0.5 & \text{for fourth channel} \\
0.4 & \text{for fifth channel} 
\end{cases}
\]

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

The following 11 lines are dimensioned for river classes. The river roughness and 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: \( R1n = \text{case sensitive} \) !!!)
- \( R2n^* \) = river channel Manning’s \( n \) (optimized) (\( R2n = \text{case sensitive} \) !!!)
- \( mndr \) = 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
- \( \text{widep} \) = width/depth ratio for the bankfull channel
- \( \text{kcond} \) = conductivity of the wetland(bank) – channel interface
- \( \text{pool} \) = average area of zero flow in channels with riffles & pools
- \( \text{rlake} \) = a multiplier for channel resistance depending on the lake area in each grid

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):
### Hydrological Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ds</td>
<td>Depression storage bare ground mm</td>
</tr>
<tr>
<td>dsfs</td>
<td>Depression storage snow covered area mm</td>
</tr>
<tr>
<td>rec</td>
<td>Interflow coefficient</td>
</tr>
<tr>
<td>ak</td>
<td>Infiltration coefficient bare ground</td>
</tr>
<tr>
<td>akfs</td>
<td>Infiltration coefficient snow covered ground</td>
</tr>
<tr>
<td>retn</td>
<td>Upper zone retention mm</td>
</tr>
<tr>
<td>ak2</td>
<td>Recharge coefficient bare ground</td>
</tr>
<tr>
<td>ak2fs</td>
<td>Recharge coefficient snow covered ground</td>
</tr>
<tr>
<td>r3</td>
<td>Overland flow roughness coefficient bare ground</td>
</tr>
<tr>
<td>r3fs</td>
<td>Overland flow roughness coefficient snow covered ground</td>
</tr>
<tr>
<td>r4</td>
<td>Overland flow roughness coefficient impervious area</td>
</tr>
<tr>
<td>fpet</td>
<td>Interception evaporation factor * pet</td>
</tr>
<tr>
<td>ftall</td>
<td>Reduction in PET for tall vegetation</td>
</tr>
<tr>
<td>flint</td>
<td>Interception flag 1=on &lt;1=off</td>
</tr>
<tr>
<td>fcap</td>
<td>Not used - replaced by retn (retention)</td>
</tr>
<tr>
<td>ffcap</td>
<td>Wilting point - mm of water in uzs</td>
</tr>
<tr>
<td>spore</td>
<td>Soil porosity</td>
</tr>
<tr>
<td>fratio</td>
<td>Int. capacity multiplier</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>SnowParameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>:fm</td>
</tr>
<tr>
<td>:base</td>
</tr>
<tr>
<td>:fnn</td>
</tr>
<tr>
<td>:uadj</td>
</tr>
<tr>
<td>:tipm</td>
</tr>
<tr>
<td>:rho</td>
</tr>
<tr>
<td>:whcl</td>
</tr>
<tr>
<td>:alb</td>
</tr>
<tr>
<td>:sublim_rate</td>
</tr>
<tr>
<td>:idump</td>
</tr>
<tr>
<td>:snocap</td>
</tr>
<tr>
<td>:nsdc</td>
</tr>
<tr>
<td>:sdcsca</td>
</tr>
<tr>
<td>:sdcd</td>
</tr>
</tbody>
</table>

Additional snowmelt parameters:

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

\[MF, BASE and sublimation \text{ rate are normally determined through optimization.}\]

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.

<table>
<thead>
<tr>
<th>month</th>
<th>jan</th>
<th>feb</th>
<th>mar</th>
<th>apr</th>
<th>may</th>
<th>jun</th>
<th>jul</th>
<th>aug</th>
<th>sep</th>
<th>oct</th>
<th>nov</th>
<th>dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>mxmn</td>
<td>10.2</td>
<td>12.3</td>
<td>12.1</td>
<td>12.3</td>
<td>14.3</td>
<td>14.2</td>
<td>13.8</td>
<td>14.0</td>
<td>13.1</td>
<td>10.6</td>
<td>8.2</td>
<td>9.3</td>
</tr>
<tr>
<td>humid</td>
<td>59.5</td>
<td>60.5</td>
<td>62.5</td>
<td>55.5</td>
<td>50.0</td>
<td>54.5</td>
<td>59.0</td>
<td>58.5</td>
<td>63.5</td>
<td>58.0</td>
<td>64.5</td>
<td>62.5</td>
</tr>
<tr>
<td>pres</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
<td>95.1</td>
</tr>
</tbody>
</table>

mxmn = the difference between the mean monthly maximum and mean monthly minimum temperatures in °C (it is converted to °F in the program).

humid = mean monthly relative humidity in percent

pres = mean monthly atmospheric pressure in kPa

4.4 Snow Cover Depletion Curve (SDC)

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

The program expects one set of values for each land cover class, including the impervious area, 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 requires 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
4. Model Parameters and Optimization

- 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.](image)

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 rffm 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:

```plaintext
: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\yyymmdd.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 rfin.txt files) and be validating on other data.

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

- NPER = 1, the delta values are a fraction of the parameter value.
- = 0, the delta value is an absolute amount. (1/10th 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:

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

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
```
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:

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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 just -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
:ddsf1g, 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:

```plaintext
! Comment lines 1 & 2: READ WITH WORD WRAP OFF. Input control file . . .
! <- Text inputs must in columns 1-24,
otherwise . . .
basiname !3 compact name for DDS output file
subdirecto . . .
watflood_batch.bat !4 .exe or .bat application name (no file exte . . .
```
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 Fort Rivers in Minnesota. “!n” refers to the line number in the DDS_init.txt file.

<table>
<thead>
<tr>
<th>Comment lines 1 &amp; 2:</th>
<th>READ WITH WORD WRAP OFF. Input control file for Fortran DDS ver1.1 algorithm. Inputs start on line 3.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 !5 number of optimization trials to run (1 to 1000)</td>
<td></td>
</tr>
<tr>
<td>300 !6 maximum number of objective function evaluations per optimization trial (7 is minimum)</td>
<td></td>
</tr>
<tr>
<td>134382176 !7 seed value</td>
<td></td>
</tr>
<tr>
<td>0 !8 Print flag: &quot;0&quot; saves all DDS outputs (max # files) or &quot;1&quot; to save only summary info (min # of files)</td>
<td></td>
</tr>
<tr>
<td>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-&gt; #sol's, cols-&gt; DVs 3) Use Watclass model input files to extract initial decision variables (coding in user obj. evaluator program handles case 3)</td>
<td></td>
</tr>
<tr>
<td>save_best.bat !15 Watclass specific input, can be blank - na !4 .exe or .bat application name (no file extension) to generate obj func value. Leave BLANK if User compiles DDS1 program &amp; their objective function together.</td>
<td></td>
</tr>
<tr>
<td>1 !12 MAX problem (enter &quot;-1&quot;) or MIN problem (enter &quot;1&quot;)</td>
<td></td>
</tr>
</tbody>
</table>
| 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.
4. Model Parameters and Optimization

![Table](https://example.com/table.png)

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
```

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.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.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

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

With radius of influence and smoothing distance also being optimized:

```bash
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.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_rev3.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:

```bash
save_best.bat
```

```bash
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.csv                best\stats.csv
You can add other files you wish to keep
```

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

**DDS.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.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.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:

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

   where
   
   - $O$ = observed flow for hour $j$
   - $P$ = predicted flow for hour $j$
   - $nhr$ = no of hours of record
   - $l$ = station number
   - $no$ = no of flow stations
   - and station weight $= sw_l = \frac{O_l}{\sum_{l=1}^{no} O_l}$

2. Sum of squared errors (SSE):

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

3. Sum of squared errors weighted with mean flow:

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

4. Volume only unweighted *(does not work too well)*:
4. Model Parameters and Optimization

\[
DDS_{error} = \sum_{i=1}^{n} \left[ \frac{\sum_{j=1}^{n} O_{ij} - \sum_{j=1}^{n} P_{ij}}{n_i} \right]^{2}
\]

where \( n_i = \text{number of observations for station } l \)

5. Volume weighted:

\[
DDS_{error} = \sum_{i=1}^{n} \left[ \frac{\sum_{j=1}^{n} O_{ij} - \sum_{j=1}^{n} P_{ij}}{n_i \cdot \sum_{j=1}^{n} O_{ij}} \right]^{2}
\]

6. Weighted sum of absolute errors:

\[
DDS_{error} = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{|O_{ij} - P_{ij}|}{O_{i}}
\]

7. Nash Efficiency (to be minimized)**

\[
DDS_{error} = \sum_{i=1}^{n} \left[ \frac{\sum_{j=1}^{n} (O_{ij} - P_{ij})}{\sum_{j=1}^{n} (\bar{O_{i}} - \bar{O})} \right]^{2}
\]

8. Nash Efficiency using \( \log(O_{ij}) \) and \( \log(P_{ij}) \) - 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 penalty is applied when \( Dv > 3\% \). \( A3 \) is a multiplier \( e^{-a3 \cdot (Dv(ii)-a4) \cdot (Dv(ii)-a4)} \) 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. 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
4. Model Parameters and Optimization

```plaintext
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:

```plaintext
copy ..\basin\gr10k_start_par.csv ..\basin\gr10k_par.csv
```plaintext
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\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:
4. Model Parameters and Optimization

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 directories 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 suffice to indicate some insensitivity 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):

<table>
<thead>
<tr>
<th>variable</th>
<th>theta</th>
<th>kcond</th>
<th>radin</th>
<th>smoot</th>
</tr>
</thead>
<tbody>
<tr>
<td>obj_fn</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>0.242454E+06</td>
<td>0.387565E+00</td>
<td>0.582581E+00</td>
<td>0.355959E+03</td>
<td>0.204289E+02</td>
</tr>
<tr>
<td>0.261004E+06</td>
<td>0.443512E+00</td>
<td>0.197076E+00</td>
<td>0.390479E+03</td>
<td>0.274989E+02</td>
</tr>
<tr>
<td>0.244470E+06</td>
<td>0.736029E+00</td>
<td>0.680491E+00</td>
<td>0.318999E+03</td>
<td>0.178311E+02</td>
</tr>
<tr>
<td>0.253440E+06</td>
<td>0.84952E+00</td>
<td>0.265174E+00</td>
<td>0.180663E+02</td>
<td>0.649235E+02</td>
</tr>
<tr>
<td>0.225530E+06</td>
<td>0.16124E+00</td>
<td>0.534536E+00</td>
<td>0.263214E+03</td>
<td>0.174199E+02</td>
</tr>
<tr>
<td>0.230213E+06</td>
<td>0.514956E+00</td>
<td>0.640026E+00</td>
<td>0.315302E+03</td>
<td>0.232514E+02</td>
</tr>
<tr>
<td>0.245022E+06</td>
<td>0.684374E+00</td>
<td>0.688238E+00</td>
<td>0.343077E+03</td>
<td>0.248711E+02</td>
</tr>
<tr>
<td>0.247493E+06</td>
<td>0.418768E+00</td>
<td>0.699992E+00</td>
<td>0.364348E+03</td>
<td>0.166421E+02</td>
</tr>
</tbody>
</table>

**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. Model Parameters and Optimization

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
f:\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

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

April 2017
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.

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

### 4.5.4 Ostrich (NEW 2022)

OSTRICH, developed by L. Shawn Matott, is a model-independent multi-algorithm parallel-friendly optimization and parameter estimation tool that implements numerous model-independent optimization 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. yyyyymmdd_rel.tb0.csv
3. yyyyymmdd_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 optimizing the coefficients in the resrl\yyyyymmdd_rel.tb0 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 yyyyymmdd_rel.tb0.csv.

```plaintext
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
```

```bash
cd ..
charm64x
```

**4.5.4.2 Resrl\yyyyymmdd_rel.tb0.csv**

This file is identical to the yyyyymmdd_rel.tb0 file but just has the .csv extension added.
4. Model Parameters and Optimization

<table>
<thead>
<tr>
<th>StartDate</th>
<th>2015/01/01</th>
</tr>
</thead>
<tbody>
<tr>
<td>StartTime</td>
<td>00:00:00.0</td>
</tr>
<tr>
<td>DeltaT</td>
<td>24</td>
</tr>
</tbody>
</table>

ColumnMetaData

<table>
<thead>
<tr>
<th>ColumnName</th>
<th>Muskoka</th>
<th>Lrossea</th>
<th>DummL</th>
<th>3MileL</th>
<th>Skeleto</th>
</tr>
</thead>
<tbody>
<tr>
<td>ColumnLocationX</td>
<td>-79.6780</td>
<td>-79.5760</td>
<td>-79.5050</td>
<td>-79.5160</td>
<td>-79.4990</td>
</tr>
<tr>
<td>ColumnLocationY</td>
<td>45.0220</td>
<td>45.1180</td>
<td>45.2440</td>
<td>45.1790</td>
<td>45.2250</td>
</tr>
<tr>
<td>coeff1</td>
<td>0.5000E-10</td>
<td>0.4000E-11</td>
<td>0.2000E-10</td>
<td>0.1000E-10</td>
<td>0.1000E-11</td>
</tr>
<tr>
<td>coeff2</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
</tr>
<tr>
<td>coeff3</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>coeff4</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>coeff5</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
</tr>
</tbody>
</table>

4.5.4.3 Resrl\yyymmdd_rel.tb0.tpl

This file is identical to the yyymmdd_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

<table>
<thead>
<tr>
<th>ColumnName</th>
<th>Muskoka</th>
<th>Lrossea</th>
<th>DummL</th>
<th>3MileL</th>
<th>Skeleto</th>
</tr>
</thead>
<tbody>
<tr>
<td>ColumnLocationX</td>
<td>-79.6780</td>
<td>-79.5760</td>
<td>-79.5050</td>
<td>-79.5160</td>
<td>-79.4990</td>
</tr>
<tr>
<td>ColumnLocationY</td>
<td>45.0220</td>
<td>45.1180</td>
<td>45.2440</td>
<td>45.1790</td>
<td>45.2250</td>
</tr>
<tr>
<td>coeff1</td>
<td>Muskoka</td>
<td>Lrossea</td>
<td>DummL</td>
<td>3MileL</td>
<td>Skeleto</td>
</tr>
<tr>
<td>coeff2</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
<td>0.1750E+01</td>
</tr>
<tr>
<td>coeff3</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>coeff4</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>coeff5</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
<td>0.0000E+00</td>
</tr>
</tbody>
</table>

4.5.4.4 Ostin.txt

ProgramType  DDS
ObjectiveFunction  GCOP
ModelExecutable  ost-CHARM.bat
PreserveBestModel  save_best.bat
# Randomseed 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 1.00E-11 5.00E-11 2.00E-11 none none none
x3MileL 1.00E-12 5.00E-12 2.00E-12 none none none
xAxrayl 5.00E-09 2.50E-09 10.00E-09 none none none
xFairy 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 5.00E-10 2.00E-10 none none none
xSmokeL 1.00E-10 5.00E-10 2.00E-10 none none none
xTeaL 1.00E-10 5.00E-10 2.00E-10 none none none

WATFLOOD/CHARM – Canadian Hydrological And Routing Model April 2017
4. Model Parameters and Optimization

4.5.4.5 Ostrich error function

CHARM will write the objective function value to the dds directory. 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 parallel-friendly
optimization and parameter estimation tool that implements numerous model-independent optimization
and calibration (parameter estimation) algorithms.

This section describes an application using DDS to optimize CHARM model

First thing: download the Ostrich 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 here to download the user manual,
demos, source code, and executables for Windows and Linux
Copy msvcr120.dll (2016 version) to your 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_par.tpl
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.

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 parameters:
4. Model Parameters and Optimization

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
:rln, 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_par.tpl file

```
:RoutingParameters
:RiverClasses, 1 ,
:RiverClassName, Default ,
:flz, flz_1 , # lower_zone_coefficient
:pwr, pwr_1 , # lower_zone_exponent
:rln, 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
:EndRoutingParameters
```

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 file and then rename it to bsnm_par.tpl
- The formats of the files have to be the same – same # lines and entries.

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-----------------
4. Model Parameters and Optimization

ProgramType ParallelDDS
#ProgramType ParaPADDSS

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

#-------------------Section3-------------------
BeginFilePairs
bsnm_par.tpl ; 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
#EndInitParams

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

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

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

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

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

April 2017
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 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 – e.g. gr10k. The program will read the event file toget 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-07  0.100000E-03 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     100.000       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 file**

`:fmadjust,fmadjust`
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

```batch
@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 $R_2$ 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 rfinv.txt files. To choose 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, …Hn) 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 Search 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. Model Parameters and Optimization

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, it 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°.

