GeoTools User's Manual

Developed at the

Daryl B. Simons Building *at the*
Engineering Research Center
Colorado State University

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GeoTools Version 4

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DISCLAIMER

Although the authors have ensured that the methods and procedures included in the computational package are valid and reliable, neither the authors, Colorado State University, the U.S. Bureau of Reclamation, nor the U.S. Army Corps of Engineers accepts responsibility for real or alleged error, loss, damage, or injury resulting from its use.

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LIST OF VARIABLES AND ABBREVIATIONS

a	=	coefficient
A	=	coefficient in two fraction sediment transport model, fitted parameter
$AnnualMean(i)$	=	average annual flow for each year
$AnnualMax(i)$	=	maximum annual flow for each year
b	=	exponent
B	=	bin index
B_N	=	number of flows in a bin
BSI	=	bed stability indicator
c	=	regression coefficient
c_B	=	sediment transport coefficient
C_{ppm}	=	concentration of sediment in parts per million
C_v	=	concentration of sediment by volume
CV	=	coefficient of variation
d	=	regression exponent
d_s	=	characteristic sediment diameter
d_*	=	dimensionless particle size
d_{16}	=	particle size at which 16% of bed material is finer by weight
d_{50}	=	particle size at which 50% of bed material is finer by weight, median particle diameter
d_{84}	=	particle size at which 84% of bed material is finer by weight
d_{90}	=	particle size at which 90% of bed material is finer by weight
D_s	=	characteristic sand size in two fraction sediment transport model
D_g	=	characteristic gravel size in two fraction sediment transport model
e	=	coefficient
e_B	=	bedload efficiency factor
f	=	exponent
F_s	=	proportion of sediment in sand fraction (value from 0 to 1)
g	=	gravitational acceleration

G = ratio of specific weight of sediment to that of water

H_c = coefficient used in calculating mean scour/fill depth

H_e = exponent used in calculating mean scour/fill depth

i = dummy counting index

LI = logarithmic bin interval

MI = mobility index

n = Manning's *n*

N = generic total number used in empirical frequency distribution function

N_B = number of bins used in effective discharge analysis

N_Q = number of flows

N_T = total number of discharges in historical flow record within period of analysis

$P(i)$ = EFD plotting position

q_{bv} = volumetric bedload transport per unit width of channel

q_g = volumetric gravel transport per unit width of channel

q_s = volumetric sand transport per unit width of channel

q_t = total sediment load per unit width of channel

Q = discharge

$Q_{1.5}$ = 1.5-year recurrence interval discharge

Q_2 = 2-year recurrence interval discharge

Q_B = discharge in bin *B*

$\overline{Q_B}$ = mean discharge in bin *B*

$Q_{B_{\max}}$ = maximum discharge in bin *B*

$Q_{B_{\min}}$ = minimum discharge in bin *B*

Q_e = effective discharge

Q_{ma} = mean annual flow

$Q_{\max}$ = maximum discharge in historical flow record within period of analysis

$Q_{mean\ annual}$ = mean annual flow

$Q_{\min}$ = minimum discharge in historical flow record within period of analysis

Q_N = average across all flows

Q_s	=	sediment discharge
Q_{s_B}	=	sediment discharge associated with bin B
$Q^T{}_{s_B}$	=	total sediment discharge for all bins $B = 1$ to N_B
$\overline{Q}_{y\max}$	=	mean of the annual maxima
R	=	hydraulic radius
$Ratio(i)$	=	average annual flow divided by the maximum flow for each year
S	=	subscript for sediment
S	=	slope
S_f	=	friction slope
u_*	=	shear velocity
V	=	mean flow velocity
V_c	=	critical velocity
w	=	channel width

Greek

α	=	coefficient used in empirical frequency distribution function
β	=	coefficient used in empirical frequency distribution function
γ	=	specific weight of water
γ_m	=	specific weight of water and sediment mixture
γ_Q	=	coefficient of skewness
θ	=	$1/\theta$ is mean scour/fill depth
ν	=	kinematic viscosity of water-sediment mixture
ξ	=	depth
ρ	=	density of water-sediment mixture
σ	=	standard deviation
σ_g	=	geometric standard deviation of the bed material
σ_{Q_N}	=	standard deviation of all flows in the flow record
$\sigma_{Q_{y\max}}$	=	standard deviation of annual maxima

τ_0	=	average boundary shear stress
τ_B	=	shear stress in bin B
τ_c	=	critical shear stress for incipient motion
τ_*	=	dimensionless shear stress
τ_{*_c}	=	critical dimensionless shear stress
τ_r^*	=	dimensionless shear stress used to normalize equation
ϕ	=	angle of repose
Π	=	value of a slope of the two parts of the function
ϑ'	=	value of a slope of the two parts of the function
ω_s	=	fall velocity of the sediment
ω	=	specific stream power
Ω	=	total stream power

Abbreviations

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
CDF	cumulative distribution function
cfs	cubic feet per second
DOS	Disk Operating System
EDF	empirical distribution functions
EFD	empirical frequency distribution
EPA	U.S. Environmental Protection Agency
ft	feet
ft^2	square feet
ft^3	cubic feet

.GTI	GeoTools Interface file
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HSPF	Hydrological Simulation Program – FORTRAN
kg	kilogram(s)
lb	pound(s)
mm	millimeter(s)
min	minutes(s)
NATHAT	NATional Hydrologic Assessment Tool
NWIS	National Water Information System
PDF	probability distribution function
ppm	parts per million
s	second(s)
SI	Metric units
SWMM	Storm Water Management Model
USBR	U. S. Bureau of Reclamation
USCS	English units
USGS	U. S. Geological Survey
WY	Water Year
X, Y	coordinates

CHAPTER 1
INTRODUCTION

GeoTools was developed at the Engineering Research Center at Colorado State University. This user's manual for GeoTools Version 4 is designed to provide a general understanding of model structure and capabilities, as well as a requisite knowledge of input options and output features necessary to implement the modeling package. Chapters 3 through 7 provide step-by-step options and background information associated with automated effective discharge computations and the "stand alone" components of sediment transport and channel change estimates. Chapter 8 provides the input and output features associated with partial frequency analyses and Chapter 9 presents information with respect to disturbance regime computations.

1.1 Overview

An important contribution that engineers and geomorphologists can make to environmental management is to develop parsimonious tools that empower non-specialists to make rational planning decisions within the context of a changing environment. Existing models may be used to assess the potential hydrologic effects of land-use change on receiving waters, but practical tools for translating these results into metrics for predicting channel stability and effects on stream biota are essentially unavailable to local watershed planners. To improve watershed management in the context of changing land uses, a flexible, changeable package of models is presented to provide estimates of long-term changes in stream erosion potential, channel processes, and instream disturbance regime. The models are developed in Visual Basic for Applications / Excel and include a suite of stream / land-use management modules designed to operate with either continuous or single-event hydrologic input in a variety of formats. The tools can also be used as a post-processor for the U.S. Environmental Protection Agency's (EPA) SWMM and HSPF models as well as for any general time series of discharges. Based on the input channel geometry and flow series, the various modules can provide users with estimates of the following characteristics for pre- and post-land use change conditions: (1) the temporal distribution of hydraulic parameters including shear stress, specific stream power, and potential mobility of various particle sizes; (2) effective discharge / sediment yield; (3) potential changes in sediment transport and yield as a result of altered flow and sedimentation regimes; (4) frequency, depth, and duration of bed scour; and (5) several geomorphically relevant hydrologic metrics relating to channel form, flow effectiveness, and "flashiness."

Although GeoTools is intended for a broad range of applications, its primary impetus has been the need for practical tools for assessing fluvial processes in urbanizing watersheds. For example, GeoTools may be used to quickly compute *time-integrated* sediment transport and scour characteristics across a range of flows and time periods associated with varying stormwater mitigation schemes. The modules give end users a suite of tools to compare the erosive potential of hydrographs and characterize channel changes that might result from a wide variety of watershed changes, as well as, to aid interpretation of biomonitoring information through quantification of stream disturbance regimes.

1.2 Manual Conventions

Actual titles for menus and frames, within these menus, are shown in a different font, namely, Arial. Figure 1-1 is a GeoTools quick reference guide for input options.

Opening menu — Figure 3-1 (p. 11)

User Options frame
- o Effective Discharge (Single File)
- o Effective Discharge Comparison (Multiple Files)
- o Sediment Transport
- o Partial Frequency Analysis
- o Disturbance Regime
- o Channel Change Indices
- o Hydrologic Metrics

☐ Suppress progress indicators
☐ Suppress log file

RUN and Quit buttons

Multiple Files Input option — Figure 3-2 (p. 12)

Reference File ____________________
File 1 ____________________
File 2 ____________________
File 3 ____________________
File 4 ____________________

RUN and Quit buttons

INPUT FILE OPTIONS menu — Figure 4-1 (p. 16)

File Format Options frame
- o Default – “date”-stage-discharge
- o File Format 2 – date-stage-discharge
- o Mean Daily USGS Download – “USGS”-site#-date-discharge
- o 15-minute USGS File – year-month-day-minute-stage-discharge
- o USGS Download “Peaks”
- o SWMM “.OUT” file
- o HSPF “P” file
- o Other

☐ Limit Input to Flows > ______

Cancel and Continue buttons

User Input Options menu — Figure 5-1 (p. 23)

Flow Data Selection frame — Left Frame, Figure 5-2 (p. 24)

Enter Range of Years to Calculate Effective Discharge:
- o All Years
- o Specify Years ______ to ______

Please select time interval for input discharge data:
- 15 minute
- 1 hour
- Daily
- Other _________

Other: _________

☐ Fill Missing Values = ________

Effective Discharge Tools frame — Right Frame, Figure 5-4 (p. 27)

Bin Variation Option
Number of Variations: ______

Type and Number of Bins:
Separate number of bins with commas.
☐ Arithmetic Bins
Number: ______
☐ Logarithmic Bins
Number: ______

Figure 1-1 – GeoTools quick reference guide.

User Input Options menu (cont.)

Sediment Transport Tools frame

Minimum Flow Transporting Sediment

☐ Critical Discharge (cfs): ______

o Qs = aQ^b

	Low Discharge (cfs)		High Discharge (cfs)
☐ Bound			
a = ______ b = ______	_______	to	______
☐ Use Two Rating Functions			
a = ______ b = ______	_______	to	______
☐ Use Three Rating Functions			
a = ______ b = ______	_______	to	______

o Use sediment transport equation

Channel Change Tools frame

☐ Bed Stability Index	Slope (ft/ft)	____
	d50 (mm)	____
	d84 (mm)	____
☐ Mobility Index	d90 (mm)	____
☐ Specific Stream Power	Characteristic Width (ft)	____
☐ Scour/Fill Depth	Specific Weight Sediment (lb/ft^3)	____

Output Options frame

☐ Use SI Units (Default = English)

o No Comparison Charts

o PDF Comparison Charts

o CDF Comparison Charts

o PDF and CDF Comparisons

☐ Leave Application Open When Finished

Cancel and Continue>> buttons

Left Frame Figure 5-3 (p. 26)

Right Top Frame Figure 5-5 (p. 31)

Right Bottom Frame Figure 5-6 (p. 31)

Channel Characteristics menu

Figure 6-2 (p. 41)

First Hydraulic Radius Function frame

Hydraulic radius as a power function as a function of flowrate. $R = cQ^d$

c coefficient = _______ d exponent = ________

☐ Click here to enable the use of two hydraulic radius relationships.

Discharge Separating Relationships frame

Enter discharge at which to switch relationships (cfs): ______

Overbank Hydraulic Radius Function frame

Hydraulic radius as a power function as a function of flowrate for depths exceeding bank height. $R = eQ^f$

e coefficient = _______ f exponent = ________

Velocity Function frame

Enter Manning roughness to calculate average channel velocity. Manning’s n = ______

Cancel and Continue>> buttons

Sediment Transport Rate Calculator (Version 1.0) menu

Figure 6-1 (p. 33)

Select Equation frame

Meyer-Peter Müller

Yang’s Sand, d50

Bagnold Total Load

Brownlie Total Load

Wilcock

Select Units frame

o Select S.I. Units

o Select English Units

Figure 1.1 (cont.) – GeoTools quick reference guide.

Sediment Transport Rate Calculator menu (cont.)

Channel Properties frame (*only English Units are listed here*)

Unit	Meyer-Peter Müller	Wilcock	Bagnold	Brownlie	Yang
Average Velocity (ft/s)			_____	_____	_____
Average Width (ft)	_____				
Bedload Efficiency			_____		
Critical Tau Star	_____				
d16 (mm)				_____	
d50 (mm)			_____	_____	_____
d84 (mm)				_____	
dg (mm)		_____			
dm (mm)	_____				
ds (mm)		_____			
Discharge (ft^3/s)		_____		_____	_____
Effective Width (ft)			_____	_____	
Energy Slope (ft/ft)	_____		_____	_____	_____
Fs		_____			
Hydraulic Radius (ft)	_____		_____	_____	_____
Temperature (ºF)			_____	_____	_____
Shear Stress (lb/ft^2)		_____			
Width (ft)		_____			

Cancel and Continue>> buttons

Partial Frequency Analysis menu

Figure 8-1 (p. 62)

Input File Name _______________________

File Characteristics frame

Please Enter Time Interval
For Input File ______ [seconds / minutes / hours / days / months / years]

o All Years
o Specify Years ______ to ______

Storm Characteristics frame

Minimum Discharge to Consider _____cfs

☐ Specify Inter Storm Duration
Inter Storm Duration ____ [seconds / minutes / hours / days / months / years]

Plotting Position Options frame

o Weibull	o Cunnane
o Median	o Gringorten
o APL	o Hazen
o Blom	

Cancel and Continue buttons

Figure 1.1 (cont.) – GeoTools quick reference guide.

Figure 9-1
(p. 66)

Duration and Time of Sediment Transport menu

Input File Attributes frame

Input File Name _______________________

Please Enter Time Interval for Input File ______

- seconds
- minutes
- hours
- days
- months
- years

o All Years
o Specify Years ______ to ______

o Metric Units
o English Units

Slope ____
Dimensionless critical shear stress for incipient motion ____
Characteristic Grain Size (mm) ____
Specific Weight of Water (lb/ft^3) ____ ☐ Assume specific weight of water
Specific Weight of Sediment (lb/ft^3) ____ ☐ Assume specific weight of sediment

Exit and Run buttons

Figure 3-3
(p. 13)

Channel Change Tool menu

Units frame

o English (Default) o Metric

Options frame

☐ Specific-Stream Power
☐ Bed Stability Indicator
☐ Mobility Index
☐ Scour/Fill Depth

Input Parameters frame

Characteristic Discharge (Q) (cfs) ________
Slope (ft/ft) ________
d50 (mm) ________
d84 (mm) ________
d90 (mm) ________
Width (ft) ________
Flow Area (ft^2) ________
Wetted Perimeter (ft) ________
Specific Weight Water (lb/ft^3) ________
Specific Weight Sediment (lb/ft^3) ________

EXIT and RUN buttons

Figure 1.1 (cont.) – GeoTools quick reference guide.

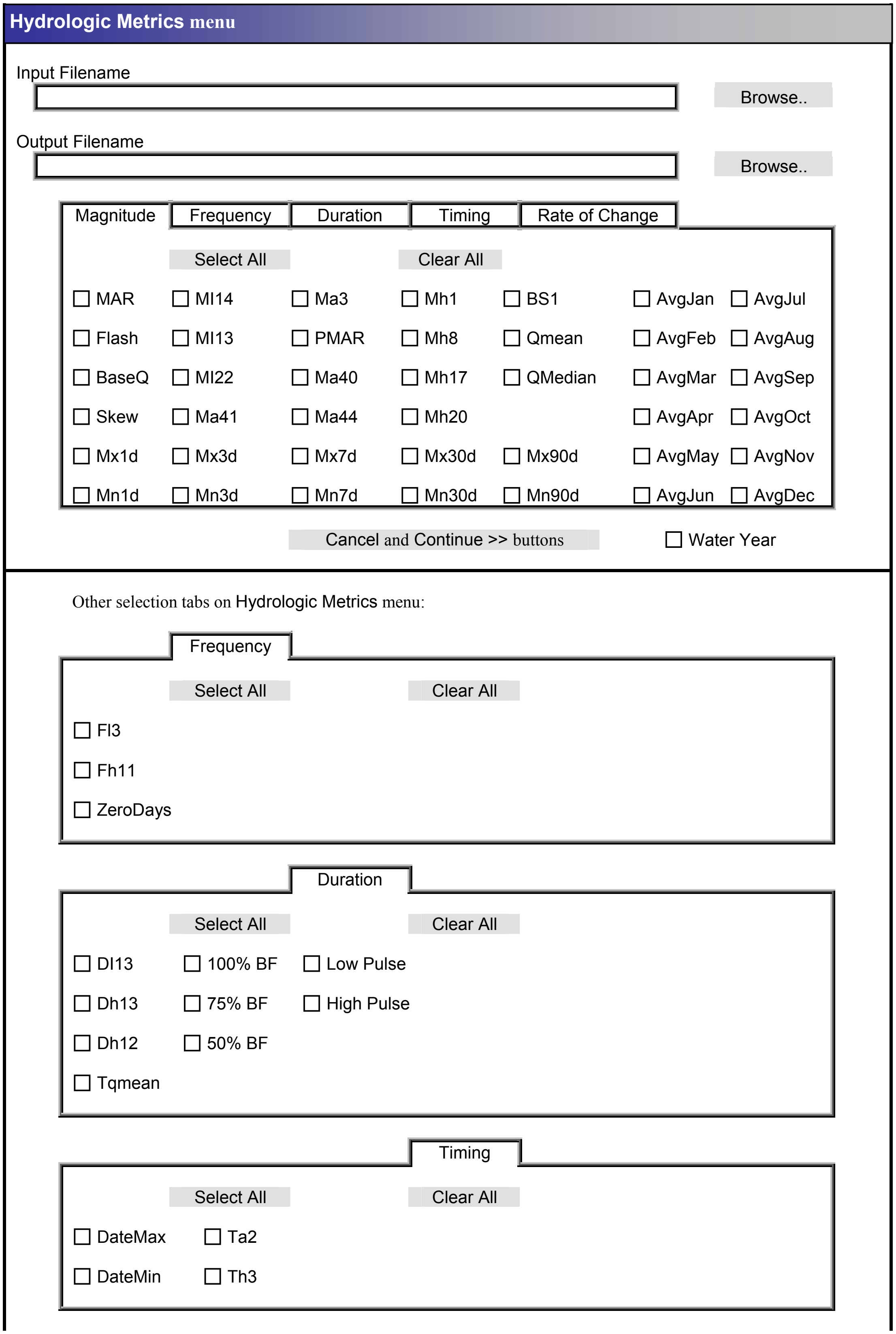


Figure 3-6 (p. 80)

Figure 3-7 (p. 81)

Figure 3-7 (p. 81)

Figure 3-7 (p. 81)

Figure 1.1 (cont.) – GeoTools quick reference guide.

Hydrologic Metrics menu (cont.)

Rate of Change

Select All   Clear All

- ☐ RiseR
- ☐ FallR
- ☐ Revs

Figure 3-7 (p. 81)

OUTPUTS

Figure 1.1 (cont.) – GeoTools quick reference guide.

CHAPTER 2

INSTALLATION

Your GeoTools distribution should have come from a "GeoTool_distribution.zip" file. The most current version of GeoTools is available at http://www.engr.colostate.edu/~bbledsoe/GeoTool or by contacting Brian Bledsoe (Brian.Bledsoe@ColoState.edu). To install and run GeoTools, unzip the distribution zip file into a directory named "GeoTool."

The current release of GeoTools was designed with Microsoft® Office 2000 and is known also to function properly on Microsoft® Office XP. In an Office XP installation, the security settings must be set to medium or low in order to operate GeoTools, as it does not come with a security certificate. It is expected that the user has installed all appropriate service packs to their installation of Office 2000 or Office XP. GeoTools has not been tested on versions earlier than Microsoft® Office 2000 and these installations are not supported. The following references are necessary within Microsoft® Visual Basic for Applications in the user's Excel installation for proper GeoTools execution:

(1) Visual Basic for Applications,
(2) Microsoft® Excel 9.0 Object Library,
(3) OLE Automation,
(4) Microsoft® Office 9.0 Object Library,
(5) Microsoft® Forms 2.0 Object Library, and
(6) Solver.

Please note that any specific references to release versions of GeoTools or its manual are valid for later release. Happy GeoTooling…

CHAPTER 3
OPENING INPUT OPTIONS

GeoTools is designed to provide users with a variety of tools to assess the geomorphic implications of watershed modifications and to examine the statistical properties and sediment transport characteristics of both simulated and historical flow series. The user is initially presented with options (Figure 3-1) to:

- perform effective discharge computations for one flow series,
- perform effective discharge computations and compare multiple flow series,
- perform stand-alone sediment transport computations,
- perform partial frequency analysis,
- calculate disturbance regime characteristics,
- calculate channel change indices, or
- calculate up to 105 hydrologic metrics for multiple series of streamflow data.

Discussion of these options follows:

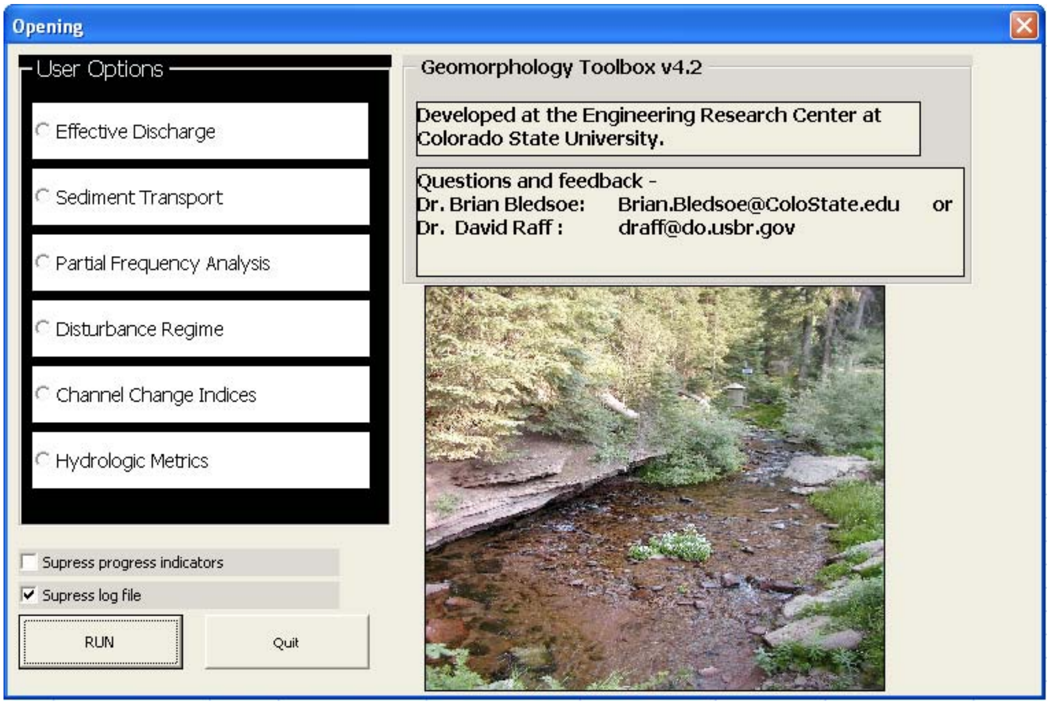


Figure 3-1 – Opening menu screen shot, where user selects one of six GeoTools modules.

