DESIGN FLOOD ESTIMATION TOOL
USER MANUAL VERSION 1.4

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FLOOD HYDROLOGY COURSE

Institute for Water and Environmental Engineering

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LIST OF ABBREVIATIONS

AMS	Annual Maximum Series
ARF	Areal Reduction Factor
ARM	Alternative Rational Method
CAPA	Catchment Parameter method
CN	Curve Number
DDF	Depth-duration-frequency
DEM	Digital Elevation Model
DFET	Design Flood Estimation Tool
DWA	Department of Water Affairs
EV1	Extreme Value Type 1
EV2	Extreme Value Type 2
EV3	Extreme Value Type 3
GEV	General Extreme Value
GIS	Geographical Information System
HRU	Hydrological Research Unit
LEV1	Log-Extreme Value 1
LM	Linear Moments
LN	Log-Normal
LP3	Log-Pearson Type III
LRH	Lag-routed Hydrograph
MAF	Mean Annual Flood
MAP	Mean Annual Precipitation
MIPI	Midgley and Pitman method
MM	Mean Moments
MS-Excel	Microsoft Office Excel
MS-VBA	Microsoft Office Visual Basic for Applications
PDS	Partial Duration Series
RLMA	Regional Linear Moment Algorithm
RLMA&SI	Regional Linear Moment Algorithm and Scale Invariance
RM	Rational Method
RMF	Regional Maximum Flood
SANRAL	South African National Roads Agency Limited
SAWS	South African Weather Services
SCS	Soil Conservation Services
SDF	Standard Design Flood
SUH	Synthetic Unit Hydrograph
TR	Technical Report

1. OPERATIONAL INSTRUCTIONS

A computer program with a graphical user interface, known as the Design Flood Estimation Tool (DFET) Version 1.4, has been developed and programmed by using Microsoft Office Visual Basic for Applications (MS-VBA) with Microsoft Office Excel 2007 as the operating environment. The DFET contains the latest design rainfall information and recognised design flood estimation methods used in South African flood hydrology.

Disclaimer:

Although every effort has been made as to the accuracy and applicability contained in this software and supporting databases, the Stellenbosch University and the developer cannot accept any legal responsibility or liability for any errors or omissions or for any other reason whatsoever.

The objective of the first section in this user manual is to assist users with the installation and running of the software. The sections thereafter present the application guidelines and instructions.

1.1 Minimum System Requirements

The minimum system requirements on a computer running the Windows operating system are:

(a) 512 Mb of RAM;

(b) 150 Mb Hard Disk capacity;

(c) Windows 2000/2000XP or more recent Windows operating system; and

(d) Microsoft Office 2007 or more recent versions.

<u>Note:</u>

- **The DFET is not compatible with Microsoft Office 2003 products.**
- **The unprotected, light-green shaded cells in each worksheet are used as the primary input cells and must contain no information before commencing with a new example. Thus, any information entered in previous application files/examples must be deleted.**

1.2 Installation of Software

The software may be installed from the CD which accompanies this report. The following files are contained on the CD:

(a) DFET Version 1-4.xlsm (MS-Excel Macro-enabled worksheet);
(b) DFET User Manual 1-4.pdf (Adobe Acrobat 9.0 document); and
(c) RLMA-SAWS Design Rainfall.pdf (Adobe Acrobat 9.0 document);

It is suggested that these files be saved in the *C:\Design Flood*\directory, as the instructions in this manual will assume that the files are at that location. However, any user-defined directory can be used, and the relevant path will need to be substituted in these instructions.

1.3 Running of Software

Once these files are saved in the applicable directory, the DFET can be executed by running MS-Excel 2007 from Start\Programs\Microsoft Office\Microsoft Office Excel 2007 or by double-clicking the MS-Excel 2007 icon on the desktop.

Make use of the following steps:

(a) In MS-Excel 2007 click on the  button and select open and browse to the relevant directory and DFET Version 1-4.xlsm file.
(b) Once the file is opened, a *Security Warning* (Macros have been disabled) will be displayed.
(c) Click on the *Options* button, after which the window displayed in Figure 1 will appear.
(d) Select the option button next to *Enable this content*.
(e) Click OK.
(f) Save the DFET Version 1-4.xlsm file by making use of *Save As* and rename the file as desired. This must be done in order to retain the original template file in the *C:\Design Flood*\directory.

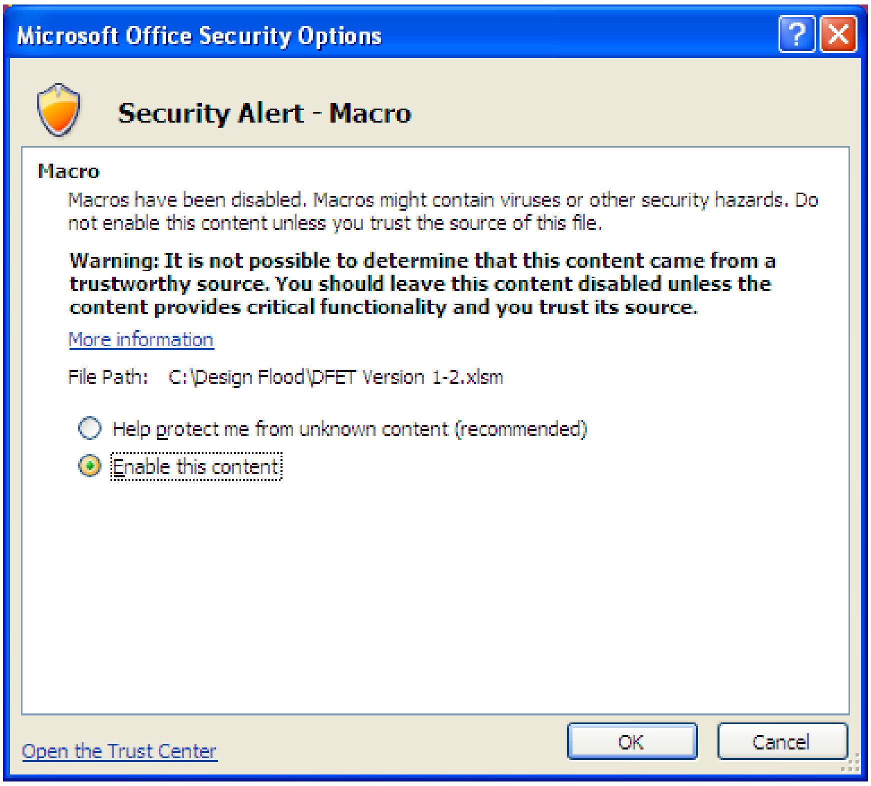


Figure 1: Microsoft Office Security Options

2. APPLICATION GUIDELINES AND INSTRUCTIONS

2.1 HOME Page

The HOME page enables the user to examine and view the contents of the relevant databases and design tables, design flood estimation methods, GIS-based maps and graphical plots contained in the various worksheets. It also serves as the primary worksheet with *click buttons* which activate macros to direct or redirect the user to any required worksheet. Figure 2 is illustrative of the HOME page as contained in the DFET, while the schematic layout of the DFET is shown in Figure 3.

2.1.1 Database and design tables

This group of 15 *click buttons* either enable the user to view, examine, edit and update the applicable worksheets or only view the content thereof. The *Catchment Information, Design Rainfall*, *SUH S-curve Lag*, *Raw Flow Data*, *Annual Maximum* and *Partial Duration Series* and *Probabilistic Plotting* worksheets are available for editing and updating, while the remaining eight worksheets are for viewing purposes only.

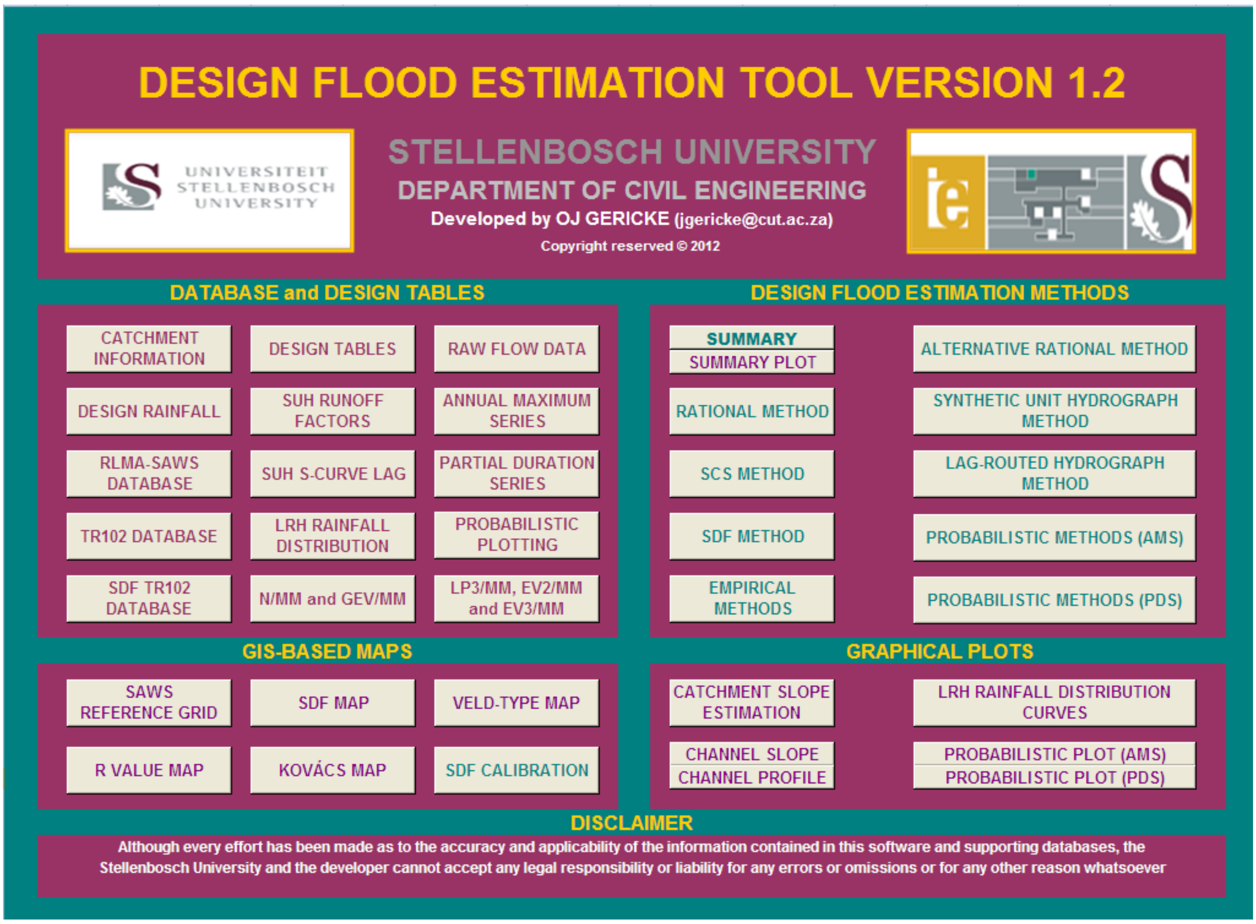


Figure 2: DFET HOME page

2.1.2 Design flood estimation methods

Nine *click buttons* in this group give the user access to the deterministic, empirical and probabilistic methods used in South Africa to estimate the design flood. The editing and updating of all these worksheets are allowed, although the user input is restricted to the light-green shaded, unprotected cells. The SUMMARY and SUMMARY PLOT buttons enable the user to view and examine the design flood estimation results summarised in both a tabular and graphical format.