At your 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. Model Parameters and Optimization

4.5.7.1 Optimization for the BOREAS Southern Study Area (SSA)
4. Model Parameters and Optimization
4. Model Parameters and Optimization

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 parameter 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.](image-url)
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.

Next, with iopt set to 1, all state variables are plotted as in the next figure. This can be done for each land cover class. It turned out that the problem originated in class 3, in this case the agricultural area, which is the most dominant in this watershed. Everything appears normal in the bottom two plots which show the snow cover information and the inputs. The lzs shows the undulations and the unusual item that stands out is that the uzs for both the bare and snow covered areas are way above the retention of 40 mm although eventually they settle down to this value. But note that the uzs drops in steps! In the model, drainage of the uz ca not occur when the temperature is below 0°C and we note that periodically, the temperature, shown in the top plot is just above this value. The problem was caused by a value for the upper zone to lower zone drainage parameter ak2 and ak2fs that was much too low. This caused an initial buildup of water in the uz which could then drain at intervals when the temperature rose above. Thus a problem that appeared to be a routing problem was not that at all.
Figure 4.6. Diagnostic tool: plot of state variable for one land cover class.
4. Model Parameters and Optimization

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 errf = ?? 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 want sensitivities on the hydrological 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
.

WATFLOOD/CHARM – Canadian Hydrological And Routing Model  April 2017
Output file: `sensitivity.txt` in the working directory:

Routing parameters:

<table>
<thead>
<tr>
<th>param</th>
<th>upper_gr</th>
<th>conestoga</th>
<th>speed</th>
<th>eramosa</th>
<th>lower_gr</th>
</tr>
</thead>
<tbody>
<tr>
<td>flz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>0.065</td>
<td>0.076</td>
<td>0.259</td>
<td>-1.127</td>
<td>-0.013</td>
</tr>
<tr>
<td>+10%</td>
<td>-0.056</td>
<td>-0.075</td>
<td>-0.225</td>
<td>1.005</td>
<td>0.011</td>
</tr>
<tr>
<td>pwr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>1.234</td>
<td>0.223</td>
<td>4.098</td>
<td>-18.711</td>
<td>-0.227</td>
</tr>
<tr>
<td>+10%</td>
<td>-0.509</td>
<td>-1.089</td>
<td>-2.000</td>
<td>12.560</td>
<td>0.097</td>
</tr>
<tr>
<td>r2n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>-0.046</td>
<td>-0.010</td>
<td>-0.089</td>
<td>0.121</td>
<td>-0.009</td>
</tr>
<tr>
<td>+10%</td>
<td>0.040</td>
<td>-0.009</td>
<td>0.083</td>
<td>-0.126</td>
<td>0.010</td>
</tr>
<tr>
<td>theta</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>0.069</td>
<td>-0.176</td>
<td>0.133</td>
<td>-0.032</td>
<td>-0.022</td>
</tr>
<tr>
<td>+10%</td>
<td>-0.003</td>
<td>0.119</td>
<td>-0.076</td>
<td>0.000</td>
<td>0.024</td>
</tr>
<tr>
<td>kcond</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>-0.171</td>
<td>0.115</td>
<td>0.016</td>
<td>0.188</td>
<td>0.006</td>
</tr>
<tr>
<td>+10%</td>
<td>0.149</td>
<td>-0.119</td>
<td>-0.013</td>
<td>-0.168</td>
<td>-0.005</td>
</tr>
<tr>
<td>rlake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>+10%</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Hydrological parameters:

<table>
<thead>
<tr>
<th>param</th>
<th>bare_soil</th>
<th>forest</th>
<th>crops</th>
<th>wetland</th>
<th>water</th>
<th>imperv</th>
</tr>
</thead>
<tbody>
<tr>
<td>rec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>0.000</td>
<td>0.071</td>
<td>0.284</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>+10%</td>
<td>0.000</td>
<td>-0.064</td>
<td>-0.276</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>ak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10%</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.033</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>+10%</td>
<td>0.000</td>
<td>0.000</td>
<td>0.041</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

...
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>
<thead>
<tr>
<th>Keyword</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoordSys</td>
<td>Coordinate system – should be one of: Cartesian, UTM, LATLONG.</td>
</tr>
<tr>
<td></td>
<td>The same coordinate system must be used in all input files for a given watershed.</td>
</tr>
<tr>
<td>Datum, Zone</td>
<td>Geodetic datum and projection zone – these depend on the coordinate system:</td>
</tr>
<tr>
<td></td>
<td>• For Cartesian coordinate system Datum and Zone are not allowed</td>
</tr>
<tr>
<td></td>
<td>• For UTM, Datum and Zone are required</td>
</tr>
<tr>
<td></td>
<td>• For LATLONG, Datum is required and Zone is not allowed</td>
</tr>
<tr>
<td>SampleTime</td>
<td>Date/time of SWE observation.</td>
</tr>
<tr>
<td>UnitConversion</td>
<td>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.</td>
</tr>
</tbody>
</table>
5. Model Initialization

| 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). |

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.

WATFLOOD/CHARM – Canadian Hydrological And Routing Model April 2017
5. Model Initialization

- After distributing the swe, open the snow1\yyyymmdd_swe.r2c file in Green Kenue and ensure that all watershed 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.

```
# File: Snow Water Equivalent
# Format: ASCII Green Kenue 2.1.23
# Application: SNW.exe
# SourceFile: snow1\19930101_crs.pt2
# Projection: UTM
# Ellipsoid: GRS80
# Zone: 17
# xOrigin: 500000.000
# yOrigin: 4790000.000
# AttributeName 1 Class 1
# AttributeName 2 Class 2
# AttributeName 3 Class 3
# AttributeName 4 Class 4
# AttributeName 5 Class 5
# AttributeName 6 Class 6
```
# 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.

## 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 value.
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
:UnitConversion 1.000
:endHeader
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 0.12
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 0.14 0.13 0.13
0.13 0.13 0.14 0.15 0.15 0.14 0.13 0.13
0.13 0.13 0.14 0.14 0.14 0.14 0.13 0.13
0.13 0.13 0.13 0.14 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
0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22         # start of class 2 data
0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22
0.22 0.22 0.22 0.22 0.22 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
# ...
```

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.tbo* 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 conditions. If this is not possible, an adequate 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 thcflg = 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 overwritten. 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. Model Initialization

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 YYYYMMDD` With this argument, the `yyyymmdd_crs.pt2` file in the event file will be ignored and the file `snow1\YYYYMMDD_crs.pt2` will be used to produce the `snow1\YYYYMMDD_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 thflg = 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

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

<table>
<thead>
<tr>
<th>File Type</th>
<th>Directory Location</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>* .SCN</td>
<td>RADAR</td>
<td>RADAR ASCII file in resolution of the radar for the whole radar field</td>
</tr>
<tr>
<td>* .RAD</td>
<td>RADUC</td>
<td>RADAR ASCII files converted to the SPL grid for the modeling area</td>
</tr>
<tr>
<td>* _RAG. tb0</td>
<td>RAIN</td>
<td>Point precip gauge data</td>
</tr>
<tr>
<td>&amp; _MET.r2c</td>
<td>RADCL</td>
<td>Distributed precip gauge data or adjusted radar data</td>
</tr>
</tbody>
</table>

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. Rainfall Data Processing

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>*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 exist 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 indicates that the
values are in mm. Each column corresponds to one station listed above.

<table>
<thead>
<tr>
<th>0.80</th>
<th>0.50</th>
<th>2.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.70</td>
<td>12.00</td>
<td>20.00</td>
</tr>
<tr>
<td>0.80</td>
<td>1.50</td>
<td>2.50</td>
</tr>
<tr>
<td>10.70</td>
<td>10.00</td>
<td>8.00</td>
</tr>
<tr>
<td>1.80</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>5.30</td>
<td>3.00</td>
<td>2.00</td>
</tr>
<tr>
<td>0.80</td>
<td>2.00</td>
<td>1.50</td>
</tr>
<tr>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.50</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>0.50</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>2.80</td>
<td>2.00</td>
<td>1.50</td>
</tr>
</tbody>
</table>

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. Rainfall Data Processing

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* file can be loaded into Green Kenue and animated. Timeseries of precipitation 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/bsmn_par.csv in the appropriate line – e.g.:

: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 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 **just** large enough so the whole watershed will have precipitation.
6. Rainfall Data Processing

- 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 influence & 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.

\[ \text{rlapse} = \text{lapse rate in mm} / 1 \text{ m elevation} \]

**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

\[ \text{precip}(n)= \frac{\text{precip}(n)}{1+\text{sta_elv}(n)\times \text{rlapse}} \]

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

\[ \text{precip}(i,j)= \text{precip}(i,j)\times(1.0+\text{elev_grid}(i,j)\times \text{rlapse}) \]

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

\[ 9150 + 610 = 9150 \times (1.0 + 1000 \times \text{rlapse}) \]

\[ \frac{9760/9150 - 1.0}{1000} = 0.00007 = \text{rlapse} \]

If the precipitation 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.

```plaintext
#-----------------------------
# :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
```

WATFLOOD/CHARM – Canadian Hydrological And Routing Model  April 2017
### Rainfall Data Processing

```
# :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
#
:UnitConversion 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 1.32 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
```
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/yyyymmdd_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.
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 polygons, you can make the weight = 10 by issuing the command:

tmp 10

Example of Point Temperature File:

FLN = temp\ymmd\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
```
7. Temperature Data

<table>
<thead>
<tr>
<th>ColumnUnits</th>
<th>dC</th>
<th>dC</th>
</tr>
</thead>
<tbody>
<tr>
<td>ColumnType</td>
<td>float</td>
<td>float</td>
</tr>
<tr>
<td>ColumnName</td>
<td>Wormwood</td>
<td>Logan_farm</td>
</tr>
<tr>
<td>ColumnLocationX</td>
<td>530000.</td>
<td>560000.</td>
</tr>
<tr>
<td>ColumnLocationY</td>
<td>4900000.</td>
<td>4800000.</td>
</tr>
<tr>
<td>Elevation</td>
<td>1700.</td>
<td>1140.</td>
</tr>
</tbody>
</table>

<- Optional

-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:

```plaintext
: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 Keneu)

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.

\[
\text{rlapse} = \text{lapse rate in } \text{dC} / \text{1 m elevation} \\
\text{elvref} = \text{elevation reference for temperature data.}
\]

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.
### 7. Temperature Data

#### 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.r2c*:

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

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

```
File: WATFLOOD - Canadian Hydrological And Routing Model
Version: 2.1.23
Written By: tmp.exe
Creation Date: 2014-01-25 21:38

### 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.r2c*:

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

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

 Namen Gridded Temperature Differences

 :Projection UTM
 :Ellipsoid GRS80
 :Zone 17

 :SourceFile tempg\19930101_tag.tb0

 :AttributeName 1 dailyTemperatureDifferences
 :AttributeUnits degreeCelcius

 :xCount 9
 :yCount 12
 :xDelta 10000.0000
 :yDelta 10000.0000

 :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 6.7 6.7 6.7
 6.7 6.7 6.8 6.8 6.8 6.8 6.8 6.8 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

 :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 4.2 4.2 4.2 4.2 4.2 4.2 4.2
 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 temp 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).

# File: _str_tb0  ASCII Green Kenue 1.0
#
# DataType       Green Kenue Table
# :Application    Green Kenue
#:Version        2.1.23
8. Flow Data

::WrittenBy: translate.
::CreationDate: 2006-09-28 15:42
#
#:---------------------------------------
#:---------------------------------------
#:SourceFile: strfw\19930101.str
#:---------------------------------------
#:Name: Streamflow
#:---------------------------------------
#:Projection: UTM
#:Ellipsoid: NAD83
#:Zone: 17
#:---------------------------------------
#:Startime: 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 18.000
-1.000 -1.000 19.800
-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 regardless of file length

The coefficients can be used for applications where only stage data is available which can be converted to flows using a polynomial 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 not included for objective function calculation
value1(n) = 1 station is included for objective function calculation
These values must be set in each str file in a continuous simulation.
Shortcut:
To avoid having to edit a number of str files, value1 can be set in the first event's str file by setting just
one of the values = -1 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 whether 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 particular station by setting Value1= -2 in the str file for the first event.