3.1 Effective Discharge

The effective discharge module allows the user to estimate the range of discharges responsible for transporting the largest amount of sediment over time. This option permits calculation of the effective discharge for a single file or comparison of multiple discharge series within a single run of GeoTools. To calculate the effective discharge for a single file, a filename is placed into the "Reference File" location shown in Figure 3-2. This option should be chosen if the user would like to analyze a single discharge series. The output includes effective discharge calculations, flow regime (flashiness) statistics as well as distributions of shear stress, stream power (total and unit), and water and sediment discharges among others. Channel change indices may also be selected.

The multiple file option permits direct comparison of geomorphically significant factors (*i.e.,* discharge, sediment transport, shear stress, and stream power) among up to four discharge series. The program and calculations are the same as the single record option, but allows the user to specify a level of detail in the output not available when using the Effective Discharge

(Single File) option. The user must use one input file as the Reference File, and at least one other file to run for comparison (Figure 3-2). GeoTools will generate comparison sheets for probability and cumulative distribution functions for water, sediment, stream power, and shear stress distributions if the user chooses these options. There is also a summary sheet produced which compares flow regimes for each time series used.

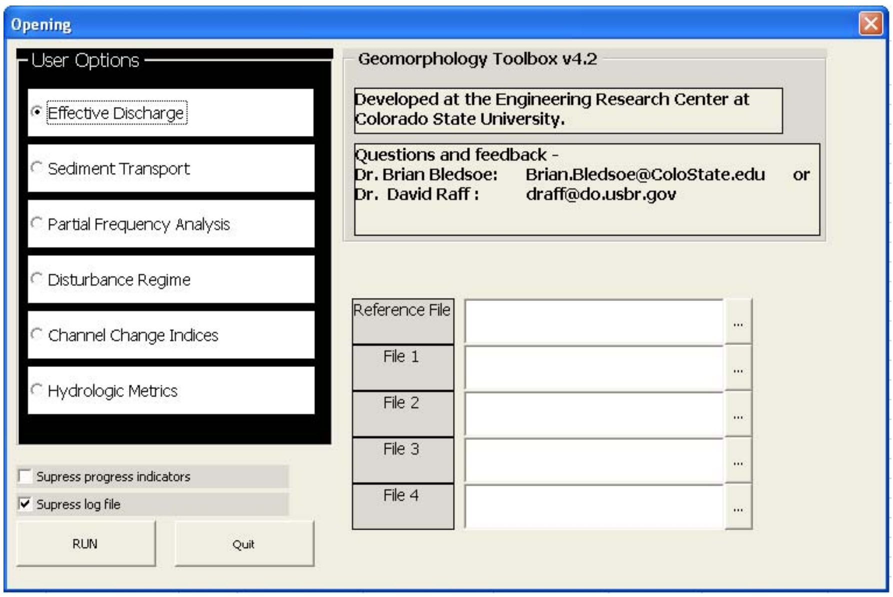


Figure 3-2 – Effective Discharge screen shot.

3.2 Sediment Transport (Stand Alone)

This option determines the amount of sediment transported for a single discharge entered by the user. The user may specify which sediment transport equation GeoTools will use (*e.g.,* Bagnold, Brownlie, Yang's Sand, or Wilcock) through the Sediment Transport Rate Calculator (Figure 6-1). See Chapter 6 for further information about entering data into the Sediment Transport Rate Calculator and a discussion of the theoretical development for the different sediment transport equations.

3.3 Partial Frequency Analysis

Often accurate flood frequencies are desired for relatively short return periods (< 10 years). In this case, frequency estimates based on annual maximum series may not be appropriate and partial flood frequency analyses are more desirable. This option computes flood frequencies using user-defined plotting positions and general storm characteristics.

3.4 Disturbance Regime

This module of GeoTools calculates the bed disturbance of a river or stream based on a historical flow record. Specifically, it calculates the number of discrete events as well as the total length of time that a specific grain size is in motion based on incipient motion criteria entered by the user.

3.5 Channel Change Indices

This option determines the channel change indices available within GeoTools. These include Bed Stability Indicator, Mobility Index, Specific Stream Power, and Scour/Fill Depth distribution. The user inputs data through the Channel Change Tool menu (Figure 3-3).

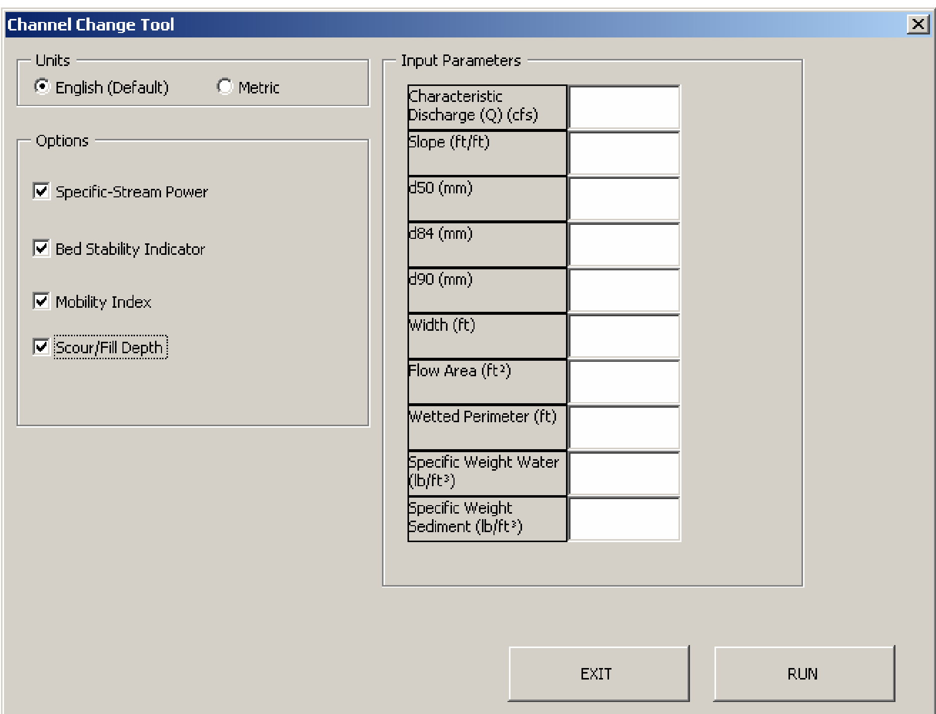


Figure 3-3 – Channel Change Tool input menu screen shot.

These indices are calculated for a single-channel flow and geomorphic parameters when running in stand alone mode. The user may chose to enter information in either English (USCS) or Metric (SI) units when running in stand alone mode. The output will be in the same units as the input. Only those text boxes within the Channel Change Tool menu (Figure 3-3), that are relevant to the user-selected channel change indices, will be enabled for input.

3.6 Hydrologic Metrics

The Hydrologic Metrics module incorporates 105 statistics that characterize flow. The hydrologic metric functionality incorporated into GeoTools was designed to facilitate the simultaneous analysis of flow regimes of a large number of fluvial systems. An effective method of describing a flow regime is through a collection of statistics that characterize its five key components: magnitude, frequency, duration, timing, and rate of change. A complete list of the 105 metrics included in GeoTools is presented in Chapter 10. The Hydrologic Metrics user form containing multiple tabs for Magnitude, Frequency, Duration, Timing, and Rate of Change is also contained in Chapter 10.

CHAPTER 4

DISCHARGE INPUT FORMAT

With the exception of the sediment transport stand alone mode, GeoTools requires the input of a flow record. The flow record may be inputted in a variety of formats, and can represent either long-term continuous flow or a single-storm event. When inputting a flow record, the file name and location are selected, and then the user is prompted to select the format of the selected file (Figure 4-1). The flow record must be in cubic feet per second (cfs). While stage data are not used in this version of GeoTools, the stage data must be included with the flow record, or placeholders must be used where stage data are expected. If the user has good reason, or files are exceptionally large and the user is only interested in censored discharges, the Limit Input to Flows > can be used, which will only load the data from the file which exceeds the censored value entered in the text box.

4.1 Input File Options

GeoTools is capable of loading seven different file formats that are commonly encountered in practice. These seven formats are discussed (with examples) as follows:

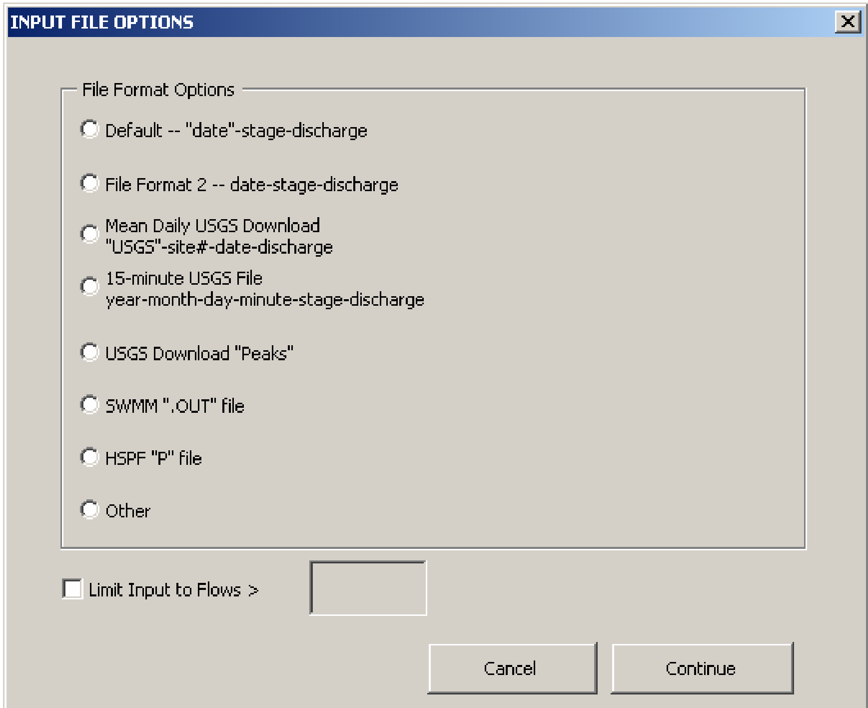


Figure 4-1 – Input File Options screen shot, where the user selects the format of the input flow record. The current version of GeoTools has the capability of reading five file types including common U.S. Geological Survey (USGS) records and SWMM model outputs.

4.2 Default – "date"-stage-discharge

The default file type within GeoTools is a comma-delimited format with the date and time entry in quotes. Files of this type may not have any header, which if necessary, can be removed using any common text editor. This is a comma-delimited file format, which has the following format:

```
"10/8/1991 5:30:00 PM",7.67,36
"10/8/1991 5:45:00 PM",7.67,36
"10/8/1991 6:00:00 PM",7.65,34
"10/8/1991 6:15:00 PM",7.67,36
"10/8/1991 6:30:00 PM",7.66,35
"10/8/1991 6:45:00 PM",7.68,37
"10/8/1991 7:00:00 PM",7.64,34
"10/8/1991 7:15:00 PM",7.68,37
```

In the above example a time stamp is provided along with the data but is not required. Also note that the stage data are not necessary, and if not present, two commas must separate the date and discharge data (*i.e.*, "10/8/1991 8:45:00 PM", ,33).

4.2.1 File Format 2 – date-stage-discharge

This format is the same as the default format only the date is not contained within quotes. An example is shown below:

```
10/8/1991 5:30:00 PM,7.67,36
10/8/1991 5:45:00 PM,7.67,36
10/8/1991 6:00:00 PM,7.65,34
10/8/1991 6:15:00 PM,7.67,36
10/8/1991 6:30:00 PM,7.66,35
10/8/1991 6:45:00 PM,7.68,37
10/8/1991 7:00:00 PM,7.64,34
```

As with the default format, the time stamps included with the data are not necessary. Additionally, there can be no header. Like the default format, stage data need not be included, and if not included, two commas must hold the place where the stage data would be (*i.e.*, 10/8/1991 8:45:00 PM, ,33).

4.2.2 Mean Daily USGS Download – "USGS"-site #-date-discharge

This input is to be used with mean daily discharge data downloaded from the USGS website. There is no data processing required. The format of a file is as follows:

```
#
# U.S. Geological Survey
# National Water Information System
# Retrieved: 2002-04-10 11:53:48 EDT
#
# This file contains published daily mean streamflow data.
#
# Further Descriptions of the dv_cd column can be found at:
# http://water.usgs.gov/nwis/help?codes_help#dv_cd
#
#
# This information includes the following fields:
#
#  agency_cd   Agency Code
```

```
#  site_no     USGS station number
#  dv_dt       date of daily mean streamflow
#  dv_va       daily mean streamflow value, in cubic-feet per-second
#  dv_cd       daily mean streamflow value qualification code
#
# Sites in this file include:
#  USGS 07287150 ABIACA CREEK NR SEVEN PINES, MS
#
#
agency_cd  site_no dv_dt   dv_va  dv_cd
5s   15s   10d     12n     3s
USGS       07287150        1991-10-01   41    e
USGS       07287150        1991-10-02   41    e
USGS       07287150        1991-10-03   41    e
USGS       07287150        1991-10-04   41    e
USGS       07287150        1991-10-05   41    e
USGS       07287150        1991-10-06   41    e
USGS       07287150        1991-10-07   41    e
USGS       07287150        1991-10-08   42    1
USGS       07287150        1991-10-09   43    1
USGS       07287150        1991-10-10   49    1
```

GeoTools identifies the "USGS" string to note the beginning of a data line. Therefore, there is no limit to the length or location of headers, and the discharge data must be in the format shown above (with "USGS" appearing at the start of every data line).

4.2.3 15-minute USGS File – year-month-day-minute-stage-discharge

This input format is intended to be compatible with 15-minute flow records provided by the USGS. This format usually has a header that must be removed before inputting into GeoTools. Any text editor capable of opening and handling large amounts of data (*e.g.,* Microsoft® WordPad, TextPad, etc.) can be used to remove the header. The form of this file type, once the header has been removed, is as follows:

1991	10	10	630	5.55	40
1991	10	10	645	5.55	40
1991	10	10	660	5.55	40
1991	10	10	675	5.55	40
1991	10	10	690	5.55	40
1991	10	10	705	5.56	41
1991	10	10	720	5.56	41
1991	10	10	735	5.6	44
1991	10	10	750	5.62	45
1991	10	10	765	5.63	46
1991	10	10	780	5.64	47
1991	10	10	795	5.65	48
1991	10	10	810	5.66	48
1991	10	10	825	5.68	50
1991	10	10	840	5.69	51
1991	10	10	855	5.72	53
1991	10	10	870	5.75	56

4.2.4 USGS Download "Peaks"

The USGS produces files of peak discharge values for annual durations available through the National Water Information System (NWIS) web site accessed at http://waterdata.usgs.gov/nwis. These files can be input into GeoTools and used to develop flood frequency analysis. It is unlikely that this file will be used with any effective discharge type of analysis; however, attempting to run the effective discharge modules with this type of input file should not generate an error.

4.2.5 SWMM ".OUT" file

The use of GeoTools as a post-processing tool for the Storm Water Management Model (SWMM)* is handled through an interface program written in FORTRAN programming language. The interface program is readSWMM.exe, and when called by the GeoTools main program it opens and operates in a DOS (Disk Operating System) shell (Figure 4-2). When the

* SWMM contacts:

Dr. Wayne C. Huber, Dept. of Civil, Construction, and Environmental Engineering, Oregon State University, 202 Apperson Hall, Corvallis, Oregon 97331-2302, Phone: (541) 737-4934, Fax: (541) 737-3099, e-mail: wayne.huber@orst.edu.

Dr. William James, Computational Hydraulics International, 36 Stuart St., Guelph, Ontario N1E 4S5, Phone: (519) 767-0197, Fax: (519) 767-2770, e-mail: wjames@uoguelph.ca.

interface program has completed a flow record, the user must signify that the interface program is complete by clicking the SWMM Interface Complete button on the Input File Options menu. The user must identify the location of the readSWMM.exe file and completed interface file. ReadSWMM.exe operates by taking a SWMM output file (filename and directory entered by the user) and converting the information into a comma delimited file with a new extension ".GTI" (GeoTools Interface) which is formatted as File Format 2. Once the ".GTI" file is created, the readSWMM executable need not be run on the same ".out" SWMM file again. The ".GTI" file can be read in using the File Format 2 option. The readSWMM executable is capable of handling output from either the "RUNOFF" or "TRANSPORT" blocks within SWMM Version 4 (or any later version with the same output format). For examples of these types of output files please consult the SWMM Manual for Version 4 (or later version with the same output format).

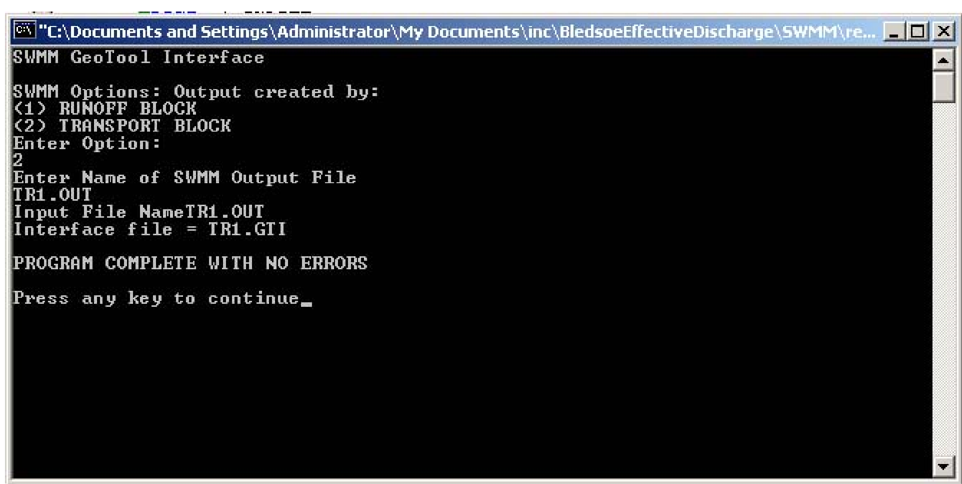


Figure 4-2 – SWMM interface screen shot. To use SWMM model output, an interface program that runs in the DOS environment is launched from within GeoTools.

4.2.6 HSPF "P" File

GeoTools is also capable of reading in Hydrological Simulation Program – FORTRAN (HSPF) files. The input algorithm for this type of file assumes that the "P" file has been generated using the following format (Table 4-1) (HSPF-12-2 documentation available at http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=hspf).

Table 4-1 – HSPF format table.

Columns	Contents
1 – 4	Identifier (first 4 characters of title)
6 – 10	Year
11 – 13	Month
14 – 16	Day
17 – 19	Hour
20 – 22	Minute
25 – 36	Value for curve 1, for this date/time
39 – 50	Value for curve 2, for this date/time
Etc... (repeats until data for all curves are supplied)	
Format: A4, 1X, I5, 4I3,20(2X,G12.5)	

Please note that the Format statement in Table 4.1 refers to the FORTRAN code used to develop HSPF. The user of GeoTools can simply open up their "P" file in any text editor and check to see whether their file conforms to the necessary format. If the user desires more information about HSPF and its output please contact the developers at the EPA, specifically the USGS Hydrologic Analysis Software Support Team, 437 National Center, Reston, VA 20192 or by e-mail at h2osoft@usgs.gov.

4.2.7 Other

This option is currently under development. A new version of GeoTools, incorporating this upgrade, will be posted as soon as possible.

CHAPTER 5
USER INPUT OPTIONS

When utilizing the effective discharge portions of GeoTools, most of the user options are provided through the User Input Options menu (Figure 5-1). The inputs are divided into five categories:

- Flow Data Selection,
- Sediment Transport Tools,
- Effective Discharge Tools (Bin Information),
- Channel Change Tools, and
- Output Options.

These frames that comprise the User Input Options menu are discussed below:

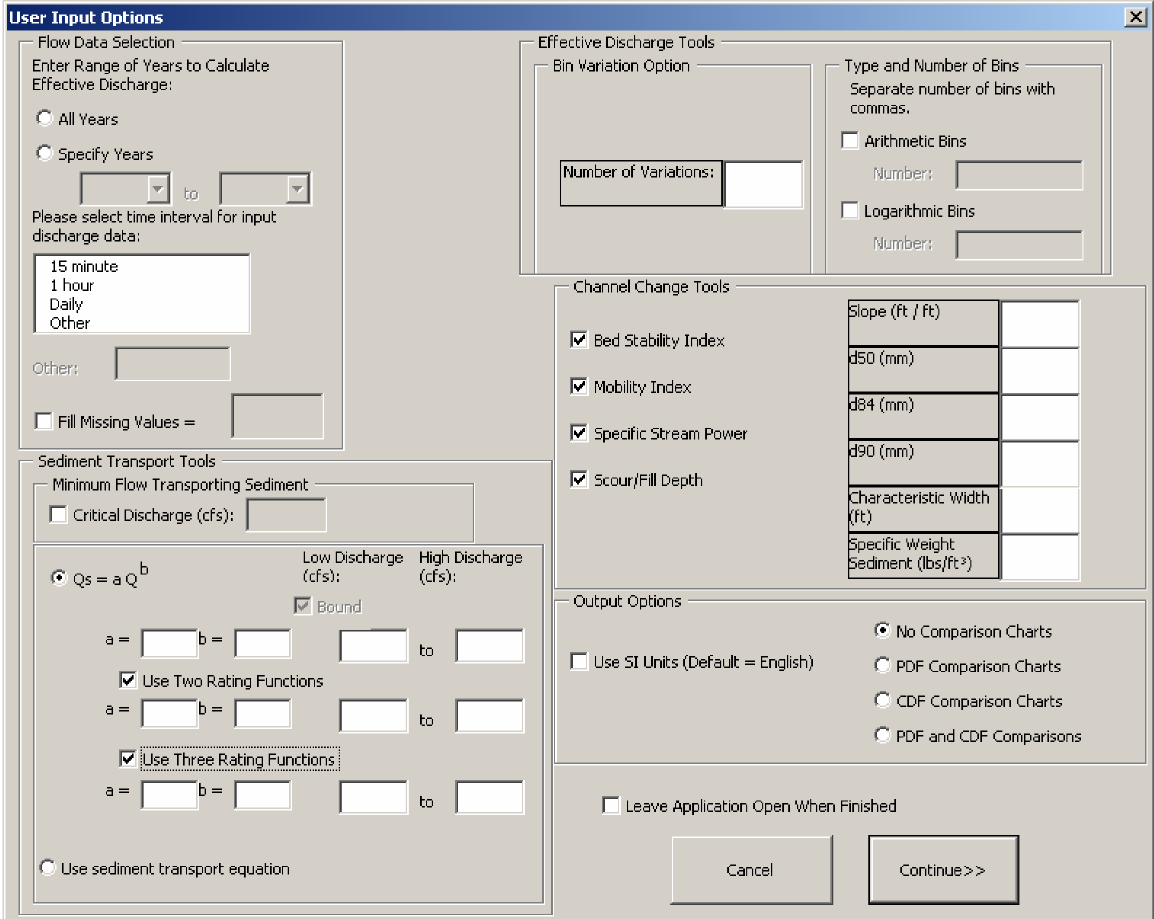


Figure 5-1 – User Input Options menu screen shot, where the user specifies most of the parameters necessary to run the effective discharge processes within GeoTools.