2.1.3 Graphical plots

This group of six *click buttons* enable the user to view, examine, edit and update the graphical plot results as obtained from the catchment information entries and design flood estimation methods listed in Figure 3. It also allows the user to view the rainfall distribution curves of the Lag-routed hydrograph (LRH) method.

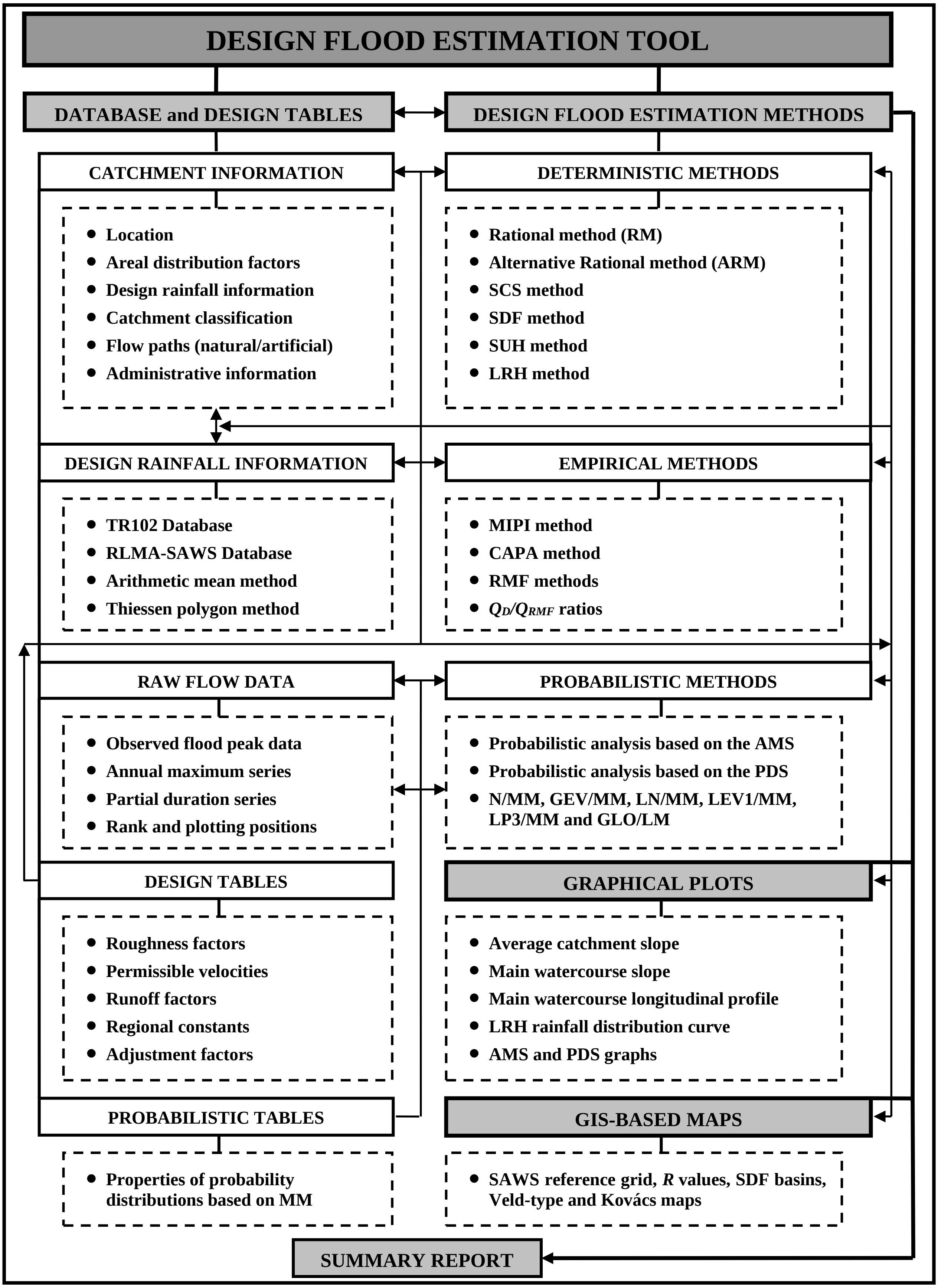


Figure 3: Schematic layout of the DFET

2.1.4 GIS-based maps

This group of five *click buttons* enable the user to view all the standard Geographical Information System (GIS)-based maps, inclusive of the *SAWS Reference Grid, R Value, SDF, Kovács* and *Veld-type* maps.

The **SDF CALIBRATION** button enables the user to have a glimpse at the procedures followed by Gericke (2010) to evaluate, calibrate en verify the original SDF method.

2.2 Catchment Information

The layout of the *Catchment Information* worksheet is displayed in Figure 4.

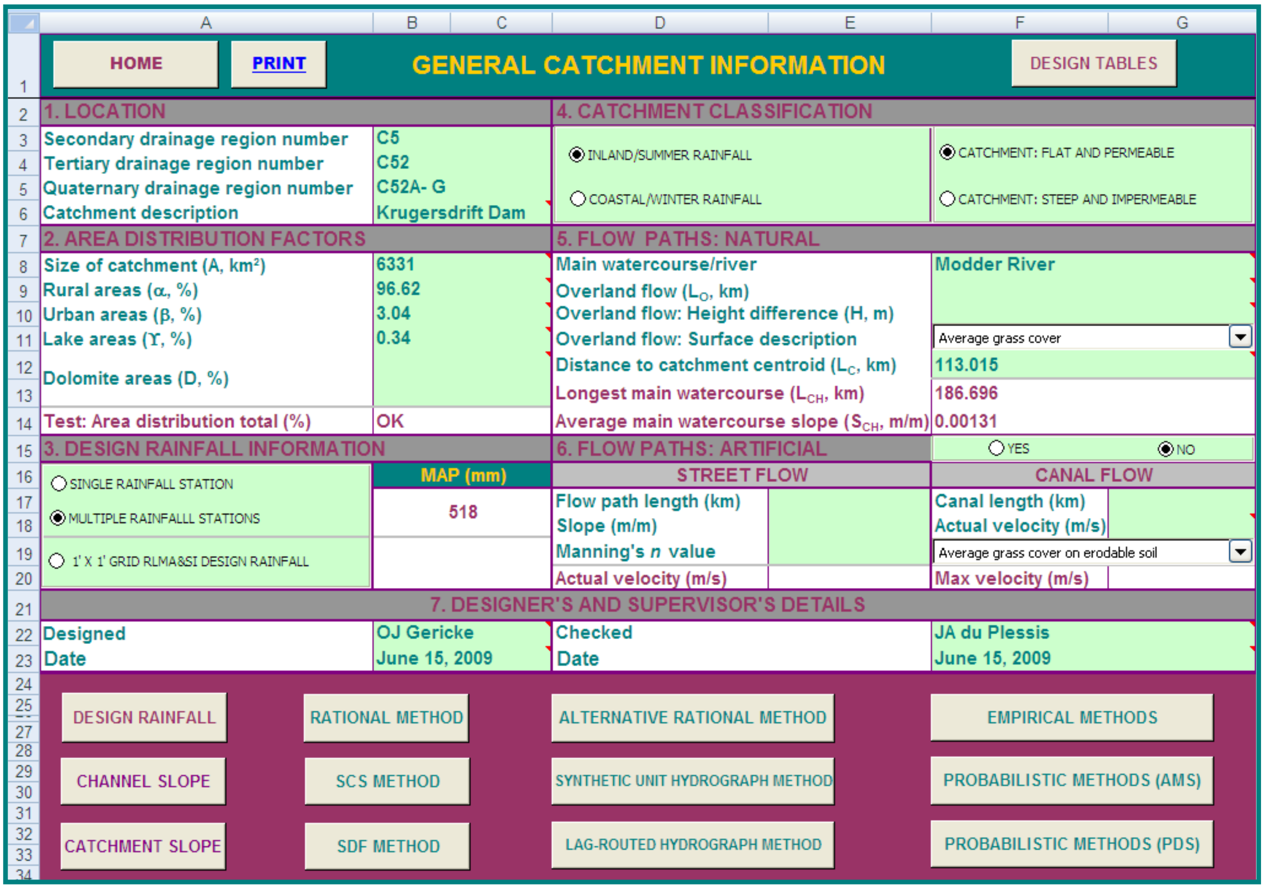


Figure 4: *Catchment Information* worksheet

2.2.1 Pre-requisite input and linked worksheets

The *Design Rainfall* and *Channel slope* worksheets must be completed to provide the MAP, length and average slope of the main watercourse listed under *Catchment Information*; however, it is not a pre-requisite. The *Catchment Information* worksheet is linked to several other worksheets (*c.f.* Figure 4), since it serves as input to these worksheets.

2.2.2 Input ranges and comments

Input range identifier:

Single cell or cell range entries (light-green shaded and unprotected), option buttons and group boxes (drop-down lists with multiple options). Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Location:

Cell B3: Enter the secondary drainage region number consisting of a descriptive letter and numerical value, *e.g.* C5.

Cell B4: Enter the tertiary drainage region number consisting of a descriptive letter and numerical values, *e.g.* C52.

Cell B5: Enter the quaternary drainage region number consisting of descriptive letters and numerical values, *e.g.* C52A.

Cell B6: Compulsory.
Enter the catchment description/name, *e.g.* Krugersdrift Dam.

Area distribution factors:

Cell B8: Compulsory.
Enter the catchment area (km^2).

Cell B9: Compulsory, if applicable.
Indicate the %-rural areas in catchment.

Cell B10: Compulsory, if applicable.
Indicate the %-urban areas in catchment.

Cell B11: Compulsory, if applicable.
Indicate the %-lake areas in catchment.

Cell B12: Compulsory, if applicable.
Indicate the %-dolomite areas in catchment.

Design rainfall information:

Select the appropriate option button contained in the design rainfall group box by indicating either whether a single or multiple rainfall stations will be used. The MAP (mm) in *cell B17* will only be listed if the *Design Rainfall* worksheet is complete. The MAP and design rainfall depth estimations could be based on either the TR102 (Adamson, 1981) or RLMA-SAWS (Smithers and Schulze, 2000a; 2000b) design rainfall information.

Alternatively, the 1' x 1'Grid RLMA&SI design rainfall depths could be selected. These design rainfall depths are based on the output generated by the software program, *Design Rainfall Estimation in South Africa* as developed by Smithers and Schulze (2003). The MAP will then be listed in *cell B19*, but this is also reliant on the pre-requisite completion of the *Design Rainfall* worksheet.