You can also 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 km² 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    -75.850   45.250    539  
GULL_RIVER   -78.819   44.732    1280  
BURNT_RIVER   -78.650   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      -78.817   46.350    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`

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>actual</th>
<th>model</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>-79.283</td>
<td>44.700</td>
<td>1</td>
<td>BLACK_WASH</td>
<td>1520.</td>
</tr>
<tr>
<td>-75.850</td>
<td>45.250</td>
<td>2</td>
<td>JOCK_RIVER</td>
<td>539.</td>
</tr>
<tr>
<td>-78.817</td>
<td>44.733</td>
<td>3</td>
<td>GULL_RIVER</td>
<td>1280.</td>
</tr>
<tr>
<td>-78.650</td>
<td>44.700</td>
<td>4</td>
<td>BURNT_RIVER</td>
<td>1270.</td>
</tr>
<tr>
<td>-77.517</td>
<td>45.333</td>
<td>5</td>
<td>MADAWASKA</td>
<td>5800.</td>
</tr>
<tr>
<td>-76.283</td>
<td>45.050</td>
<td>6</td>
<td>MISSISSIPPI</td>
<td>2620.</td>
</tr>
<tr>
<td>-80.483</td>
<td>45.767</td>
<td>7</td>
<td>MAGNETWAN</td>
<td>2850.</td>
</tr>
<tr>
<td>-77.783</td>
<td>44.367</td>
<td>8</td>
<td>TRENT_RIVE</td>
<td>9090.</td>
</tr>
<tr>
<td>-76.830</td>
<td>44.340</td>
<td>9</td>
<td>NAPANEE_R</td>
<td>694.</td>
</tr>
<tr>
<td>-77.350</td>
<td>45.883</td>
<td>10</td>
<td>PETAWAWA</td>
<td>4120.</td>
</tr>
<tr>
<td>-79.883</td>
<td>47.883</td>
<td>11</td>
<td>BLANCHE_RIV</td>
<td>1780.</td>
</tr>
<tr>
<td>-77.817</td>
<td>46.350</td>
<td>12</td>
<td>DUMOINE</td>
<td>3760.</td>
</tr>
</tbody>
</table>

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
#: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
8. Flow Data

<table>
<thead>
<tr>
<th>Location</th>
<th>Release</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.500</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>7.500</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>7.500</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>7.500</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

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 rule for 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.
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. | STORE |
| 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 |
| Coeff3          | 6.45E-13 | 1.08E-15 | -1.05E-14 | 0.00E-00 | STORE |
| Coeff4          | 0.00E+00 | -1.22E-20 | 1.26E-19 | 0.00E-00 | STORE |
| Coeff5          | 0.00E+00 | 7.80E-26 | 0.00E+00 | 0.00E-00 | STORE |

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 are(a) 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 2\textsuperscript{nd} 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:

\[
\text{Elevation} = \text{coeff3(datum)} + \text{coeff4}*\text{storage}^{\text{coeff5}}
\]

**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:

```plaintext
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 – e.g. a continuously rising or falling reservoir 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.

<table>
<thead>
<tr>
<th>Sta_No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skunk_falls</td>
<td>regulated</td>
<td>Skunk_falls</td>
<td>Shiny_Rapids</td>
<td>Beaver_GS</td>
<td>HiHo_GS</td>
<td>Moonshine</td>
</tr>
<tr>
<td>YEAR</td>
<td>weir</td>
<td>regulated</td>
<td>regulated</td>
<td>regulated</td>
<td>regulated</td>
<td>regulated</td>
</tr>
<tr>
<td>2002</td>
<td>1</td>
<td>1</td>
<td>0.95</td>
<td>1.05</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2003</td>
<td>1</td>
<td>1</td>
<td>0.95</td>
<td>1.05</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2004</td>
<td>1.2</td>
<td>1</td>
<td>1.255</td>
<td>1.25</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2005</td>
<td>1.2</td>
<td>1</td>
<td>1.255</td>
<td>1.25</td>
<td>1.6</td>
<td>1</td>
</tr>
<tr>
<td>2006</td>
<td>1.2</td>
<td>1</td>
<td>1.255</td>
<td>1.15</td>
<td>1.6</td>
<td>1</td>
</tr>
<tr>
<td>2007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.15</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>2008</td>
<td>0.85</td>
<td>1</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>2009</td>
<td>0.85</td>
<td>1</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>2010</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>2011</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>2012</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>2013</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>2014</td>
<td>1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
<td>1.1</td>
<td>1</td>
</tr>
</tbody>
</table>

8.3 Reservoir/Lake Routing with Target Water levels

CHARM has an option to read in target upper and 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.
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 resfl*_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.exe
:CreationDate           2013-09-12 09:36
#
#----------------------------------------
:SourceFile             lake_inflow_data
#
```

Figure 8.2. Example operating rule – GRCA
### 8. Flow Data

:Name lakeInflows

:Projection LATLONG

:Ellipsoid WGS84

:StartDate 1985/01/01

:StartTime 00:00:00.0

:DeltaT 24

:ColumnMetaData

<table>
<thead>
<tr>
<th>ColumnName</th>
<th>ColumnLocationX</th>
<th>ColumnLocationY</th>
<th>ColumnUnits</th>
<th>ColumnType</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_o_t_Woods</td>
<td>-94.5131</td>
<td>49.7844</td>
<td>cms</td>
<td>float</td>
</tr>
<tr>
<td>Lac_Seuil</td>
<td>-93.1990</td>
<td>50.6333</td>
<td>cms</td>
<td>float</td>
</tr>
<tr>
<td>L_St_Joseph</td>
<td>-90.2010</td>
<td>51.1000</td>
<td>cms</td>
<td>float</td>
</tr>
</tbody>
</table>

:Value1 1 1 1

:endColumnMetaData

:endHeader

<table>
<thead>
<tr>
<th>Value1</th>
<th>Value2</th>
<th>Value3</th>
</tr>
</thead>
<tbody>
<tr>
<td>300.900</td>
<td>140.300</td>
<td>33.100</td>
</tr>
<tr>
<td>227.300</td>
<td>190.300</td>
<td>32.300</td>
</tr>
<tr>
<td>240.300</td>
<td>226.800</td>
<td>139.800</td>
</tr>
<tr>
<td>233.200</td>
<td>224.000</td>
<td>140.500</td>
</tr>
<tr>
<td>89.500</td>
<td>224.600</td>
<td>87.200</td>
</tr>
</tbody>
</table>

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
```

---

WATFLOOD/CHARM — Canadian Hydrological And Routing Model  
April 2017
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

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 polygons, 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
# Commented [AN8]: Why grayed out?
# :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   9.000
-1.000 28.000  26.000
ect.

tot.
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
#
#---------------------------------------
#
: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 90.000
-1.000 150.000 80.000
-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
#
#:radius of influence km 243.6560059
#:smoothing distance km 44.9729996
#
#:endHeader
#:Frame 1 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
### 9. Wind Speed and Direction Data

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>1.00</th>
<th>4.17</th>
<th>4.17</th>
<th>4.18</th>
<th>4.20</th>
<th>4.25</th>
<th>4.33</th>
<th>4.44</th>
<th>5.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.67</td>
<td>4.09</td>
<td>4.07</td>
<td>4.05</td>
<td>4.05</td>
<td>4.06</td>
<td>4.09</td>
<td>4.17</td>
<td>3.99</td>
<td>3.87</td>
</tr>
<tr>
<td>4.00</td>
<td>3.97</td>
<td>3.94</td>
<td>3.91</td>
<td>3.90</td>
<td>3.92</td>
<td>3.75</td>
<td>3.85</td>
<td>3.78</td>
<td></td>
</tr>
</tbody>
</table>

...
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
#
# radius of influence  km                     243.6560059
#smoothing distance   km                      44.9729996
#
:endHeader

:Frame         l     1     1   "1990/1/1  4:00:00.000"
  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.    4.    4.    4.    4.    4.
etc.
NOTE: Wind direction is used in 8 compass 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 an 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:

`\\\BSNM\RFLUX\YYMDD.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.

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 plots and 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:

Commented [AN9]: Why not just use different directories?
<table>
<thead>
<tr>
<th>File Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class_distribution.txt</td>
<td>The percent of each land cover above each flow gauge (including all sub-basins).</td>
</tr>
<tr>
<td>Error.r2c **</td>
<td>An r2c file for showing a 2D plot of flow error in Green Kenue</td>
</tr>
<tr>
<td>Evap.txt</td>
<td>For program development – output from s/r AET.f</td>
</tr>
<tr>
<td>Evt means.csv</td>
<td>Mean flows for each event: observed &amp; computed.</td>
</tr>
<tr>
<td>Gridflow.r2c</td>
<td>An r2c file for showing grid outflow in Green Kenue. This can also be done with the watflood.wfo file</td>
</tr>
<tr>
<td>lake_sd.csv **</td>
<td>Lake elevation, storage, inflow and outflows and some other derived variables are listed &amp; can be plotted as time series. For instance, computed lake levels can be compared with observed lake levels in a separate file.</td>
</tr>
<tr>
<td>Mrb_master_inflow.tb0</td>
<td>Reach inflows that can be used directly as input to the 1D hydraulic model Flow1D. These reaches can also be lakes or reservoirs.</td>
</tr>
<tr>
<td>Nash_eff.r2c</td>
<td>An r2c file for showing a 2D plot of Nash efficiency in Green Kenue</td>
</tr>
<tr>
<td>Opt.txt</td>
<td>Parameter values and errors are written for each iteration when optimizing</td>
</tr>
<tr>
<td>Peaks.txt</td>
<td>Not used</td>
</tr>
<tr>
<td>Pic.txt</td>
<td>Gridded bankfull index values used by the mapper.exe program to do the watershed animation</td>
</tr>
<tr>
<td>Precip.txt</td>
<td>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</td>
</tr>
<tr>
<td>Res.txt</td>
<td>Reservoir information when running with IOPT &gt;0</td>
</tr>
<tr>
<td>Resin.txt</td>
<td>Reservoir inflows. Used if reservoir inflow (yymmdd.rin) files are used and resinfy is set='y'. Compares computed to observed reservoir inflows. Similar to spl.csv file.</td>
</tr>
<tr>
<td>Rff(1-class#) **</td>
<td>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</td>
</tr>
<tr>
<td>Rte.txt</td>
<td>Echoed streamflow data and gridded information about the initialization of streamflow and lower zone storage based on streamflow. Shows more data with higher IOPT.</td>
</tr>
<tr>
<td>Sed.csv</td>
<td>Sediment routine output. Sediment concentration graphs. (Not for general use).</td>
</tr>
<tr>
<td>Snw.csv</td>
<td>Snow debug file for debug grid and class</td>
</tr>
<tr>
<td>Snw.txt</td>
<td>Diagnostic data for the melt routines</td>
</tr>
<tr>
<td>Snw1.txt</td>
<td>Diagnostic file for melt routines with IOPT &gt;0</td>
</tr>
</tbody>
</table>
## 11. Output Files

<table>
<thead>
<tr>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snowdebug.txt</td>
<td>Write swe at designated snow courses</td>
</tr>
<tr>
<td>Spl.csv</td>
<td>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.</td>
</tr>
<tr>
<td>Spl.tb0</td>
<td>Pairs of observed/computed streamflow for use in Green Kenue (same data as spl.csv below)</td>
</tr>
<tr>
<td>Spl_dly.csv</td>
<td>A file with daily flows created when the input hydrograph has time steps less than 24 hours.</td>
</tr>
<tr>
<td>Spl_mly.csv</td>
<td>A file with monthly flows observed &amp; computed</td>
</tr>
<tr>
<td>Stg.plt</td>
<td>Computed streamflow used by stgplt.exe (DOS) to plot stage hydrographs</td>
</tr>
<tr>
<td>Strout(1-10)</td>
<td>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.</td>
</tr>
<tr>
<td>Temp_junk.txt</td>
<td>As the name implies. Used for program development.</td>
</tr>
<tr>
<td>Volumes.txt</td>
<td>Not used</td>
</tr>
<tr>
<td>Watbal(1 &amp; 2)</td>
<td>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.</td>
</tr>
<tr>
<td>Watflood.wfo</td>
<td>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</td>
</tr>
<tr>
<td>Wetland.csv</td>
<td>Lists all wetland state variables for the debug grid specified in the bsmn_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.</td>
</tr>
</tbody>
</table>
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.
5545000.000 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_DRAVT 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. = 249 file no 39 = raing\19930101_rag.tb0
Unit no. = 35 file no 5 = raing\19930101_tag.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 = rearl\19930101_rwl.tb0
Unit no. = 38 file no 8 = rearl\19930101_rin.tb0
Unit no. = 285 file no 35 = snow\19930101_rss.pt2
Unit no. = 39 file no 9 = radar\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 = snow\19930101_swe.r2c
```
11. Output Files

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 19 = tempr\19930101_tem.r2c
Unit no. = 284 file no 34 =
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
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 in the working directory:

<table>
<thead>
<tr>
<th>yy</th>
<th>xx</th>
<th>l name</th>
<th>frac</th>
<th>imp</th>
<th>classes 1-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>-114.183</td>
<td>49.914</td>
<td>A0023</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00 0.20 0.00 0.11 0.45 0.38 0.00 0.05 0.00</td>
</tr>
<tr>
<td>-115.569</td>
<td>51.175</td>
<td>BB001</td>
<td>1.00</td>
<td>0.00</td>
<td>0.03 0.00 0.12 0.35 0.38 0.00 0.00 0.07 0.04</td>
</tr>
<tr>
<td>-114.139</td>
<td>52.028</td>
<td>CB001</td>
<td>1.00</td>
<td>0.00</td>
<td>0.12 0.00 0.02 0.03 0.30 0.00 0.03 0.00</td>
</tr>
<tr>
<td>-118.475</td>
<td>49.844</td>
<td>HD036</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00 0.00 0.94 0.06 0.00 0.00</td>
</tr>
<tr>
<td>-112.875</td>
<td>49.708</td>
<td>A007</td>
<td>1.00</td>
<td>0.00</td>
<td>0.14 0.01 0.02 0.07 0.72 0.01 0.03 0.00</td>
</tr>
<tr>
<td>-112.844</td>
<td>49.333</td>
<td>E006</td>
<td>1.00</td>
<td>0.00</td>
<td>0.01 0.08 0.00 0.23 0.61 0.04 0.00 0.02</td>
</tr>
<tr>
<td>-110.678</td>
<td>50.043</td>
<td>A001</td>
<td>1.00</td>
<td>0.01</td>
<td>0.00 0.07 0.02 0.05 0.75 0.08 0.01 0.01</td>
</tr>
<tr>
<td>-114.050</td>
<td>51.050</td>
<td>BB004</td>
<td>1.00</td>
<td>0.07</td>
<td>0.01 0.14 0.04 0.19 0.16 0.29 0.00 0.08 0.02</td>
</tr>
<tr>
<td>-112.844</td>
<td>49.333</td>
<td>E006</td>
<td>1.00</td>
<td>0.00</td>
<td>0.01 0.08 0.00 0.23 0.61 0.04 0.00 0.02</td>
</tr>
<tr>
<td>-110.678</td>
<td>50.043</td>
<td>A001</td>
<td>1.00</td>
<td>0.01</td>
<td>0.00 0.07 0.02 0.05 0.75 0.08 0.01 0.01</td>
</tr>
<tr>
<td>-114.050</td>
<td>51.050</td>
<td>BB004</td>
<td>1.00</td>
<td>0.07</td>
<td>0.01 0.14 0.04 0.19 0.16 0.29 0.00 0.08 0.02</td>
</tr>
<tr>
<td>-112.844</td>
<td>49.333</td>
<td>E006</td>
<td>1.00</td>
<td>0.00</td>
<td>0.01 0.08 0.00 0.23 0.61 0.04 0.00 0.02</td>
</tr>
<tr>
<td>-110.678</td>
<td>50.043</td>
<td>A001</td>
<td>1.00</td>
<td>0.01</td>
<td>0.00 0.07 0.02 0.05 0.75 0.08 0.01 0.01</td>
</tr>
<tr>
<td>-114.050</td>
<td>51.050</td>
<td>BB004</td>
<td>1.00</td>
<td>0.07</td>
<td>0.01 0.14 0.04 0.19 0.16 0.29 0.00 0.08 0.02</td>
</tr>
<tr>
<td>-112.844</td>
<td>49.333</td>
<td>E006</td>
<td>1.00</td>
<td>0.00</td>
<td>0.01 0.08 0.00 0.23 0.61 0.04 0.00 0.02</td>
</tr>
</tbody>
</table>

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 0.