5.1 Flow Data Selection

After specifying the file name and the format, the user must identify the time period of the analysis and whether it corresponds to all of the dates within the flow record or whether the analysis should be performed on subsets of the data (Figure 5-2). For example, if the user would like to perform an analysis comparing the years 1950 through 1970 to 1970 through 1999 of one flow record, the single file can be entered in the Reference File and File 2 text boxes on the Opening menu with GeoTools running in Effective Discharge Comparison (Multiple Files) mode and selecting the two time periods, respectively.

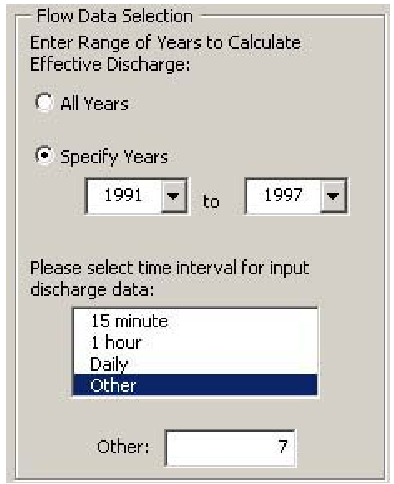


Figure 5-2 – Flow Data Selection screen shot, where the user chooses the period of the flow record analysis, the data time interval, and whether missing values will be filled in.

In addition, the user must specify the time interval for the discharge data (*e.g.*, daily, hourly, 15-minute, etc.). GeoTools offers a series of common data time intervals but if the user wishes to select a different value, they can enter an integer number of hours corresponding to the file time step. Additionally GeoTools offers some data filling for files that may have holes in their data. If probability distribution function (PDF) and cumulative distribution function (CDF) comparisons are to be made among multiple files with differing amounts of missing data, these values will be misrepresented unless the missing data are filled. We suggest filling in the missing values with an appropriate base flow value for the system being analyzed.

5.1.1 Range of Years to Calculate Effective Discharge

5.1.1.1 All Years

Select this option if you would like the entire data set to be analyzed. The years within the pull-down menus should correspond to the dates within the inputted flow record and is a good way to verify that the data were loaded correctly.

5.1.1.2 Specify Years

This option should be selected if there is a specific period within the flow record for which the analysis is desired. If this option is selected, the earliest year must be selected from the pull-down menu on the left and the latest year must be selected from the pull-down menu on the right. The values within the pull-down menus should represent the extent of the entire flow record. If there is a discrepancy between the dates in the pull-down menu and the inputted flow record, then there is an error with the input data process that must be resolved prior to analysis.

5.1.1.3 Select time interval for input discharge data

The time format of the input file must be selected here. The standard options are:

15 minute
1 hour
Daily
Other

If Other is selected, then the actual time step must be specified as an integer number of hours.

5.1.1.4 Fill Missing Values

GeoTools calculates the maximum total number of records that should appear within the first and last records of the input file given the time interval selected by the user. If the actual number of records loaded is not equal to the maximum value, then the user can choose to fill in the missing values with a value entered in cfs. This option is particularly useful when comparing flow files which differ in the number of missing days because these values influence the CDFs and PDFs. The missing values are not entered date specific, meaning that they will not affect the annual maximum and minimum series that are used to calculate the flood statistics.

5.2 Sediment Transport Tools

The GeoTools effective discharge calculations provide the user with multiple sediment transport solutions to analyze their data set including theoretical and empirical equations (Figure 5-3).

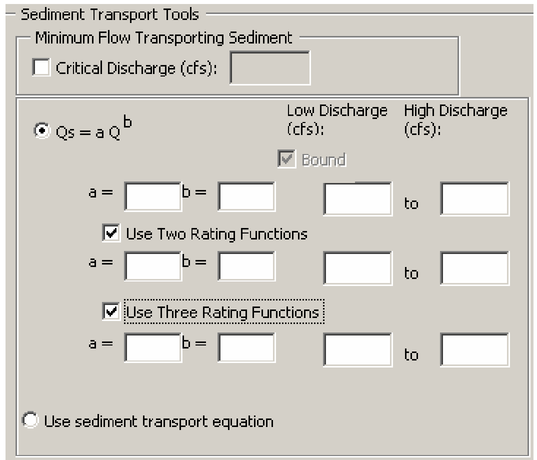


Figure 5-3 – Sediment Transport Tools screen shot, where the user specifies the parameters of rating curve(s) describing sediment transport and its applicability range or selects a total load or bedload transport equation.

5.2.1 Minimum Flow Transporting Sediment

5.2.1.1 Critical Discharge (cfs)

If a discharge exists below which it is known that no sediment is transported, then the Critical Discharge (cfs) check box should be selected and the value inputted in the enabled text box.

5.2.2 Sediment Transport Relationships

5.2.2.1 Qs = aQb

This option should be selected if an appropriate rating curve is known for the river segment being studied. **Sediment transport capacity (Qs) is assumed to have units of tons/day. Therefore, a and b must be specified such that an input Q in cfs yields Qs in tons/day.** If the rating curve is only valid for a range of flows, than those values can be entered by selecting Bound. Any flows not within these values will be assigned a sediment discharge of zero. If a rating curve is only valid above a certain flow, a Critical Discharge (cfs) can be specified and all flows below this value will be assigned a sediment discharge of zero.

Up to three different rating curves may be selected for flows of increasing magnitude. The High Discharge box of rating curve 1 must correspond to the Low Discharge box of rating curve 2 and the High Discharge box of rating curve 2 must correspond to the Low Discharge of rating curve 3. If a High Discharge is identified for any rating curve it must be selected for all rating curves and any discharge inputs above the largest High Discharge boundary will be assigned a zero sediment discharge.

5.2.3 Use Sediment Transport Equation

The user may select the Use sediment transport equation instead of a sediment transport rating curve. This option will trigger an additional menu once the Continue button is pressed. See Chapter 6 for a description of sediment transport options.

5.3 Effective Discharge Tool (Bin Information)

The effective discharge method as performed within GeoTools is categorized as a magnitude-frequency analysis. The distribution of flows is divided into a number of "bins" (Figure 5-4), which span from the minimum discharge to the maximum discharge. The distribution of these bins can be either arithmetically or logarithmically distributed (henceforth called the "type" of binning). The number and type of bins substantially affects the determination of the effective discharge and great care should be taken when making these choices. GeoTools provides the user an efficient method of examining many different bin size distributions for making the "best" determination of the effective discharge.

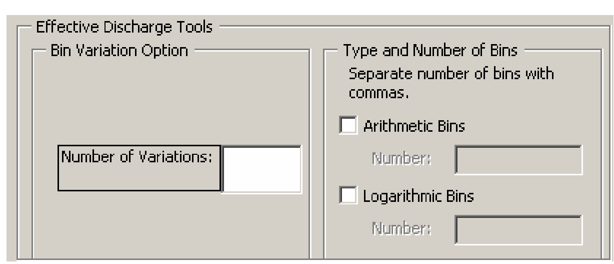


Figure 5-4 – Bin Selection screen shot, where the user specifies the number and type of bins to use in the effective discharge analysis.

5.3.1 Bin Variation Option

5.3.1.1 Number of Variations

It is well known that bin specification is an important factor when determining an effective discharge (*e.g.*, Bidenharn *et al.* 2000, Hey 1997, Holmquist-Johnson 2002). Holmquist-Johnson (2002) also discussed some standards for selecting the number and type (*i.e.*, Arithmetic or Logarithmic) of bins. Therefore, it may be desirable to run many different bin set ups for the same input file. It is possible to run the program multiple times for each flow record file specifying a different number of bins for each run only when no file comparisons are being made. If Effective Discharge (Single File) was selected on the Opening menu than the user may enter up to 50 different bin number variations that they would like run for a single type. If Effective Discharge (Compare Multiple Files) was chosen from the Opening menu the Number of Variations option will be disabled and the integer 1 will be observed in this text box. This is to ensure that the same numbers of bins are being used for each of the files being compared.

5.3.1.2 Type and Number of Bins

As stated previously, it has been documented that bin specification plays an important role in effective discharge results (Holmquist-Johnson 2002). Therefore, care should be taken when choosing the Type and Number of Bins. When multiple numbers of variations have been entered (Figure 5-4), each variation must be entered into the text box next to either the Arithmetic or Logarithmic option in a comma-delimited manner. Only one choice may be made for program execution. Thus, if five has been entered into the Number of Variations text box (Figure 5-4) then five integers must be entered into either the text box corresponding to the Arithmetic option or the text field corresponding to the Logarithmic option. An example of an incorrect entry is to put three integers into the Arithmetic text box and two integers into the Logarithmic text box. This will generate an error.

- **Arithmetic Bins**

Arithmetic Bins are specified as follows. The lowest bin boundary is set to the minimum flow in the flow record. Each bin has a domain size equal to:

$$\frac{Q_{\max} - Q_{\min}}{N_B}, \qquad \textbf{(5.1)}$$

where:

$Q_{\max}$ = maximum flow in the record;

$Q_{\min}$ = minimum flow in the record; and

N_B = number of bins.

Thus if the user specifies 10 bins for a flow record with a maximum value of 110 cfs and a minimum value of 10 cfs then the bins will be divided as shown in Table 5-1.

Table 5-1 – Sample arithmetic bin distribution.

Bin Number	Lower Bin Boundary	Upper Bin Boundary
1	10	20
2	20	30
3	30	40
4	40	50
5	50	60
6	60	70
7	70	80
8	80	90
9	90	100
10	100	110

If a flow corresponds exactly to one of the bin boundaries, it is assigned to the lower bin, except in the case of the minimum flow in the record, which always goes into the first bin.

- **Logarithmic Bins**

If Logarithmic Bins are selected, the specification is as follows. A preliminary bin is specified with a flow range of 0 to 0 (Table 5-2). The rest of the flow record is divided into the number of bins selected by the user, where the lower and upper bin boundaries are:

$$e^{(Log(Q_{min})+(B-2)*LI)} \text{ and} \quad (5.2)$$

$$e^{(Log(Q_{min})+(B-1)*LI)} , \quad (5.3)$$

respectively, where B is the bin number (*i.e.,* $B \in 1, N_B$, where N_B is the total number of bins; for the case represented in Table 5-1, $N_B = 10$), LI is the Logarithmic interval between the minimum and maximum flows defined as:

$$LI = \frac{\ln(Q_{max}) - \ln(Q_{min})}{N_B - 1} . \quad (5.4)$$

Table 5-2 – Sample logarithmic bin distribution with minimum nonzero flow equal to 3.11(10^{-4}) and maximum flow equal to 37.1. The dimensions are L^3/T.

Bin Number	Lower Bin Boundary	Upper Bin Boundary
	0.00E+00	0.00E+00
1	3.11E-04	1.00E-03
2	1.00E-03	3.22E-03
3	3.22E-03	1.04E-02
4	1.04E-02	3.33E-02
5	3.33E-02	1.07E-01
6	1.07E-01	3.46E-01
7	3.46E-01	1.11E+00
8	1.11E+00	3.58E+00
9	3.58E+00	1.15E+01
10	1.15E+01	3.71E+01

5.4 Channel Change Tools

GeoTools offers the opportunity to calculate four indices related to channel stability and change:

- Bed Stability Index,
- Mobility Index,
- Specific Stream Power, and
- Scour/Fill Depth.

The actual calculations of these indices are described in the output section of this manual (see Section 7.1.1). The user must enter the information required to make the calculations for each of the indices that they select to have calculated. Only those text boxes relevant to the chosen indices are enabled in Figure 5-5.

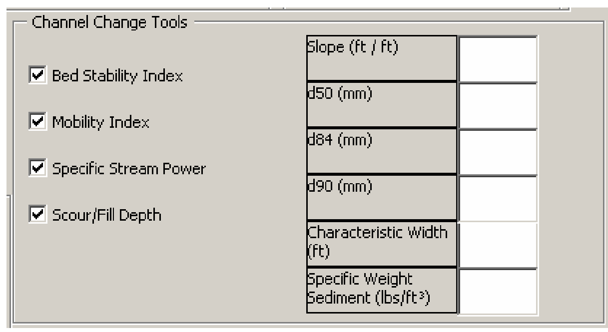


Figure 5-5 – Channel Change Tools frame screen shot. Only the input text fields necessary to calculate the desired indices are enabled.

5.5 Output Options

Although GeoTools requires input files to have English units, the user can specify that outputs have either English or SI units (Figure 5-6). In addition, GeoTools output in effective discharge file comparison mode allows the user to specify whether comparison is made between PDFs, CDFs, both PDF and CDF, or neither. If PDF/CDF comparisons are to be made, the parameters compared are discharge, sediment transport, shear stress, stream power and specific stream power, and scour/fill depths.

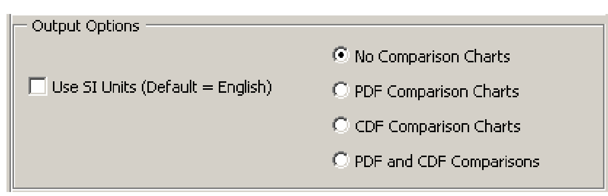


Figure 5-6 – Output Options screen shot, where the user specifies which units are used for outputs. For comparisons of multiple flow records the user can specify what types of comparisons are made. The user can also elect to leave the application open when computations are complete.

By default, GeoTools closes itself at the end of effective discharge calculations. If the user would like to keep the program open and restart it from the Input Sheet they can choose this option by checking the Leave Application Open When Finished check box.

CHAPTER 6

SEDIMENT TRANSPORT OPTIONS

In addition to using a sediment rating curve (described in Section 5.2.2), the user also has the option to use one of several theoretical sediment transport equations. The sediment transport equation interface is shown in Figure 6-1. This interface allows the user to specify which sediment transport equation they would like to implement as well as prompts for the required parameters to perform the calculations. Sediment transport options are discussed below.

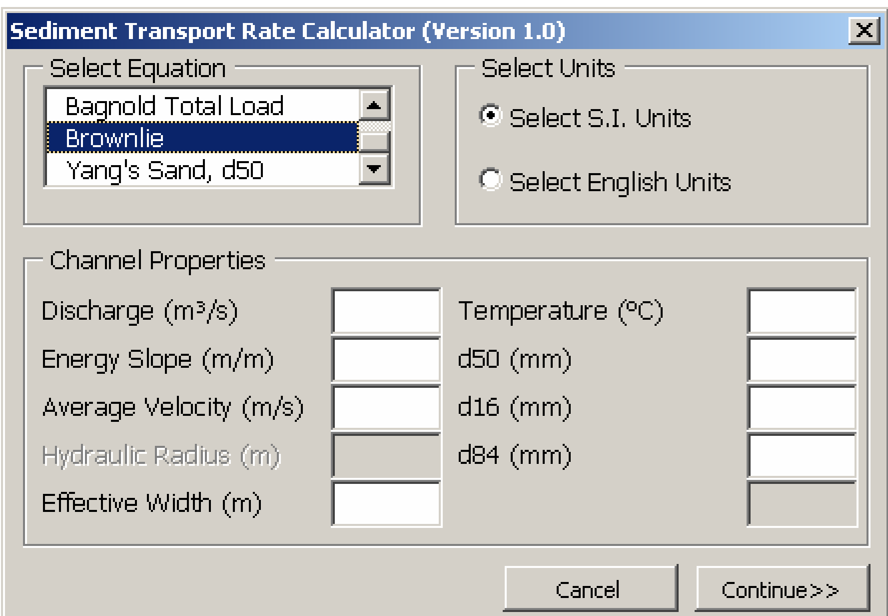


Figure 6-1 – Sediment Transport Rate Calculator screen shot, where the user selects a sediment transport equation to use and inputs the necessary parameters to complete the computations.

6.1 Select Equation

In the Select Equation frame (upper left corner of the sediment transport equation interface, Figure 6-1), the sediment transport equation list is displayed. For each calculation of effective discharge the user can choose one of five sediment transport equations that have been previously developed and are widely used in calculations of sediment transport rate. These equations are discussed in the following sections.

6.1.1 Brownlie Total Load

The Brownlie (1981) total load equation is given as:

$$C_{ppm} = 7115 c_B \left(\frac{V - V_c}{\sqrt{(G-1) g d_s}} \right)^{1.978} S_f^{\ 0.6601} \left(\frac{R}{d_s} \right)^{-0.3301} \quad \textbf{(6.1)}$$

where:

C_{ppm} = concentration of sediment (parts per million (ppm));

c_B = coefficient that is assumed to be 1.268 for field data [dimensionless];

V = mean flow velocity [L/T];

V_c = critical velocity [L/T];

G = ratio of the specific weight of sediment to that of water;

g = gravitational acceleration [L/T^2];

d_s = diameter of sediment [L];

S_f = friction slope [L/L]; and

R = hydraulic radius [L].

The critical velocity, V_c, is determined by the following equation:

$$V_c = 4.596 \tau_{*c}^{0.529} S_f^{\ -0.1405} \sigma_g^{-0.1606} \sqrt{(G-1) g d_s} \quad \textbf{(6.2)}$$

where:

τ_{*c} = critical dimensionless shear stress; and

σ_g = geometric standard deviation of the bed material [dimensionless].

The geometric standard deviation is calculated as:

$$\sigma_g = \left(\frac{d_{84}}{d_{16}}\right)^{1/2} \tag{6.3}$$

in which d_{84} is the particle size at which 84 % of the bed material is finer by weight and d_{16} is the particle size at which 16 % of the bed material is finer by weight. Note that d_{84} and d_{16} must be of the same dimension for σ_g to be dimensionless. If σ_g is calculated to be greater than 5 it defaults to 5. The critical dimensionless shear stress is a function of the dimensionless particle size, d_*, which can be expressed as:

$$d_* = d_s\left(\frac{(G-1)g}{\nu^2}\right)^{1/3} \tag{6.4}$$

where ν is the kinematic viscosity of the water-sediment mixture. The concentration of sediment is assumed low enough to approximate the viscosity of the water-sediment mixture as the viscosity of clear water. Furthermore, the median particle diameter, d_{50} (m), is used as d_s in Equations (6.2) and (6.4). The critical dimensionless shear stress is determined by solving the following equations (Brownlie 1981):

$$\tau_{*_c} = 0.22Y + 0.06(10)^{-7.7Y} \tag{6.5}$$

where:

$$Y = \left(\sqrt{\frac{\rho_s - \rho}{\rho}}\frac{u_* d_s}{\nu}\right)^{-0.6}. \tag{6.6}$$

The sediment discharge, Q_s, is computed as:

$$Q_S = C_V Q \tag{6.7}$$

where:

Q = water discharge [L^3/T]; and

C_V = concentration of sediment by volume [dimensionless].

C_V is determined from the concentration in ppm and specific weight of the sediment. The units of the sediment discharge, Q_S, are volume of sediment per time. The sediment discharge can be converted to units of weight of sediment per unit time (*e.g.,* sediment discharge is commonly reported in units of U.S. tons per day, a U.S. ton is a short ton = 907.18 kg) using the specific weight of sediment.

6.1.2 Bagnold Total Load

The Bagnold (1966) Total Load equation may be expressed as (Julien 1995):

$$q_t = \frac{\tau_0 V}{(G-1)}\left(e_B + 0.01\frac{V}{\omega_s}\right) \tag{6.8}$$

where:

q_t = total sediment load per unit width of channel [F/L/T];

τ_0 = average boundary shear stress [F/L^2];

e_B = bedload efficiency factor and is typically between 0.2 to 0.3 [dimensionless]; and

ω_s = fall velocity of the sediment [L/T].

The average boundary shear is computed from:

$$\tau_0 = \gamma R S_f \tag{6.9}$$

where γ is the specific weight of water. The bedload efficiency factor, e_B, is assumed 0.25.

The particle fall velocity, ω_s, is computed according to Rubey's (1933) equation, which Julien (1995) presents as:

$$\omega_s = \left[\sqrt{\frac{2}{3} + \frac{36\nu^2}{(G-1)gd_s^3}} - \sqrt{\frac{36\nu^2}{(G-1)gd_s^3}}\right]\sqrt{(G-1)gd_s}\,. \tag{6.10}$$

Multiplying q_t by the channel width gives the sediment load in units of weight of sediment per unit time, which is converted into units of U.S. tons per day (1 U.S. ton = 907.18 kg). Julien (1995) notes that the Bagnold equation is best suited for fully turbulent flows where the transport rate is large.

6.1.3 Meyer-Peter and Müller Bedload

The Meyer-Peter and Müller (1948) equation computes the volumetric bedload transport rate per unit width of channel. The simplified form (Chien 1956) is presented by Julien (1995) as:

$$q_{bv} = 8\left(\tau_* - \tau_{*c}\right)^{3/2}\sqrt{(G-1)gd_s^3}\ , \qquad \textbf{(6.11)}$$

where

q_{bv} = volumetric bedload transport rate per unit width of channel [$L^3/T/L$]; and

τ_* = dimensionless shear stress.

For the Meyer-Peter and Müller (1948) equation, a value of 0.047 is recommended for the critical dimensionless shear stress, τ_{*c}. The dimensionless shear stress is computed as:

$$\tau_* = \frac{\tau_0}{(G-1)\gamma d_s} = \frac{RS_f}{(G-1)d_s}\ . \qquad \textbf{(6.12)}$$

Note that the Meyer-Peter and Müller equation is valid only for $\tau_* > \tau_{*c}$. Therefore, when $\tau_* < \tau_{*c}$ the bedload transport rate is zero.

Knowing the specific weight of the sediment and the width of the channel, the volumetric bedload transport rate, q_{bv}, is converted to a daily sediment load in units of tons per day.