Catchment classification:

Two group boxes, *e.g.* rainfall regions and catchment description must be completed. In the rainfall regions, select the appropriate option by indicating either whether the region can be classified as an "inland/summer rainfall" or a "coastal/winter rainfall" region. In catchment description, select the appropriate option by indicating either whether the catchment can be classified as "flat and permeable" or "steep and impermeable." The selections made here will have an influence on the return period adjustment factors (F_T) used in both the Rational method (RM) and alternative Rational method (ARM).

Flow paths: Natural:

Cell F8: Compulsory.
Enter the main watercourse/river name, *e.g.* Modder River.

Cell F9: Compulsory, if applicable.
Enter the distance of overland flow (km).

Cell F10: Compulsory, if *cell F9* was completed.
Enter the height difference (m) along the overland flow path.

Cell F11: Select the appropriate overland flow surface description from the group box (drop-down list, 14 options available).

Cell F12: Compulsory, if the Synthetic unit hydrograph (SUH), LRH and empirical methods are to be used. Enter the distance to the catchment centroid (km), normally between 0.5 - 0.6 times the longest watercourse length.

Flow paths*:* Artificial:

Select the appropriate option button contained in the artificial flow path group box by indicating either "Yes" or "No." If "Yes" is selected, then complete *cell ranges E17:E19* and *G17:G18*, otherwise these cells can be left blank. The artificial flow path could consist of either street or canal flow or a combination thereof. The applicable cell ranges must be completed accordingly. The following applies:

Cell E17: Enter the length of the street flow path (km), if applicable.

Cell E18: Enter the slope of the street flow path (m/m), if *cell E17* was completed.

Cell E19: Enter a Manning's *n* value, if *cell range E17:E18* was completed.

Cell G17: Enter the canal flow path length (km), if applicable.

Cell G18: Enter the design/actual velocity if different from the maximum velocity indicated in *cell G20*. Manning's or Chézy's equation for open-channel flow can be used.

Cell G19: Select the appropriate canal lining material description from the group box (drop-down list, 16 options available) to establish the maximum allowable velocity in *cell G20*.

Designer's and supervisor's details:

Cell B22: Enter the details of the person responsible for the design.

Cell B23: Enter the design date (month, day, year), *e.g.* June 15, 2009.

Cell F22: Enter the details of the person responsible for the supervision.

Cell F23: Enter the approval date.

2.2.3 Calculation procedure

Area distribution factors:

Cell B14: Calculate the sum of *cell range B9:B11*. If # 100%, a "%-Error" message will appear. Revisit the input values.

Design rainfall information:

Cell B17: Input from linked worksheet, *Design Rainfall*.

Cell B19: Input from linked worksheet, *Design Rainfall*.

Flow paths: Natural:

Cell F13: Input from linked worksheet, *Channel Slope*.

Cell F14: Input from linked worksheet, *Channel Slope*.

Flow paths: Artificial:

Cell E20: The actual velocity is based on Manning's equation (Equation 1) for street flow incorporating a cross-slope of 2%.

Cell G20: Maximum allowable velocity based on the canal lining material selected from the drop-down list in *cell G19*.

$$v = \frac{1}{n}\left(\frac{0.1225}{3.57}\right)^{\frac{2}{3}} S^{\frac{1}{2}} \quad (1)$$

where:

v = actual velocity [m/s],

n = Manning's n value, and

S = longitudinal slope [m/m].

2.3 Design Rainfall

Two design rainfall databases are included in the DFET containing the design rainfall information based on the methodologies followed by Adamson (1981) and Smithers and Schulze (2000a; 2000b). These databases are collectively referred to as the TR102 (Adamson, 1981) and Regional Linear Moment Algorithm South African Weather Services *n*-day (RLMA-SAWS) (Smithers and Schulze, 2000a; 2000b) design point rainfall databases. The following pertaining these databases are of importance:

- **TR102:** The 1, 2, 3 and 7-day extreme design rainfall depths for return periods of 2, 5, 10, 20, 50, 100 and 200 years were estimated by Adamson (1981) using approximately 1 946 rainfall stations. A censored Log-Normal (LN) distribution based on the partial duration series (PDS) was used to estimate the design rainfall depths at a single site. Despite the fact that this database was last updated in 1981, it was still included in the DFET, since the recognised design rainfall estimation procedures used in both the ARM and Standard design flood (SDF) method require input from this particular database.
- **RLMA-SAWS:** Smithers and Schulze (2000b) conducted frequency analyses based on the General Extreme Value (GEV) probability distribution, at 1 789 rainfall stations with at least 40 years of record, to estimate the 1-day design rainfall values in South Africa. This was followed by a regionalisation process (based on Linear Moment (LM) estimators) and establishment of 78 relatively homogeneous rainfall regions and associated index values derived from at-site data. Quantile growth curves, representative of the ratio between design rainfall depth and an index storm to return period, were developed for each of the homogeneous rainfall regions and storm durations of 1 to 7 days. These regionalised growth curves and at-site index values were then used to estimate design rainfall depths at 3 946 rainfall stations in South Africa.

2.3.1 Pre-requisite input and linked worksheets

The *Catchment Information* worksheet is pre-requisite input for this worksheet. The *Design Rainfall* worksheet is linked to the *Catchment Information* worksheet and also serves as the primary input for all the deterministic and empirical flood estimation methods.

2.3.2 Input ranges and comments

The following three options are available to estimate average/catchment rainfall:

(a) RLMA-SAWS design rainfall depths based on either the arithmetic mean or Thiessen polygon methods.

(b) TR102 design rainfall depths based on either the arithmetic mean or Thiessen polygon methods.

(c) 1’ x 1’ Grid RLMA&SI design rainfall depths based on the output generated by the software program, *Design Rainfall Estimation in South Africa*.

Only one option can be selected at a time.

Input range identifier:

Single cell or cell range entries (light-green shaded and unprotected), option buttons and check boxes. In both these databases, the SAWS rainfall station numbers are used as the primary identifier. In other words, by entering the station numbers manually or by importing those from a database file in ArcGIS^{TM}, all the details (*e.g*. number, name, MAP, and design rainfall depths) become available. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

RLMA-SAWS/TR102 design rainfall information:

The procedure to follow will depend on whether or not a user-defined MAP value is specified or whether or not the user want to use a selection of rainfall stations in the catchment under consideration. The user-defined MAP value (which is associated with the selection of the ‘*Single rainfall station*” option button contained in the *Catchment Information* worksheet) must be entered in *cell C41* if the first option is applicable. This MAP value overwrites any other estimated MAP value. Alternatively, *cell C41* could be left empty to ensure that the MAP will be based on the selected single rainfall station’s design rainfall information.

The following procedure is relevant to the second option in cases where the user still has to identify the SAWS rainfall stations within/nearby the catchment boundary:

Click on the **SAWS REFERENCE GRID** button to view the SAWS rainfall station reference grid map (Figure 5) in order to establish in which grid the catchment under consideration is situated. The grid reference, *e.g.* 262, contains all the rainfall stations with numbering starting with 0262??? This 7-digit number will either be followed by an A, B, P, S or W, depending on which institution/company is responsible for the station.

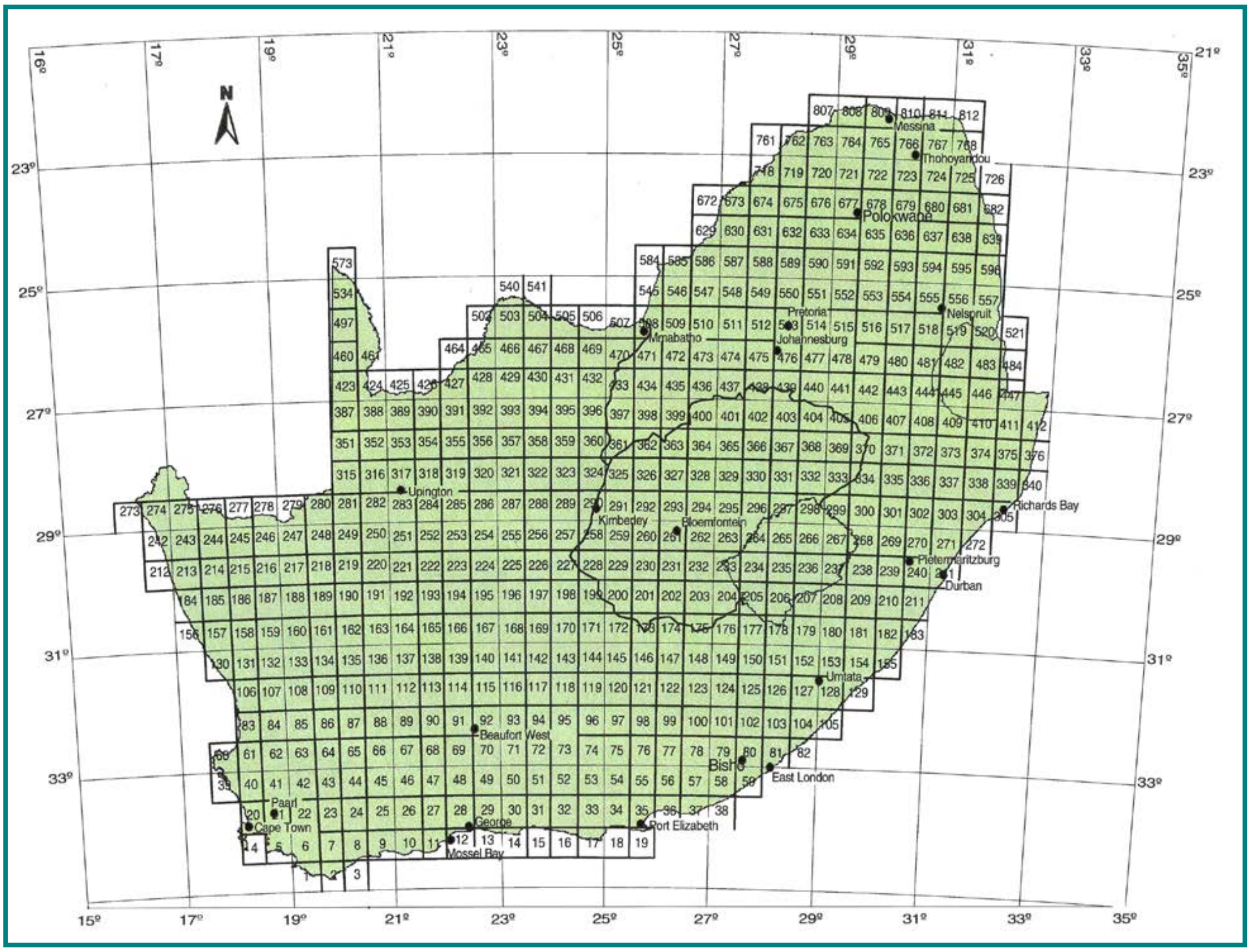


Figure 5: SAWS reference grid map (SANRAL, 2006)

Click on the **DESIGN RAINFALL** button to return to the *Design Rainfall* worksheet.