qlzfrac = 1.00 in runof5 <<<<<<<<
11. Output Files

11.2.4 Reservoir Locations and Operating Rules

<table>
<thead>
<tr>
<th>i</th>
<th>ires(i)</th>
<th>jres(i)</th>
<th>b1(i)</th>
<th>b2(i)</th>
<th>b3(i)</th>
<th>b4(i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>6</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>6</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

11.2.5 Information for Each Grid

lst: the maximum calculated flows are:

<table>
<thead>
<tr>
<th>n</th>
<th>yyy(n)</th>
<th>xxx(n)</th>
<th>da(n)</th>
<th>qmax(n)</th>
<th>sump(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>5</td>
<td>10.0</td>
<td>4.8</td>
<td>140.5</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>6</td>
<td>60.0</td>
<td>30.1</td>
<td>133.9</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>6</td>
<td>160.0</td>
<td>48.2</td>
<td>139.7</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>5</td>
<td>30.0</td>
<td>6.8</td>
<td>146.7</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>6</td>
<td>290.0</td>
<td>76.3</td>
<td>134.9</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>7</td>
<td>68.0</td>
<td>15.3</td>
<td>126.4</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>44</td>
<td>3</td>
<td>6</td>
<td>693.0</td>
<td>100.6</td>
<td>129.3</td>
</tr>
<tr>
<td>45</td>
<td>2</td>
<td>5</td>
<td>2628.0</td>
<td>302.2</td>
<td>140.2</td>
</tr>
<tr>
<td>46</td>
<td>2</td>
<td>6</td>
<td>3520.0</td>
<td>434.5</td>
<td>147.1</td>
</tr>
</tbody>
</table>

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 0.30 0.30 0.30 0.30 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30
0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 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. 0. 141. 134. 0. 0. 0. 0.
0. 0. 0. 0. 147. 140. 0. 0. 0. 0.
0. 0. 0. 0. 144. 135. 126. 0. 0. 0.
0. 0. 0. 0. 141. 145. 135. 128. 0. 0.
0. 0. 145. 142. 142. 146. 140. 0. 0. 0.
0. 132. 138. 140. 143. 140. 137. 133. 0. 0.
0. 137. 142. 138. 134. 139. 134. 131. 0. 0.
0. 0. 139. 127. 127. 129. 132. 136. 0. 0.
0. 0. 129. 134. 131. 129. 140. 146. 0. 0.
0. 0. 0. 132. 140. 147. 144. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
### 11. Output Files

<table>
<thead>
<tr>
<th>Location</th>
<th>Area</th>
<th>Precip</th>
<th>RR</th>
<th>PR</th>
<th>CR</th>
<th>CR(t)</th>
<th>Dv%</th>
<th>Nash</th>
<th>Qp/m</th>
<th>Qp/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRND</td>
<td>3520</td>
<td>137.</td>
<td>57</td>
<td>56</td>
<td>78</td>
<td>-2</td>
<td>0.8</td>
<td>507</td>
<td>451</td>
<td></td>
</tr>
<tr>
<td>OSA/GUEL CON</td>
<td>1170</td>
<td>141.</td>
<td>58</td>
<td>46</td>
<td>65</td>
<td>-22</td>
<td>0.7</td>
<td>219</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>DARMAR</td>
<td>694</td>
<td>-10.</td>
<td>51</td>
<td>66</td>
<td>76</td>
<td>-10</td>
<td>0.7</td>
<td>262</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td></td>
<td>235</td>
<td>133.</td>
<td>52</td>
<td>58</td>
<td>90</td>
<td>11</td>
<td>0.3</td>
<td>29</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>365</td>
<td>141.</td>
<td>26</td>
<td>83</td>
<td>64</td>
<td>98</td>
<td>0.9</td>
<td>54</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>167</td>
<td>137.</td>
<td>81</td>
<td>65</td>
<td>100</td>
<td>-20</td>
<td>0.6</td>
<td>60</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>593</td>
<td>130.</td>
<td>49</td>
<td>67</td>
<td>95</td>
<td>36</td>
<td>0.6</td>
<td>54</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>118</td>
<td>138.</td>
<td>0</td>
<td>54</td>
<td>-1</td>
<td>-99</td>
<td>0.0</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>694</td>
<td>137.</td>
<td>42</td>
<td>52</td>
<td>76</td>
<td>23</td>
<td>0.8</td>
<td>181</td>
<td>154</td>
<td></td>
</tr>
</tbody>
</table>

#### 11.2.7 Cumulative Statistics for Each Event

<table>
<thead>
<tr>
<th>Location</th>
<th>Area</th>
<th>Precip</th>
<th>RR</th>
<th>PR</th>
<th>CR</th>
<th>CR(t)</th>
<th>Dv%</th>
<th>Nash</th>
<th>Qp/m</th>
<th>Qp/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRND</td>
<td>3520</td>
<td>137.</td>
<td>57</td>
<td>56</td>
<td>78</td>
<td>-2</td>
<td>0.8</td>
<td>507</td>
<td>451</td>
<td></td>
</tr>
<tr>
<td>OSA/GUEL CON</td>
<td>1170</td>
<td>141.</td>
<td>58</td>
<td>46</td>
<td>65</td>
<td>-22</td>
<td>0.7</td>
<td>219</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>DARMAR</td>
<td>694</td>
<td>-10.</td>
<td>51</td>
<td>66</td>
<td>76</td>
<td>-10</td>
<td>0.7</td>
<td>262</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td></td>
<td>235</td>
<td>133.</td>
<td>52</td>
<td>58</td>
<td>90</td>
<td>11</td>
<td>0.3</td>
<td>29</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>365</td>
<td>141.</td>
<td>26</td>
<td>83</td>
<td>64</td>
<td>98</td>
<td>0.9</td>
<td>54</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>167</td>
<td>137.</td>
<td>81</td>
<td>65</td>
<td>100</td>
<td>-20</td>
<td>0.6</td>
<td>60</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>593</td>
<td>130.</td>
<td>49</td>
<td>67</td>
<td>95</td>
<td>36</td>
<td>0.6</td>
<td>54</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>118</td>
<td>138.</td>
<td>0</td>
<td>54</td>
<td>-1</td>
<td>-99</td>
<td>0.0</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>694</td>
<td>137.</td>
<td>42</td>
<td>52</td>
<td>76</td>
<td>23</td>
<td>0.8</td>
<td>181</td>
<td>154</td>
<td></td>
</tr>
</tbody>
</table>
11. Output Files

11.2.8 Repeated for Each Event

<table>
<thead>
<tr>
<th>Time</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>68.</td>
<td>69.</td>
<td>67.</td>
<td>59.</td>
<td>59.</td>
<td>70.</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>68.</td>
<td>68.</td>
<td>34.</td>
<td>65.</td>
<td>65.</td>
<td>60.</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>70.</td>
<td>68.</td>
<td>90.</td>
<td>63.</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>runtime</td>
<td>14:13:59</td>
<td>2007-02-13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>location</td>
<td>area</td>
<td>precip</td>
<td>o/ro&lt;-&gt;c/ro</td>
<td>o/ro</td>
<td>Dv%</td>
<td>nash</td>
<td>qp/m</td>
<td>qp/c</td>
</tr>
<tr>
<td>GRND</td>
<td>3520.</td>
<td>182.</td>
<td>57.</td>
<td>56.</td>
<td>98.</td>
<td>-2.</td>
<td>0.8</td>
<td>507.</td>
</tr>
<tr>
<td>GSA/GUEL CON</td>
<td>1170.</td>
<td>186.</td>
<td>61.</td>
<td>46.</td>
<td>76.</td>
<td>-24.</td>
<td>0.7</td>
<td>219.</td>
</tr>
<tr>
<td>DERMAR</td>
<td>694.</td>
<td>-10.</td>
<td>51.</td>
<td>46.</td>
<td>98.</td>
<td>-10.</td>
<td>0.7</td>
<td>262.</td>
</tr>
<tr>
<td>235.</td>
<td>184.</td>
<td>54.</td>
<td>60.</td>
<td>127.</td>
<td>10.</td>
<td>0.3</td>
<td>29.</td>
<td>52.</td>
</tr>
<tr>
<td>365.</td>
<td>187.</td>
<td>26.</td>
<td>43.</td>
<td>109.</td>
<td>65.</td>
<td>0.9</td>
<td>98.</td>
<td>88.</td>
</tr>
<tr>
<td>167.</td>
<td>184.</td>
<td>83.</td>
<td>65.</td>
<td>134.</td>
<td>-20.</td>
<td>0.6</td>
<td>60.</td>
<td>25.</td>
</tr>
<tr>
<td>593.</td>
<td>180.</td>
<td>51.</td>
<td>68.</td>
<td>121.</td>
<td>34.</td>
<td>0.6</td>
<td>54.</td>
<td>74.</td>
</tr>
<tr>
<td>118.</td>
<td>182.</td>
<td>0.0</td>
<td>0.</td>
<td>75.</td>
<td>-1.</td>
<td>-99.0</td>
<td>0.</td>
<td>28.</td>
</tr>
<tr>
<td>694.</td>
<td>183.</td>
<td>44.</td>
<td>53.</td>
<td>98.</td>
<td>19.</td>
<td>0.8</td>
<td>181.</td>
<td>154.</td>
</tr>
</tbody>
</table>

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 _sh.d2c 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. ...

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Variable description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>hours</td>
<td></td>
</tr>
<tr>
<td>intevt</td>
<td>mm</td>
<td>cumulative interception evaporation</td>
</tr>
<tr>
<td>evt</td>
<td>mm</td>
<td>cumulative soil evaporation</td>
</tr>
<tr>
<td>p</td>
<td>mm</td>
<td>precipitation</td>
</tr>
<tr>
<td>sump</td>
<td>mm</td>
<td>cumulative precipitation</td>
</tr>
<tr>
<td>sumr</td>
<td>mm</td>
<td>net precipitation (hitting the ground)</td>
</tr>
<tr>
<td>fake</td>
<td>mm/hour</td>
<td>infiltration capacity</td>
</tr>
<tr>
<td>fakefs</td>
<td>mm/hour</td>
<td>infiltration capacity under snow</td>
</tr>
<tr>
<td>sca</td>
<td>fraction</td>
<td>snow covered area</td>
</tr>
<tr>
<td>snowc</td>
<td>mm</td>
<td>snow water equivalent</td>
</tr>
<tr>
<td>d1</td>
<td>mm</td>
<td>surface storage</td>
</tr>
<tr>
<td>d1fs</td>
<td>mm</td>
<td>surface storage under snow</td>
</tr>
<tr>
<td>sumf</td>
<td>mm</td>
<td>cumulative infiltration</td>
</tr>
<tr>
<td>sumffs</td>
<td>mm</td>
<td>cumulative infiltration under snow</td>
</tr>
<tr>
<td>uzs</td>
<td>mm</td>
<td>upper zone storage</td>
</tr>
<tr>
<td>uzsfs</td>
<td>mm</td>
<td>upper zone storage under snow</td>
</tr>
<tr>
<td>lzs</td>
<td>mm</td>
<td>lower zone storage (groundwater)</td>
</tr>
</tbody>
</table>
11. Output Files

| 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| mm  | melt factor adjustment for ripeness |
| sql   | mm  | cumulative surface runoff |
| sqlfs  | mm  | cumulative surface runoff under snow |
| sqint  | mm  | cumulative interflow |
| sqintfs| mm  | cumulative 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  | °C  | temperature in degree Celcius |
| Tempvmin| °C  | minimum temperature for the day set at 00:00 + A8 hours |
| Rh     | Percent | calculated relative humidity |
| Psmear | mm  | Amount of precip smeared |
| Punused| mm  | Amount of precip remaining |
| API    | Antecedent precipitation index = m, in the model |
| Sublim | mm  | Amount of new snow sublimated |
| sumsublim | mm  | Cumulative 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.
11. Output Files

The FOR.mnn files are scratch files or unused unit numbers. See Section 1.8 for a description of the output files.

```
results\gpi.txt
results\opt.txt
results\res.txt
not_in_use
results\rte.txt
results\pio.txt
results\swu.txt
not_in_use
result\\vp_glt
results\gpi.csv
results\swu.r2c
results\swu.csv
results\strout.1
results\nedbug.txt
results\watflood.wfo
results\nash_eff.r2c
results\error.r2c
results\wetland.csv
results\sed.csv
results\web_master_inflows.tb0
results\gpi_dly.csv
results\gridflow.r2c
results\resin.csv
results\evap.txt
results\vt_means.csv
results\peake.txt
results\volumes.txt
results\gpi_dly.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\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).

<table>
<thead>
<tr>
<th>Column name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station No</td>
<td>Sequential gauge number</td>
</tr>
<tr>
<td>Location</td>
<td>Station name</td>
</tr>
<tr>
<td>Area</td>
<td>Drainage area</td>
</tr>
</tbody>
</table>

WATFLOOD/CHARM – Canadian Hydrological And Routing Model  

April 2017
### 11. Output Files

<table>
<thead>
<tr>
<th>Precip</th>
<th>Average upstream precip</th>
</tr>
</thead>
<tbody>
<tr>
<td>o/ro</td>
<td>Observed runoff during recorded streamflow period</td>
</tr>
<tr>
<td>c/ro</td>
<td>Modelled runoff during recorded streamflow period – can be compared</td>
</tr>
<tr>
<td>c/ro(t)</td>
<td>Total modelled runoff for entire simulation period – can not be compared</td>
</tr>
<tr>
<td>Dv%</td>
<td>Volumetric error for observed flow period</td>
</tr>
<tr>
<td>Nash E</td>
<td>Nash –Sutcliffe efficiency for period of observed flow period</td>
</tr>
<tr>
<td>Qp/m</td>
<td>Max. observed peak flow</td>
</tr>
<tr>
<td>Qp/c</td>
<td>Max. computed peak flow</td>
</tr>
<tr>
<td>WS_A</td>
<td>Actual drainage area (can be supplied in basin\flow_station_info.txt)</td>
</tr>
<tr>
<td>Spl A</td>
<td>Model drainage area</td>
</tr>
<tr>
<td>%Diff</td>
<td>% difference between model &amp; actual drainage area</td>
</tr>
<tr>
<td>Class fractions</td>
<td>Fractions of each land cover class (total ~ 1.00)</td>
</tr>
</tbody>
</table>
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 FLOWINIT.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 (-routefg=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
##:UnitConversion             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
#
##: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
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
```
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
#: rOrigin              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
#: :UnitConversion             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
: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
  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

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
#  "----------------------------------------------------------------------
#
Example flow_init.r2c file (routeflag=y)

 sábado 12 de Noviembre de 2017

---

WATFLOOD/CHARM — Canadian Hydrological And Routing Model

April 2017
12. WATROUTE

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 \textit{runoff}, \textit{rchrg} and \textit{lkage} subdirectories in the working directory e.g. \texttt{spl\gr10k\runof}, \texttt{spl\gr10k\rchrg} and \texttt{spl\gr10k\lkage}

3. Provide names for files in the event files as shown below:

\begin{verbatim}
:griddedrunoff              runof\*_rff.r2c
:griddedrecharge            rchrg\*_rch.r2c
:griddedleakage             lkage\*_lkg.r2c
\end{verbatim}

\textbf{Note}: The reason the files are not in the \texttt{results} directory and are not included in the \texttt{outfiles.new} file is that they are output files of \texttt{CHARM} and input files for \texttt{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 \texttt{*_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 \texttt{WATROUTE}. The units are mm averaged for the nominal grid size.