6.1.4 Yang's Sand, d50 Total Load

The total sediment concentration in ppm can also be estimated using the method presented by Yang (1996). For bed material consisting of predominately sand, Yang's relationship is:

$$\log C_{ppm} = 5.435 - 0.286\log\frac{\omega_s d_s}{\nu} - 0.457\log\frac{u_*}{\omega_s} + \left(1.799 - 0.409\log\frac{\omega_s d_s}{\nu} - 0.314\log\frac{u_*}{\omega_s}\right)\log\left(\frac{V}{\omega_s}S_f - \frac{V_c}{\omega_s}S_f\right), \quad \textbf{(6.13)}$$

where u_* is the shear velocity [L/T], and is computed as:

$$u_* = \sqrt{\frac{\tau_0}{\rho}} = \sqrt{gRS_f} \ , \quad \textbf{(6.14)}$$

where ρ is the density of the water sediment mixture [M/L^3], which is assumed to be equal to the density of clear water at 20°C. In the Yang equation, the ratio of critical velocity to particle fall velocity is given according to the following equation (Yang 1995):

$$\frac{V_c}{\omega_s} = \frac{2.5}{\log\left(\frac{u_* d_s}{\nu}\right) - 0.06} + 0.66 \qquad \text{for} \qquad 1.2 < \frac{u_* d_s}{\nu} < 70 \quad \textbf{(6.15)}$$

and

$$\frac{V_c}{\omega_s} = 2.05 \qquad \text{for} \qquad \frac{u_* d_s}{\nu} \geq 70 \ . \quad \textbf{(6.16)}$$

Note that the Yang approach yields a zero concentration when $V_c \geq V$ or when $u_* d_s / \nu < 1.2$.

6.1.5 Wilcock Two-phase Bedload Transport

GeoTools can also compute sediment transport based on the work of Wilcock and Kenworthy (2002). This method uses a two fraction, sand and gravel, transport model which accounts for the nonlinear effects of sand mixing with gravel on total sediment transport rates. The surface transport model from Wilcock and Kenworthy (2002) is implemented within GeoTools. The user must provide GeoTools with values of D_s and D_g characteristic surface grain sizes for the sand and gravel fractions, respectively. The value of F_s, somewhere between 0 and 1, is the proportion of the surface sediment in the sand fraction and must also be provided along with values of channel width, w, and slope, S. The sediment transport is calculated for sand and gravel size fractions separately. In Equations (6.17) through (6.21), the subscript i represents either the sand or gravel size fraction. To calculate the sediment transport per unit channel width the following procedure is completed. First the dimensionless incipient motion criteria is solved for as:

$$\tau_{ri}^* = \left(\tau_{ri}^*\right)_1 + \left[\left(\tau_{ri}^*\right)_0 - \left(\tau_{ri}^*\right)_1\right] e^{-14F_s} \qquad \textbf{(6.17)}$$

where the incipient motion parameters are given for the surface transport model in Wilcock and Kenworthy (2002) Table 3 as $\left(\tau_{rg}^*\right)_0 = 0.035$, $\left(\tau_{rg}^*\right)_1 = 0.011$, $\left(\tau_{rs}^*\right)_1 = 0.065$, and

$$\left(\tau_{rs}^*\right)_0 = \left(\tau_{rg}^*\right)_0 \left(D_g \big/ D_s \right). \qquad \textbf{(6.18)}$$

The reference shear stress for each size fraction is then calculated as:

$$\tau_{ri} = \tau_{ri}^* (G-1) \rho g D_i \ . \qquad \textbf{(6.19)}$$

A parameter designated as the ratio of actual shear stress to reference shear stress:

$$\phi = \frac{\tau}{\tau_{ri}} \qquad \textbf{(6.20)}$$

is necessary to calculate the transport function of the form:

$$W_i^* = \begin{cases} 0.002\phi^{7.5} & \text{for } \phi < \phi' \\ A\left(1 - \dfrac{\chi}{\phi^{0.25}}\right)^{4.5} & \text{for} \phi \ge \phi' \end{cases} . \qquad \textbf{(6.21)}$$

Within the transport function in Equation (6.21), A is a fitted parameter, and ϕ' and χ are chosen to match the value of a slope of the two parts of the function. The values implemented within GeoTools are taken from the calibration for field data from Wilcock and Kenworthy

(2002) in which A = 115, ϕ' = 1.27, and χ = 0.923. The sediment transport per unit channel width is then calculated for each size fraction as:

$$q_{bi} = \frac{F_i u_*^3 W_i^*}{g\left(G-1\right)} \quad . \tag{6.22}$$

The total sediment transport, per unit channel width, is calculated as the sum of q_s and q_g.

6.2 Select Units

Although the current release of GeoTools allows the user to select whether output data will be displayed in either SI or English units, the user must enter sediment transport equation parameters in units consistent with the English system of measurement (*e.g.,* ft, ft/s, and °F). The only exception is substrate particle diameter, which must be entered in units of millimeters. The toggle to Select SI Units is disabled for the sediment transport equation interface when computing effective discharge, and English units will be selected automatically.

6.3 Channel Properties

Once a sediment transport equation has been selected from the Select Equation frame, labels will appear in the Channel Properties frame for only those text boxes where Channel Properties must be entered. The labels will instruct the user as to which property is to be entered, as well as the necessary units (see Figure 6-1). The user is prompted to enter the required information about the channel geometry and substrate in the text boxes at the center of the interface based on the equation selected. Since the different equations require different input data, the program will enable only those text boxes and labels for the required values. All other text boxes and their corresponding labels will be disabled. If a user opts to change equations, the text boxes and their labels will change accordingly, and clear the data already entered into text boxes.

6.4 Effective Discharge Information

When the user selects Continue on the sediment transport equation interface after entering all pertinent data, the Channel Characteristics menu appears (Figure 6-2). Because some of the sediment transport equations utilized by GeoTools rely upon parameters that vary with discharge (specifically, mean flow velocity, V, and hydraulic radius, R), GeoTools has the capability to allow these parameters to vary with discharge.

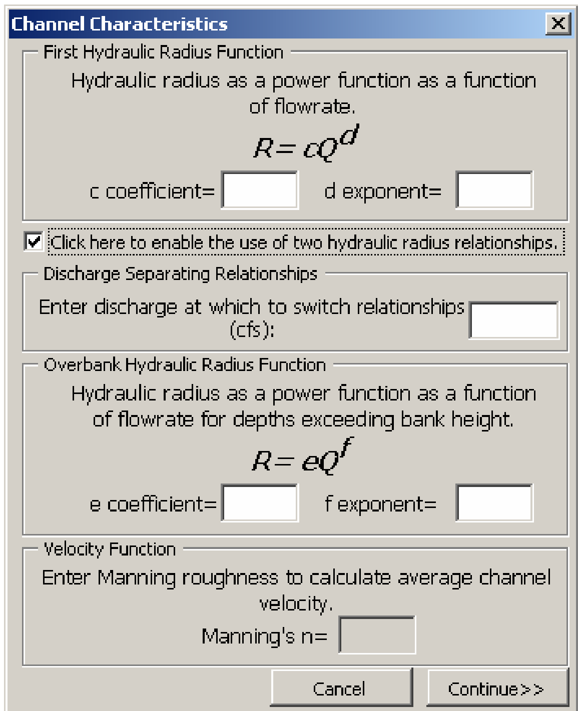


Figure 6-2 – Channel Characteristics screen shot, where the user defines information about channel geometry as a function of volumetric flow rate. The user can simulate a floodplain as well as define channel roughness if necessary.

6.4.1 First Hydraulic Radius Function

To obtain the hydraulic radius for each bin of the input flow record, the following relationship is utilized by GeoTools:

$$R = cQ^d \quad \textbf{(6.23)}$$

where

c = regression coefficient; and

d = regression exponent.

In the current version of GeoTools, the user must specify the values of the coefficient and exponent for *R* = *f*(*Q*) in English Units corresponding to *R* in ft and *Q* in cfs. It is recommended that the user determine c and d from regression of concurrent observations of hydraulic radius, R, and discharge, Q. If concurrent measurements of hydraulic radius and discharge are unavailable, the user may consider using a hydraulic simulation model such as HEC-RAS (http://www.hec.usace.army.mil/) to generate values of hydraulic radius over a range of discharges. Then, nonlinear regression methods may be used to determine the regression parameters. A nonlinear regression approach is more appropriate when the input flow record contains discharges across several orders of magnitude.

6.4.2 Discharge Separating Relationships and Overbank Hydraulic Radius Function

Recognizing that relationships describing hydraulic radius may be different depending on whether the flow is in-channel or overbank, an option is available to input a second relationship for hydraulic radius. This allows the user to specify hydraulic radius for those discharges in the input record that produce stages above the bankfull stage. The user simply selects the option to use a second function (Figure 6-2), and enters the coefficient and exponent of the second function. The user then inputs the discharge above which the second relationship is to be used. If the discharge corresponding to the overbank stage is not known one method of estimating it is to visually inspect or utilize a statistical technique (*e.g.,* piecewise regression plot of hydraulic radius versus discharge) to discern the discharge that coincides with the approximate overbank stage. Regardless of the technique utilized, the effort should determine the discharge at which a change in the slope of a regression line in the log-log domain between hydraulic radius and discharge occurs.

6.4.3 Velocity Function

Sediment transport equations requiring a mean flow velocity as an input will require that the user input the Manning roughness coefficient. The user is cautioned that the value selected for the Manning roughness coefficient should be representative of the entire flow record. When possible, it may be reasonable to estimate the Manning roughness coefficient at various values of discharge and subsequently use an average value. Again, a hydraulic simulation model may be utilized when observations are unavailable.

It is also suggested that the user consider the idea that the friction slope may change significantly with changes in discharge. Hence, for sediment transport equations where a friction slope is required, the value should be representative of the entire flow record. Again, the user may utilize some average value determined by using a hydraulic simulation model to generate friction slope at various values of discharge.

6.5 Comments on Selecting Sediment Transport Formulae

It is expected that users have some familiarity with the underlying concepts of sediment transport. Specifically, the user should understand that the various sediment transport equations were developed with differing field/experimental conditions, data, assumptions, and purposes. The user is strongly encouraged to carefully assess the flow, channel, and substrate characteristics against the range of applicability for a specific sediment transport equation. The user should carefully consider the predominant mode of transport in their situation. One method of determining the mode of sediment transport suggested by Julien (1995) utilizes the ratio of shear velocity, u_*, to particle fall velocity, ω_s, and the criteria listed in Table 6.1.

Table 6-1 – Identifying the mode of sediment transport.

u_*/ω_s	Transport Mode
< 0.4	Bedload
$0.4 < u_*/\omega_s < 2.5$	Mixed load
> 2.5	Suspended load

The user should also consider that all sediment transport equations yield estimates of sediment transport capacity. However, the actual amount of sediment available for transport may be less than the transport capacity of the channel (*i.e.*, supply limited). The sediment transport capacity as determined through use of sediment transport equations will be equivalent to the *actual* sediment transport rate only when the sediment supply exceeds the sediment transport capacity (*i.e.*, capacity limited). The user is encouraged to refer to Julien (1995), Reid and

Dunne (1996), Yang (1996), and Richardson *et al.* (2001) for further guidance on selection criteria for sediment transport relationships.

CHAPTER 7

OUTPUTS

7.1 Single File Effective Discharge

When using the Effective Discharge portion of GeoTools, each flow record generates a summary sheet of outputs as well as a sheet with the input values selected by the user.

7.1.1 Summary Sheet

The summary sheet generated by GeoTools provides a variety of information. The items included are the flow parameters associated with the:

- effective discharge calculations,
- scour/fill distributions,
- annual maximum flow series,
- annual minimum flow series, and
- annual average series.

Additionally, a table of flow regime statistics and a series of charts are displayed. The output provides the user with data that describes the parameters for each bin. Each of these components of the summary sheet is discussed in the following sections, including a description of how the parameters are derived.

7.1.1.1 Bin Outputs

GeoTools calculates 20 values associated with the bin index and the flow record for each bin, except the 0 – 0 bin with logarithmic distributions. A sample output sheet is presented in Figure 7-1. The specific equations used for the calculations are as follows:

Effective Discharge Chart | Non-Exceedance Chart | Scour/Fill Distribution Chart | Effective Discharge Scour/Fill Chart

Lower Bin Boundary [cfs]	Upper Bin Boundary [cfs]	Average Flow [cfs]	Flow Frequency	PDF	CDF	Sediment Transport [tons/day] / 1000	Bin Sediment Load	Hydraulic Radius [ft]	Shear Stress [lb/ft²]
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00				
1.1E-01	5.7E+00	2.9E+00	7.0E+03	7.0E-01	7.0E-01	2.9E-03	2.0E+00	6.1E-01	3.8E-01
5.7E+00	1.1E+01	8.5E+00	1.9E+03	1.9E-01	8.9E-01	8.5E-03	1.6E+00	9.4E-01	5.9E-01
1.1E+01	1.7E+01	1.4E+01	6.0E+02	6.0E-02	9.5E-01	1.4E-02	8.4E-01	1.2E+00	7.2E-01
1.7E+01	2.2E+01	2.0E+01	2.5E+02	2.5E-02	9.7E-01	2.0E-02	4.9E-01	1.3E+00	8.2E-01
2.2E+01	2.8E+01	2.5E+01	9.2E+01	9.2E-03	9.8E-01	2.5E-02	2.3E-01	1.5E+00	9.1E-01
2.8E+01	3.4E+01	3.1E+01	6.1E+01	6.1E-03	9.9E-01	3.1E-02	1.9E-01	1.6E+00	9.8E-01
3.4E+01	3.9E+01	3.6E+01	3.7E+01	3.7E-03	9.9E-01	3.6E-02	1.3E-01	1.7E+00	1.1E+00
3.9E+01	4.5E+01	4.2E+01	2.5E+01	2.5E-03	1.0E+00	4.2E-02	1.1E-01	1.8E+00	1.1E+00
4.5E+01	5.0E+01	4.8E+01	1.6E+01	1.6E-03	1.0E+00	4.8E-02	7.6E-02	1.9E+00	1.2E+00
5.0E+01	5.6E+01	5.3E+01	1.0E+01	1.0E-03	1.0E+00	5.3E-02	5.3E-02	2.0E+00	1.2E+00
5.6E+01	6.2E+01	5.9E+01	1.0E+01	1.0E-03	1.0E+00	5.9E-02	5.9E-02	2.0E+00	1.3E+00
6.2E+01	6.7E+01	6.4E+01	3.0E+00	3.0E-04	1.0E+00	6.4E-02	1.9E-02	2.1E+00	1.3E+00
6.7E+01	7.3E+01	7.0E+01	4.0E+00	4.0E-04	1.0E+00	7.0E-02	2.8E-02	2.2E+00	1.4E+00
7.3E+01	7.8E+01	7.6E+01	0.0E+00	0.0E+00	1.0E+00	7.6E-02	0.0E+00	2.3E+00	1.4E+00
7.8E+01	8.4E+01	8.1E+01	1.0E+00	1.0E-04	1.0E+00	8.1E-02	8.1E-03	2.3E+00	1.4E+00
8.4E+01	9.0E+01	8.7E+01	1.0E+00	1.0E-04	1.0E+00	8.7E-02	8.7E-03	2.4E+00	1.5E+00
9.0E+01	9.5E+01	9.2E+01	0.0E+00	0.0E+00	1.0E+00	9.2E-02	0.0E+00	2.4E+00	1.5E+00
9.5E+01	1.0E+02	9.8E+01	1.0E+00	1.0E-04	1.0E+00	9.8E-02	9.8E-03	2.5E+00	1.6E+00
1.0E+02	1.1E+02	1.0E+02	2.0E+00	2.0E-04	1.0E+00	1.0E-01	2.1E-02	2.6E+00	1.6E+00
1.1E+02	1.1E+02	1.1E+02	0.0E+00	0.0E+00	1.0E+00	1.1E-01	0.0E+00	2.6E+00	1.6E+00
1.1E+02	1.2E+02	1.1E+02	0.0E+00	0.0E+00	1.0E+00	1.1E-01	0.0E+00	2.7E+00	1.7E+00
1.2E+02	1.2E+02	1.2E+02	0.0E+00	0.0E+00	1.0E+00	1.2E-01	0.0E+00	2.7E+00	1.7E+00
1.2E+02	1.3E+02	1.3E+02	0.0E+00	0.0E+00	1.0E+00	1.3E-01	0.0E+00	2.8E+00	1.7E+00
1.3E+02	1.3E+02	1.3E+02	0.0E+00	0.0E+00	1.0E+00	1.3E-01	0.0E+00	2.8E+00	1.8E+00
1.3E+02	1.4E+02	1.4E+02	1.0E+00	1.0E-04	1.0E+00	1.4E-01	1.4E-02	2.9E+00	1.8E+00
						SUM BIN SEDIMENT LOAD	5.9E+00		

Lower Bin Boundary [cfs]	Stream Power [lb/s]	Water PDF	Water CDF	Sediment PDF	Sediment CDF	Mobility Index [ft/s^0.5]	Specific Stream Power [lb/ft*s]	Bed Stability Index []	Mean Scour /Fill Depth [ft]	90% Scour /Fill Depth [ft]
0.0E+00										
1.1E-01	1.8E+00	3.4E-01	3.4E-01	3.4E-01	3.4E-01	N/A	0.0E+00	6.8E+01	N/A	N/A
5.7E+00	5.3E+00	2.7E-01	6.1E-01	2.7E-01	6.1E-01	N/A	2.6E-01	1.0E+02	N/A	N/A
1.1E+01	8.8E+00	1.4E-01	7.6E-01	1.4E-01	7.6E-01	N/A	7.6E-01	1.3E+02	N/A	N/A
1.7E+01	1.2E+01	8.3E-02	8.4E-01	8.3E-02	8.4E-01	N/A	1.3E+00	1.5E+02	N/A	N/A
2.2E+01	1.6E+01	3.9E-02	8.8E-01	3.9E-02	8.8E-01	N/A	1.8E+00	1.6E+02	N/A	N/A
2.8E+01	1.9E+01	3.2E-02	9.1E-01	3.2E-02	9.1E-01	N/A	2.3E+00	1.7E+02	N/A	N/A
3.4E+01	2.3E+01	2.3E-02	9.3E-01	2.3E-02	9.3E-01	N/A	2.8E+00	1.9E+02	N/A	N/A
3.9E+01	2.6E+01	1.8E-02	9.5E-01	1.8E-02	9.5E-01	N/A	3.3E+00	2.0E+02	N/A	N/A
4.5E+01	3.0E+01	1.3E-02	9.6E-01	1.3E-02	9.6E-01	N/A	3.8E+00	2.1E+02	N/A	N/A
5.0E+01	3.3E+01	9.0E-03	9.7E-01	9.0E-03	9.7E-01	N/A	4.2E+00	2.2E+02	N/A	N/A
5.6E+01	3.7E+01	9.9E-03	9.8E-01	9.9E-03	9.8E-01	N/A	4.7E+00	2.3E+02	N/A	N/A
6.2E+01	4.0E+01	3.3E-03	9.8E-01	3.3E-03	9.8E-01	N/A	5.2E+00	2.3E+02	N/A	N/A
6.7E+01	4.4E+01	4.7E-03	9.9E-01	4.7E-03	9.9E-01	N/A	5.7E+00	2.4E+02	N/A	N/A
7.3E+01	4.7E+01	0.0E+00	9.9E-01	0.0E+00	9.9E-01	N/A	6.2E+00	2.5E+02	N/A	N/A
7.8E+01	5.1E+01	1.4E-03	9.9E-01	1.4E-03	9.9E-01	N/A	6.7E+00	2.6E+02	N/A	N/A
8.4E+01	5.4E+01	1.5E-03	9.9E-01	1.5E-03	9.9E-01	N/A	7.2E+00	2.6E+02	N/A	N/A
9.0E+01	5.8E+01	0.0E+00	9.9E-01	0.0E+00	9.9E-01	N/A	7.7E+00	2.7E+02	N/A	N/A
9.5E+01	6.1E+01	1.7E-03	9.9E-01	1.7E-03	9.9E-01	N/A	8.2E+00	2.8E+02	N/A	N/A
1.0E+02	6.5E+01	3.5E-03	1.0E+00	3.5E-03	1.0E+00	N/A	8.7E+00	2.8E+02	N/A	N/A
1.1E+02	6.8E+01	0.0E+00	1.0E+00	0.0E+00	1.0E+00	N/A	9.2E+00	2.9E+02	N/A	N/A
1.1E+02	7.2E+01	0.0E+00	1.0E+00	0.0E+00	1.0E+00	N/A	9.7E+00	3.0E+02	N/A	N/A
1.2E+02	7.5E+01	0.0E+00	1.0E+00	0.0E+00	1.0E+00	N/A	1.0E+01	3.0E+02	N/A	N/A
1.2E+02	7.9E+01	0.0E+00	1.0E+00	0.0E+00	1.0E+00	N/A	1.1E+01	3.1E+02	N/A	N/A
1.3E+02	8.2E+01	0.0E+00	1.0E+00	0.0E+00	1.0E+00	N/A	1.1E+01	3.1E+02	N/A	N/A
1.3E+02	8.6E+01	2.3E-03	1.0E+00	2.3E-03	1.0E+00	N/A	1.2E+01	3.2E+02	N/A	N/A

Figure 7-1 – Sample bin outputs section screen shot from a summary sheet generated by GeoTools when running 35 logarithmic bins in effective discharge calculation mode.

The bin boundaries are calculated as specified in the Effective Discharge Tool (Bin Information) (Section 5.3). The average flow within the bin is the arithmetic average for arithmetic bins (Equation (7.1)) and geometric average for logarithmic bins (Equation (7.2)),

$$\overline{Q}_B = \frac{Q_{B_{\min}} + Q_{B_{\max}}}{2} \text{ and} \qquad \textbf{(7.1)}$$

$$\overline{Q}_B = \sqrt{Q_{B_{\min}} Q_{B_{\max}}} \qquad \textbf{(7.2)}$$

where:

$\overline{Q}_B$ = mean discharge for the bin (units/dim);

$Q_{B_{\min}}$ = minimum discharge (units/dim) for the bin; and

$Q_{B_{\max}}$ = maximum discharge (units/dim) for the bin.