Click on either the **RLMA-SAWS DATABASE** **TR102 DATABASE** s to view the rainfall stations numbered in an ascending order and their associated design rainfall depths. The station numbers can be individually copied to the *Design Rainfall* worksheet (refer to instructions below, *cell A71*) or a customised data file/sheet can be populated for later use. Alternatively, if the GIS-based information of the rainfall stations is available, the relevant database file (.dbf) can be accessed in MS-Excel, highlighted and copied to the *Design Rainfall* worksheet (refer to instructions below, *cell A71*).

Cell A71: Click and hold the mouse cursor in position. The following comment box with instructions will appear on screen:

CLICK ON THE RLMA-SAWS/TR102 DATABASE BUTTON TO ACCESS THE APPLICABLE DATABASE.

THE SAWS STATION NUMBERS OF UP TO 200 RAINFALL STATIONS WITHIN/NEARBY THE CATCHMENT BOUNDARY CAN BE ENTERED IN CELL RANGE A58: A157 & G58: G157, IF APPLICABLE.

THE SAWS STATION NUMBER MUST BE A 7-DIGIT NUMBER FOLLOWED EITHER BY AN A, B, P, S OR W.

THE CHECK BOXES "Outside catchment", CELL RANGE C58: C157 & G58: G157 MUST BE SELECTED IN CASES WHERE THE THIESSEN POLYGON METHOD IS BASED ON STATIONS OUTSIDE THE CATCHMENT BOUNDARY. THESE SELECTIONS WILL ALSO HAVE AN INFLUENCE ON THE ARITHMETIC MEAN METHOD, SINCE THIS METHOD CONSIDERS ONLY THE STATIONS WITHIN THE CATCHMENT BOUNDARY.

ENTER THE THIESSEN POLYGON AREAS IN CELL RANGE D58: D157 & I58: I157, IF THE THIESSEN POLYGON METHOD IS TO BE CONSIDERED.

IN ALL CASES, USE COPY & PASTE VALUES FOR MULTIPLE ENTRIES.

Figure 6 is illustrative of the data entries based on the instructions listed in the above-mentioned comment box. On completion of the above-listed instructions, the user can view the results from both the RLMA-SAWS and TR102 database.

	A–B	C	D	E	F	G	H–I	J
1	HOME	CATCHMENT INFORMATION	PRINT 1	DESIGN RAINFALL	PRINT 2		RLMA-SAWS DATABASE	TR102 DATABASE
2	Secondary drainage region number		C5		Main watercourse/river		Modder River	
3	Tertiary drainage region number		C52		Designed		OJ Gericke	
4	Quaternary drainage region number		C52A- G		Checked		JA du Plessis	
5	Catchment description		Krugersdrift Dam		Date		June 15, 2009	

	SELECTION OF DAILY SAWS RAINFALL STATIONS (RLMA-SAWS/TR102)							
72	Number	Station number	Area (km²)	Station name	Number	Station number	Area (km²)	Station name
73	1	0232123W ☐ Outside catchment	118.728	ROODEPOORT	101	☐ Outside catchment		
74	2	0232181W ☐ Outside catchment	100.857	ROODEPOORT	102	☐ Outside catchment		
75	3	0232211W ☐ Outside catchment	40.136	NIEUWEJAARSFONTEIN	103	☐ Outside catchment		
76	4	0232275W ☐ Outside catchment	86.589	DEWETSDORP (Police)	104	☐ Outside catchment		
77	5	0232301W ☐ Outside catchment	74.032	KILDARE	105	☐ Outside catchment		
78	6	0232512W ☐ Outside catchment	98.538	THORLEY	106	☐ Outside catchment		
79	7	0261307W ☐ Outside catchment	20.406	BLOEMFONTEIN	107	☐ Outside catchment		
80	8	0261365W ☐ Outside catchment	60.038	BLOEMFONTEIN (BAYSWATER)	108	☐ Outside catchment		
81	9	0261366W ☐ Outside catchment	7.003	BLOEMFONTEIN (ARBORETUM)	109	☐ Outside catchment		
82	10	0261367W ☐ Outside catchment	6.978	BLOEMFONTEIN (ST. MICHAEL'S)	110	☐ Outside catchment		
83	11	0261368W ☐ Outside catchment	10.861	BLOEMFONTEIN (KING'S PARK)	111	☐ Outside catchment		
84	12	0261369W ☐ Outside catchment	39.344	BLOEMFONTEIN (HAMILTON)	112	☐ Outside catchment		
85	13	0261425W ☐ Outside catchment	45.539	BLOEMFONTEIN (WAVERLEY)	113	☐ Outside catchment		
86	14	0261426W ☐ Outside catchment	14.995	BLOEMFONTEIN (ESTIORE)	114	☐ Outside catchment		
87	15	0261516W ☐ Outside catchment	55.974	BLOEMFONTEIN (ESTIORE)	115	☐ Outside catchment		

Figure 6: Example of the SAWS daily rainfall station selection and entries

The averaged MAP, design rainfall depths associated with different return periods and number of thunder days per year are contained in *cell range A6:I39* and illustrated in Figure 7.

HOME | CATCHMENT INFORMATION | PRINT 1 | **DESIGN RAINFALL** | PRINT 2 | RLMA-SAWS DATABASE | TR102 DATABASE

Secondary drainage region number	C5	Main watercourse/river	Modder River
Tertiary drainage region number	C52	Designed	OJ Gericke
Quaternary drainage region number	C52A- G	Checked	JA du Plessis
Catchment description	Krugersdrift Dam	Date	June 15, 2009

SAWS REFERENCE GRID

RLMA-SAWS DAILY DESIGN RAINFALL INFORMATION

ARITHMETIC MEAN METHOD

Average MAP (mm): 530.2 — Average number of thunder days/year (R): 61.8

Duration (days)	Design rainfall depth (P_T, mm) and associated return period (T, years)						
	2	5	10	20	50	100	200
1	48.7	65.8	77.9	90.0	106.5	119.5	133.1
2	61.6	82.9	97.8	112.7	133.0	148.9	165.4
3	68.6	92.0	108.0	123.9	145.2	161.7	178.5
7	86.2	116.0	136.3	156.2	182.7	203.1	223.8

THIESSEN POLYGON METHOD

Average MAP (mm): 518.5 — Average number of thunder days/year (R): 62.3

Duration (days)	Design rainfall depth (P_T, mm) and associated return period (T, years)						
	2	5	10	20	50	100	200
1	48.5	65.5	77.5	89.6	106.0	119.0	132.5
2	61.2	82.3	97.1	112.0	132.1	147.9	164.4
3	68.0	91.2	107.2	122.9	144.0	160.4	177.1
7	85.9	115.7	135.9	155.8	182.2	202.5	223.2

TR102 DAILY DESIGN RAINFALL INFORMATION

ARITHMETIC MEAN METHOD

Average MAP (mm): 522.5 — Average number of thunder days/year (R): 61.7

Duration (days)	Design rainfall depth (P_T, mm) and associated return period (T, years)						
	2	5	10	20	50	100	200
1	49.0	67.7	77.8	97.3	119.8	138.6	159.6
2	61.1	84.9	102.7	121.8	149.7	172.8	198.0
3	67.9	94.5	114.7	136.3	167.7	193.0	222.6
7	85.2	121.4	148.6	175.2	218.9	253.3	287.4

THIESSEN POLYGON METHOD

Average MAP (mm): 511.2 — Average number of thunder days/year (R): 62.1

Duration (days)	Design rainfall depth (P_T, mm) and associated return period (T, years)						
	2	5	10	20	50	100	200
1	48.7	67.2	77.2	96.3	118.4	136.8	157.5
2	60.6	84.1	101.7	120.3	147.6	170.3	195.0
3	67.3	93.7	113.6	135.0	165.9	190.9	219.8
7	84.3	120.2	147.2	173.6	217.0	251.2	284.9

Figure 7: Example of averaged MAP and design rainfall depths

Based on the results viewed and evaluated in the previous step, the appropriate option buttons contained in the design rainfall results group box (*cell range F68:J70*) must be selected by indicating either whether the RLMA-SAWS or TR102 database will be used and whether the results based on either the Thiessen polygon or Arithmetic mean method must be included. The design rainfall results group box is displayed in Figure 8.

SELECTION OF FINAL DESIGN RAINFALL ESTIMATION RESULTS

PREFERRED DAILY DESIGN RAINFALL DATABASE	◉ RLMA-SAWS DATABASE	○ TR102 DATABASE
PREFERRED AVERAGING METHOD	○ ARITHMETIC MEAN METHOD	◉ THIESSEN POLYGON METHOD
USER-DEFINED AVERAGE NUMBER OF THUNDER DAYS/YEAR (R) — R VALUE MAP		

Figure 8: Design rainfall results group box

In cases where the estimated average number of thunder days per year is deemed as questionable, the user can enter a user-defined *R* value in *cell F70* with the use of the *R* value map (Figure 9). This value overwrites all estimated values.

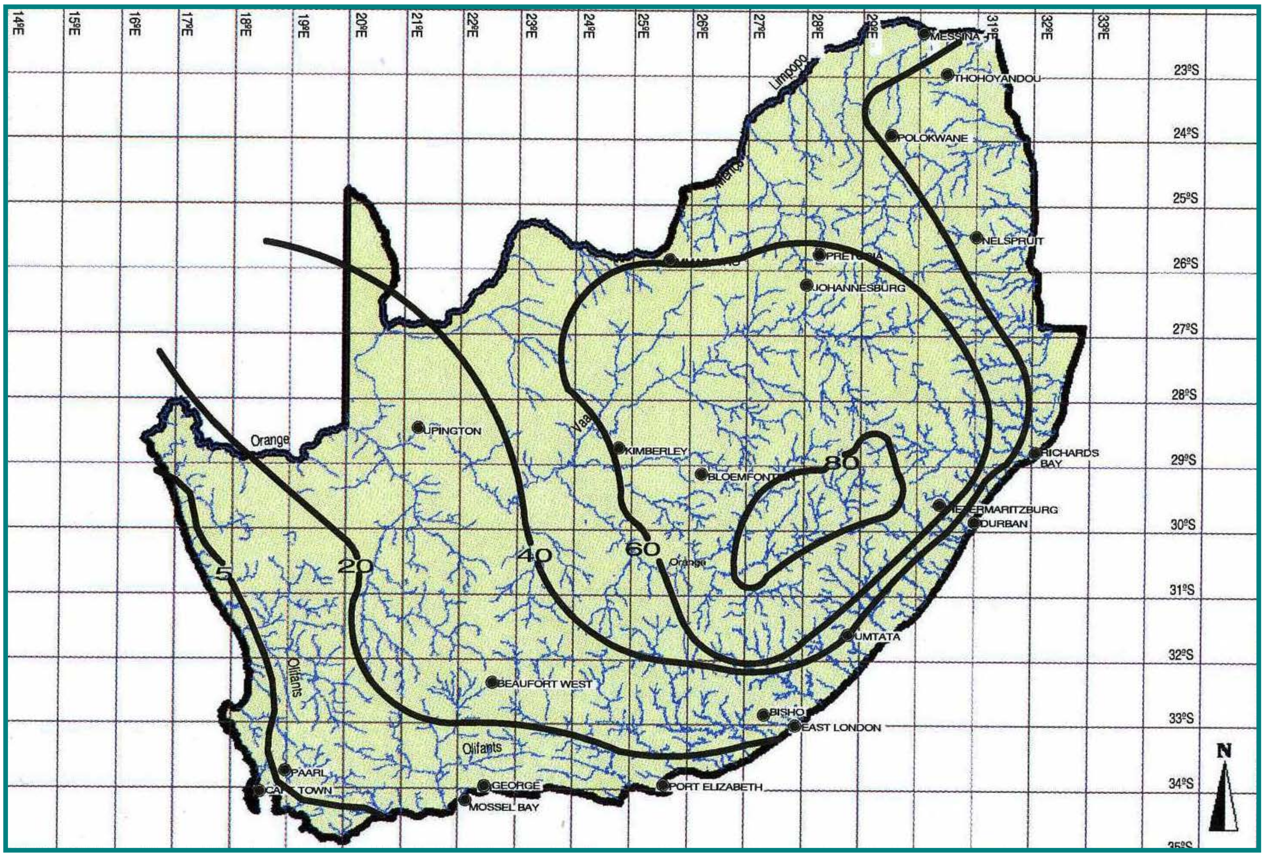


Figure 9: Average number of thunder days per year (SANRAL, 2006)