The \texttt{*_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 \texttt{*_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
#:Kenuflg 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
```
12.3 Recharge Files for MODFLOW

WATFLOOD can write files in the format for MODFLOW (a groundwater model). If MODFLOW and WATFLOOD have the same grid. To create this file, set the route flag to m.

Example .rch file (routeflag=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 1 0 /jz,ju-1
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 1 0 /jz,ju-1
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 1 0 /jz,ju-1
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 1 0 /jz,ju-1
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 1 0 /jz,ju-1
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1 0 /jz,ju-1
```

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

April 2017
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 the 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
```

### Note

The end reporting time for Green Kenue is marked as 8784 hours. However, there seems to be a discrepancy in the document as it is mentioned as 87842 hours. This could be an error in the document or a misinterpretation of the data. It would be advisable to cross-check with the actual software output to ensure accuracy.
### 14. WATFLOOD Options

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>Upper Zone Storage Class 6</td>
<td>43</td>
<td>Upper Zone Storage (Snow) Class 1</td>
<td>44</td>
<td>Upper Zone Storage (Snow) Class 2</td>
</tr>
<tr>
<td>45</td>
<td>Upper Zone Storage (Snow) Class 3</td>
<td>46</td>
<td>Upper Zone Storage (Snow) Class 4</td>
<td>47</td>
<td>Upper Zone Storage (Snow) Class 5</td>
</tr>
<tr>
<td>48</td>
<td>Upper Zone Storage (Snow) Class 6</td>
<td>49</td>
<td>Surface Flow m^3/s Class 1</td>
<td>50</td>
<td>Surface Flow m^3/s Class 2</td>
</tr>
<tr>
<td>51</td>
<td>Surface Flow m^3/s Class 3</td>
<td>52</td>
<td>Surface Flow m^3/s Class 4</td>
<td>53</td>
<td>Surface Flow m^3/s Class 5</td>
</tr>
<tr>
<td>54</td>
<td>Surface Flow m^3/s Class 6</td>
<td>55</td>
<td>Surface Flow (snow) m^3/s Class 1</td>
<td>56</td>
<td>Surface Flow (snow) m^3/s Class 2</td>
</tr>
<tr>
<td>57</td>
<td>Surface Flow (snow) m^3/s Class 3</td>
<td>58</td>
<td>Surface Flow (snow) m^3/s Class 4</td>
<td>59</td>
<td>Surface Flow (snow) m^3/s Class 5</td>
</tr>
<tr>
<td>60</td>
<td>Surface Flow (snow) m^3/s Class 6</td>
<td>61</td>
<td>Interflow m^3/s Class 1</td>
<td>62</td>
<td>Interflow m^3/s Class 2</td>
</tr>
<tr>
<td>63</td>
<td>Interflow m^3/s Class 3</td>
<td>64</td>
<td>Interflow m^3/s Class 4</td>
<td>65</td>
<td>Interflow m^3/s Class 5</td>
</tr>
<tr>
<td>66</td>
<td>Interflow m^3/s Class 6</td>
<td>67</td>
<td>Interflow (snow) m^3/s Class 1</td>
<td>68</td>
<td>Interflow (snow) m^3/s Class 2</td>
</tr>
<tr>
<td>69</td>
<td>Interflow (snow) m^3/s Class 3</td>
<td>70</td>
<td>Interflow (snow) m^3/s Class 4</td>
<td>71</td>
<td>Interflow (snow) m^3/s Class 5</td>
</tr>
<tr>
<td>72</td>
<td>Interflow (snow) m^3/s Class 6</td>
<td>73</td>
<td>Recharge mm Class 1</td>
<td>74</td>
<td>Recharge mm Class 2</td>
</tr>
<tr>
<td>75</td>
<td>Recharge mm Class 3</td>
<td>76</td>
<td>Recharge mm Class 4</td>
<td>77</td>
<td>Recharge mm Class 5</td>
</tr>
<tr>
<td>78</td>
<td>Recharge mm Class 6</td>
<td>79</td>
<td>Recharge mm (snow) Class 1</td>
<td>80</td>
<td>Recharge mm (snow) Class 2</td>
</tr>
<tr>
<td>81</td>
<td>Recharge mm (snow) Class 3</td>
<td>82</td>
<td>Recharge mm (snow) Class 4</td>
<td>83</td>
<td>Recharge mm (snow) Class 5</td>
</tr>
<tr>
<td>84</td>
<td>Recharge mm (snow) Class 6</td>
<td>85</td>
<td>PET (average) mm Class 1</td>
<td>86</td>
<td>PET (average) mm Class 2</td>
</tr>
<tr>
<td>87</td>
<td>PET (average) mm Class 3</td>
<td>88</td>
<td>PET (average) mm Class 4</td>
<td>89</td>
<td>PET (average) mm Class 5</td>
</tr>
<tr>
<td>90</td>
<td>PET (average) mm Class 6</td>
<td>91</td>
<td>ET (cumulative) mm Class 1</td>
<td>92</td>
<td>ET (cumulative) mm Class 2</td>
</tr>
<tr>
<td>93</td>
<td>ET (cumulative) mm Class 3</td>
<td>94</td>
<td>ET (cumulative) mm Class 4</td>
<td>95</td>
<td>ET (cumulative) mm Class 5</td>
</tr>
<tr>
<td>96</td>
<td>ET (cumulative) mm Class 6</td>
<td>97</td>
<td>Sublimation Cumulative mm (snow) Class 1</td>
<td>98</td>
<td>Sublimation Cumulative mm (snow) Class 2</td>
</tr>
<tr>
<td>99</td>
<td>Sublimation Cumulative mm (snow) Class 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
14. WATFLOOD Options

*** 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 column 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 10 year 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 potential 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.

Another 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.

<table>
<thead>
<tr>
<th>1 Errors in %.Runtime 07:58:40 2013-08-07</th>
</tr>
</thead>
<tbody>
<tr>
<td>:xcount         9</td>
</tr>
<tr>
<td>:ycount         12</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 5. 94. 94. -18. -18. -18. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 5. 5. 5. 5. -18. -37. -37. -37. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 5. 5. 5. 5. 5. 5. 5. 5. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 Errors in %.Runtime 07:58:44 2013-08-07</th>
</tr>
</thead>
<tbody>
<tr>
<td>:xcount         9</td>
</tr>
<tr>
<td>:ycount         12</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 Errors in %.Runtime 07:58:47 2013-08-07</th>
</tr>
</thead>
<tbody>
<tr>
<td>:xcount         9</td>
</tr>
<tr>
<td>:ycount         12</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
<tr>
<td>0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.</td>
</tr>
</tbody>
</table>

WATFLOOD/CHARM – Canadian Hydrological And Routing Model April 2017
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-basin which 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 smooths 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:

```plaintext
: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.
14. WATFLOOD Options

<table>
<thead>
<tr>
<th># runtime</th>
<th>11:07:40</th>
</tr>
</thead>
<tbody>
<tr>
<td># rundate</td>
<td>2004-04-29</td>
</tr>
<tr>
<td>ver</td>
<td>9.200 parameter file version number</td>
</tr>
<tr>
<td>iopt</td>
<td>01 debug level</td>
</tr>
<tr>
<td>itype</td>
<td>0</td>
</tr>
<tr>
<td>numa</td>
<td>0 PS optimization 0=no 1=yes</td>
</tr>
<tr>
<td>nper</td>
<td>0 opt delta 0-absolute</td>
</tr>
<tr>
<td>kc</td>
<td>5 no of times delta halved</td>
</tr>
<tr>
<td>maxn</td>
<td>10 max no of trials</td>
</tr>
<tr>
<td>dsfl</td>
<td>0 DDS optimization 0=no 1=yes</td>
</tr>
<tr>
<td>trce</td>
<td>100</td>
</tr>
<tr>
<td>iiout</td>
<td>4</td>
</tr>
<tr>
<td>typeo</td>
<td>4 no of land classes optimized(part 2)</td>
</tr>
<tr>
<td>nban</td>
<td>5 no of river classes optimized (part 2)</td>
</tr>
<tr>
<td>a1</td>
<td>-999.999 ice factor</td>
</tr>
<tr>
<td>a2</td>
<td>1.0 Manning’s n correction for instream lakes</td>
</tr>
<tr>
<td>a3</td>
<td>-999.999</td>
</tr>
<tr>
<td>a4</td>
<td>-999.999</td>
</tr>
<tr>
<td>a5</td>
<td>0.985 API coefficient</td>
</tr>
<tr>
<td>a6</td>
<td>900.000 Minimum routing time step in seconds</td>
</tr>
<tr>
<td>a7</td>
<td>0.500 weighting factor - old vs. new sca value</td>
</tr>
<tr>
<td>a8</td>
<td>0.100 min temperature time offset</td>
</tr>
<tr>
<td>a9</td>
<td>0.333 max heat deficit to swe ratio</td>
</tr>
<tr>
<td>a10</td>
<td>1.000 ux discharge function exponent</td>
</tr>
<tr>
<td>a11</td>
<td>0.010</td>
</tr>
<tr>
<td>a12</td>
<td>0.000 min precip rate for smearing</td>
</tr>
</tbody>
</table>

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
Rln 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+00 0.100E+00 0.100E+00 0.100E+00 0.100E+00
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
kocond 0.100E+00 0.100E+00 0.100E+00 0.100E+00 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
dfs 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+01 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
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 its 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.
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
```
14. WATFLOOD Options

:hour 00
#
:snwflg y
:sedflg n
:vapflg y
:smrflg n
:resinflg n
:tbcflg n
:resumflg y
:contflg n
:routeflg n
:icrseflg y
:Kenueflg n
:picflg n
:wetflg n
:modelflg n
:shdflg n
:trcflg y (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-BASIN
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, 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. Conversion to Green Kenue Formats (translate)

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    7,314,678 621001_met.r2c
   10/17\2006  01:03 PM    7,078,758 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.
15. Conversion to Green Kenue Formats

4. In DOS, run this batch file:
   \texttt{I:\spl\ssrb\ef\radcl}\texttt{met\_rn \&}

5. Do the same in the temp, 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 \texttt{MAKE_EVT.exe} in the working directory eg. \texttt{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 \texttt{makeevt.exe} in the working directory and a complete set of event files will be created.

\texttt{I:\spl\ssrb\ef}\texttt{\makeevt}

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

will you be running the snow conversion factor
eg. 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
15. Conversion to Green Kenue Formats

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\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 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
15. Conversion to Green Kenue Formats (translate) | 15-7

#
: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 ASCII Green 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
```

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. 1994 - added ireach(n) for dwoper input
- rev. 7.3 dec. 20/94 - added us & ls 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 opt 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 separates snow covered and bare ground
  - modified for separation of snow covered and bare ground
  - bare ground by Frank Seglenieks Feb/1995 new
  - runof5 debugged and interrogated 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 main
- rev. 7.6 nov. 13/95 - added andrea's sediment routine
- rev. 7.7 dec. 29/95 - 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 mar. 23/96 - include lapse rate & elv ref
  - as part of .tmp file
- rev. 7.75 may. 27/96 - added sx2s 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 - filesio: modified for error checking
- rev. 7.80 oct. 29/96 - spl7 added yrenderd.rin for res inflows
  - unit = 39 fin = 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-rets 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 jun. 3/97 - added initial uzs values in evap.par
- rev. 8.32 jun. 13/97 - bypassed non-flagged parameters in opt
- rev. 8.4 jul. 16/97 - fixed melt routine and added init def
- rev. 8.41 jul. 21/97 - added tips to the optimization table
- rev. 8.42 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 s2 to the intercept flow calculation
- rev. 8.61 dec. 12/97 - added config for statistics count'n
- rev. 8.62 dec. 30/97 - fixed param s/r comb'd et & par flags
- 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 f3qvwp2 data statement to
  - spl.for
- rev. 8.73 mar. 1/98 - changed mhdr to mhtot in flowinit
16. Program Revisions

Conversion to Green Kenue Formats (translate)

rev. 8.74 Mar. 31/98 - reinvented fe stuff in opt
rev. 8.75 Apr. 27/98 - took da out of the resume file
rev. 8.76 May 26/98 - added precdat 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 snowing
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.
rev. 8.87 Nov. 17/98 - added watbal.for for water balance
rev. 8.88 Nov. 23/98 - madjust function of degree days
rev. 8.89 Nov. 30/98 - simplified uses 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 - creafig 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. 8.94cd 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
rev. 8.96 Apr. 26/99 - lower zone function related to bmbn
rev. 8.96.1 May 12/99 - added import for reporting interval
rev. 8.97 July 12/99 - demonstration copy addition
rev. 8.98 July 15/99 - wet grid shifting for weather models
rev. 8.99 Aug. 18/99 - replaced err= with iostat= for f90
rev. 8.99a Jul. 99 - 1st-long watershed data
rev. 8.99b Sept. 27/99 - divvy up interflow & drainaes
rev. 8.99c Oct. 5/99 - irough -> s12 input in shed
rev. 8.99e Nov. 29/99 - heat deficit initialilization
rev. 8.99f Jan. 7/00 - changed uses cols re: shar'i's data
rev. 8.99g Feb. 7/00 - added ttoinit to init evaporation
rev. 8.99h Feb. 15/2001 - fixed deficit calc in melt.for see 8.99k
rev. 8.99i Oct. 2001 - fixed reservoir release timing in spl8
rev. 8.99j Dec. 13/2001 - added check for <= 0 init res flow
rev. 8.99k Dec. 31/2001 - fixed nat. res initial flow (JW)
rev. 9.0 Mar. 21/00 - ts: converted to fortran 90
rev. 9.01 Aug. 1/00 - added look up for minimum temperature
rev. 9.02 Oct. 5/00 - added option to debug on one grid
rev. 9.03 Jan. 7/01 - set min precip rate for snowing
rev. 9.04 Jan 16/01 - fixed grid diagnosis in flowinit
rev. 9.05 Feb. 6/01 - chngd unit 61 to rawl.ocl for surfer
rev. 9.06k Feb. 15/01 - fixed deficit calc in melt (rem. qtr.txt) -8.99k
rev. 9.07 Mar. 14/01 - fixed use of opt par's for numa-o
rev. 9.08 Mar. 26/01 - checked limits on heat def.
rev. 9.08p Apr. 3/01 - check wetland designation in param
rev. 9.1 May 7/01 - updated lisa'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 soc in melt
rev. 9.1.05 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 - nrnv 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 see 8.99l
rev. 9.1.10 Jan. 23/02 - flow nudging added for nopt(2)=2
rev. 9.1.11 Feb. 07/02 - fixed bug in reservoir routing
rev. 9.1.12 Mar. 15/02 - added adelita and yehilta for ensim
rev. 9.1.13 Mar. 23/02 - fixed resv. timing, moved to beginning of dt

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

April 2017
16. Program Revisions

Conversion to Green Kenue Formats (translate)