The flow frequency, B_N, is the number of flows that occurred during the length of record between the lower and upper bin boundary. The Bin Probability is:

$$\text{Bin Probability} = \frac{B_N}{N_T}, \quad \textbf{(7.3)}$$

where, N_T is the total number of flows within the record. The Cumulative Bin Probability is:

$$\text{Cumulative Bin Probability} = \sum_{i=1}^{N_B} \text{Bin Probability}_i \,. \quad \textbf{(7.4)}$$

The sediment transport, Q_s, is determined from mean bin flow, $\overline{Q_B}$, using the sediment transport relationship selected by the user on the User Input Options menu (Figure 5-1). The bin sediment load, Q_{S_B}, is:

$$Q_{S_B} = Q_S \cdot \text{Bin Probability}. \quad \textbf{(7.5)}$$

Since effective discharge is the term applied to the single value of discharge responsible for transporting the most flow over a range of flows, it is often identified as the bin with the highest value of Q_{S_B}. The row with the bin reflecting the highest value of Q_{S_B} is highlighted in green (Figure 7-1). Frequently two peaks exist in the distribution of sediment transport across the range of bins. In this situation, one of the peaks may reflect the sediment transported by very large, infrequent flow events or very frequent low flows in fine-grained channels. While flow events with extremely high or low frequencies are geomorphically influential, research indicates that more frequent flow events with recurrence intervals between 1 to 5 years are primarily responsible for channel dimensions in many instances. Therefore, when the effective discharge algorithm results in more than one peak in the distribution of sediment transported across the bins, the bin (row) corresponding to the second peak is highlighted in light blue. The total sediment transport over time, $Q^T{}_{S_B}$, in the flow record is:

$$Q^T{}_{S_B} = \sum_{i=1}^{N_B} Q^i{}_{S_B} \,, \quad \textbf{(7.6)}$$

and is shown at the bottom of the Q_{S_B} column on the summary sheet and is highlighted in bright blue. The hydraulic radius, R, is calculated at $\overline{Q}_B$ as a power function using the parameters specified by the user in the Channel Characteristics menu (Figure 6-2). For additional information and help interpreting effective discharge calculations, the user is directed to Watson *et al.* (1997), Soar (2000), and Holmquist-Johnson (2002).

The shear stress is defined as in Equation (6.9). The slope entered in the User Input Options menu or Sediment Transport Options menu is either the bed slope or friction slope as determined by the user. If no slope is entered, a default value of 0.01 [L/L] is used. The stream power, Ω , is:

$$\Omega = \gamma \overline{Q_B} S_f \, . \qquad \textbf{(7.7)}$$

The flow Bin Probability and Cumulative Bin Probability, Bin Probability$_\Omega$ and Cumulative Bin Probability$_\Omega$, respectively, are:

$$\text{Bin Probability}_\Omega = \frac{\overline{Q_B}}{\sum_{i=1}^{N_B} \overline{Q_{B\,i}}} \text{ and} \qquad \textbf{(7.8)}$$

$$\text{Cumulative Bin Probability}_\Omega = \sum_{i=1}^{B} \text{Bin Probability}_\Omega \, , \qquad \textbf{(7.9)}$$

where:

N_B = total number of bins; and

B = bin of interest.

The sediment PDF and CDF, PDF$_S$ and CDF$_S$, respectively, are calculated as in Equations (7.8) and (7.9), using Q_{S_B} in lieu of Q_B. The mobility index (*MI*) is defined as:

$$MI = S\sqrt{\frac{Q}{d_{50}}} \, , \qquad \textbf{(7.10)}$$

where, d_{50} is the median grain size [L] (Chang 1988, Bledsoe and Watson 2001). This index was developed in part as a measure of channel form and adjustment in cases where channel width data are unavailable (*e.g.*, van den Berg 1995). Specific stream power is:

$$\omega = \frac{\Omega}{w} = \frac{\gamma_m \overline{Q} S}{w}, \qquad \textbf{(7.11)}$$

where:

w = channel width [L]; and

γ_m = specific weight of water and sediment mixture.

The user should acknowledge that in this version of GeoTools, discharge and width are not partitioned to floodplain and channel values. Therefore, GeoTools inadequately represents the stream power for a floodplain scenario with overbank flows. Specific stream power has also been used as a measure of channel form and response (*e.g.,* Bledsoe and Watson 2001).

The bed stability indicator (*BSI*) is (Olsen *et al.* 1997):

$$BSI = \frac{\tau_{Bi}}{\tau_c}, \qquad \textbf{(7.12)}$$

where:

τ_B = shear stress associated with $\overline{Q_B}$; and

τ_c = shear stress at which d_{84} is mobilized [L].

The *BSI* represents excess energy relative to that which mobilizes d_{84}, the grain size often held as the grain size responsible for controlling channel form.

The mean scour fill depth and the 90% confidence interval scour fill depth are determined (after Haschenburger 1999) as:

$$\overline{\theta} = H_c e^{-H_e \frac{\tau_*}{\tau_r^*}}, \qquad \textbf{(7.13)}$$

where:

$1/\overline{\theta}$ = mean scour/fill depth (cm);

τ_* = dimensionless shear stress at $\overline{Q_B}$;

τ_r^* = dimensionless shear stress used to normalize the equation (assumed as 0.04);

H_c = characteristic constant assumed 3.33; and

H_e = characteristic exponent assumed 1.52 (after Haschenburger 1999).

Future modifications to GeoTools will allow the user to specify these parameters. If $1/\theta$ is greater than a theoretical maximum ($2d_{90}$, after DeVries 2002), the corresponding cells will be highlighted in red. If τ_* is determined to be less than a critical value (0.045), then the cell within the summary sheet will be identified as "OUT OF RANGE." The 90% confidence interval scour/fill depth is determined using the exponential density function (Haschenburger 1999):

$$f(\xi) = \theta e^{-\theta\xi} \quad \textbf{(7.14)}$$

where, ξ is the depth in cm.

7.1.1.2 Scour Depth/Fill Table

If the user selects the option to calculate the scour depth/fill table in the User Input Options menu (Scour/Fill Depth box selected), then GeoTools will provide an output table of depths associated with the exponential distribution at the effective discharge (Figure 7-2). Each depth associated with a non-exceedance probability is calculated using Equation (7.14).

Scour Depth/Fill Table	
Depth [ft]	**Non-Exceedance Probability**
3.5E-01	9.0E-01
2.4E-01	8.0E-01
1.8E-01	7.0E-01
1.4E-01	6.0E-01
1.0E-01	5.0E-01
7.7E-02	4.0E-01
5.4E-02	3.0E-01
3.4E-02	2.0E-01
1.6E-02	1.0E-01
7.7E-03	5.0E-02

Figure 7-2 – Scour Depth/Fill Table screen shot, provides the scour/fill depths associated with 10 non-exceedance probabilities ranging from 5 to 90 %.

7.1.1.3 Annual Time Series

For each year over the period of analysis specified by the user, GeoTools outputs the maximum discharge in that year as well as the minimum discharge in that year and the annual average discharge (Figure 7-3). The annual maximum series is used to determine the recurrence interval of flow events.

Year	Annual Maximum [cfs]	Annual Minimum [cfs]	Annual Average Flow [cfs]
1948	6.0E+00	8.9E-01	6.3E-04
1949	1.6E+01	1.3E+00	8.7E-04
1950	1.3E+01	7.8E-01	3.4E-03
1952	5.7E+00	1.0E+00	5.7E-04
1956	2.0E+01	9.9E-01	1.1E-03
1959	2.6E+00	7.3E-01	1.5E-04
1960	1.6E+01	7.0E-01	1.0E-03
1961	2.3E+01	1.8E+00	2.7E-03
1962	3.9E+00	8.0E-01	4.4E-04
1964	2.4E+01	2.0E+00	2.8E-03
1966	1.1E+00	7.2E-01	2.0E-04
1969	1.2E+00	7.1E-01	1.3E-04
1973	7.5E-01	7.5E-01	2.1E-05
1975	6.5E+00	8.0E-01	1.0E-03
1977	2.7E+01	9.5E-01	3.3E-03
1978	3.2E+00	7.4E-01	3.7E-04
1979	4.6E+00	8.4E-01	2.4E-04
1980	8.4E-01	8.4E-01	2.4E-05
1982	1.4E+01	8.4E-01	9.9E-04
1984	5.3E+00	7.3E-01	5.0E-04
1987	2.0E+00	7.8E-01	2.1E-04
1989	1.0E+00	1.0E+00	2.9E-05
1990	2.9E+00	7.4E-01	1.7E-04
1991	2.9E+01	7.8E-01	3.1E-03
1993	1.0E+01	8.9E-01	1.4E-03
1996	3.7E+01	0.0E+00	7.4E-03

Figure 7-3 – Annual Time Series table screen shot, includes all of the years analyzed and the respective maximum, minimum, and average discharges.

7.1.1.4 Flow Regime Statistics

Figure 7-4 lists the flow statistics and indices of the flow record. This figure includes the mean annual flow, $Q_{mean\ annual}$ or Q_{ma}, effective discharge, and flows with 1.5- and 2-year recurrence intervals. Effective discharge is the green highlighted row in Figure 7-1. The flow with recurrence intervals of 1.5 and 2 years is calculated from the Annual Maximum Series (Figure 7-3), using an empirical frequency distribution (EFD):

$$P(i) = \frac{i - \alpha}{N + \beta - 2\alpha}, \tag{7.15}$$

where, N is the number of years, and α and β are assumed as 0.4 and 1, respectively, an approximation when the underlying distribution is not known (Cunnane 1978).

Flow Regime Statistics	
Qmean annual [cfs]	5.4E+00
Q effective [cfs]	5.1E+00
Q1_5 [cfs]	5.4E+01
Q2 [cfs]	5.8E+01
Q1_5 / Qma	1.0E+01
Q1_5 / Q_e	1.1E+01
Q2 / Qma	1.1E+01
Q2 / Q_e	1.1E+01
Mean Discharge [cfs]	5.5E+00
Mean Discharge Exceedance Time	1.3E-01
CV annual maximums	3.8E-01
coefficient of skewness	4.8E+00
Sediment Transport [tons/year]	2.6E+03

Figure 7-4 – Sample Flow Regime Statistics table screen shot.

The flood with 1.5- and 2-year recurrence intervals have $P(i)$ = 0.3333 and 0.5, respectively. Linear interpolation is used to determine a flood rate if necessary. Flashiness indices ($Q_{1.5}/Q_{ma}$, $Q_{1.5}/Q_e$, Q_2/Q_{ma}, and Q_2/Q_e) are provided as measures of the skew within the distributions and thus the flashiness of the flow regime. The Mean Discharge is simply the mean of all of the flows over the given period of interest including the filled data if specified by the user. The mean discharge exceedance time is calculated by determining the 1 – Cumulative Bin Probability of the mean discharge. The coefficient of variation (CV) of the annual maximum series is:

$$CV = \frac{\sigma_{Q_{y\max}}}{\overline{Q}_{y\max}}, \qquad \textbf{(7.16)}$$

where:

$\overline{Q}_{y\max}$ = mean of the annual maxima; and

$\sigma_{Q_{y\max}}$ = standard deviation of annual maxima.

The coefficient of skewness, γ_Q, is:

$$\gamma_Q = \frac{N_T}{(N_T - 1)(N_T - 2)} \sum_{i=1}^{N_Q} \frac{Q_i - \overline{Q_N}}{\sigma_{Q_N}} \quad . \qquad \textbf{(7.17)}$$

where:

N_Q = number of flows;

Q_N = average across all flows; and

σ_{Q_N} = standard deviation of all flows in the flow record.

7.1.1.5 Output Charts

GeoTools provides graphical outputs of CDF, PDF, effective discharge, and non-exceedance probabilities. Figure 7-5 is a CDF of flow and sediment and represents the amount of time that water and sediment are being transported.

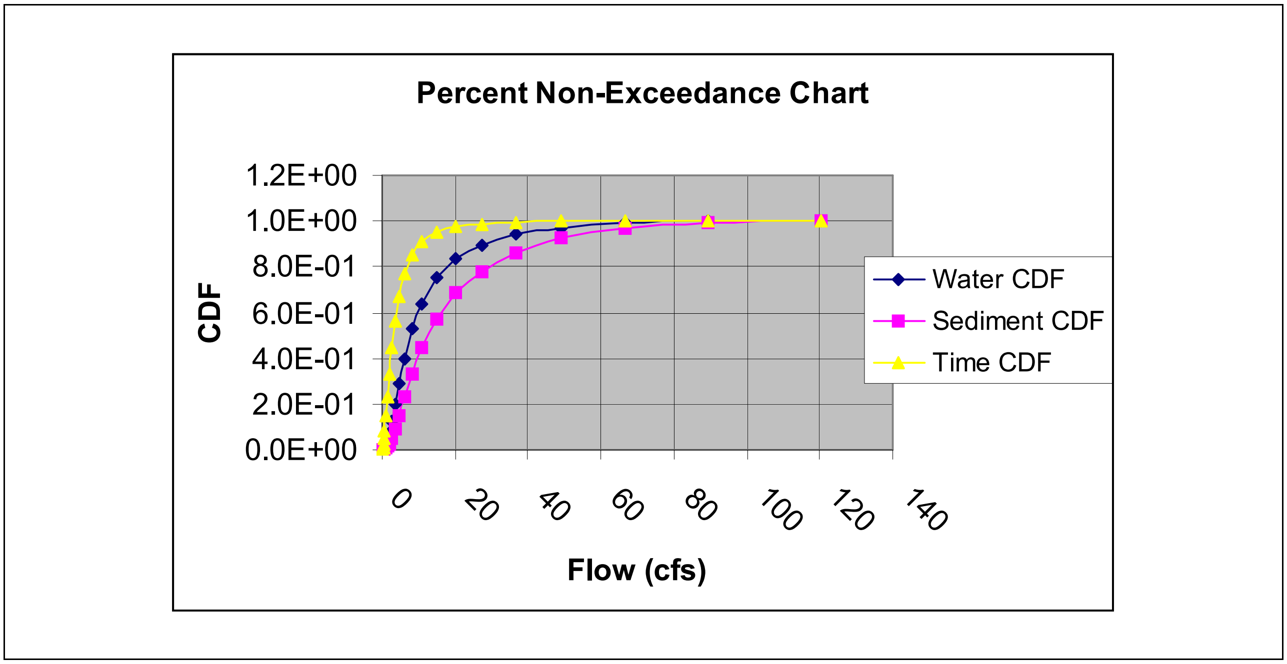


Figure 7-5 – Percent Non-Exceedance Chart. This chart provides information about the amount of time that a given flow, corresponding to a given sediment transport rate, is exceeded in time.

For example, Figure 7-5 demonstrates that 82% of the flow events are less than or equal to 20 cfs, and that 70% of the sediment is transported by flows ≤ 20 cfs. Further, 97% of the time, flows are ≤ 20 cfs. The Effective Discharge characteristics are presented in Figure 7-6. Figure 7-6 presents the distribution of water, the sediment transport function, as well as, the bin sediment load. As described previously, the effective discharge is defined as the flow responsible for the largest bin sediment transport. The maximum value is identified with the green data point. As described in Bin Outputs (Section 7.1.1.1), a second peak in bin sediment load is identified by a light blue data point. The probability distribution of flow is presented on the effective discharge plot.

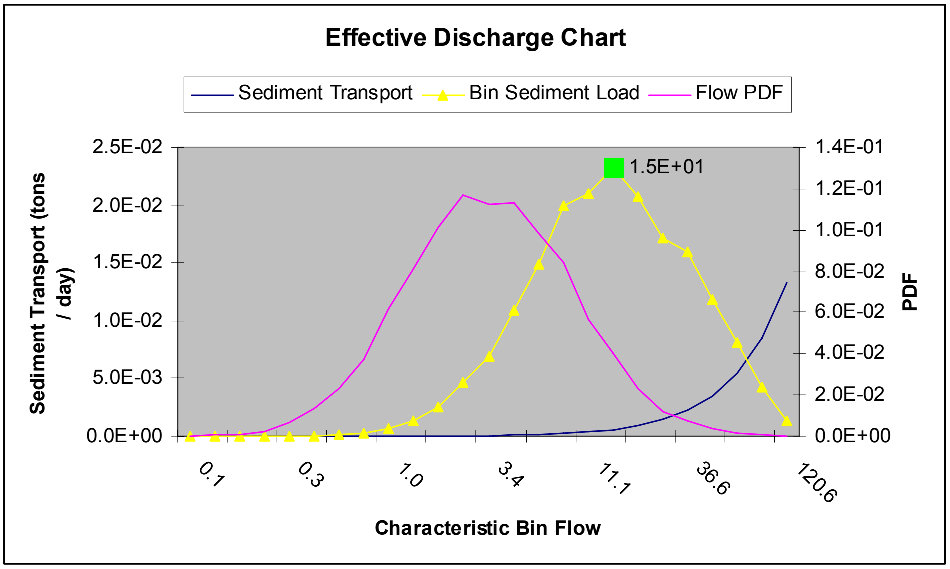
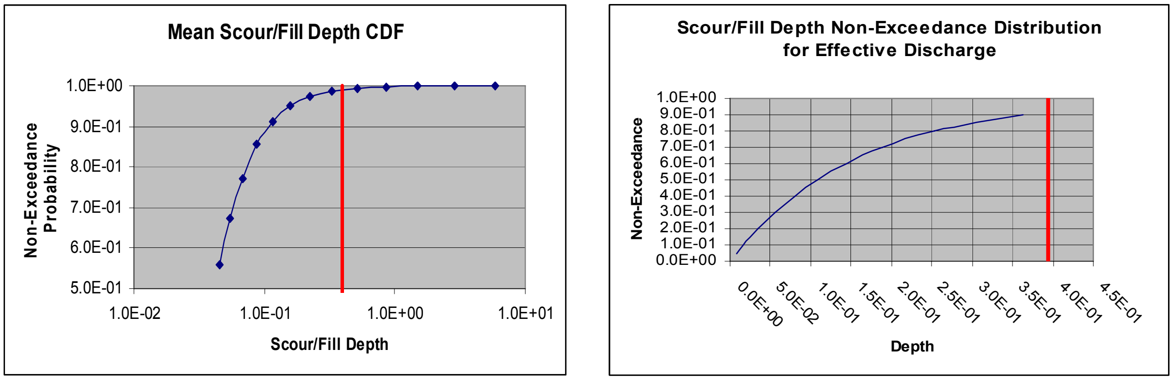


Figure 7-6 – Effective Discharge Chart depicting the flow distribution, sediment transport function, and corresponding bin sediment load. The effective discharge is flagged as the green data point corresponding to the green highlighted row on the bin summary output (Figure 7-1).

GeoTools outputs two charts associated with the scour/fill option. Figure 7-7(a) presents the time distribution of scour/fill depths associated with each bin. Figure 7-7(b) is the distribution of scour/fill depths associated with the effective discharge and corresponds to the values in the scour/fill table (Figure 7-2). The red line in both plots represents the theoretical maximum value of scour depth ($2d_{90}$).



(a) (b)

Figure 7-7 – Scour/Fill Depth Charts: (a) The Mean Scour/Fill Depth CDF Chart is a plot of the time distribution of scour/fill depths associated with each bin. (b) The Scour/Fill Depth Non-Exceedance Distribution is a chart corresponding to the Scour/Fill Depth Table (Figure 7-1).

7.1.2 Input Summary

User-specified inputs are provided in an Input Summary table (Figure 7-8). The Input Sheet summarizes the years used in the analysis, and the time interval for flow record. The Input Sheet also identifies the mode of hydraulic radius determination as well as mode of sediment transport selected, and the corresponding input variables are listed.

Input Type	Option	Option Value
All Years	Selected	
Time Interval for Discharges	Daily	
Hydraulic Radius Input	a coefficient	0.4
Hydraulic Radius Input	b coefficient	0.5
Meyer-Peter Müller Input	Slope	0.012
Meyer-Peter Müller Input	Effective Width	3.5
Meyer-Peter Müller Input	dm (mm)	30
Meyer-Peter Müller Input	Critical Shear Stress	0.047

Figure 7-8 – Sample Input Summary screen shot, lists the input used in the effective discharge calculation.

7.2 Effective Discharge File Comparison

When used to compare multiple files in the effective discharge mode, GeoTools provides output and summary sheets similar to those discussed in previous sections (Figure 7-1 to Figure 7-7). In addition, the input summary is provided as in Figure 7-8. Comparison of flow statistics and indices between flow records is presented in the Flow Regime Statistics comparison sheet (Figure 7-9).

	_earlyArith bin = 25	t_lateArith bin = 25	teCompArith bin = 25
Flow Regime Statistics			
Qmean annual [cfs]	5.4E+00	1.9E+01	3.2E+01
Q effective [cfs]	8.5E+00	4.4E+01	7.2E+01
Q1_5 [cfs]	5.4E+01	3.3E+02	5.4E+02
Q2 [cfs]	5.8E+01	4.0E+02	6.6E+02
Q1_5 / Qma	1.0E+01	1.7E+01	1.7E+01
Q1_5 / Q_e	6.3E+00	7.5E+00	7.5E+00
Q2 / Qma	1.1E+01	2.0E+01	2.0E+01
Q2 / Q_e	6.8E+00	9.1E+00	9.1E+00
Mean Discharge [cfs]	5.5E+00	2.0E+01	3.3E+01
Mean Discharge Exceedance Time	2.1E-01	5.6E-01	5.6E-01
CV annual maximums	3.8E-01	7.6E-01	7.6E-01
coefficient of skewness	4.8E+00	1.5E+01	1.5E+01
Sediment Transport [tons/year]	3.0E+02	1.4E+04	4.3E+04
Sum Bin Sediment Load	8.17E-01	3.86E+01	1.18E+02

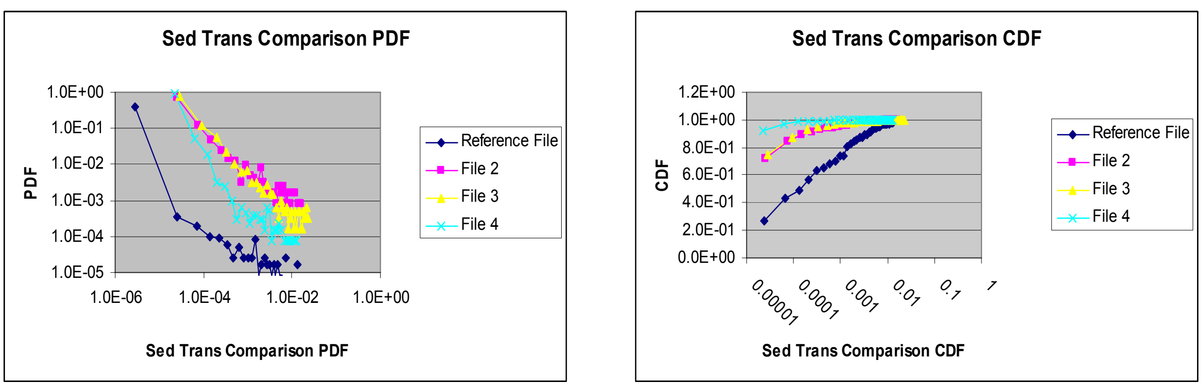
Figure 7-9 – The Sample Flow Regime Statistics comparison sheet screen shot, depicts the comparison of three different historical records.

The user has the option of specifying whether they want comparisons made of PDFs, CDFs, both, or neither. If a comparison is desired, then discharge, sediment transport, stream power, shear stress, scour/fill depths,* and specific stream power* are all determined for comparison. An additional sheet is added to the output workbook (Figure 7-10) in which columns providing the PDF, CDF, and other values (*e.g.,* sediment transport and shear stress) are presented for each flow file. As illustrated in Figure 7-10 the effective discharge and second peak, if appropriate, are highlighted in green and blue, respectively. In addition to the tabular comparison, a chart is presented which graphically presents the variables (Figure 7-11).