1' x 1' Grid RLMA&SI design rainfall information:

The following guidelines and/or instructions assume that the output file generated by the software program, *Design Rainfall Estimation in South Africa* is ready for use in the DFET. In other words, the user-defined ASCII output file, which echoes the user selections and lists the design rainfall depths, is converted to a MS-Excel file, of which the averages of the grid-based rainfall estimates associated with durations in excess of the time of concentration, were calculated.

Cell D41: Compulsory, if applicable. By entering this MAP value, all other estimated MAP values are overwritten if the '*1'*1' Grid RLMA&SI design rainfall*" option button contained in the *Catchment Information* worksheet was also selected.

Cell A43: Click and hold the mouse cursor in position. The following comment box with instructions will appear on screen:

SEVEN (7) DESIGN RAINFALL DEPTHS ASSOCIATED WITH EACH RETURN PERIOD AND TWO (2) GROUPED USER-DEFINED STORM DURATIONS OF BETWEEN 0.083 hour (5 minutes) & 168 hours (7 days) CAN BE SELECTED BY ACTIVATING THE CHECK BOXES "10 min, 6 hr & 2 day, etc." IN CELL RANGE A44: B66.

THE SELECTED STORM DURATIONS MUST FOLLOW ONE ANOTHER/ BE GROUPED WITHIN A CONTINUOUS TIME PERIOD. THE TIME OF CONCENTRATION MUST BE WITHIN THE SELECTED TIME PERIOD.

THE CORRESPONDING 24-hour DESIGN RAINFALL DEPTH VALUES MUST ALWAYS BE ENTERED/COPIED TO CELL RANGE C59: I59, SINCE THIS SERVES AS PRIMARY RAINFALL INPUT FOR THE SCS METHOD.

THE CORRESPONDING 1, 2, 3 AND 7 day DESIGN RAINFALL DEPTH VALUES MUST ALWAYS BE ENTERED/COPIED TO CELL RANGE C60: I62 & C66: I66, SINCE THIS SERVES AS PRIMARY RAINFALL INPUT FOR THE ALTERNATIVE RATIONAL METHOD.

IN ALL CASES, USE COPY & PASTE VALUES FOR MULTIPLE ENTRIES.

Cell range

C44:I66: Compulsory, if applicable.

The seven design rainfall depths associated with each return period and selected storm durations must be copied to the relevant cells.

Figure 10 displays the layout of the information screen representative of the 1' x 1'Grid RLMA&SI design rainfall entries.

HOME | CATCHMENT INFORMATION | PRINT 1 | **DESIGN RAINFALL** | PRINT 2 | RLMA-SAWS DATABASE | TR102 DATABASE

Secondary drainage region number	C5	Main watercourse/river	Modder River
Tertiary drainage region number	C52	Designed	OJ Gericke
Quaternary drainage region number	C52A- G	Checked	JA du Plessis
Catchment description	Krugersdrift Dam	Date	June 15, 2009

1' x 1' GRID RLMA&SI DESIGN RAINFALL INFORMATION

User-defined MAP (mm): 550.0 | 520.0 | Grid MAP (mm) | SYNTHETIC UNIT HYDROGRAPH | LAG-ROUTED HYDROGRAPH

Duration (minutes/hours)	1' x 1' Grid design rainfall depth (P_T, mm) and associated return period (T, years)						
	2	5	10	20	50	100	200
☐ 5 MINUTES							
☐ 10 MINUTES							
☐ 15 MINUTES							
☐ 30 MINUTES							
☐ 45 MINUTES							
☐ 1 HOUR							
☐ 1.5 HOURS							
☐ 2 HOURS							
☐ 4 HOURS							
☐ 6 HOURS							
☐ 8 HOURS							
☐ 10 HOURS							
☐ 12 HOURS	36.0	45.0	62.0	74.0	82.0	90.0	104.0
☐ 16 HOURS	38.0	55.0	68.0	76.0	89.0	98.0	112.0
☐ 20 HOURS	40.0	62.0	74.0	78.0	95.0	106.0	122.0
☐ ≤24 HOURS	51.0	76.0	87.0	94.0	120.0	133.0	144.0
☑ ≥1 DAY	46.0	68.0	78.0	85.0	108.0	120.0	130.0
☑ 2 DAYS	54.0	76.0	91.0	105.0	123.0	137.0	152.0
☐ 3 DAYS	65.0	88.0	103.0	118.0	140.0	155.0	172.0
☐ 4 DAYS	68.0	92.0	109.0	127.0	148.0	166.0	184.0
☐ 5 DAYS	70.0	98.0	118.0	138.0	156.0	178.0	192.0
☐ 6 DAYS	75.0	105.0	124.0	145.0	165.0	190.0	205.0
☐ 7 DAYS	82.0	110.0	130.0	150.0	178.0	198.0	218.0

Figure 10: Example of the 1' x 1' Grid RLMA&SI design rainfall entries

2.3.3 Calculation procedure

Arithmetic mean method:

$$\overline{X} = \sum \frac{X_i}{N_i} \tag{2}$$

Thiessen polygon method:

$$\overline{X} = \frac{\sum X_i A_i}{\sum A_i} \tag{3}$$

where:

$\overline{X}$ = averaged MAP [mm], averaged design point rainfall depth [mm] or average number of thunder days/year,

A = area [km²],

N_i = number of rainfall stations within catchment area, and

X_i = MAP [mm], design point rainfall depth [mm] or thunder days/year.

2.4 Average Catchment Slope

The Grid method (Equation 4; Alexander, 2001), Empirical method (Equation 5; Schulze *et al.*, 1992) and Neighbourhood method (ESRI, 2006) can be used in conjunction with standard tools available in the ArcGIS™ environment. The latter method is only used as input to the DFET, since it is the standard ArcGIS™ slope algorithm used to generate slope rasters from raw Digital Elevation Model (DEM) and/or point elevation GIS data sets to enable the determination of average catchment slopes and slope frequency distributions.

2.4.1 Pre-requisite input and linked worksheets

The *Catchment Information* worksheet is a pre-requisite input for this worksheet. The *Catchment Slope* worksheet is linked to all the worksheets containing the deterministic and empirical flood estimation methods.

2.4.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected) and option buttons. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

The layout of the *Catchment Slope* worksheet is displayed in Figure 11.

	A	B	C	D	E	F	G	H	I
1	HOME / PRINT	AVERAGE CATCHMENT SLOPE						CATCHMENT INFORMATION	
2	Secondary drainage region number	C5			Main watercourse/river			Modder River	
3	Tertiary drainage region number	C52			Designed			OJ Gericke	
4	Quaternary drainage region number	C52A- G			Checked			JA du Plessis	
5	Catchment description	Krugersdrift Dam			Date			June 15, 2009	
6	AVERAGE CATCHMENT SLOPE ESTIMATION METHODS								
7	Contour interval (ΔH, m)	20			Map scale (1:X)			50000	
8	Total length of contour lines in catchment (M, m)	10776515.778			Average slope (DEM or user input, m/m)			0.04186	
9	Number of grid points (N)	2220			Average slope (Grid method, m/m)			0.02919	
10	Sum of horizontal distances (m)	1520901.832			Average slope (Empirical method, m/m)			0.03404	
11	PREFERRED ESTIMATION METHOD	DEM or USER INPUT			GRID METHOD			EMPIRICAL METHOD	
12	SLOPE FREQUENCY DISTRIBUTION CLASSES (%) BASED ON THE GRID METHOD								
13	0-3% Slope	40.6%			10-30% Slope			17.4%	
14	3-10% Slope	28.4%			> 30% Slope			13.6%	
15	HORIZONTAL DISTANCES BETWEEN CONSECUTIVE CONTOURS (L_i)				Unit of measurement		METRES	MILLIMETRES	
16	L_i (1)	L_i (2)	L_i (3)	L_i (4)	L_i (5)	L_i (6)	L_i (7)	L_i (8)	L_i (9)
17	455.528	1097.569	716.775	1354.745	495.303	1167.265	103.195	884.918	577.794
18	710.563	832.916	817.544	716.269	1170.613	683.076	214.482	1123.665	398.061
19	759.956	92.130	329.824	314.050	1133.771	362.170	272.185	976.753	818.630
20	432.349	888.657	152.769	283.368	1348.716	176.315	463.034	1186.414	1275.530
21	1021.848	365.607	121.937	2251.562	606.373	409.959	856.379	1558.020	608.861
22	610.638	336.021	1245.117	1466.786	1398.645	737.146	1083.361	1458.320	727.940
23	463.924	519.589	233.786	3376.404	625.470	809.243	338.645	1104.519	1467.619
24	104.574	1226.638	53.150	2723.262	703.148	417.843	989.719	1032.078	271.831
25	86.993	614.254	130.000	2153.730	142.459	727.931	809.438	1881.625	36.218
26	145.849	1956.578	614.358	2100.528	94.406	401.781	979.958	420.372	116.965
27	100.954	976.222	43.782	997.445	74.077	803.645	745.462	295.632	533.646

Figure 11: Example of the *Catchment Slope* worksheet

DEM (user input)/Grid method/Empirical method:

Cell B7: Compulsory, applicable to both the Grid and Empirical methods.

Enter the contour interval in metres as obtained from GIS, orthophotos or topographical maps, *e.g.* 20 m.

Cell B8: Compulsory, if the Empirical method is to be used.