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/o 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/sw ratio
rev. 9.1.20 Jun. 25/02 - Added A10 as the power on the G2 discharge function
rev. 9.1.21 Jun. 28/02 - Added wetland storage & outflow to the wfo file
rev. 9.1.22 Jul. 21/02 - 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 Aug. 11/02 - Added scalealnaw to set snw scale in event 1
rev. 9.1.25 Aug. 11/02 - Added All as base ground equiv. vegn height
rev. 9.1.26 Sep. 11/02 - Fixed wetland evaporation re: ussi
rev. 9.1.27 Sep. 19/02 - Added ishsflg
rev. 9.1.28 Sep. 19/02 - Added shedr in to replace the bsm.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 qL, qist, qdrx & qix 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 ctmn() wrt. h()
rev. 9.1.33 Nov. 20/02 - Fixed instability in wetland flow
rev. 9.1.34 Dec. 23/02 - Added ensimfig - if ensimfig='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 LIF < 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 strf 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 mobile added - first try
rev. 9.1.43 Jun. 01/03 - Fixed the qvpr.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 Aug. 08/03 - NK: sumrechrge() added to get total recharge
rev. 9.1.49 Aug. 23/03 - TS: Added wetlands to GW Tracer + Wetland Tracer
rev. 9.1.50 Aug. 14/04 - NK: version number added to the wfo_spec.txt file
rev. 9.1.51 Aug. 28/04 - NK: added iz.ne.jz conditional to ENSIM output
rev. 9.1.51 Aug. 28/04 - NK: continuous water quality modelling
rev. 9.1.52 Aug. 28/04 - NK: continuous water quality modelling
rev. 9.1.53 Mar. 14/04 - NK: hasp key configured
rev. 9.1.54 Apr. 12/04 - NK: SEDFLAG set for multiple events at event No. 1
rev. 9.1.55 Jun. 12/04 - NK: write new str files to strf\newstr folder.
rev. 9.1.56 Jun. 18/04 - NK: write new rel & rin files to res\newstr folder.
rev. 9.1.57 Jul. 06/04 - NK: Fixed major bug in shed.for 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 - NRK: reversed definitions for s11 & s12 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 (conv)
rev. 9.1.63 Sep. 29/04 - NK: Added lopt_start as an arg for quick filecheck
rev. 9.1.64 Oct. 03/04 - NK: Coded up new header in ragsdr.for
rev. 9.1.65 Oct. 03/04 - NK: Coded up new header for snow course file
rev. 9.1.65 Oct. 03/04 - NK: Coded up new header for snow course file
rev. 9.1.66 Oct. 17/04 - NK: petfall for loss from water instead of pet
rev. 9.1.67 Oct. 21/04 - NK: added unit 58 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 rdtrain 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 rdresv c/w memory allocation
rev. 9.1.74 Feb. 08/05 - NK: trasched rscrse replaced with rdaw
rev. 9.1.75 Feb. 08/05 - NK: added rdgpm (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 .pm .gpm & .giz files
rev. 9.1.78 Mar. 15/05 - NK: added WQG 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. 9.1.82 Jun. 02/05 - NK: Numerous changes to program organization
rev. 9.1.83 Jun. 02/05 - NK: Added write.r2s
rev. 9.1.83 Jun. 02/05 - NK: Added write.r2s
rev. 9.1.84 Jun. 29/05 - NK: Added read.r2s
rev. 9.1.85 Jul. 11/05 - NK: Added s/r precip_adjust
rev. 9.1.86 Jul. 13/05 - NK: Allocation check for resi

WATFLOOD/CHARM – Canadian Hydrological And Routing Model

April 2017
16. Program Revisions

Conversion to Green Kenue Formats (translate)

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 exp 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. 9.2.17 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 - NK: 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 rsw coeff first event only
rev. 9.2.30 Feb. 07/06 - NK: Added class_distribution.txt to output
rev. 9.2.31 Feb. 09/06 - NK: Added area check to rdresume
rev. 9.2.32 Feb. 10/06 - NK: Added area_check.csv to output
rev. 9.2.33 Feb. 14/06 - NK: str stations from first event ONLY!!
rev. 9.2.34 Mar. 21/06 - NK: Activated glacier tracer1
rev. 9.2.35 Mar. 22/06 - NK: Glacier flow bypasses wetlands
rev. 9.2.36 Mar. 30/06 - NK: Scaleallsnow changed to 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 resn.txt file to reslin.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 runoff, 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: added write_flowinit.for to flowinit.for
rev. 9.3.06 Dec. 09/06 - NK: added precp 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_r2c output to sub.for
rev. 9.3.09 Jan. 17/07 - NK: all file name lengths = 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, rfs from areaeq 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 lso
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 gwp + getream - storms 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 qwp>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
16. Program Revisions
Conversion to Green Kenue Formats (translate)

- 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 precpl_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 reavatore for iso model
- rev. 9.5.21 Mar. 06/08 - NK: fixed dtmin for first time step each event
- rev. 9.5.22 Mar. 06/08 - NK: added gridflg 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. 15/08 - NK: fixed missing data in read_resv_ef
- rev. 9.5.25 Mar. 20/08 - NK: fixed lake initialization - 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 inbml 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 totalsn(m) 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 grader 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_st Location to flowinit
- rev. 9.5.36 Oct. 01/08 - NK: fixed ird bug for uneven 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 coeff & 7 to rel file for lake levels
- rev. 9.5.39 Oct. 15/08 - NK: fixed bug in reservoir routing
- rev. 9.5.40 Oct. 21/08 - NK: added diversions to reroute
- 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 core & obj modules for haap & rainbow
- rev. 9.5.45 Dec. 16/08 - NK: added various error calculation s - user's choice with errflg
- rev. 9.5.46 Dec. 17/08 - NK: trying to fix problem with -ve storage. Changed conditional to.
- rev. 9.5.47 Dec. 26/08 - NK: add flowinitflg to warn about initial flows
- rev. 9.5.48 Dec. 26/08 - NK: added event_fin() to allow unlimited events
- rev. 9.5.49 Dec. 31/08 - NK: changed conditional to read releases in reroute
- rev. 9.5.50 Jan. 05/09 - NK: read evap data for reaches only
- rev. 9.5.51 Jan. 13/09 - NK: added reading _l1l.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. 9.5.28
- 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 ntrflg 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 fpnptake for each lake in l11 file
- rev. 9.5.60 Jul. 26/09 - NK: added deltat_report for lake_sd.csv file
- rev. 9.5.61 Sep. 03/09 - NK: bug/wtoess - added water class for WFO weighted evap
- rev. 9.5.62 Sep. 04/09 - NK: new tk0 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: lapase 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 flws < 1.0
- rev. 9.5.67 Oct. 06/09 - NK: fixed bug in reroute
- rev. 9.5.68 Oct. 07/09 - NK: debugged read_resvEf.f
- rev. 9.5.69 Oct. 10/09 - NK: added axount & 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 jst for setting value for rhyd(l)
- rev. 9.5.72 Oct. 12/09 - NK: fixed bug in rdpar setting init values for fpet & ftal
- rev. 9.5.73 Dec. 12/09 - NK: bypass using lake levels when optimizing
- rev. 9.5.74 Dec. 21/09 - NK: in opt - made optin abs(optim)
- rev. 9.5.75 Dec. 26/09 - NK: commented "deallocatesub in sub for watroute reads
- rev. 9.5.76 Dec. 26/09 - NK: fixed some inits for out of basin gauges
- rev. 9.5.77 Dec. 26/09 - NK: fixed some mints for out of basin gauges
- rev. 9.5.78 Nov. 04/09 - NK: fixed resvinit locations to reach numbers
- rev. 9.5.79 Nov. 04/09 - NK: added resvinitflg='s' for read_soilinit ONLY
16. Program Revisions
Conversion to Green Kenue Formats (translate)

Program Revisions
Conversion to Green Kenue Formats

| 16-7 |

- rev. 9.8.27 Sep. 27/13 - NK: changed action on resumflg='s' - keep tbflag='y'
- rev. 9.8.28 Oct. 12/13 - 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 phi(j)=0.0 from precip_adjust
- rev. 9.8.31 Oct. 16/12 - NK: continue rff files for config - 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.sf to check # columns = no
- rev. 9.8.38 Nov. 13/12 - NK: changed name level_ploting.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: h1, h2, h3, fratio()
- rev. 9.8.41 Jan. 31/13 - NK: fixed bug in read_resin; npoint int conversion
- rev. 9.8.42 Jan. 31/13 - NK: fixed bug in read_list.f; undefined output for lat=99
- rev. 9.8.43 Jan. 31/13 - NK: fixed bug in sub.f; uninitialized course_calc(n,j)
- rev. 9.8.44 Jan. 31/13 - NK: disabled some writes for lat=99
- rev. 9.8.45 Feb. 04/13 - NK: Fixed some write formats in lst,stats,waterb
- rev. 9.8.46 Feb. 04/13 - NK: Headers added for spl & resin csv files
- rev. 9.8.47 Feb. 12/13 - NK: Replaced spl.plt with spl.tb0 file
- rev. 9.8.48 Feb. 20/13 - NK: Added n-municipal & irrigation withdrawals
- rev. 9.8.49 Feb. 27/13 - NK: Initialize storez2() for zero lake outflow
- rev. 9.8.50 Mar. 11/13 - NK: Link skiphours in s/r stats to valuel in the str file
- rev. 9.8.51 Mar. 20/13 - NK: deleted a pause for dds runs in route
- rev. 9.8.52 Mar. 20/13 - NK: Add Lake St. Joseph diversion algorithm to REROUT.f
- rev. 9.8.53 Apr. 02/13 - NK: dds conversion seconds to hours
- rev. 9.8.54 Apr. 10/13 - NK: fixed pause for dds runs in route
- rev. 9.8.55 Apr. 10/13 - NK: Added check in rerout for =ve storage due to evaporation
- rev. 9.8.56 Apr. 12/13 - NK: Added lakeinit file to stop lake evaporation when levels very low
- rev. 9.8.57 Apr. 12/13 - NK: REVised Family Lake (WPEGR) O/R in rerout
- rev. 9.8.58 May 14/13 - NK: Removed psmear & punused from the program
- rev. 9.8.59 May 14/13 - NK: fixed ice factor for whole x-section
- rev. 9.8.60 May 22/13 - NK: Introduced flag1 to speed up runoff6
- rev. 9.8.61 May 22/13 - NK: Fixed bug in runof6: (classcount-3) to (classcount-2)
- rev. 9.8.62 May 22/13 - NK: Fixed bug in s/r SUB.f argument list: "jan" missing
- rev. 9.8.63 May 28/13 - NK: Undocumented debug file
- rev. 9.8.64 May 28/13 - NK: Dimensioned firstpass_local() in REROUT
- rev. 9.8.65 Jun 03/13 - NK: Added error_Dv.txt output in stats.f
- rev. 9.8.66 Jun 28/13 - NK: Uncommented debug file
- rev. 9.8.67 Jun 28/13 - NK: Added allocation for flagi
- rev. 9.8.68 Jun 17/13 - NK: Added dds_override file
- rev. 9.8.69 Jun 17/13 - NK: Fixed bug in allocating clummmuts in SUB.f
- rev. 9.8.70 Jun 17/13 - NK: for PAF: change error & PAF files to use GK formats
- rev. 9.8.71 Jul 08/13 - NK: Made universal the use of wetland_flag(m)
- rev. 9.8.72 Jul 16/13 - NK: Fixed divot2 for the first event file value
- rev. 9.8.73 Jul 16/13 - NK: Fixed wetland conditional screwed up with rev 9.8.77 in runof6
- rev. 9.8.74 Aug 09/13 - NK: Added withdraw.rzo output file in route.f
- rev. 9.8.75 Aug 09/13 - NK: Add pafflg and update precip adjustment factors
- rev. 9.8.76 Aug 09/13 - NK: Replaced scorl & score1 files by subl & sub2 files
- rev. 9.8.77 Aug 09/13 - NK: Introduced for subroutine in route.f
- rev. 9.8.78 Aug 09/13 - NK: Add debug file
- rev. 9.8.79 Aug 09/13 - NK: Added pafflg and update precip adjustment factors
- rev. 9.8.80 Aug 09/13 - NK: Add debug file
- rev. 9.8.81 Sep. 13/13 - NK: Disabled some writes for iopt = 99
- rev. 9.8.82 Sep. 13/13 - NK: Bypass of hard-coded lake rules when coeff1=0
- rev. 9.8.83 Sep. 10/13 - NK: Set classcount=0 for fil.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 lss_init.rzo - data is in flow_init.rzo 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 _fint.rzo
- 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 98 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 Feb. 17/13 - NK: Change to gridded climat normals to diff
- rev. 9.9.05 Jan. 02/14 - NK: Add check 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 Endin spec

WATFLOOD/CHARM — Canadian Hydrological And Routing Model
April 2017
WATFLOOD/CHARM – Canadian Hydrological And Routing Model

April 2017

16. Program Revisions

Conversion to Green Kenue Formats (translate)