* Only if these options are selected (Figure 5.5)

Bin Number	Sediment Transport [tons/day] / 1000	0%imp.GTLog bin = 35	Sediment Transport [tons/day] / 1000	6%imp.GTLog bin = 35	Sediment Transport [tons/day] / 1000	7%imp.GTLog bin = 35	Sediment Transport [tons/day] / 1000	0&2yr.GTLog bin = 35	Sediment Transport [tons/day] / 1000	0&BMP.GTLog bin = 35
1	0.0E+00	5.9E-07	0.0E+00	5.7E-07	0.0E+00	5.7E-07	0.0E+00	5.8E-07	0.0E+00	5.7E-07
2	0.0E+00	1.1E-05	0.0E+00	3.9E-04	0.0E+00	6.3E-04	0.0E+00	2.4E-03	0.0E+00	6.9E-05
3	0.0E+00	1.1E-05	0.0E+00	1.4E-04	0.0E+00	6.3E-04	0.0E+00	2.8E-03	0.0E+00	7.7E-05
4	0.0E+00	8.9E-06	0.0E+00	1.3E-04	0.0E+00	6.7E-04	0.0E+00	2.0E-03	0.0E+00	1.0E-04
5	0.0E+00	5.9E-06	0.0E+00	1.0E-04	0.0E+00	7.4E-04	0.0E+00	1.4E-03	0.0E+00	1.4E-04
6	0.0E+00	2.4E-06	0.0E+00	1.2E-04	0.0E+00	4.2E-04	0.0E+00	1.8E-03	0.0E+00	8.8E-05
7	0.0E+00	5.3E-06	0.0E+00	8.7E-05	0.0E+00	3.3E-04	0.0E+00	1.2E-03	0.0E+00	6.5E-05
8	0.0E+00	4.2E-06	0.0E+00	9.2E-05	0.0E+00	2.9E-04	0.0E+00	1.1E-03	0.0E+00	5.9E-05
9	0.0E+00	2.4E-06	0.0E+00	4.9E-05	0.0E+00	2.4E-04	0.0E+00	9.8E-04	0.0E+00	1.4E-04
10	0.0E+00	4.7E-06	0.0E+00	5.3E-05	0.0E+00	2.7E-04	0.0E+00	5.8E-04	0.0E+00	1.7E-04
11	0.0E+00	5.9E-06	0.0E+00	3.3E-05	0.0E+00	2.7E-04	0.0E+00	2.8E-04	0.0E+00	5.0E-05
12	0.0E+00	2.4E-06	0.0E+00	3.4E-05	0.0E+00	1.3E-04	0.0E+00	4.8E-05	0.0E+00	4.2E-05
13	0.0E+00	4.2E-06	0.0E+00	1.3E-05	5.2E-04	1.2E-04	0.0E+00	5.3E-05	0.0E+00	3.5E-05
14	1.4E-03	3.0E-06	3.0E-03	2.7E-05	6.8E-03	1.1E-04	1.0E-03	4.2E-05	1.1E-03	2.7E-05
15	8.1E-03	1.8E-06	1.1E-02	1.3E-05	1.7E-02	8.9E-05	7.4E-03	6.5E-05	7.5E-03	2.2E-05
16	1.8E-02	3.0E-06	2.3E-02	1.1E-05	3.1E-02	8.5E-05	1.7E-02	6.0E-05	1.7E-02	1.7E-05
17	3.2E-02	3.0E-06	3.7E-02	1.3E-05	4.9E-02	5.9E-05	3.0E-02	1.3E-05	3.0E-02	2.0E-05
18	4.8E-02	3.6E-06	5.5E-02	9.1E-06	7.0E-02	4.7E-05	4.6E-02	1.2E-05	4.7E-02	3.7E-05
19	6.7E-02	4.7E-06	7.7E-02	7.4E-06	9.5E-02	3.1E-05	6.5E-02	1.3E-05	6.6E-02	2.1E-05
20	9.0E-02	2.4E-06	1.0E-01	5.1E-06	1.2E-01	2.5E-05	8.7E-02	6.9E-06	8.8E-02	1.7E-05
21	1.2E-01	5.9E-07	1.3E-01	6.9E-06	1.6E-01	1.8E-05	1.1E-01	5.8E-06	1.1E-01	2.2E-05
22	1.4E-01	3.0E-06	1.6E-01	2.3E-06	1.9E-01	2.4E-05	1.4E-01	2.3E-06	1.4E-01	2.6E-05
23	1.8E-01	1.8E-06	2.0E-01	7.4E-06	2.3E-01	1.4E-05	1.7E-01	4.6E-06	1.7E-01	1.9E-05
24	2.1E-01	3.0E-06	2.4E-01	3.4E-06	2.8E-01	1.0E-05	2.1E-01	3.5E-06	2.1E-01	9.1E-06
25	2.6E-01	1.2E-06	2.8E-01	4.0E-06	3.3E-01	1.3E-05	2.5E-01	2.3E-06	2.5E-01	2.9E-06
26	3.0E-01	7.1E-06	3.3E-01	4.0E-06	3.9E-01	8.6E-06	2.9E-01	5.2E-06	3.0E-01	3.4E-06
27	3.5E-01	1.2E-06	3.9E-01	5.1E-06	4.5E-01	1.1E-05	3.4E-01	2.3E-06	3.5E-01	1.7E-06
28	4.1E-01	3.0E-06	4.5E-01	3.4E-06	5.2E-01	9.7E-06	4.0E-01	3.5E-06	4.0E-01	3.4E-06
29	4.7E-01	1.2E-06	5.1E-01	2.3E-06	6.0E-01	3.4E-06	4.6E-01	8.7E-06	4.6E-01	4.0E-06
30	5.3E-01	1.8E-06	5.9E-01	2.3E-06	6.8E-01	6.3E-06	5.2E-01	1.7E-06	5.3E-01	6.3E-06
31	6.1E-01	2.4E-06	6.7E-01	1.1E-06	7.8E-01	3.4E-06	5.9E-01	2.3E-06	6.0E-01	3.4E-06
32	6.9E-01	1.2E-06	7.5E-01	3.4E-06	8.8E-01	3.4E-06	6.7E-01	3.5E-06	6.8E-01	4.0E-06
33	7.7E-01	2.4E-06	8.5E-01	1.1E-06	9.9E-01	4.0E-06	7.6E-01	1.2E-06	7.6E-01	3.4E-06
34	8.7E-01	0.0E+00	9.5E-01	2.3E-06	1.1E+00	4.0E-06	8.5E-01	5.8E-07	8.6E-01	1.7E-06
35	9.7E-01	1.8E-06	1.1E+00	1.7E-06	1.2E+00	5.2E-06	9.5E-01	2.3E-06	9.6E-01	1.7E-06

Figure 7-10 – Sample PDF comparison of sediment transports for five files. For each file there is a column of sediment transports and a column of PDF values.



(a) (b)

Figure 7-11 – Sample comparison sheet charts for (a) PDF comparison, and (b) CDF comparison, each for four files.

7.3 Stand Alone Sediment Transport

When running GeoTools in the Sediment Transport mode (Figure 3-1 and Figure 6-1), the output is Sediment Transport Rate and Sediment Concentration (Figure 7-12). The user can chose to Write Sediment Transport Rate to Excel? to create a new sheet within a new Excel book that the user can save.

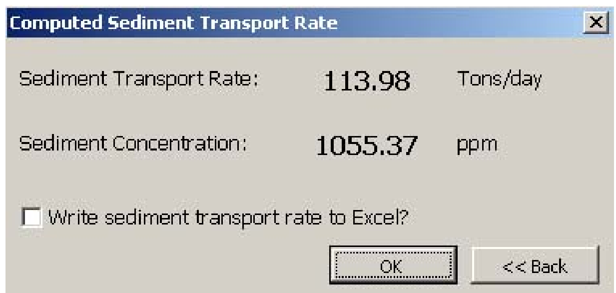
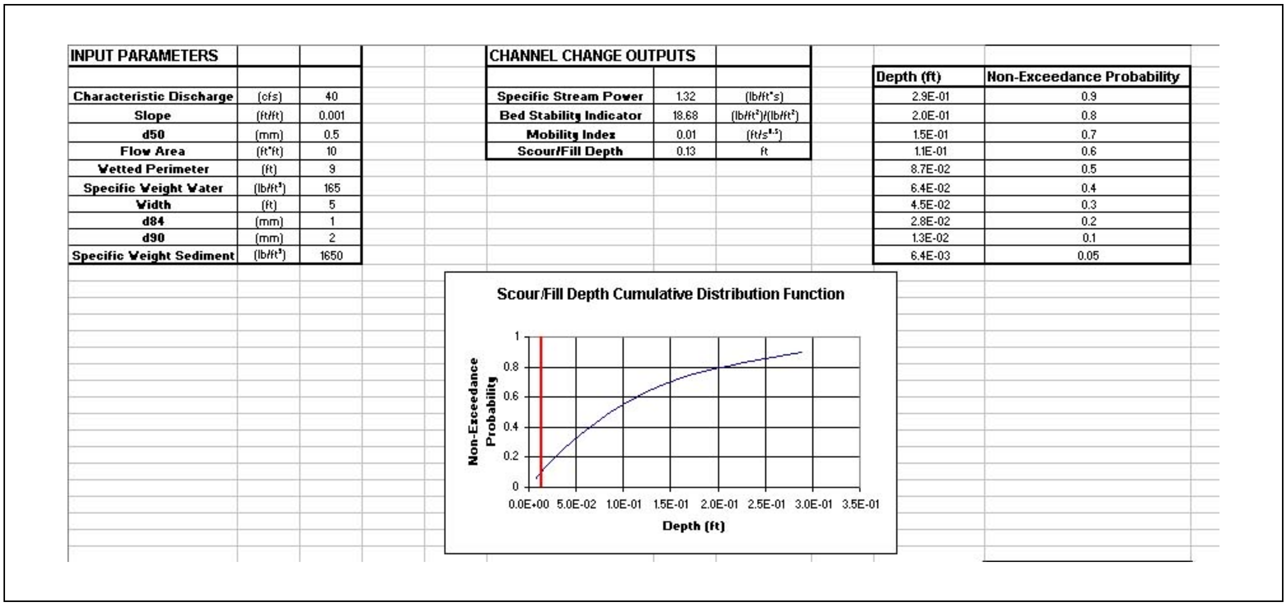


Figure 7-12 – Computed Sediment Transport Rate menu screen shot. Output format when using the Sediment Transport (Stand Alone) module.

7.4 Stand Alone Channel Change Indices

If GeoTools is run in Channel Change mode, then the output is a new worksheet within a new Excel workbook. The new sheet contains up to three tables and one chart, depending on the number of channel change indices selected. The tables list the input parameters, the channel change outputs, and a scour/fill depth non-exceedance table; the chart is a plot of the non-exceedance table (Figure 7-13). The Mobility Index, Specific Stream Power, Bed Stability Indicator, and mean Scour/fill Depth are determined as within the effective discharge mode (Equation (7.9) through (7.12), respectively). The scour/fill depth table is similar to the scour/fill depth table under the effective discharge output (Figure 7-2) and the chart is similar to Figure 7-7(b).



INPUT PARAMETERS		
Characteristic Discharge	(cfs)	40
Slope	(ft/ft)	0.001
d50	(mm)	0.5
Flow Area	(ft*ft)	10
Vetted Perimeter	(ft)	9
Specific Veight Vater	(lb/ft^3)	165
Vidth	(ft)	5
d84	(mm)	1
d90	(mm)	2
Specific Veight Sediment	(lb/ft^3)	1650

CHANNEL CHANGE OUTPUTS		
Specific Stream Power	1.32	(lb/ft*s)
Bed Stability Indicator	18.68	(lb/ft^2)/(lb/ft^2)
Mobility Index	0.01	(ft/s$^{1.5}$)
Scour/Fill Depth	0.13	ft

Depth (ft)	Non-Exceedance Probability
2.9E-01	0.9
2.0E-01	0.8
1.5E-01	0.7
1.1E-01	0.6
8.7E-02	0.5
6.4E-02	0.4
4.5E-02	0.3
2.8E-02	0.2
1.3E-02	0.1
6.4E-03	0.05

Figure 7-13 – Channel Change Indices output sheet screen shot. Output sheet generated when using the stand alone Channel Change module.

CHAPTER 8
PARTIAL FREQUENCY ANALYSIS

Flood recurrence intervals are based on user-defined empirical distribution functions (EDFs). The EDF is based in turn on a plotting position characterization of the flow data. The user must define the characteristics of a discrete event as well as the parameters used within the EDF. The plotting position is a measure of the historical relative exceedance frequencies of events; the inverse of the plotting position is a measure of the non-exceedance frequency. The partial frequency analysis theoretically gives a better estimate of events of recurrence intervals less than 10 years than does the exceedance/non-exceedance probabilities associated with the annual maximum series. This is because events that may not be an annual maximum in one year but would be in another are ignored in the annual maximum series but are considered in the Partial Frequency Analysis.

8.1 Partial Frequency Inputs

The input for the Partial Frequency Analysis menu (Figure 8-1) is a stream flow record in any of the formats described previously (Chapter 4). The time properties of the input file must be specified. As mentioned above, the user must define the characteristics of a discrete event; specifically the minimum discharge to consider and optionally an inter-event duration. The minimum discharge to consider is treated as a strict censoring border below which any discharge cannot be considered a flood. An inter-event duration is a period over which only one discharge will be considered a discrete event specifying an inter-event duration prevents multiple peaks in the same event from being considered as two different events. The user must also specify the plotting position function used to calculate the relative exceedance frequencies of events.

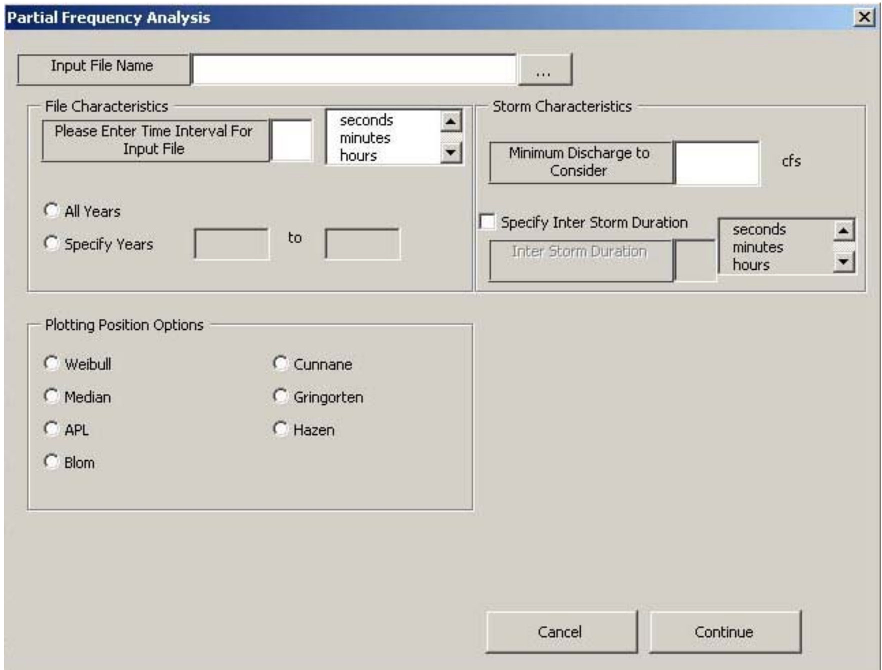


Figure 8-1 – Partial Frequency Analysis menu screen shot, where the user specifies the necessary input arguments for computing empirical distributions and return periods of elements within a hydrologic time series.

The recurrence interval for events is based of an EDF. The flow data are ordered from greatest to smallest and each flood is then assigned a plotting position. The general plotting position formula is described by:

$$PP(i) = \frac{(i-\alpha)}{N+\beta-2\alpha} \quad . \tag{8.1}$$

Many various alterations of the α and β parameters have been developed in the literature corresponding to assumptions about the underlying distribution of the floods. A good description of the various plotting positions is provided by Salas *et al*. (2000):

> "Various plotting position formulas have been suggested in the literature. Two commonly used formulas are *i/N* and *i/(N+1)*. Cunnane (1978) compared various plotting positions and suggested a general plotting position formula [after some slight modification] which will give unbiased quantile estimates….. when $\beta = 1$, α

= 0 for a uniform distribution, α = 3/8 for a normal distribution, and α = 0.44 for the Gumbel distribution…”

The plotting position formulas included in GeoTools are listed in Table 8-1.

Table 8-1 – Plotting function choices for use in partial flood duration analyses. The user has a choice of seven plotting position formulas.

Weibull (1939)	$\frac{i}{N+1}$
Median	$\frac{i-0.3175}{N+0.365}$
APL	$\frac{i-0.35}{N}$
Blom (1958)	$\frac{i-3/8}{N+1/4}$
Cunnane (1978)	$\frac{i-0.4}{N+0.2}$
Gringorten (1963)	$\frac{i-0.44}{N+0.12}$
Hazen (1914)	$\frac{i-0.5}{N}$

It is noted here that regardless of the plotting position formula chosen, the same flood will always come from the same quantile of the population of floods (Klemeš 2000a). Additionally, Klemeš (2000a,b) notes that plotting position formulas can under and/or over estimate a flood’s position by a number of quantiles, a function of the sample size, and assumptions of sample independence. Caution is therefore recommended when using this information to make assumptions about the underlying distribution of the data and making extrapolations from historical data to events of rare occurrence.

8.2 Partial Frequency Output

8.2.1 Partial Frequency Tabular Output

The tabular output produced by the Partial Frequency Analysis module (Figure 8-2) is two columns of sorted flow rates from least to greatest in column ("B") and the number of exceedances per year in column ("A"). The number of exceedances per year is assumed equal to the plotting position as calculated above. The inverse of the plotting position or the inverse of the number of exceedances per year is interpreted as the probability of observing an event of equal or larger magnitude in any one particular year.

Number of Exceedances Per Year	Flowrate (cfs)
1.21	49.02
1.17	49.78
1.14	50.63
1.10	50.76
1.07	50.86
1.03	51.09
.	.
.	.
.	.
0.21	82.27
0.17	86.76
0.14	95.95
0.10	102.26
0.07	103.25
0.03	139.99

Figure 8-2 – Sample tabular output for Partial Frequency Analysis module. This output lists the number of exceedances of a specific (or greater) value in any one year.

Because the Partial Frequency Analysis module uses an Excel worksheet to output the table of events, it is possible that there are more events than rows within a worksheet. This number is approximately 65,000; omissions will occur if the number of events exceeds the number of rows.

8.2.2 Partial Frequency Graphical Output

The graphical output associated with the partial frequency analysis module is a chart of discharge versus number of exceedances per year (Figure 8-3). The data for the graph is taken from the partial frequency analysis output table (Figure 8-2).

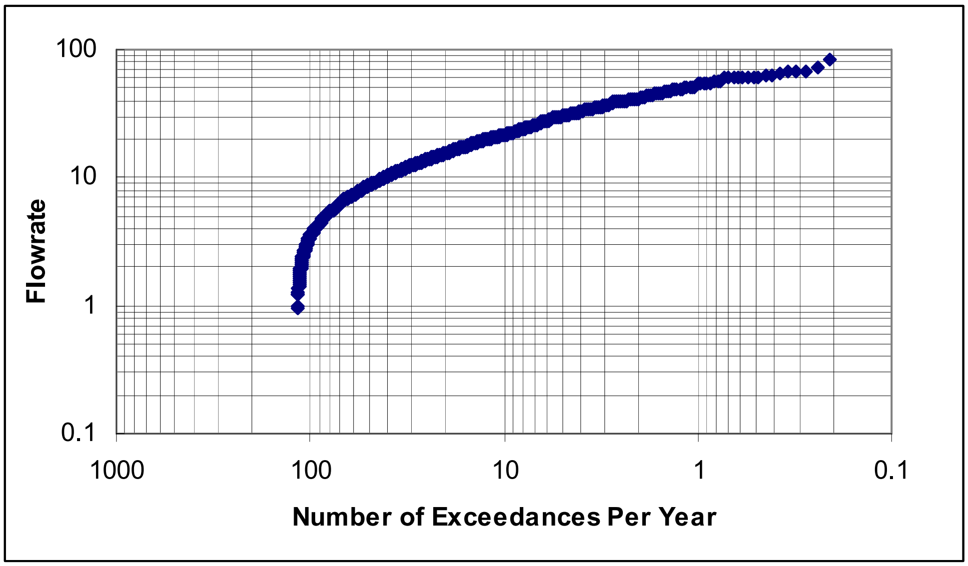


Figure 8-3 – Sample graphical output for the Partial Frequency Analysis module depicting the data listed in Figure 8-2.

CHAPTER 9

DISTURBANCE REGIME

9.1 Disturbance Regime Input

The input for the disturbance regime module is a stream flow record in any of the formats described previously (Chapter 4). The time properties of the input file must be specified. The user must also specify the attributes pertaining to incipient motion, namely the slope of the channel, the dimensionless critical shear stress for incipient motion, a characteristic grain size, specific weight of the water, and the specific weight of the sediment. Default options are provided for the specific weights of the water and sediment (Figure 9-1).

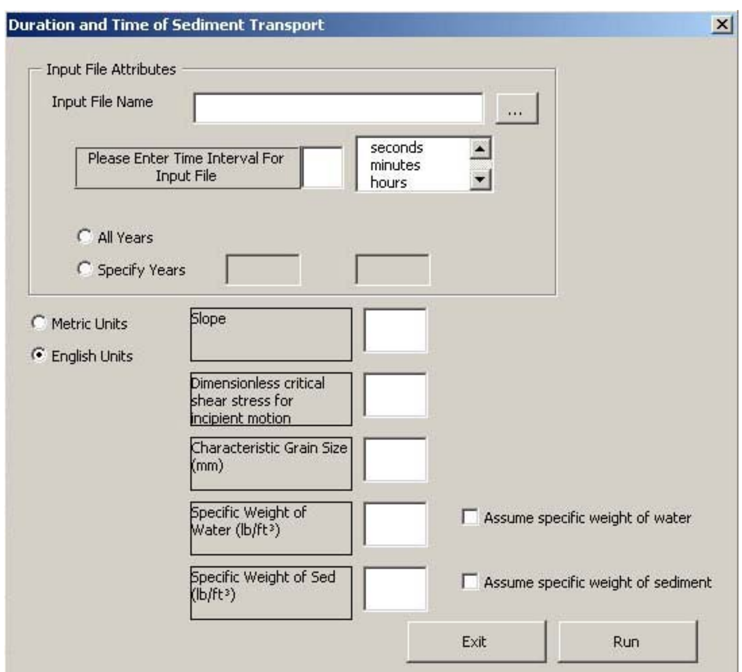


Figure 9-1 – Duration and Time of Sediment Transport menu screen shot, where the user specifies the necessary input arguments to calculate threshold for, the number of, and durations of sediment transport within a hydrologic time series.