Use ArcGIS^{TM} (Hawth's Analysis Tools) to estimate the total length of all contour lines within a catchment (polygons).

Cell H7: Compulsory, if the Grid method is to be used.

Enter the map scale (1*:* X) as obtained from GIS, orthophotos or topographical maps, *e.g.* 50 000.

Cell H8: Enter the average slope (m/m) as obtained from a DEM in ArcGIS^{TM}.

Cell B11: Based on the values entered and results viewed in the previous steps, the appropriate option button contained in the average slope group box (*cell range B11:I11*) must be selected by indicating either whether the average slope results based on the DEM (user input), Grid method (Alexander, 2001) or Empirical method (Schulze *et al.*, 1992) must be used.

Cell A15: Comment: "A total of 7 506 horizontal distances between consecutive contours can be entered in *cell range A17:I850*, if applicable. In all cases, use *Copy & Paste values* for multiple entries."

Cell E15: Comment*:* "Indicate the unit in which the actual distances between consecutive contours on a map were measured, either in metres or millimetres."

Cell G15: Unit of measurement group box: Select the appropriate option button by indicating either whether the unit of measurement was in "metres" or "millimetres".

Cell range A17:I850: Refer to the comment made in *cell A15*.

2.4.3 Calculation procedure

Grid method (Alexander, 2001):

$$S_1 = \frac{\Delta H}{\sum_{i=1}^{N} \frac{L_i}{N}} \tag{4}$$

Empirical method (Schulze *et al.*, 1992):

$$S_2 = \frac{M \Delta H * 10^{-2}}{A} \tag{5}$$

where:

$S_{1\text{-}2}$ = average catchment slope [m/m],

A = catchment area [km²],

ΔH = contour interval [m],

L_i = horizontal distance between consecutive contours [m],

M = total length of all contour lines within the catchment [m], and

N = number of grid points.

Frequency distribution of grid points:

The results (based on Equation 4) contained in *cells B13, B14, H13 and H14* are representative of the slope frequency distribution of the grid points using the four standard slope classification classes applicable to the RM and ARM, *e.g.* 0 - 3%, 3 - 10%, 10 - 30% and > 30%.

2.5 Average Main Watercourse Slope

The 10-85 method (Equation 6; SANRAL, 2006), Taylor-Schwarz method (Equation 7; Van der Spuy and Rademeyer, 2010) and Equal-area method (Equation 8; Van der Spuy and Rademeyer, 2010), using either manual or GIS-based longitudinal profile information, are available options in the DFET.

2.5.1 Pre-requisite input and linked worksheets

The *Catchment Information* worksheet is a pre-requisite input for this worksheet. The *Channel Slope* worksheet is linked to the *Channel Plot* chart, the *Catchment Information* worksheet and all the worksheets containing the deterministic and empirical flood estimation methods.

2.5.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected) and option buttons. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Longitudinal profile:

Cell B20: Click and hold the mouse cursor in position. The following comment box with instructions will appear on screen:

> A TOTAL OF 150 HORIZONTAL DISTANCES AND REDUCED HEIGHTS REPRESENTATIVE OF THE LONGITUDINAL PROFILE CAN BE ENTERED IN CELL RANGE B22: C171.
>
> IN ALL CASES, USE COPY & PASTE VALUES FOR MULTIPLE ENTRIES.
>
> CLICK ON THE CHANNEL PLOT BUTTON TO ACCESS THE CHANNEL PROFILE CHART.
>
> THE X (HORIZONTAL DISTANCE) AND Y (REDUCED HEIGHT) SCALES OF THE CHANNEL PROFILE CHART MUST BE EDITED ACCORDING TO THE INFORMATION USED IN CELL RANGE B22: C171.
>
> RIGHT-CLICK ON THE RELEVANT SCALE BAR (X- OR Y- AXIS) AND SELECT FORMAT AXIS FOLLOWED BY AXIS OPTIONS.
>
> SET THE MAXIMUM AND MINIMUM VALUES, AS WELL AS THE MAJOR AND MINOR UNITS, IF REQUIRED.
>
> CLICK ON THE CHANNEL SLOPE BUTTON TO RETURN TO THE CHANNEL SLOPE WORKSHEET.

Average catchment slope results:

Cell C19: Based on the values entered and results viewed in the previous steps, the appropriate option button contained in the average slope group box (*cell range C19:J19*) must be selected by indicating either whether the 10-85, Taylor-Schwarz or Equal-area methods must be used.

2.5.3 Calculation procedure

10-85 method (SANRAL, 2006):

$$S_{CH1} = \frac{\left(H_{0.85L_{CH}} - H_{0.10L_{CH}}\right)}{\left(0.75L_{CH}\right)} \tag{6}$$

Taylor-Schwarz method (Van der Spuy and Rademeyer, 2010):

$$S_{CH2} = \left(\frac{L_{CH}}{\sum_{i=1}^{N} \frac{L_i}{\sqrt{S_i}}} \right)^2 \tag{7}$$

Equal-area method (Van der Spuy and Rademeyer, 2010):

$$S_{CH3} = \frac{\left(H_T - H_B\right)}{L_{CH}} \tag{8}$$

where:

S_{CH1-3} = average main watercourse slope [m/m],

$A_i = \left(\frac{H_i + H_{i+1}}{2} - H_B\right)L_i$ [m²],

$H_T = \frac{\left(\sum_{i=1}^{N} A_i * 2\right)}{L_{CH}} + H_B$ [m],

H_B = height at catchment outlet [m],

H_i = specific contour interval height [m],

$H_{0.85L}$ = height of main watercourse at length $0.85L_{CH}$ [m],

$H_{0.10L}$ = height of main watercourse at length $0.10L_{CH}$ [m],

L_{CH} = length of main watercourse [m],

L_i = distance between two consecutive contours [m], and

S_i = slope between two consecutive contours [m/m].

The layout of the *Channel Slope* worksheet is displayed in Figure 12, while a typical longitudinal profile plot example is shown in Figure 13.

HOME | **AVERAGE MAIN WATERCOURSE SLOPE** | CHANNEL PLOT

PRINT

Secondary drainage region number	C5	Main watercourse/river	Modder River
Tertiary drainage region number	C52	Designed	OJ Gericke
Quaternary drainage region number	C52A- G	Checked	JA du Plessis
Catchment description	Krugersdrift Dam	Date	June 15, 2009

AVERAGE MAIN WATERCOURSE SLOPE ESTIMATION METHODS

10-85 method

	Horizontal distance (m)	Height (m)	10-85 Height difference (m)	Average slope (m/m)
10%	18669.604	1243.596	183.491	0.00131
85%	158691.633	1427.087		

Taylor-Schwarz method

	Horizontal distance (m)	Height (m)	Height difference (m)	Average slope (m/m)
Min	0.000	1229.850	211.694	0.00113
Max	186696.039	1441.544		

Equal-area method

	Horizontal distance (m)	Height (m)	Height difference (m)	Average slope (m/m)
Min	0.000	1229.850	190.149	0.00102
Max	186696.039	1419.999		

PREFERRED ESTIMATION METHOD: ◉ 10-85 METHOD ○ TAYLOR-SCHWARZ METHOD ○ EQUAL-AREA METHOD

LONGITUDINAL PROFILE INFORMATION OF MAIN WATERCOURSE

Horizontal distances (m)	Reduced heights (m)	Progressive distances (m)	10%-Height (m)	85%-Height (m)
0.000	1229.850	0.000		
40949.944	1260.000	40949.944	1243.596	
31106.001	1280.000	72055.945		
18655.357	1300.000	90711.302		
15979.525	1320.000	106690.827		
19896.583	1340.000	126587.410		
6516.592	1360.000	133104.002		
11644.911	1380.000	144748.913		
3218.920	1400.000	147967.833		
6919.501	1420.000	154887.334		
10736.110	1440.000	165623.444		1427.087
7358.500	1460.000	172981.944		
5963.350	1480.000	178945.294		
3743.127	1500.000	182688.421		
3089.079	1520.000	185777.500		
918.539	1530.000	186696.039		

Figure 12: Layout of the *Channel Slope* worksheet

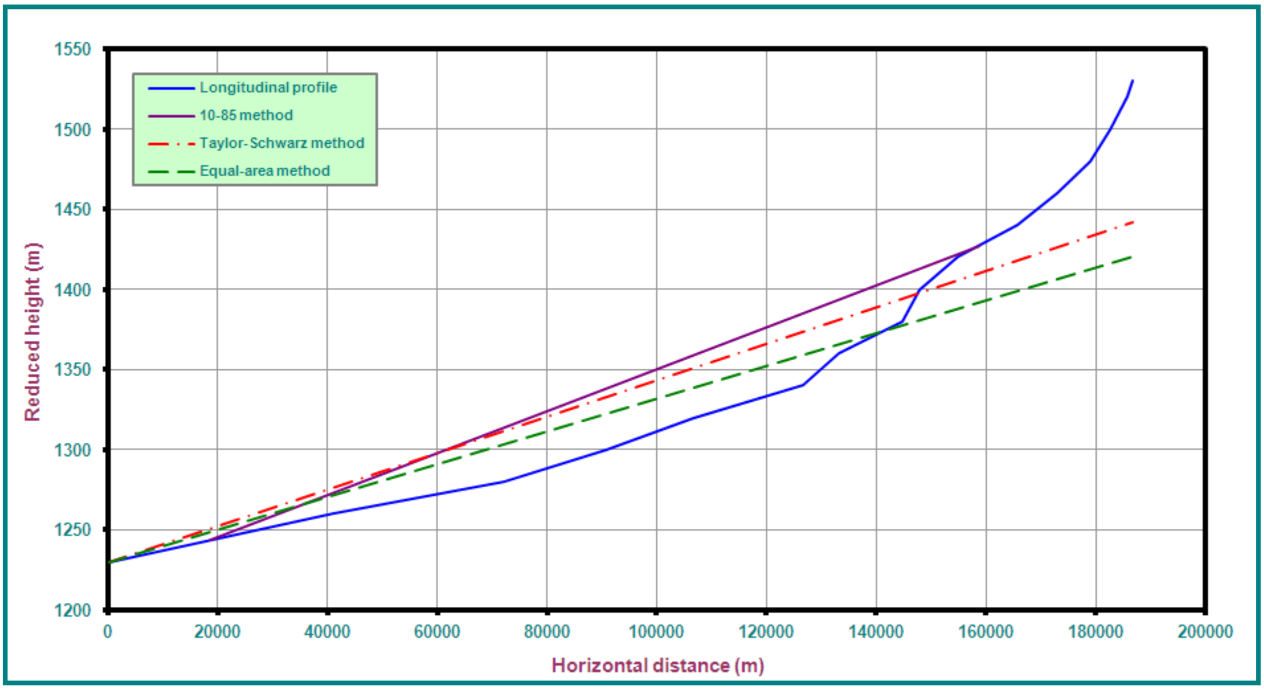


Figure 13: Example of the main watercourse longitudinal profile plot

2.6 Rational Method (RM)

2.6.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Design Rainfall* worksheets are pre-requisite input for this worksheet. The *Rational Method* worksheet is also linked to the *Catchment Slope, Channel Slope* and *Design Tables* worksheets. The *Design Tables* worksheet contains all the input information and design parameters used in both the deterministic and empirical flood estimation methods. The latter worksheet can be accessed by clicking on the DESIGN TABLES button.