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 sww 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 1 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_death"
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 apy_mly_n.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 & fctstflg
rev. 9.9.27 Sep. 18/14 - NK: Added zero class bypass in intercept.f
rev. 9.9.28 Sep. 18/14 - NK: Added 'a' as option for strflg & smrflg
rev. 9.9.29 Sep. 30/14 - NK: Remove unnecessary writes for watepute
rev. 9.9.30 Sep. 30/14 - NK: Fixed allocation for qhyd_mly & qyn_mly
rev. 9.9.31 Oct. 13/14 - NK: Changed flow initialization RE: zero init flows
rev. 9.9.32 Oct. 16/14 - NK: Added checks for files existing for a resume'
rev. 9.9.33 Oct. 17/14 - NK: Added re-compute of lake storage re: new lake levels
rev. 9.9.34 Oct. 20/14 - NK: Added sww & file checks
rev. 9.9.35 Nov. 03/14 - NK: Revised error message for daily diff choices
rev. 9.9.36 Nov. 05/14 - NK: Added 'newDataFlag' check to WATROUTE
rev. 9.9.37 Nov. 12/14 - NK: Added swwdepth to ill file
rev. 9.9.38 Nov. 14/14 - NK: Modifications for watepute
rev. 9.9.39 Nov. 15/14 - NK: Modified the 'a' option for strflg
rev. 9.9.40 Nov. 20/14 - NK: Added check if diversion = in-basin
rev. 9.9.41 Nov. 26/14 - NK: Added error check if diversion does not exist
rev. 9.9.42 Nov. 26/14 - NK: Allocation for divertflg = 'g'
rev. 9.9.43 Nov. 28/14 - NK: Added dead storage to reservoirs
rev. 9.9.44 Dec. 03/14 - NK: revamped read_pt2 for general use
rev. 9.9.45 Dec. 10/14 - NK: Added check on initial lake outflow
rev. 9.9.46 Dec. 24/14 - NK: Added lakeflg for lake evaporation option
rev. 9.9.47 Jan. 06/15 - NK: Added wetland cond. function for a/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. 19/15 - NK: Prevent mode switch during iteration in wetland routing
rev. 9.9.54 Jan. 27/15 - 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 reaw 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: striss option freqflg y/n
rev. 9.9.59 Mar. 29/15 - NK: In route: restored hcha2(n)-store2(n)/chaarea(n)
rev. 9.9.59 Mar. 21/15 - NK: Change zone from character to integers
rev. 9.9.59 Mar. 21/15 - NK: Changed reaw_resv to carry on with last known release(s)
rev. 9.9.60 Apr. 08/15 - NK: DDS bypass in sub for single runs
rev. 9.9.60 Apr. 08/15 - NK: DDS bypass in sub for single runs
rev. 9.9.61 Apr. 08/15 - NK: Added rule s/r, rules.txt & ruledflg
rev. 9.9.62 Apr. 08/15 - NK: Added options to write_t60 str files
rev. 9.9.63 Apr. 08/15 - NK: Deleted mid file headers in with txtflg
rev. 9.9.64 Apr. 08/15 - NK: Fixed tt reaw with resume
rev. 9.9.65 Apr. 08/15 - NK: Prevent write ro sff if there is no class area
rev. 9.9.66 Apr. 08/15 - NK: Add del_rain, and dst3noffc2 to the wfo file
rev. 9.9.67 Apr. 08/15 - NK: DSS obj function taken out of sub > s/r obj_fn
rev. 9.9.68 Apr. 08/15 - NK: Prevent write ro sff if there is no class area
rev. 9.9.69 Jun. 10/15 - NK: Add del_rain, and dst3noffc2 to the wfo file
rev. 9.9.70 Jun. 12/15 - NK: Add del_rain, and dst3noffc2 to the wfo file
rev. 9.9.71 Jun. 13/15 - NK: DSS obj function taken out of sub > s/r obj_fn
rev. 9.9.72 Jul. 21/15 - NK: DSS obj function taken out of sub > s/r obj_fn
rev. 9.9.73 Aug. 31/15 - NK: Fixed rounded errors s/r, for beta testing
rev. 9.9.74 Sep. 11/15 - NK: Added output to unit 53 in flowinit.f
rev. 9.9.75 Sep. 11/15 - NK: Added recorded isotope concentrations
rev. 9.9.76 Sep. 11/15 - NK: s/r read_rsf created
rev. 9.9.77 Sep. 16/15 - NK: Fixed vol in melt.f
rev. 9.9.78 Sep. 16/15 - NK: Fixed upt 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 & qyn_mly
16. Program Revisions

Conversion to Green Kenue Formats (translate)

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct. 09/15</td>
<td>NK: Added units 81-83 for isotope output</td>
</tr>
<tr>
<td>Oct. 10/15</td>
<td>NK: Added year_last variable for use in reading isotope data</td>
</tr>
<tr>
<td>Oct. 11/15</td>
<td>NK: Iso RMS error</td>
</tr>
<tr>
<td>Nov. 19/15</td>
<td>NK: Added area_check with can_discharge_sites.xyz</td>
</tr>
<tr>
<td>Dec. 02/15</td>
<td>NK: Added ice_for(n) to route</td>
</tr>
<tr>
<td>Dec. 04/15</td>
<td>NK: Added msg rer: replacing “mean_observed_flows.txt”</td>
</tr>
<tr>
<td>Dec. 07/15</td>
<td>NK: Add blank line for missing data in the precip.txt file in lst.f</td>
</tr>
<tr>
<td>Dec. 11/15</td>
<td>NK: Revised ice factor initialization and calculation</td>
</tr>
<tr>
<td>Dec. 12/15</td>
<td>NK: Added Nash Efficiency nashEff.r2c file unit=66</td>
</tr>
<tr>
<td>Dec. 28/15</td>
<td>NK: Rearranged the par file blocks &amp; contents</td>
</tr>
<tr>
<td>Jan. 08/16</td>
<td>NK: Custom coding for Mackenzie River Basin Hydraulic Model</td>
</tr>
<tr>
<td>Jan. 11/16</td>
<td>NK: Added subroutine ice_factor.f</td>
</tr>
<tr>
<td>Jan. 11/16</td>
<td>NK: Added fpetLakeOverride factor</td>
</tr>
<tr>
<td>Jan. 15/16</td>
<td>NK: Made opening of the master_inflow file optional with routeflg=q</td>
</tr>
<tr>
<td>Jan. 15/16</td>
<td>NK: Fixed initialization of ice_factr - moved from lake_ice &gt; runof6</td>
</tr>
<tr>
<td>Jan. 22/16</td>
<td>NK: Fixed initialization of ice_factr - moved from lake_ice &gt; runof6</td>
</tr>
<tr>
<td>Jan. 23/16</td>
<td>NK: Fixed lake init flow bug in flowinit</td>
</tr>
<tr>
<td>Jan. 25/16</td>
<td>NK: Fixed flowinit for partial basins</td>
</tr>
<tr>
<td>Jan. 28/16</td>
<td>NK: Added abort when water class not specified</td>
</tr>
<tr>
<td>Jan. 30/16</td>
<td>NK: Added qUS1 &amp; qUS2 for wathal</td>
</tr>
<tr>
<td>Feb. 21/16</td>
<td>NK: Added nudge_flags.txt</td>
</tr>
<tr>
<td>Mar. 23/16</td>
<td>NK: Fixed comment for spinup period</td>
</tr>
<tr>
<td>Apr. 19/16</td>
<td>NK: Moved outfiles code in sp19 (below)</td>
</tr>
<tr>
<td>Apr. 26/16</td>
<td>NK: Fixed first day of output for master_inflows file</td>
</tr>
<tr>
<td>Apr. 28/16</td>
<td>NK: Added parity comments</td>
</tr>
<tr>
<td>May 08/16</td>
<td>NK: Added smoothdist warning in read_par_parser</td>
</tr>
<tr>
<td>May 15/16</td>
<td>NK: Revised output to precip.txt : include all str stations</td>
</tr>
<tr>
<td>Jun 20/16</td>
<td>NK: Change the time stamp in the watflood.wfo file</td>
</tr>
<tr>
<td>Jul 05/16</td>
<td>NK: Added Obs. &amp; Model mean flows to wfo file</td>
</tr>
<tr>
<td>Jul 07/16</td>
<td>NK: Added simulation start time to the wfo file</td>
</tr>
<tr>
<td>Jul 12/16</td>
<td>NK: Added results\lakeName.tb0</td>
</tr>
<tr>
<td>Jul 28/16</td>
<td>NK: Added “Ellipsoid to the WFO header”</td>
</tr>
<tr>
<td>Jul 28/16</td>
<td>NK: Added noDataValue to wfo &amp; tb0 files</td>
</tr>
<tr>
<td>Sep 16/16</td>
<td>NK: Fixed stations outside the watershed for tb0</td>
</tr>
<tr>
<td>Oct 11/16</td>
<td>NK: Fixed bug in read_divert for missing u/s DA</td>
</tr>
<tr>
<td>Oct 11/16</td>
<td>NK: Added tb0fig to write lake_.tb0 files</td>
</tr>
<tr>
<td>Oct 20/16</td>
<td>NK: Reinstitated read_ice_factor.f as default if present</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>NK: lake_ice_factor changed from : to ;:</td>
</tr>
<tr>
<td>Nov 22/16</td>
<td>NK: Reworked icerivfig &amp; iceLakefig</td>
</tr>
<tr>
<td>Dec 16/16</td>
<td>NK: Added allocation check for qdivert in rerout</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: Changed B1 - 5 to real^8</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: Major changes in the ISO part of AET.f</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: added fpet(li_water) to the wetland evaporation</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: Overhauled lake evaporation</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: Overhauled lst for new isotope output</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: removed unused isotope related calculations, merged two</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: isotope related calc sections to reduce if statements</td>
</tr>
<tr>
<td>Nov 08/16</td>
<td>TH: changed levels.txt to levels.csv</td>
</tr>
<tr>
<td>Nov 09/16</td>
<td>NK: Moved tdum under call timer in sub</td>
</tr>
<tr>
<td>Nov 10/16</td>
<td>NK: Fixed sumf &amp; sumffs in runof6</td>
</tr>
<tr>
<td>Dec 05/16</td>
<td>NK: Fixed evt in AET.f to account for sca</td>
</tr>
<tr>
<td>Dec 06/16</td>
<td>NK: Added smWNN.txt files for iopt &gt; 0</td>
</tr>
<tr>
<td>Dec 06/16</td>
<td>NK: corrected tdum &gt; tdum1 for modelfig=1</td>
</tr>
<tr>
<td>Dec 18/16</td>
<td>NK: Fixed missing # channel correction chnl(1-5)</td>
</tr>
<tr>
<td>Jan 03/17</td>
<td>NK: Fixed conditional in route</td>
</tr>
<tr>
<td>Jan 03/17</td>
<td>NK: Changed results\peaks.txt to write peak flows</td>
</tr>
<tr>
<td>Jan 08/17</td>
<td>NK: Checkup on strloss effect on low flows</td>
</tr>
<tr>
<td>Jan 25/17</td>
<td>NK: Intel® Parallel Studio XE 2017 Update 1</td>
</tr>
<tr>
<td>Jan 26/17</td>
<td>NK: Added XML output file</td>
</tr>
<tr>
<td>Jan 28/17</td>
<td>NK: Fixed allocate lake_elv from read_flow</td>
</tr>
</tbody>
</table>
16. Program Revisions
Conversion to Green Kenue Formats (translate)

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 18/17</td>
<td>10.1.66</td>
<td>NK: Fixed leap year in timer</td>
</tr>
<tr>
<td>Feb. 18/17</td>
<td>10.1.67</td>
<td>NK: Ignore start year in subsequent event files</td>
</tr>
<tr>
<td>Mar. 03/17</td>
<td>10.1.68</td>
<td>NK: Made midnight 00 instead of 24</td>
</tr>
<tr>
<td>Mar. 03/17</td>
<td>10.1.69</td>
<td>NK: Changed allocation for lvl_reach in read_lvl.f</td>
</tr>
<tr>
<td>Mar. 03/17</td>
<td>10.1.70</td>
<td>NK: Added year_now2 etc. for converting GriB2 files</td>
</tr>
<tr>
<td>Mar. 14/17</td>
<td>10.1.71</td>
<td>NK: Revised reading mean_observed_flows in sub</td>
</tr>
<tr>
<td>Mar. 20/17</td>
<td>10.1.72</td>
<td>NK: Fixed bug in sub for error_flag = 4</td>
</tr>
<tr>
<td>Mar. 27/17</td>
<td>10.1.73</td>
<td>NK: Advisory message set in precip.txt for iopt=0</td>
</tr>
<tr>
<td>Apr. 01/17</td>
<td>10.1.74</td>
<td>NK: Changed timer to fix 1 day-off problem</td>
</tr>
<tr>
<td>Apr. 03/17</td>
<td>10.1.75</td>
<td>NK: Fixed time &amp; thr in runof6 arg list</td>
</tr>
<tr>
<td>Apr. 05/17</td>
<td>10.1.76</td>
<td>NK: Reorganized the outfile.* file</td>
</tr>
<tr>
<td>Apr. 17/17</td>
<td>10.1.77</td>
<td>NK: Moved DDS err calcs to new dds_code s/r's</td>
</tr>
<tr>
<td>Apr. 17/17</td>
<td>10.1.78</td>
<td>NK: New s/r dds_UZS to calculate low flow penalty</td>
</tr>
<tr>
<td>Apr. 18/17</td>
<td>10.1.79</td>
<td>NK: Set trcflg=0 for all dds except errflg=10</td>
</tr>
<tr>
<td>Apr. 26/17</td>
<td>10.1.80</td>
<td>NK: Fixed tracer turnover for -ve resv. storage</td>
</tr>
<tr>
<td>May 05/17</td>
<td>10.1.81</td>
<td>NK: Added snowg/yyyyymmdd_swe.tb0 obs. swe</td>
</tr>
<tr>
<td>May 09/17</td>
<td>10.1.82</td>
<td>NK: Added reservoir_fudge_factors.csv</td>
</tr>
<tr>
<td>May 09/17</td>
<td>10.1.83</td>
<td>NK: Fixed lake evap bug - moved it outside lake-only loop</td>
</tr>
<tr>
<td>May 09/17</td>
<td>10.1.84</td>
<td>NK: Put drng(n,ii)=drng(n,ii)*fraction back into runof6</td>
</tr>
<tr>
<td>May 17/17</td>
<td>10.1.85</td>
<td>NK: Level_station_location.xyx for iopt &gt; 0 only</td>
</tr>
<tr>
<td>May 17/17</td>
<td>10.1.86</td>
<td>NK: Division_location.xyx for iopt &gt; 0 only</td>
</tr>
<tr>
<td>May 18/17</td>
<td>10.1.87</td>
<td>NK: Added DA to reservoir_location.xyx</td>
</tr>
<tr>
<td>May 23/17</td>
<td>10.1.88</td>
<td>NK: Fixed Julian_day problems for iso R/W</td>
</tr>
<tr>
<td>May 25/17</td>
<td>10.1.89</td>
<td>NK: Added errflg = 11 for isotope DDS</td>
</tr>
<tr>
<td>Jul. 27/17</td>
<td>10.1.90</td>
<td>NK: Added date_now for i/o files</td>
</tr>
<tr>
<td>May 25/17</td>
<td>10.1.91</td>
<td>NK: Added errflg = 12 for isotope DDS</td>
</tr>
<tr>
<td>May 25/17</td>
<td>10.1.92</td>
<td>NK: Changed to max 200 dds variables</td>
</tr>
<tr>
<td>Aug 17/17</td>
<td>10.1.93</td>
<td>NK: allow year1 etc. to be passed for each event</td>
</tr>
<tr>
<td>Aug 29/17</td>
<td>10.1.94</td>
<td>NK: Fixed col check bug in read_lvl</td>
</tr>
<tr>
<td>Sep 11/17</td>
<td>10.1.95</td>
<td>NK: Fixed Ldepth bug in sub</td>
</tr>
<tr>
<td>Sep 11/17</td>
<td>10.1.96</td>
<td>NK: Added variable lake depth calculation</td>
</tr>
<tr>
<td>Sep 11/17</td>
<td>10.1.97</td>
<td>NK: Moved hdrflg action in runof6.f</td>
</tr>
<tr>
<td>Oct 04/17</td>
<td>10.1.98</td>
<td>NK: Deal with -ve flows in route</td>
</tr>
<tr>
<td>Oct 08/17</td>
<td>10.1.99</td>
<td>NK: Added error check for # sdc classes in Melt.f</td>
</tr>
<tr>
<td>Oct 08/17</td>
<td>10.1.10</td>
<td>NK: Moved ruleflg from sub.f to spl.f</td>
</tr>
<tr>
<td>Oct 24/17</td>
<td>10.2.02</td>
<td>NK: Revert to old G format for lakeSD.csv</td>
</tr>
<tr>
<td>Oct 28/17</td>
<td>10.2.03</td>
<td>NK: Change to one xml output file for computed flow</td>
</tr>
<tr>
<td>Oct 28/17</td>
<td>10.2.04</td>
<td>NK: Killed off stats_info.txt for iopt.ge.1</td>
</tr>
<tr>
<td>Oct 28/17</td>
<td>10.2.06</td>
<td>NK: wfo_spec.txt in working OR basin directory</td>
</tr>
<tr>
<td>Oct 03/17</td>
<td>10.2.07</td>
<td>NK: New rt_pond subroutine for channel pond routing</td>
</tr>
<tr>
<td>Nov. 04/17</td>
<td>10.2.08</td>
<td>NK: New rt_channel &amp; rt_wetland subroutines</td>
</tr>
<tr>
<td>Nov. 04/17</td>
<td>10.2.09</td>
<td>NK: Reinstated old Manning's n correction for legacy files</td>
</tr>
<tr>
<td>Nov. 04/17</td>
<td>10.2.10</td>
<td>NK: Fixed XML file</td>
</tr>
<tr>
<td>Dec. 18/17</td>
<td>10.2.11</td>
<td>NK: 4 files added for BLEND.exe</td>
</tr>
<tr>
<td>Dec. 30/17</td>
<td>10.2.12</td>
<td>NK: Added frame headers to static r2c files incl. shd file</td>
</tr>
<tr>
<td>Jan. 31/18</td>
<td>10.2.13</td>
<td>NK: Re-wrote rules.f to mimic stop log operations</td>
</tr>
<tr>
<td>Feb. 05/18</td>
<td>10.2.15</td>
<td>NK: Added 'results\monthly_peaks'</td>
</tr>
<tr>
<td>Feb. 14/18</td>
<td>10.2.16</td>
<td>NK: Added bankfull flow calculation</td>
</tr>
</tbody>
</table>

WATFLOOD/CHARM – Canadian Hydrological And Routing Model
April 2017
17 BIBLIOGRAPHY

17.1 General References


17.2 Radar Related References


18  WATFLOOD/GREEN KENUE WORKSHOP (2 DAYS)

This workshop was held at McMaster using the TRCA domain, Toronto, 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 have it at.