9.2 Disturbance Regime Output

9.2.1 Disturbance Regime Tabular Output

The tabular output (Figure 9-2) produced by the disturbance regime output consists of (a) the threshold for sediment transport; (b) the total duration of time that the threshold for incipient motion was exceeded in the input file; (c) the number of discrete times that the threshold for incipient motion was crossed; and (d) the average length of time that once the threshold for incipient motion was exceeded that sediment stayed in motion. It is assumed by GeoTools that if there are missing records within the input file that the missing time periods had the same sediment transport as the time period immediately preceding the missing records.

Number of Discrete Times Exceeding Incipient Motion	2172			
Total Duration Incipient Motion Exceeded	586483200	**seconds =**	6788	**days**
Average Length of Event Exceeding Incipient Motion	270019.89	**seconds =**	3.13	**days**
Coefficient of Variation of Events Exceeding Incipient Motion	0.82	**seconds =**	0	**days**
Flow Necessary for Incipient Motion		**cfs**	2.11	

Figure 9-2 – Sample tabular Disturbance Regime output screen shot containing the values associated with incipient motion and the numbers and durations of times that incipient motion was exceeded in the input time series.

9.2.2 Disturbance Regime Graphical Output

A chart is also provided showing the discharge time series provided by the user's input file along with the threshold for sediment transport (Figure 9-3). It is possible for the user to alter the scale of the chart in order to examine more specific aspects of transport regime (*e.g.,* seasonality).

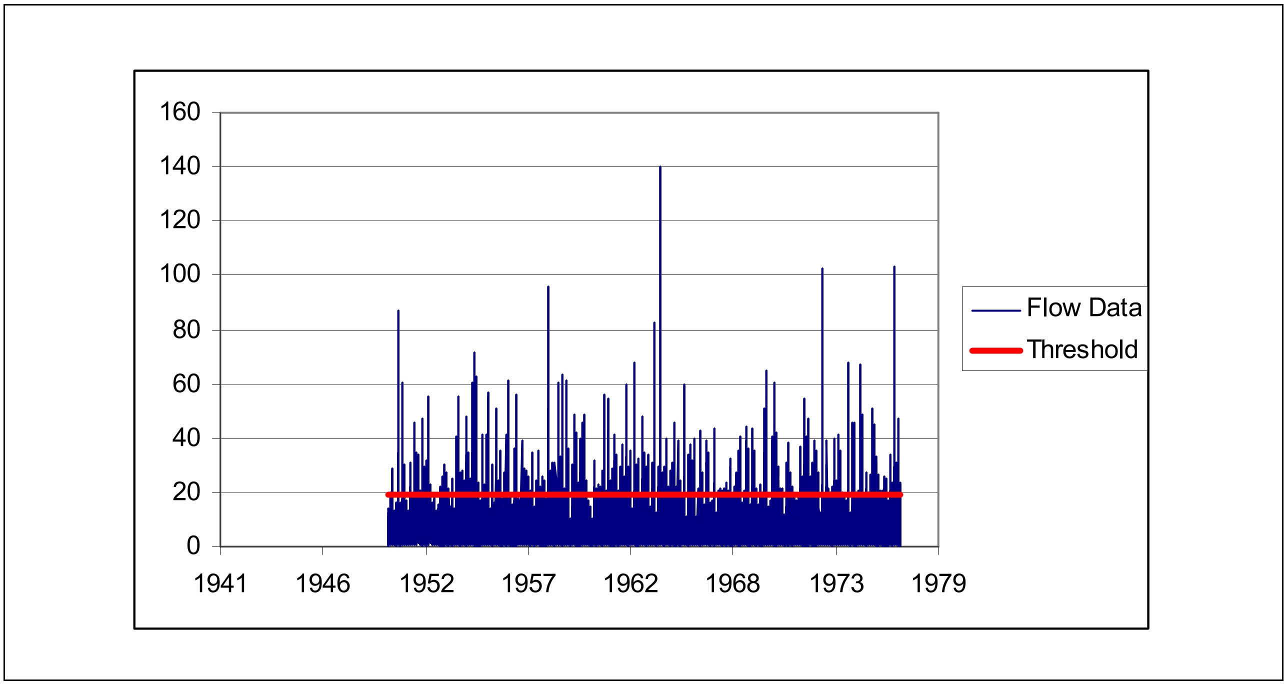


Figure 9-3 – Sample graphical output for Disturbance Regime module. The abscissa represents time (years) and the ordinates are discharge values (ft^3/s).

CHAPTER 10
HYDROLOGIC METRICS

The Hydrologic Metrics module incorporates over 105 statistics that characterize the magnitude, frequency, duration, timing, and rate of change flow series. These statistics include several metrics recommended by Olden and Poff (2003), mean annual discharge, 1.5- and 2-year recurrence intervals, discharge exceedance times, a subset of the Indicators of Hydrologic Alteration (Richter *et al*. 1996), flashiness indices (Sanborn and Bledsoe 2006), and metrics sensitive to urbanization and disturbance regimes in urban streams (Konrad *et al*. 2005, Konrad and Booth 2002).

The hydrologic metric functionality incorporated into GeoTools was designed to facilitate the simultaneous analysis of flow regimes of a large number of fluvial systems. An effective method of describing a flow regime is through a collection of statistics that characterize its five key components: magnitude, frequency, duration, timing, and rate of change (Poff *et al*. 1997). The number of metrics required to describe a regime in sufficient detail is a subject of debate. Too many metrics can lead to redundant information and misleading intercorrelation. Too few can leave out important information. In their original paper, Richter *et al*. (1996) introduced 64 metrics for measuring changes in a flow regime. Other authors introduced, more to the point, that Olden and Poff (2003) collected 171 metrics from published sources for review. Their results showed a high level of redundancy metrics, which led to a recommendation that a representative non-redundant subset be chosen by stream type. Sanborn and Bledsoe (2006) selected **101** metrics for a modeling study based on recommendations, physical interpretability, and economy of computation. This list serves as the source for the metrics included in GeoTools with four additions. Konrad (2000) introduced the proportion of time that channel discharge is above the annual daily-averaged mean level. This ratio of days above total days, Tqmean, has been shown to correlate with geomorphic response of streams in urbanizing watersheds. Three other metrics are included that measure the duration of mean-daily flows exceeding the thresholds of 50%, 75%, and 100% of the 1.67-year recurrence flood level. A complete list of the **105** metrics included in GeoTools is shown in Table 10-1. The individual metrics can be referred to by the coding convention introduced by Olden and Poff (2003).

Table 10-1 – Hydrologic Metrics descriptions (units: V – volume, L – length, S – seconds, D – days, A – drainage area).

	Name	Code	Description	Units
1	Mean Flow Variability	MA3	Mean of the coefficients of variation for each year	--
2	Mean January Flow	MA12	Mean flow value for January	V/S
3	Mean February Flow	MA13	Mean flow value for February	V/S
4	Mean March Flow	MA14	Mean flow value for March	V/S
5	Mean April Flow	MA15	Mean flow value for April	V/S
6	Mean May Flow	MA16	Mean flow value for May	V/S
7	Mean June Flow	MA17	Mean flow value for June	V/S
8	Mean July Flow	MA18	Mean flow value for July	V/S
9	Mean August Flow	MA19	Mean flow value for August	V/S
10	Mean September Flow	MA20	Mean flow value for September	V/S
11	Mean October Flow	MA21	Mean flow value for October	V/S
12	Mean November Flow	MA22	Mean flow value for November	V/S
13	Mean December	MA23	Mean flow value for December	V/S
14	Variability of January Flow	MA24	The standard deviation for flow in January divided by the mean flow for this month	--
15	Variability of February Flow	MA25	The standard deviation for flow in February divided by the mean flow for this month	--
16	Variability of March Flow	MA26	The standard deviation for flow in March divided by the mean flow for this month	--
17	Variability of April Flow	MA27	The standard deviation for flow in April divided by the mean flow for this month	--
18	Variability of May Flow	MA28	The standard deviation for flow in May divided by the mean flow for this month	--
19	Variability of June Flow	MA29	The standard deviation for flow in June divided by the mean flow for this month	--
20	Variability of July Flow	MA30	The standard deviation for flow in July divided by the mean flow for this month	--
21	Variability of August Flow	MA31	The standard deviation for flow in August divided by the mean flow for this month	--
22	Variability of September Flow	MA32	The standard deviation for flow in September divided by the mean flow for this month	--
23	Variability of October Flow	MA33	The standard deviation for flow in October divided by the mean flow for this month	--
24	Variability of November Flow	MA34	The standard deviation for flow in November divided by the mean flow for this month	--
25	Variability of December Flow	MA35	The standard deviation for flow in December divided by the mean flow for this month	--
26	Skewness in Monthly Flow	MA40	The mean of the monthly flows minus the median of the monthly flows, all divide by the median of the monthly flows	--
27	Specific Mean Runoff	MA41	The mean of the list of mean annual flows for each year divided by the drainage area	--
28	Variability of Annual Flows	MA44	The 90^{th} percentile flow minus the 10^{th} flow discharge all divided by the median of the annual mean flows	--
29	Mean Annual Runoff	MA46	The average daily flow multiplied by 365.24 (days per year)	V
30	January Percent Mean Annual Runoff	MA47	The monthly average flow for January multiplied by the number of days in the month all divided by the total runoff volume for the year	--
31	February Percent Mean Annual Runoff	MA48	The monthly average flow for February multiplied by the number of days in the month all divided by the total runoff volume for the year	--

	Name	Code	Description	Units
32	March Percent Mean Annual Runoff	MA49	The monthly average flow for March multiplied by the number of days in the month all divided by the total runoff volume for the year	--
33	April Percent Mean Annual Runoff	MA50	The monthly average flow for April multiplied by the number of days in the month all divided by the total runoff volume for the year	--
34	May Percent Mean Annual Runoff	MA51	The monthly average flow for May multiplied by the number of days in the month all divided by the total runoff volume for the year	--
35	June Percent Mean Annual Runoff	MA52	The monthly average flow for June multiplied by the number of days in the month all divided by the total runoff volume for the year	--
36	July Percent Mean Annual Runoff	MA53	The monthly average flow for July multiplied by the number of days in the month all divided by the total runoff volume for the year	--
37	August Percent Mean Annual Runoff	MA54	The monthly average flow for August multiplied by the number of days in the month all divided by the total runoff volume for the year	--
38	September Percent Mean Annual Runoff	MA55	The monthly average flow for September multiplied by the number of days in the month all divided by the total runoff volume for the year	--
39	October Percent Mean Annual Runoff	MA56	The monthly average flow for October multiplied by the number of days in the month all divided by the total runoff volume for the year	--
40	November Percent Mean Annual Runoff	MA57	The monthly average flow for November multiplied by the number of days in the month all divided by the total runoff volume for the year	--
41	December Percent Mean Annual Runoff	MA58	The monthly average flow for December multiplied by the number of days in the month all divided by the total runoff volume for the year	--
42	Total Skewness	MA59	The mean of the total record minus the median of the total record all divided by the mean of the total record	--
43	Variability of Minimum Monthly Flow	ML13	The standard deviation for the minimum monthly flows of the entire flow record divided by the mean multiplied by 100	--
44	Mean Minimum Flow Ratios	ML14	The metric is then the mean of the series of minimum flow by the median flow for each year	--
45	Baseflow	ML17	The mean of the series of minimum 7-day moving average flows for each year divided by the mean annual flow for that year	--
46	Variability of Baseflow	ML18	The coefficient of variation of the series of minimum 7-day moving average flows for each year divided by the mean annual flow for that year	--
47	Specific Mean Annual Minimum Flow	ML22	The mean of the series of minimum flows for each year divided by drainage area	V/L^2
48	High Flow Index	MH17	The 25% exceedance value for the entire record divided by the median flow for the entire record	--
49	Mean Maximum October Flow	MH1	Mean of the series of maximum flows in October for each year	V/S
50	Mean Maximum May Flow	MH8	Mean of the series of maximum flows in May for each year	V/S
51	Variability of Maximum October Flow	MH28	Coefficient of variation of the series of maximum flows in October for each year	--
52	Variability of Maximum May Flow	MH29	Coefficient of variation of the series of maximum flows in May for each year	--
53	Specific Mean Annual Maximum Flow	MH20	Mean of the series of maximum flows for each year divided by drainage area	V/L^2

	Name	Code	Description	Units
54	Specific Mean Minimum 1-Day Flows	DL1	Mean of the series of minimum 1-day moving average flow for each year divided by the drainage area	V/L^2
55	Specific Mean Minimum 3-Day Flows	DL2	Mean of the series of minimum 3-day moving average flow for each year divided by the drainage area	V/L^2
56	Specific Mean Minimum 7-Day Flows	DL3	Mean of the series of minimum 7-day moving average flow for each year divided by the drainage area	V/L^2
57	Specific Mean Minimum 30-Day Flows	DL4	Mean of the series of minimum 30-day moving average flow for each year divided by the drainage area	V/L^2
58	Specific Mean Minimum 90-Day Flows	DL5	Mean of the series of minimum 90-day moving average flow for each year divided by the drainage area	V/L^2
59	Variability of Mean Minimum 1-Day Flows	DL6	Coefficient of variation of the series of minimum 1-day moving average flow for each year divided by the drainage area	--
60	Variability of Mean Minimum 3-Day Flows	DL7	Coefficient of variation of the series of minimum 3-day moving average flow for each year divided by the drainage area	--
61	Variability of Mean Minimum 7-Day Flows	DL8	Coefficient of variation of the series of minimum 7-day moving average flow for each year divided by the drainage area	--
62	Variability of Mean Minimum 30-Day Flows	DL9	Coefficient of variation of the series of minimum 30-day moving average flow for each year divided by the drainage area	--
63	Variability of Mean Minimum 90-Day Flows	DL10	Coefficient of variation of the series of minimum 90-day moving average flow for each year divided by the drainage area	--
64	Annual Minimum 30 Day Median Flow	DL13	Annual Minimum 30 day flow divided by the median flow for the entire record	--
65	Low Flow Pulse Duration	DL16	Median of the series of average pulse durations for flow events below the 25th percentile (calculated for the entire record) of each year	D
66	Variability in Low Flow Pulse Duration	DL17	Coefficient of variation of the yearly average low pulse durations multiplied by 100	--
67	Number of 0-day flows	DL18	Mean number of days per year with zero flow	D
68	Variability of 0-day flows	DL19	Coefficient of variation of number of days per year with zero flow multiplied by 100	--
69	Specific Mean Maximum 1-Day Flows	DH1	Mean of the series of maximum 1-day moving average flow for each year divided by the drainage area	V/A
70	Specific Mean Maximum 3-Day Flows	DH2	Mean of the series of maximum 3-day moving average flow for each year divided by the drainage area	V/A
71	Specific Mean Maximum 7-Day Flows	DH3	Mean of the series of maximum 7-day moving average flow for each year divided by the drainage area	V/A
72	Specific Mean Maximum 30-Day Flows	DH4	Mean of the series of maximum 30-day moving average flow for each year divided by the drainage area	V/A
73	Specific Mean Maximum 90-Day Flows	DH5	Mean of the series of maximum 90-day moving average flow for each year divided by the drainage area	V/A
74	Variability of Mean Maximum 1-Day Flows	DH6	Coefficient of variation of the series of minimum 1-day moving average flow for each year divided by the drainage area	--

	Name	Code	Description	Units
75	Variability of Mean Maximum 3-Day Flows	DH7	Coefficient of variation of the series of minimum 3-day moving average flow for each year divided by the drainage area	--
76	Variability of Mean Maximum 7-Day Flows	DH8	Coefficient of variation of the series of minimum 7-day moving average flow for each year divided by the drainage area	--
77	Variability of Mean Maximum 30-Day Flows	DH9	Coefficient of variation of the series of minimum 30-day moving average flow for each year divided by the drainage area	--
78	Variability of Mean Maximum 90-Day Flows	DH10	Coefficient of variation of the series of minimum 90-day moving average flow for each year divided by the drainage area	--
79	Annual Maximum 7 Day Median Flow	DH12	Annual maximum 7-day flow divided by the median flow for the entire record	--
80	Annual Maximum 30 Day Median Flow	DH13	Annual maximum 30-day flow divided by the median flow for the entire record	-
81	High Flow Pulse Duration	DH15	Median of the series of average pulse durations for each year for flow events above the 75^{th} percentile (calculated for the entire record) of each year	D
82	Variability of High Flow Pulse Duration	DH16	Coefficient of variation of the yearly average high pulse durations multiplied by 100	--
83	Days Above Q_{mean} (Tqmean)	DH25	Total number of days in the flow record that are above the mean of the record divided by the total number of days in the record	--
84	Days at Q1.67	DH26	Total number of days in the flow record that are at or above the $Q_{1.67}$ value	D
85	Days at 75% of Q1.67	DH27	Total number of days in the flow record that are at or above 75% of the $Q_{1.67}$ value	D
86	Days at 50% of Q1.67	DH28	Total number of days in the flow record that are at or above 50% of the $Q_{1.67}$ value	D
87	Predictability	TA2	Colwell's predictability index	--
88	Julian Date of Minimum Flow	TL1	Mean of the series of Julian Dates on which the minimum flow of each year occurred	--
89	Variability of Minimum Flow Date	TL2	Julian date representing the coefficient of variation of minimum flow dates This should not be interpreted as a specific day of the year	--
90	Julian Date of Maximum Flow	TH1	Mean of the series of Julian Dates on which the maximum flow of each year occurred	--
91	Variability of Maximum Flow Date	TH2	Julian date representing the coefficient of variation of maximum flow dates This should not be interpreted as a specific day of the year	--
92	Maximum Proportion of Number of Floods	TH3	Maximum number of days in a row during which no flood ($Q_{1.67}$) has ever occurred throughout the flow record divided by the number of days per year	--
93	Low Flood Pulse Count	FL1	Mean of the number of flow events per year with flows below the 25^{th} percentile threshold	--
94	Variability of Low Flood Pulse Count	FL2	Coefficient of variation of the average number of low pulse events per year multiplied by 100	--
95	High Flood Pulse Count	FH1	Mean of the number of flow events per year with flows above the 75^{th} percentile threshold	--
96	Variability of High Flood Pulse Count	FH2	Coefficient of variation of the average number of high pulse events per year multiplied by 100	--
97	Flood Frequency	FH11	Compute the average number of flow events above the $Q_{1.67}$ recurrence interval discharge per year The metric is the average number of this series	--

	Name	Code	Description	Units
98	Rise Rate	RA1	Mean of the series of change in flow values for days in which the change is positive for the entire record	V/T
99	Variability of Rise Rate	RA1	Coefficient of variation of the series of change in flow values for days in which the change is positive for the entire record multiplied by 100	--
100	Fall Rate	RA3	Mean of the series of change in flow values for days in which the change is negative for the entire record	V/T
101	Variability of Fall Rate	RA4	Coefficient of variation of the series of change in flow values for days in which the change is negative for the entire record multiplied by 100	--
102	Reversals	RA8	Mean of the series of the number of days in each year when the change in flow from one day to the next changes direction (*i.e.*, positive vs. negative change)	--
103	Variability of Reversals	RA9	Coefficient of variation of the number of yearly reversals by the mean and multiply by 100	--
104	Annual Flash Index	RA10	Mean of the series of maximum flows for each year divided by the mean discharge value for the entire record	--
105	Bledsoe/Sanborn Flash Index	RA11	Sum of the absolute differences between the flow of each day in the record and the next day divided by the total number of days in the record minus one, all divided by mean flow of the entire record	--

10.1 Batch Processing

The addition of hydrologic metric functionality creates the opportunity to study trends across different stream types and locales. In order to generate the data sets necessary for statistical study, many individual flow records must be processed and organized. In some circumstances, this can be a time-consuming and error-prone process, which reduces the productivity of research. A high demand of time and resources in generating a data set reduces the pool available to analyze results. It may also limit the number of treatments considered and discourage the pursuit of some hypotheses. Including an inherent ability to process a large number of flow records removes the labor burden, reduces errors, and facilitates a larger application to research. For these reasons, the ability to produce these hydrologic metrics in large batches has also been incorporated. With this functionality, users will be able to create a single input file that contains the information necessary to run multiple flow records.

10.2 Design Considerations

In order to define the design considerations for the new hydrologic functionality, a case study was developed based on needs expressed by the U.S. Bureau of Reclamation (USBR). The general requirements were to demonstrate the value of GeoTools in analyzing the association between the operations of a series of USBR dams and the ecological health downstream. It was against this background that the following assumptions were made. Dam operation information would be in the form of a flow-discharge record. The user would be asked to provide input and output file names and be given the ability to choose which metrics would be calculated. For annual statistics, the user would also have the ability to indicate whether a Calendar Year (January through December) or Water Year (October through September) format would be used. The output would be a presentation of the selected metrics in a form that could be readily accessed by the user.

10.2.1 Input and Output Requirements

The primary input requirement of the Hydrologic Metrics module was that it must be able to read in a single, daily-averaged flow file or set of files and produce a set of predefined metrics. The USGS provides daily-averaged discharge results for its streamflow gages through the NWIS website. Users have great freedom in selecting gages and time periods to download to a text file.

It was assumed that most hydrologic studies would begin with data from the NWIS site and so the format of this text file was chosen as the standard. The general structure to the text file (Figure 10-1) is a series of descriptive header records that begin with the '#' symbol followed by two records of column headings and then a series of tab-delimited records containing the data. Although all of the columns are necessary, the most important data fields are the third and fourth columns, containing the date and daily-averaged discharge value.

```
# ---------------------------------- WARNING ----------------------------------------
# The data you have obtained from this automated U.S. Geological Survey database
# have not received Director's approval and as such are provisional and subject to
# revision.  The data are released on the condition that neither the USGS nor the
# United States Government may be held liable for any damages resulting from its use.
# Additional info: http://waterdata.usgs.gov/co/nwis/help/?provisional
#
# File-format description:  http://waterdata.usgs.gov/nwis/?tab_delimited_format_info
# Automated-retrieval info: http://waterdata.usgs.gov/nwis/?automated_retrieval_info
#
# Contact:   gs-w_support_nwisweb@usgs.gov
# retrieved: 2006-11-05 16:50:57 EST
#
# Data for the following site(s) are contained in this file
#    USGS 06752260 CACHE LA POUDRE RIVER AT FORT COLLINS, CO.
# -----------------------------------------------------------------------------------
#
# Data provided for site 06752260
#    DD parameter statistic   Description
#    04   00060     00003     Discharge, cubic feet per second (Mean)
#
# Data-value qualification codes included in this output:
#     P  Provisional data subject to revision.
#     e  Value has been estimated.
#
agency_cd       site_no datetime        04_00060_00003  04_00060_00003_cd
5s      15s     16s     14s     14s
USGS    06752260        2005-11-05      4.4     P
USGS    06752260        2005-11-06      4.2     P
USGS    06752260        2005-11-07      4.7     P
USGS    06752260        2005-11-08      5.8     P
USGS    06752260        2005-11-09      5.8     P
USGS    06752260        2005-11-10      4.1     P
USGS    06752260        2005-11-11      4.1     P
USGS    06752260        2005-11-12      3.8     P
```

Figure 10-1 – USGS gage date sample file.