2.6.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected) and option buttons. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Physical catchment characteristics:

Rural runoff coefficients (C_1):

The average catchment slope, hydrological soil group/permeability and land use/vegetation classes are used to describe the physical characteristics of the rural catchment component of the RM.

The following applies:

Cell range

B19:B22: Average catchment slope: Enter the %-distribution of the area associated with the slope class description in *cell range A19:A22*, if applicable. Alternatively, use the results contained in *cells B13, B14, H13* and *H14* of the *Catchment Slope* worksheet, which are representative of the slope frequency distribution of the grid points used in the Grid method.

Note: The sum of *cell range B19:B22* must be equal to 100% (*cell B23*).

Cell range

B25:B31: Hydrological soil group/permeability: Enter the %-distribution of the area associated with the soil class description in *cell range A25:A31*, if applicable.

Note: The sum of *cell range B25:B31* must be equal to 100% (*cell B32*).

Cell range

B34:B39: Land use/vegetation: Enter the %-distribution of the area associated with the land use/vegetation description in *cell range A34:A39*, if applicable.

Note: The sum of *cell range B34:B39* must be equal to 100% (*cell B40*).

Urban runoff coefficients (C_2):

Lawns, residential areas, industry and business are used to describe the physical characteristics of the urban catchment component of the RM. The following applies:

Cell range

G19:G22: Lawns: Enter the %-distribution of the area associated with the lawn description in *cell range E19:E22*, if applicable.

Cell range

G25:G26: Residential areas: Enter the %-distribution of the area associated with the residential area description in *cell range E25:E26*, if applicable.

Cell range

G29:G31: Industry: Enter the %-distribution of the area associated with the industry description in *cell range E29:E31*, if applicable.

Cell range

G34:G37: Business: Enter the %-distribution of the area associated with the business description in *cell range E34:E37*, if applicable.

Note: The sum of *cell ranges G19:G22; G25:G26; G29:G31* and *G34:G37* must be equal to 100% (*cell G41*).

Figure 14 displays the layout of the runoff coefficient information applicable to the RM.

	A	B	C	D	E	F	G	H	I
1	HOME	DESIGN TABLES	RATIONAL METHOD			CATCHMENT INFORMATION		DESIGN RAINFALL	
2	Secondary drainage region number	C5		PRINT	Main watercourse/river			Modder River	
3	Tertiary drainage region number	C52			Designed			OJ Gericke	
4	Quaternary drainage region number	C52A- G			Checked			JA du Plessis	
5	Catchment description	Krugersdrift Dam			Date			June 15, 2009	
17	RURAL RUNOFF COEFFICIENTS (C_1)				URBAN RUNOFF COEFFICIENTS (C_2)				
18	Average catchment slope	%	Factor	C_s	Lawns		%	Factor	C_2
19	Vleis and pans (0-3%)	57.6	0.010	0.006	Sandy, flat (<2%)			0.100	
20	Flat areas (3-10%)	34.3	0.060	0.021	Sandy, steep (>7%)			0.200	
21	Hilly (10-30%) CATCHMENT SLOPE	6.7	0.120	0.008	Heavy soil, flat (<2%)			0.170	
22	Steep areas (>30%)	1.4	0.220	0.003	Heavy soil, steep (>7%)			0.350	
23	Total	100	Total	0.037	Total		0	Total	0.000
24	Hydrological soil group/permeability	%	Factor	C_p	Residential areas		%	Factor	C_2
25	Very permeable (A)		0.030		Houses		59.12	0.500	0.296
26	Very permeable (A/B)	23.15	0.040	0.009	Flats		0.14	0.700	0.001
27	Permeable (B)	27.31	0.060	0.016	Total		59.26	Total	0.297
28	Permeable (B/C)	2.82	0.080	0.002	Industry		%	Factor	C_2
29	Semi-permeable (C)		0.120		Light industry		11.53	0.800	0.092
30	Semi-permeable (C/D)	15.69	0.160	0.025	Average industry			0.850	
31	Impermeable (D)	31.03	0.210	0.065	Heavy industry		0.03	0.900	0.000
32	Total	100	Total	0.118	Total		11.56	Total	0.093
33	Land use/vegetation	%	Factor	C_v	Business		%	Factor	C_2
34	Thick bush and plantations	4.34	0.030	0.001	City centre		4.63	0.950	0.044
35	Light bush and farm lands	0.73	0.070	0.001	Suburban		24.55	0.700	0.172
36	Grasslands	80.18	0.170	0.136	Streets			0.950	
37	Cultivated land, contoured		0.070	0.000	Maximum flood			1.000	
38	Cultivated land	14.29	0.170	0.024					
39	No vegetation	0.46	0.260	0.001					
40	Total	100	Total	0.164	Total		29.18	Total	0.216
41	Total	100	Total C_1	0.319	Total		100	Total C_2	0.605

Figure 14: Rural and urban runoff coefficients applicable to the RM

Time of concentration:

Cell range

D43:E43: Select the appropriate option button contained in the time of concentration group box by indicating either "Yes" or "No." If "Yes" is selected, the time of concentration in a defined main watercourse (Equation 10) will be adjusted by a correction factor (τ). The correction factor is a function of the catchment area and was proposed by Kovács (unpublished; cited by Van der Spuy & Rademeyer, 2010). These correction factors as proposed by Kovács are listed in Table 1.

Table 1: Correction factors (τ) for T_C

Area [A, km²]	**Correction factor [τ]**
< 1	2
1 - 100	2-0.5log$A$
100 - 5 000	1
5000 - 100 000	2.42-0.385log$A$
> 100 000	0.5

Design notes:

Cell range

A47:A50: The user can enter any comments/design notes/recommendations in this cell range.

Design rainfall information:

Cell B64: Only applicable if the 1' x 1'Grid RLMA&SI design rainfall method was selected at the *Catchment Information* worksheet.

Comment: "Enter a user-defined ARF or an ARF equal to the default ARF in *cell range B63:H63*. To exclude the use of an ARF, enter a value of 100 (recommended)."

2.6.3 Calculation procedure

Time of concentration (T_C):

$$T_{C1} = 0.604\left(\frac{rL_1}{\sqrt{\frac{H}{1000L_1}}}\right)^{0.467} \quad (9)$$

$$T_{C2} = \left(\frac{0.87L_2^{\,2}}{1000S_{CH}}\right)^{0.385} \quad (10)$$

$$T_{C3} = \left(\frac{L_3}{3.6v}\right) \quad (11)$$

$$T_C = T_{C1} + T_{C2} + T_{C3} \tag{12}$$

where:

$T_{C1\text{-}3}$ = time of concentration [hours],

H = height difference along overland flow path [m],

L_1 = hydraulic length of overland flow path [km],

L_2 = length of longest watercourse [km],

L_3 = length of artificial flow path [km],

r = roughness coefficient for overland flow,

S_{CH} = average main watercourse slope [m/m] as determined in Section 2.5, and

$\bar{v}$ = average/design velocity [m/s].

Weighted runoff coefficients:

$$C_1 = C_s + C_p + C_v \tag{13}$$

$$C_{1D} = C_1(1 - D_{\%}) + C_1 D_{\%}\left(\sum\left(D_{factor} C_{S\%}\right)\right) \tag{14}$$

$$C_{1T} = F_T C_{1D} \tag{15}$$

$$C_T = \alpha C_{1T} + \beta C_2 + \gamma C_3 \tag{16}$$

where:

α = rural area distribution factor [%],

β = urban area distribution factor [%],

γ = lake area distribution factor [%],

C_1 = rural runoff coefficient between zero and one,

C_{1D} = rural runoff coefficient incorporating the effect of dolomite areas,

C_{1T} = rural runoff coefficient incorporating the effect of initial saturation,

C_2 = urban runoff coefficient between zero and one,

C_3 = lake runoff coefficient,

C_p = runoff coefficient according to average soil permeability,

C_s = runoff coefficient according to average catchment slope,

C_T = weighted runoff coefficient for T-year return period,

C_v = runoff coefficient according to average land use/vegetation, and

F_T = adjustment factor.

Design rainfall information:

The following depth-duration-frequency (DDF) relationships of averaged design rainfall information associated with the T_C are possible options in the RM:

(a) Midgley and Pitman (M&P) DDF relationship based on Log-Extreme Value Type 1 (LEV1) distributions (Midgley and Pitman, 1978); and

(b) DDF relationship based on the RLMA&SI approach.

Design point rainfall ($P_{T\ M\&P}$):

$$P_T = (I_{W,S})(T_C)(M_F)(F) \tag{17}$$

$$I_W = \frac{122.8}{(1+4.779T_C)^{0.7372}} \tag{18}$$

$$I_S = \frac{217.8}{(1+4.164T_C)^{0.8832}} \tag{19}$$

$$M_F = \frac{(18.79+0.17MAP)}{100} \tag{20}$$

Design point rainfall ($P_{T\ RLMA\&SI}$):

These design point rainfall values are based on the 1' x 1' Grid RLMA&SI design rainfall depths from the linked worksheet, *Design Rainfall*.

General:

$$I_T = \frac{P_T}{T_C} \tag{21}$$

$$ARF = (90\,000 - 12\,800 \ln A + 9\,830 \ln(60T_C))^{0.4} \tag{22}$$

$$I_{TAvg} = I_T\left(\frac{ARF}{100}\right) \tag{23}$$

Peak flow:

$$Q_T = \frac{C_T I_{TAvg} A}{3.6} \tag{24}$$

where:

A = catchment area [km²],

ARF = areal reduction factor [%],

F = frequency factor,

I_S = rainfall intensity in summer/inland regions [mm/h],

I_T = design point rainfall intensity [mm/h],

I_{TAvg} = average design rainfall intensity [mm/h],

I_W = rainfall intensity in winter/coastal regions [mm/h],

MAP = mean annual precipitation [mm],

M_F = MAP factor,

P_T = design point rainfall depth [mm],

Q_T = peak flow for T-year return period [m^3/s], and

T_C = time of concentration [hours].

Figure 15 displays the layout of the input screen associated with the time of concentration and the design notes, while the estimation results of the time of concentration, weighted runoff coefficients, design rainfall information and peak flows are also shown.