WINDOWS 7

Right click on My Computer and go to Properties. Click on Advanced and go to Environment Variables and select Path under System variables. Click on EDIT and add ;c:\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\Documents\watflood

### 18.2 Working with Green Kenue (GK)

GK may be downloaded from

### 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 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.


   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 file 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, monochrome 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 (KENUEWorkSpace). 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 watersheds 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.

   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:

      ![Properties of new Watflood Map](image)

      Note: This is very tricky. These numbers were chosen so the cells will be almost square and the cell boundaries coincide with the 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 = masl

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. Dblck 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
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. Dblck 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 on the `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**

```
R:\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

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 grids enter 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 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 watersheds 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 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 system - e.g. 0.001
Min accepted value = 0.0000001
Max value accepted is 1.0 (45 degrees!)
0.0001
Do you want to incorporate
non-contributing areas (nca) y/n?
To incorporate nca 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.r2s 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_response.txt file will be created
Any old file will be overwritten with:

version_4
map_file_name trca.map
par_file_name na
initial nk
no_outlets_&_locations 0
no_inlets_&_locations 0
wetland_split_4 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
Ensimm compatible free format map file expected:

projection=LATLONG
datums=GRS80
zone=unknown
xorigin= -79.58750
yorigin= 43.61666
xcount= 37
ycount= 37
xdelta= 1.2500000E-02
ydelta= 8.3330004E-03
cintv= 1.000000
aimpr= 0.000000000
antype= 20.000000
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 area?
area17 allocated
frac will NOT be adjusted for mca
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
#: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  8.3333335E-04
#:yDelta  8.3333335E-04
#: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)
1.25000000E-02  8.3333335E-04  8.3333335E-04  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 ?
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 ForestPlantations-63
map file class name: 9 RedPine-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 match up with the table in the
class_combine.csv file
Warning: / are read as commas so change to _

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!
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 eliminate 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 s/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

-ve slopes eliminated
frame= 5 written
frame= 6 written
frame= 7 written
frame= 8 written
frame= 38 written
# Undifferentiated=99
frame= 39 written
# Class frame= 40 written
new_shd.r2c written

Closed unit 99 Filename= elv_means.r2c
1 1
elv_means.r2c written
Closed unit 99 Filename= elv_max.r2c
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

c. Save as trca_shd.r2c in the \watflood\basin\ folder

e. Save your workspace

f. Check some of the data: Dblck 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 formatted 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 – snow\yyyymmdd_crs.pt2
b. Init. soil moisture – moist\yyyymmdd_psm.pt2
c. strf\yyyymmmd_str.t0

d. Point precip – raing\yyyymmdd_rag.t0

e. Point Temp. – tempg\yyyymmdd_tag.t0

f. Reservoir releases (optional) – resrl\yyyymmdd_rel.t0

g. Parameter file – basin\trca_par.csv
   i. Pre-processing: Distribute data from point form to gridded form:
      1. distribute snow  snw64.t
      2. distribute moisture  moist64.t
      3. distribute rainfall  ragmet64x.t
      4. distribute temperature  tmp64x.t
h. Initial run
   i. Edit the `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 visible 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 numbered 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` to `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 same 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: Click click on the 1D window, then View and then Select Sync 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:

```
:grdfig                       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 drag it in to a 1D view

ix. x. drag the 3rd swe time series into the 1D view

xi. x. 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 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

### A
- Actual evapotranspiration (AET), 2-8
- AET, 2-9
- Antecedent temperature index (ATI), 2-26
- ATI, 2-26

### B
- Bank storage model, 2-19
- Bankfull area – drainage area, 2-18, 2-22
- Bankfull capacities, 3-14
- Base flow, 2-15
- Basin file, 3-20, 3-27
- Bogs, 2-21, 3-14
- See also Wetlands, 2-21
- Brandes method, 6-7
- BSN.exe, 3-20, 18-6
- bsn_responses.txt file, 3-32
- BSNM.map file. See Map file
- BSNM.pdl file, 3-33
- BSNM_par.csv file. See Parameter file

### C
- CALMET.exe, 1-34
- calmet.par file, 3-42, 6-10
- Capillary potential, 2-4
- Channel density (ICHNL), 3-10
- invert elevation (ELV), 3-7
- width-depth ratio (WIDEP), 2-16, 2-20
- config event flag, 1-25
- Continuous modelling, 1-27
- Contour density (IROUGH), 3-9
- Coordinates, 3-5
- crsfign event flag, 1-25

### D
- Data requirements, 3-1
- Debugging level (IOPT), 4-9
- Debugging SPL, 1-42
- Disaggregation of temporal data precipitation, 6-6
- Distribution of point spatial data precipitation, 1-34
- snow course data, 1-34
- soil moisture, 1-35
- temperature, 3-35
- Diversions, 8-11
- divertflg event flag, 1-26
- DOS, 1-31
- Drainage areas, 3-29
- Drainage direction (S), 3-8

### E
- Edit menu, 1-32
- ELV, 3-7
- elv_max.r2c file, 3-43
- elv_means.r2c file, 3-43
- Equations
  - Green-Ampt, 2-3
  - Hargreaves, 2-7
  - Manning, 2-17
  - Penman, 2-8
  - Philip, 2-3
  - Priestley-Taylor, 2-6
- Evapotranspiration, 2-5
  - actual, 2-8
  - potential, 2-5
  - α coefficient, 2-6
- Event
  - creating event files, 1-27
  - event file, 1-21
  - event flags, 1-24
  - example event file, 1-22
  - existing event, 1-32
  - length of event, 1-21
  - multiple events, chaining, 1-27
  - simulation length, 1-21

### F
- Farm ponds, 8-6
- Fens, 2-21, 3-14
- See also Wetlands, 2-21, 3-14
- Fetch, 3-19
- File naming convention, 1-20
- File structure, 1-18
- flowflg event flag, 1-26
- Flood plain roughness, 4-12
- Flow animation, 1-40
- Flow data, 8-1
- Flow stations, 1-48, 8-3
- flow_init.r2c file, 1-25, 12-1, 12-4
- Forecast mode, 1-37, 1-39, 4-9
- Forest vegetation coefficient (FTALL), 2-10
- FRAC, 2-20, 3-8
- FRATIO, 4-8
- frcflg event flag, 1-26
- FTALL, 2-10
G
Georeference requirements, 3-1
Glaciers, 3-12, 3-14
gridflg event flag, 1-26
Green Kenuse, 13-1
conversion to Green Kenuse formats, 15-1
debugging with, 13-3
Green-Ampt equation, 2-3
Grid drainage area (FRAC), 3-8
Grid origin, 3-1
Gridded rain file, 6-13
Gridded temperature file, 7-3
Groundwater recharge, 2-14
Grouped Response Units (GRU), 1-2

H
Hargreaves equation, 2-7
Help, 1-50
Hydrological model, 2-1

I
IAK, 3-11
IBN, 3-9
ICHNL, 3-10
Infiltration, 2-3
initflg event flag, 1-26
Initial conditions. See Model initialization
Instream lakes, 2-22
Interception, 2-11, 4-15
Interflow, 2-13
IOPT, 4-9
IREACH, 3-11
IROUGH, 3-9
ITYPE, 4-9

K
KCOND, 2-19, 2-20
kenuflg event flag, 1-25

L
lake_level_init.pt2 file, 1-25
Lakes and reservoirs
effect on routing, 2-18
inflow files, 8-10
initial levels, 8-7
instream lakes, 2-22
operating rule, 8-6
outflow (release) files, 8-4
routing, 2-21
storage-discharge curves, 3-36, 8-6
Land cover classes (IAK), 3-11
combining and reordering classes, 3-15
Lapse rate, 3-43, 4-7
Leakage
input files for WATROUTE, 12-3, 12-6
Lower zone drainage, 4-12

M
Main channel flow, 2-17
MAKE_EVT.exe, 15-5
Manning equation, 2-17
Map file, 1-49, 3-1, 3-2, 3-3
Meaning factor (MNDR), 4-12
Melt factor (MF), 2-25
MF, 2-25
MNDR, 4-12
Model calibration mode, 1-38
Model initialization, 1-27, 5-1
initial channel storage, 5-6
levels (lakes and reservoirs), 8-7
lower zone storage, 5-7
snow cover, 5-1
soil moisture, 5-4
resuming from previous run, 5-7
modelflg event flag, 1-25
Modeling aspects, 2-1
MODFLOW, 12-9
MOIST.exe, 1-35
Moisture optimization, 4-9

N
Natural flows, 8-8
Negative melt factor (NMF), 2-26
New watershed setup, 3-1
NMF, 2-26
ntrtflg event flag, 1-26
nudgeflg event flag, 1-26
Nudging, 1-26
NUMA, 4-9

O
Optimization, 4-1, 4-9, 4-16
Dynamically Dimensioned Search (DDS), 4-21
error criterion, 4-20
hints, 4-32
Pattern Search (PS), 4-19
selecting parameters, 4-19, 4-21
outfiles.new file, 11-2
outfiles.txt file, 11-2
Output files, 11-2
Overbank flow, 2-17
Overland flow, 2-14

P
paffflg event flag, 1-26
Parameter file, 4-1
Parameter sensitivity, 4-41
Parameters, 1-38, 4-1, 4-9
19. Index

Penman equation, 2-8
Philip equation, 2-3
picflg event flag, 1-25
Plotting hydrographs, 11-5
Pond routing, 2-22
POOL, 4-12
Potential evapotranspiration, 2-5
precip.txt file, 4-18, 11-11
Precipitation
data, 6-1
data processing, 6-1
disaggregation, 6-6
distribute point data, 1-36
grid shifting, 14-9
lapse rate, 6-5
missing data, 6-3
optimization, 4-10
point (rain gauge) data file, 6-2
radius of influence, 6-4
scaling, 4-10
Priestley-Taylor equation, 2-6

R
Radar
adjustment and calibration of radar data, 1-36, 6-9
Brandes method, 6-9
calibrate radar, 1-34
calibrated radar file, 6-11
CAPPI or PPI, 6-8
read CAPPI, 1-35
Radiation data, 10-1
Radiation-temperature index, 2-27
Radius of influence. See Precipitation; Temperature
RADMET.exe, 1-34
RAGMET.exe, 1-34
Rainfall. See Precipitation
Reach number (REACH), 2-21, 3-11
Recharge
input files for MODFLOW, 12-9
input files for WATROUTE, 12-3, 12-6
to groundwater (upper zone to lower zone drainage), 2-14
Reservoirs. See Lakes and reservoirs
resetflg event flag, 1-26
resetflg event flag, 1-24
resume.txt file, 1-27
resumflg event flag, 1-25
Revisions, 16-1
River class (IBN), 3-9, 4-12
RLAKE, 4-12
routeflg event flag, 1-25
Routting model, 2-16
rules.pt5, 3-38
Running
SPL.exe, 1-37
SPLD.exe, 1-35
SPLX.exe, 1-35
Runoff
base flow, 2-15
input files for WATROUTE, 12-2, 12-6
interflow, 2-13
overland (surface) flow, 2-14
total, 2-16

S
SDC, 1-33, 4-15
sedflg event flag, 1-24
shdflg event flag, 1-25
Single event mode, 1-37
Single run, 4-9
Smoothing distance. See Precipitation; Temperature
smwflg event flag, 1-24
Snow
distribute snow course data, 1-36
initial snow cover, 5-1
snow course, 5-1
snow cover depletion curve (SDC), 1-33, 4-15
snow water equivalent (SWE)
gridded data file, 5-2
point data file, 5-1
Snowmelt model, 2-25
SWK.exe, 1-34
smwflg event flag, 1-24
Soil moisture
distribute point data, 1-36
gridded data file, 5-5
initial, 1-37
point data file, 5-4
Soil moisture coefficient, 2-9
Soil temperature coefficient, 2-9
soil_init.r2c file, 1-25
SPLD.exe, 1-35
SPLX.exe, 1-35
Stage hydrographs, 1-39, 3-35
State variable updating, 5-7
STATS.exe, 1-35
Streamflow file, 8-1
Sub-watersheds, 3-31
Surface detention values, 2-3
Surface parameters, 4-12
SWE, 5-1

T
tbcflg event flag, 1-24
Temperature
daily temperature differences, 7-4
data, 7-1
distribute point data, 1-37
lapse rate, 7-3
point data file, 7-1
radius of influence, 7-2
smoothing distance, 7-2
Temperature index model, 2-25
TMP.exe, 1-35
Tracer model, 14-10
trcflg event flag, 1-26
Tutorial, 1-27, 1-30
19. Index

V
Valley type (ITYPE), 4-9
vapflg event flag, 1-24

W
Watershed coordinates, 3-5
Watershed data, 3-3
WATFLOOD options, 14-6
WATFLOOD program revisions, 16-1
WATFLOOD programs, 1-34
CALMET.exe, 1-34
MAKE_EVT.exe, 15-5
MOIST.exe, 1-35
RADMET.exe, 1-34
RAGMET.exe, 1-34
SNW.exe, 1-34
SPLD.exe, 1-35
SPLX.exe, 1-35
STATS.exe, 1-35
TMP.exe, 1-35
WATROUTE, 12-1
options, 12-6
wetflg event flag, 1-25
Wetland model, 14-7
Wetlands, 2-21, 3-12, 3-14
outflow, 2-19
routint, 2-19
splitting into bogs and fens, 3-14
WDFP, 2-16, 2-20
Wind speed and direction, 9-1
Workshop, 18-1