The output requirements are simply to display the generated results in a form accessible to the user. In order to be as flexible as possible, the output will appear as an Excel worksheet with the file name specified. The actual data file itself will be saved as a simple tab-delimited text file of the same name. This generic format makes it easier to transfer the data to other programs if desired.

10.2.2 Batch Processing Input File

The batch input file was designed for simplicity. Each line of the file has two columns of information (Figure 10-2). The first field is the filename of the flow record, including the complete path. The second field is the drainage area, in either square miles or square kilometers keeping consistent with the flow record. The columns must be separated by a 'Tab' action. The end of the line should be designated by a carriage return/line-feed action. Simply hitting the enter key is sufficient when creating this file. There is no limit to the number of individual flow records that can be included in a batch file. As a convenience feature, any line that begins with a '#' symbol will be skipped by the program. This allows the user to run a subset of the total records without having to create an entirely new file.

```
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\07091200       504.32
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\07134180       2.3
#C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\393109104464500       51.89
#C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06708800      117
#C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06752260      16.9
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06745000       34.6
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06747000       56.6
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06747500       345.6
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06748000       457.4
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06748500       590.8
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06748600       693.4
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06749000       736.7
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06749500       807.9
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06751150       1963.4
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06751490       2001.7
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06751500       2308.6
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06752000       5902.5
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06752258       7295.9
C:\Documents and Settings\Owner\My Documents\GeoTools\Gage Files\06752270       10673.7
```

Figure 10-2 – Batch processing input file.

10.2.3 Process Workflow

The workflow describes the series of steps necessary to direct the software as to the task to be completed. This includes all of the input preparation, data entry, and on-screen actions. There are two workflows possible in which GeoTools will calculate Hydrologic Metrics: (1) Standalone, and (2) Effective Discharge Integrated.

10.2.3.1 Standalone

Most of the time, a user will be interested in only dealing with the metrics and will follow the Standalone workflow. Prior to engaging GeoTools, the appropriate flow record file(s) and batch file, if necessary, should be prepared. The user will invoke the Hydrologic Metrics module directly from the Opening menu. A user form will provide fields for input and output filenames, with the ability to browse through the computer's directory structure to locate previously created files. The flow metrics will be grouped and presented for selection. To begin with, all the metrics will be indicated for generation. The user will be able to de-select individual or groups of metrics before proceeding. Additionally, the user will specify whether to use the Water Year or Calendar Year format for annual statistics. When these steps are completed, the user will click a Continue >> button and the software will begin processing. If the input file is a single flow record, a second user form will appear with a field for the drainage area of the gage. When this is entered, processing will continue. A progress window will appear and report the status of the task. When all processing is complete, the requested metrics will be presented in an Excel worksheet.

10.2.3.2 Effective Discharge Integrated

Situations may exist where the user wants to produce metrics while calculating the Effective Discharge. The main difference between this workflow and the Standalone workflow is that the user must proceed through the steps associated with calculating the effective discharge first. Selecting Effective Discharge from the Opening menu, the user must proceed through the normal process of entering the required data. The input and output files will be specified in this way and the final step in this process will be a metric selection tool. The metric output will then appear as a worksheet in the overall effective discharge output file.

10.2.4 User Forms

A new user form (Figure 10-3) was created to allow the user to provide input and output file information as well as select the metrics to be processed. Metrics are grouped on tabs by flow-regime component (Magnitude, Frequency, Duration, Timing, and Rate of Change)

(Figure 10-4). Metrics may be selected or de-selected, either individually or by tab, using the Select All and Clear All buttons.

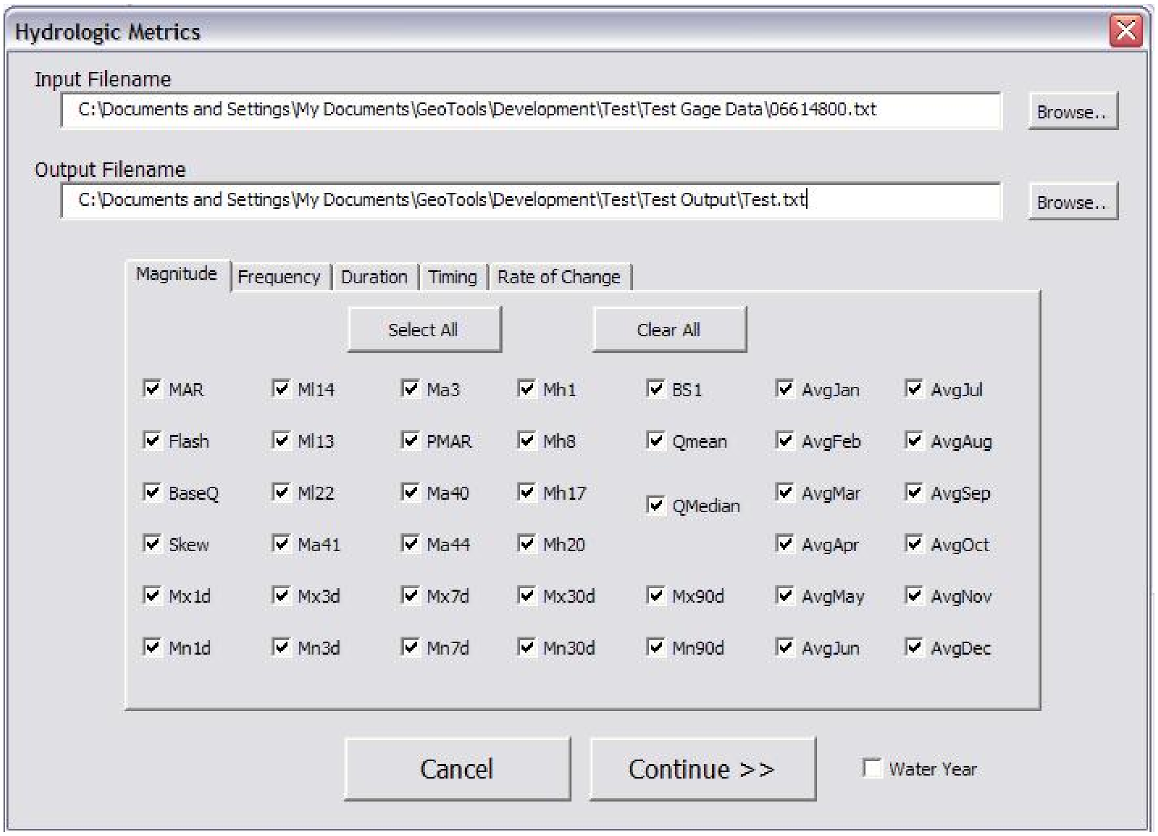


Figure 10-3 – Hydrologic Metrics user form screen shot.

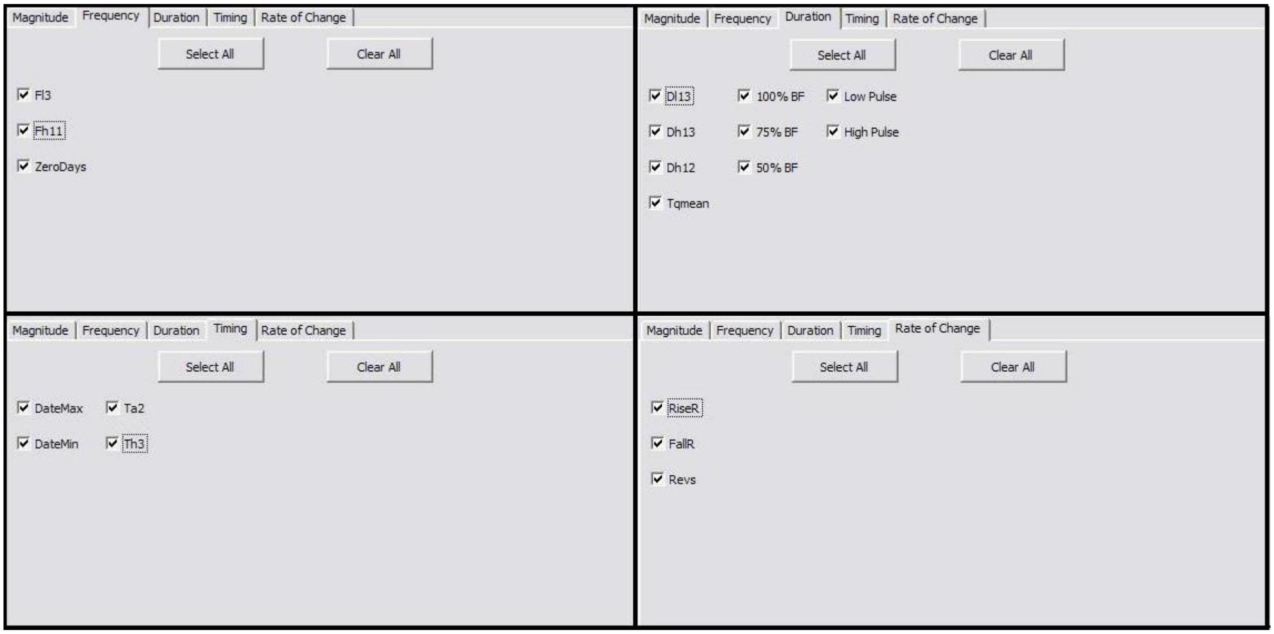


Figure 10-4 – Other Hydrologic Metrics selection tabs screen shot.

10.3 Code Development

Two guidelines were identified when designing the metric functionality: (1) meet the immediate processing needs of current studies, and (2) be flexible enough to use in future situations. In terms of general software design, a common tendency is to create a framework that meets only those requirements specified at the beginning. While producing an adequate tool for the specific task, this approach limits the longevity of the software and misses an opportunity to benefit from the original effort. Therefore, a key component of meeting the guideline (2) was to develop a structure that could be expanded by future developers. In creating modular routines and broadly scoped data-handling structures, it will be possible to quickly change or augment the software to meet future needs as they develop. This approach does increase the initial development effort. However, in addition to the future benefits, this investment in design time can lead to a return in the testing and validation processes of even the same development effort.

The coding effort consisted of two main parts. The first part was to create a data structure that would support the processing demands of the new functionality and that could adapt to future development. The second part was to create a series of modular routines that could be individually validated and tested. A modular approach increases the clarity of the code and simplifies testing.

10.3.1 Data Structure

The "non-metric" convention of annual time keeping presents some unique challenges to data storage and access. Variable days per month, leap years, and Water Year formats complicate the steps necessary to calculate temporal statistics. Data are read sequentially from the input file, but may need to be accessed in an endless number of ways. Added to this, is the challenge of variable input file lengths and potential gaps in the flow record. To address this issue, the Streamflow object was created to handle the storage and access of the flow data. Objects are the blocks of code that form the foundation of the Object-oriented style of programming. A further discussion of object-oriented programming is beyond the scope of this user's manual and the reader is referred to a computer science textbook for more detail. For the purpose of this discussion, however, it is sufficient to say that the Streamflow object contains both the flow data and all of the logic necessary to sort through the flow data and perform a desired function. By encapsulating the logic within the object, the code can be more easily verified and maintained. Several key parts are explained in further detail.

10.3.1.1 Data reading and checking

Although the input file format for this user's manual was previously established, there are potentially many others that may be called into use. Modeling programs and other water resource agencies may have subtle or extreme differences in how data are stored within a file. Yet once these data have been incorporated into the program, where they came from is irrelevant. Therefore, it makes sense that the Streamflow object handles the data-reading process. In this manner, the main program need only request that the object fill itself with data from a particular file and not include specifics about how to do it. As file formats change or are added, the main routine does not need to be updated and potential errors are reduced.

10.3.1.2 Discharge value

The most important function that the Streamflow object performs is the organization of the data for access. With logic encapsulated within the object, the flow data can be referenced by simply the Year and Julian Day. For example, for the Streamflow object *Flow* that has read in a series of data from 01/01/1960 through 12/31/1969, to access the daily-averaged flow on 02/01/1962 the developer only need code:

Flow.dischargevalue(*3*,*32*,*1*)

where "*3*" is the Year in the record (1960 = *1*, 1961 = *2*, 1962 = *3*), "*32*" is the Julian Day for February 1st, and "*1*" is a third value for Time, which is used if there is more than one value recorded for each day, as in 15-min instantaneous data. The convention of referring to Year as the sequential number of the year in the flow record makes sense from the perspective of calculating statistics where the "name" of the year (1962) is not as relevant as the sequence in the flow record. To be sure, the overall logic is complex. For example, it is necessary to recognize that even if the first data record in the input file is August 28th, that this is still Julian Day 241 in a Calendar Year.

10.3.1.3 Year format

The Water Year (WY) convention is derived from the desire to organize flow data based on hydrologic behavior and not the standard calendar. Typically, a water year will begin and end during dry periods and the USGS designated period of October 1 through September 30 is commonly used. While this may make sense in some circumstances, this convention is not a universal standard and can lead to confusion when discussing annual statistics. To provide the greatest flexibility, the Streamflow object attribute *Year_Format* was created to record the user's preference and report data accordingly. If the format is Water Year, then the 32nd day of the year is November 1. If the format is Calendar Year, then 32nd day of the year is February 1.

10.3.2 Code Structure

A total of seven new modules were added to GeoTools: two Form Modules, four Code Modules, and one Class Module (Table 10-2).

Table 10-2 – New GeoTools code modules.

Type	Module Name	Description
Form Module	frm_Hydrologic_Metrics	Form for selecting desired metrics
	frm_Request_Input	General form for requesting input from user
Code Module	General_Functions	27 routines that perform general reading, writing, conversion, and error-checking functions
	Global_Variables	List of global variables used throughout GeoTools
	Hydrologic_Metrics	39 routines used for the calculation of Hydrologic Metrics
	Math_Routines	6 routines that perform standard statistical operations
Class Module	Streamflow	Flow record object

GeoTools has had a number of developers throughout its history. This pattern will most likely continue as old functions are refined and new ones are created. It is also likely that new metrics will be added as they are developed and found useful. In order to increase efficiency of such additions, a list of *Collections* has been created and are described in Table 10-3. A Collection is a Visual Basic specific dynamic array-like object, that can be thought of as a list of data values. Collections have several advantageous over standard arrays that are used throughout this program. First, memory is dynamically allocated for a collection which eliminates the need to declare a size at the outset. As flow records may range from tens to tens of thousands of values this attribute is helpful in reducing the amount of "overhead" logic necessary to allocate, check, and reallocate memory that is common with arrays. Collections are also not associated with a particular data type (integer, string, date, etc. . .), which makes them more straightforward to pass through routines. This simplifies code development and testing. Finally, collections are objects in that they contain the data as well as the methods that perform operations on the data. In particular, the *Count* method, which returns the number of data values in the list, is used extensively in the code. A more detailed discussion of collections can be found in many common Visual Basic textbooks.

Table 10-3 – Hydrologic metric collections.

Collection	Description	*Collection.Count*
TotalRecord	List of every data value in the flow record	Total number of days in the record
AnnualMin	List of the lowest flow for each year in the flow record	Total number of years in the record
AnnualMax	List of the highest flow for each year in the record	Total number of years in the record
AnnualMean	List of the averaged flow for each year in the record	Total number of years in the record
AnnualMedian	List of the median flow for each year in the record	Total number of years in the record

The advantage of these predefined objects is seen when developing the logic to calculate metrics. For example, in order to calculate a series of ratios that represent the average annual flow divided by the maximum flow for each year the pseudo code is simply:

For $i = 1$ to 10

$$Ratio(i) = \frac{AnnualMean(i)}{AnnualMax(i)} \tag{10-1}$$

Next i

instead of the more complicated logic necessary to deal with individual discharge values. With such metric "precursors" created, code development and testing are more efficient and easier to refine as new requirements are identified.

10.4 Testing

The importance of testing a completed program is self-evident. It is common for developers to verify that individual routines provide accurate results as they are developed. However, the formal testing of a final aggregate product can be quite arduous. The steps necessary are time consuming and can be hard to justify when resources are tight. Structured and thoughtful programming techniques greatly reduce the time spent testing, but it can never be assumed that a program works without positive verification. There are inevitable conflicts and errors that are only apparent when all of the elements are integrated together. This is especially true in the cases like the hydrologic metrics functionality, where accuracy of the results is difficult to intuit.

10.4.1 Input Test Data

In order to validate the hydrologic functionality, it was necessary to develop a set of previously verified results that could be used for comparison. A decision was made to use the results produced by NATional Hydrologic Assessment Tool (NATHAT) as the list of expected results for the bulk of the metrics. This decision was supported by documentation from the USGS that includes a detailed discussion of the NATHAT testing processes and results. NATHAT was tested using data from USGS gage 01396500 (South Branch Raritan River in New Jersey) for the period 10/01/1949 through 9/30/1985. For the GeoTools metrics that are not produced by NATHAT, an Excel spreadsheet was used to calculate a list of expected results for the same test data.

10.4.2 Comparing Expected and Calculated Results

Metrics were calculated using both GeoTools and NATHAT for the gage and time period specified. Of the **86** metrics produced in common between the two programs, **44** of them match exactly. Of the remaining **42** metrics, **15** are coefficient of variation metrics that differ by a multiplier of 100 and **6** are normalized by drainage area in GeoTools. This verifies **65** of the common metrics. The remaining **21** required some investigation.

Some discrepancy is to be expected between the two programs. NATHAT uses a peak discharge flow file to calculate recurrence intervals and as such calculates a $Q_{1.67}$ of **1,752 cfs**. GeoTools, which bases its recurrence-interval calculations on a single, daily-averaged flow file, calculates a $Q_{1.67}$ of **1,170 cfs**. This difference affects the number of floods per year calculated by each program and accounts for the discrepancy in FH11.

A potential error was discovered in the way NATHAT handles rolling time periods. As mentioned earlier, the presence of leap years adds complexity to the associated logic. For example, the period between February 27th and March 4th is normally 6 days, except in leap years where the presence of February 29th makes it 7 days. It appears that NATHAT does not handle this correctly which results in a slight error in time-period calculations. While the effect is pervasive, it is most notable in DH2-DH5, DH7-DH13, and ML17.

Handling Julian dates can be problematic. TH1 and TL2 represent the average dates of the maximum and minimum flow, respectively. The technique of considering days 1 through 366 as points around a unit circle and averaging the X and Y coordinate values is the same in both programs. At first glance, the reported results from GeoTools and NATHAT are markedly different. Closer examination reveals that the difference is merely formatting. The GeoTools results are in the Water Year format, as specified by the user, and the NATHAT results are in the Calendar Year format. With this in mind, both programs calculate metric TH1 as March 3rd (CY-62, WY-155) and TL1 as September 18th (CY-262, WY-354). The corresponding discrepancies with the coefficient of variation metrics, TH2 and TL2, are more difficult to explain. The nature of these metrics is, in the opinion of the author, of questionable inherent value. Computing the coefficient of variation of the X and Y coordinates and translating the results into a Julian date does not correlate to a meaningful value. For any given series of Julian dates, the X and Y coordinate values are related by the trigonomic functions COS and SIN. As the dates are shifted around the unit circle, the variation of the X and Y values change. Resolving the X and Y variations back into a Julian date, via the ARCTAN relationship, can result in vastly different results for the same spread of dates. Comparing the results of two different formats is, therefore, meaningless. While GeoTools calculates TH2 to be 122 (January 30), the NATHAT result is 62 (March 2). The specifics of the GeoTools function have been checked thoroughly and are consistent with the definition of the metric.

The final **5** common metric discrepancies cannot be definitively explained because of the inaccessibility of NATHAT's inner workings. Colwell's Predictor, TA2, only differs by 0.15% and is most likely the result of how leap years are handled between the two programs. DL17, TH3, MA44, and ML18 all match hand calculations for the expected results and are consistent with the NATHAT metric definitions. Additionally, GeoTools produces **20** metrics that are not available in any other program. Verification of these results was done by working the results individually with the help of a spreadsheet. In all cases, GeoTools matched the expected results. This may also serve as a base line for testing future development of GeoTools.

10.5 Program Limitations

While the specific algorithms in GeoTools have been sufficiently tested, a list of limitations should be kept in mind when using the program:

(1) The integrity of input flow data should be verified before use. Incomplete years, missing or invalid flow values (*i.e.*, 'ICE' values) will have unpredictable results on the calculations.

(2) As much of the flow data reside in RAM memory, excessively large files may slow processing times.

(3) Metrics will be calculated for the entire record in the flow file. This is especially relevant when using the Effective Discharge functionality. The years selected for Effective Discharge will not translate to the metric functionality. Different input files should be used for different time periods.

(4) The Batch Processing functionality works as described and can be useful in generating large amounts of data. However, in order to avoid potential problems with memory and other associated computer resource problems, batches should be kept to a reasonable number of files, around 50. Users are encouraged to experiment with this number as it is very situation dependant.

CHAPTER 11
COMMON ERRORS

The most frequent GeoTools error reported to date, is a missing add-in or reference library in the user's Visual Basic for Application installation. The following files are necessary for proper GeoTools execution:

(1) Visual Basic For Applications,

(2) Microsoft® Excel 9.0 Object Library,

(3) OLE Automation,

(4) Microsoft® Office 9.0 Object Library,

(5) Microsoft® Forms 2.0 Object Library, and

(6) Solver.

The Analysis ToolPack, Analysis Toolpack-VBA, and Solver Add-Ins should be installed under the Excel → Tools → Add-Ins tool bar. Additional errors may be generated during code execution if all available service packs from Microsoft® have not been installed for the user's version of Excel.

These files should be checked in the Visual Basic for Applications editor under the "Tools/References" menu. If any of these files are listed as "MISSING" it will cause a run-time error in GeoTools. **To fix this error uncheck the "MISSING" and try to install the missing reference.**

There are a number of variations on SWMM programs as well as HSPF programs and, therefore, there will be circumstances for which an input file may generate an error in GeoTools. The input conditions for these types of files are very specific to a format expected. In this event, please contact David Raff at raff@daraff.net with specific information about the version of the program used to generate the input file and send this information along with the input file to the e-mail address above. Another option is to convert your SWMM or HSPF file into a GeoTools default file.

In the event that an error occurs during operation of GeoTools and it is not addressed within this user's manual, please contact David Raff at raff@daraff.net or Brian Bledsoe at Brian.Bledsoe@ColoState.edu. Please include as much information as possible in your message in addition to the "log.out" file, which GeoTools creates in your base directory. For Windows users, the base directory is most likely your "My Documents" folder unless you have changed the default settings.

CHAPTER 12
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