HOME | DESIGN TABLES | **RATIONAL METHOD** | CATCHMENT INFORMATION | DESIGN RAINFALL

Secondary drainage region number	C5	Main watercourse/river	Modder River
Tertiary drainage region number	C52	Designed	OJ Gericke
Quaternary drainage region number	C52A- G	Checked	JA du Plessis
Catchment description	Krugersdrift Dam	Date	June 15, 2009

PRINT

TIME OF CONCENTRATION (T_C)							
Correction factor (τ) for defined main watercourse		0.956	YES / ◉ NO				
Overland flow (T_{C1})		Defined main watercourse (T_{C2})		Artificial flow (T_{C3})		Total T_C	
0.000	hours	47.894	hours	0.000	hours	47.9	hours

DESIGN NOTES

WEIGHTED RUNOFF COEFFICIENTS							
Return period (T, years)	2	5	10	20	50	100	200
Rural runoff coefficient (C_1)	0.319	0.319	0.319	0.319	0.319	0.319	0.319
Dolomitic rural runoff coefficient (C_{1D})	0.319	0.319	0.319	0.319	0.319	0.319	0.319
Adjustment factor (F_T)	0.500	0.550	0.600	0.670	0.830	1.000	1.200
Adjusted rural runoff coefficient (C_{1T})	0.160	0.176	0.192	0.214	0.265	0.319	0.383
Weighted runoff coefficient (C_T)	**0.173**	**0.188**	**0.203**	**0.225**	**0.274**	**0.327**	**0.389**

DESIGN RAINFALL INFORMATION							
Return period (T, years)	2	5	10	20	50	100	200
Design point rainfall ($P_{T\ M\&P}$, mm)	48.578	66.149	83.719	103.357	134.365	165.372	186.043
Design point rainfall ($P_{T\ RLMA\&SI}$, mm)							
Design point rainfall intensity (I_T, mm/h)	1.014	1.381	1.748	2.158	2.805	3.453	3.884
Areal reduction factor (ARF, %)	79.435	79.435	79.435	79.435	79.435	79.435	79.435
Areal reduction factor ($ARF_{RLMA\&SI}$)							
Average design rainfall intensity ($I_{T\ Avg}$, mm/h)	0.806	1.097	1.389	1.714	2.229	2.743	3.086
Peak flow (Q_T, m^3/s)	**245**	**363**	**497**	**678**	**1075**	**1576**	**2108**

Figure 15: Design information and estimation results

2.7 Alternative Rational Method (ARM)

2.7.1 Pre-requisite input and linked worksheets

The *Catchment Information*, *Design Rainfall* and *Rational Method* worksheets are pre-requisite input for this worksheet. The *Alternative Rational Method* worksheet is also linked to the *Catchment Slope*, *Channel Slope* and *Design Tables* worksheets.

2.7.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected) and option buttons.

Time of concentration:

Cell range

D53:E53: Select the appropriate option button contained in the time of concentration group box by indicating either "Yes" or "No." If "Yes" is selected, the time of concentration in a defined main watercourse will be adjusted by a correction factor (τ, Table 1).

Design notes:

Cell range

A57:A60: The user can enter any comments/design notes/recommendations in this cell range.

2.7.3 Calculation procedure

Time of concentration (T_C):

Refer to Section 2.6.3.

Weighted runoff coefficients:

Refer to Section 2.6.3.

Design rainfall information:

The following DDF relationships of averaged design rainfall information associated with the T_C are possible options in the ARM:

(a) Hershfield DDF relationship based on the modified Hershfield equation (Equation 25, $T_C \leq 6$ hours) (Alexander, 2001) and/or TR102/RLMA-SAWS *n*-day design rainfall information; and

(b) DDF relationship based on the RLMA&SI approach.

Design point rainfall ($P_{T\ \text{Hershfield},\ Tc \leq 6\text{-h}}$):

$$P_T = 1.13(0.41 + 0.64 \ln T)(-0.11 + 0.27 \ln(60T_C))(0.79M^{0.69}R^{0.20}) \qquad (25)$$

where:

P_T = design point rainfall depth [mm],

M = 2-year mean of the annual daily maxima rainfall [mm],

R = average number of days per year on which thunder was heard,

T = return period [years], and

T_C = time of concentration [hours].

Design point rainfall ($P_{T\ \text{TR102/RLMA-SAWS},\ 6\text{-h} < Tc \leq 168\text{-h}}$):

If the time of concentration (T_C) is longer than 6 hours and less than 24 hours, then linear interpolation between Equation 25 and the 1-day design point rainfall depth from either the TR102 or RLMA-SAWS database is used. If the T_C exceeds 24 hours, then linear interpolation between the *n*-day design point rainfall values is applicable.

Design point rainfall ($P_{T\ \text{RLMA\&SI}}$):

These design point rainfall values are based on the 1’ x 1’ Grid RLMA&SI design rainfall depths from the linked worksheet, *Design Rainfall*.

General:

Refer to Section 2.6.3.

Peak flow:

Refer to Section 2.6.3.

An example of the RLMA-SAWS/TR102 *n*-day design rainfall information and the physical catchment characteristics is shown in Figure 16.

	A	B	C	D	E	F	G	H	I
1	HOME / DESIGN TABLES	ALTERNATIVE RATIONAL METHOD					CATCHMENT INFORMATION	DESIGN RAINFALL	
2	Secondary drainage region number	C5		PRINT	Main watercourse/river			Modder River	
3	Tertiary drainage region number	C52			Designed			OJ Gericke	
4	Quaternary drainage region number	C52A- G			Checked			JA du Plessis	
5	Catchment description	Krugersdrift Dam			Date			June 15, 2009	
6	RLMA-SAWS/TR102 N-DAY DESIGN RAINFALL INFORMATION								
7	SAWS rainfall station number	Multiple stations			Number of thunder days/year (R)			62	
8	SAWS rainfall station name	Multiple station numbers			2-year 1-day mean annual maxima (M, mm)			48	
9	Rainfall region	Inland/summer			MAP (mm)			518	
10	Duration (days)	Design rainfall depth (P_T, mm) and associated return period (T, years)							
11		2	5	10	20	50	100	200	
12	1	48	66	78	90	106	119	133	
13	2	61	82	97	112	132	148	164	
14	3	68	91	107	123	144	160	177	
15	7	86	116	136	156	182	203	223	
16	PHYSICAL CATCHMENT CHARACTERISTICS								
17	NATURAL FLOW				AREA DISTRIBUTION FACTORS				
18					Rural areas (α)			96.62	%
19	Size of catchment (A)	6331.000		km²	Urban areas (β)			3.04	%
20	Overland flow distance (L_O)			km	Lakes (T)			0.34	%
21	Overland flow height difference (H)			m	Dolomite area (D)			0	%
22	Average overland slope (S_O)			m/m	ARTIFICIAL FLOW				
23	Overland flow surface (r value)				Street flow			Canal flow	
24	Longest main watercourse (L_{CH})	186.696		km	Flow path length (km)			Canal length (km)	
25	Average channel slope (S_{CH}) CHANNEL SLOPE	0.00131		m/m	Slope (m/m)			Actual velocity (m/s)	
26					Actual velocity (m/s)			Max velocity (m/s)	

Figure 16: Design rainfall and physical catchment information (ARM)

Figure 17 displays the estimated design rainfall depths and peak flows associated with the T_C.

	A	B	C	D	E	F	G	H	I
1	HOME / DESIGN TABLES	ALTERNATIVE RATIONAL METHOD					CATCHMENT INFORMATION	DESIGN RAINFALL	
2	Secondary drainage region number	C5		PRINT	Main watercourse/river			Modder River	
3	Tertiary drainage region number	C52			Designed			OJ Gericke	
4	Quaternary drainage region number	C52A- G			Checked			JA du Plessis	
5	Catchment description	Krugersdrift Dam			Date			June 15, 2009	
68	DESIGN RAINFALL INFORMATION								
69	Return period (T, years)	2	5	10	20	50	100	200	
70	Design point rainfall ($P_{T\ Hershfield,\ Tc \le 6\text{-}h}$, mm)	37.478	63.225	82.702	102.179	127.926	147.403	166.880	
71	Design point rainfall ($P_{T\ TR102/RLMA\text{-}SAWS,\ 6\text{-}h < Tc \le 168\text{-}h}$, mm)	61.117	82.271	97.040	111.912	132.030	147.802	164.222	
72	Design point rainfall ($P_{T\ RLMA\&SI}$, mm)								
73	Design point rainfall intensity (I_T, mm/h)	1.276	1.718	2.026	2.337	2.757	3.086	3.484	
74	Areal reduction factor (ARF, %)	79.435	79.435	79.435	79.435	79.435	79.435	79.435	
75	Areal reduction factor ($ARF_{RLMA\&SI}$)								
76	Average design rainfall intensity ($I_{T\ Avg}$, mm/h)	1.014	1.365	1.609	1.856	2.190	2.451	2.768	
77	**Peak flow (Q_T, m^3/s)**	**308**	**451**	**576**	**735**	**1057**	**1409**	**1891**	

Figure 17: Design rainfall information and associated peak flows

2.8 Soil Conservation Services (SCS) Method

2.8.1 Pre-requisite input and linked worksheets

The *Catchment Information, Design Rainfall* and *Rational Method* worksheets are pre-requisite input for this worksheet. The *SCS Method* worksheet is also linked to the *Catchment Slope* and *Channel Slope* worksheets.

2.8.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected) and option buttons. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Runoff volume:

Initial weighted CN: Land use and hydrological soil groups:

Cell range

D26:J71: Select the appropriate option button contained in the CN hydrological soil group box next to the identified/appropriate land-use description by indicating either "A, A/B, B, B/C, C, C/D or D."

Cell K23: Comment: "Enter the area (%) associated with the selected hydrological soil groups (*cell range D26:J71*), if applicable."

Cell range

P26:V71: Select the appropriate option button contained in the CN hydrological soil group box next to the identified/appropriate land-use description by indicating either "A, A/B, B, B/C, C, C/D or D."

Cell W23: Comment: "Enter the area (%) associated with the selected hydrological soil groups (*cell range P26:V71*), if applicable."

Figure 18 is an illustrative example of the option button-based table used in the DFET to establish the initial weighted CN values for selected land use and hydrological soil groups.

	A	B	C	D	E	F	G	H	I	J	K	L
22	INITIAL WEIGHTED CURVE NUMBER (CN, LAND USE AND HYDROLOGICAL SOIL GROUPS)											
23–24	Description	Runoff potential		Hydrological soil group							Area (%)	Weighted CN value
25	Generalised CN numbers			A	A/B	B	B/C	C	C/D	D	100	75.146
26	Agriculture			○	○	○	●	○	○	○	14.1	10.434
27	Open space			○	○	○	○	○	●	○	78.2	59.432
28	Forest			○	○	●	○	○	○	○	4.2	2.31
29	Disturbed land			○	○	○	○	○	●	○	0.4	0.356
30	Residential			○	○	●	○	○	○	○	1.8	1.368
31	Paved			○	○	○	○	○	●	○	0.9	0.882
32	Commercial/Industrial			○	○	○	○	○	●	○	0.4	0.364
33	Garden crops			A	A/B	B	B/C	C	C/D	D	0	0
34	Straight row	High		●	○	○	○	○	○	○		0
35	Straight row	Low		●	○	○	○	○	○	○		0
36	Small grain			A	A/B	B	B/C	C	C/D	D	0	0
37	Straight row	High		●	○	○	○	○	○	○		0
38	Straight row	Low		●	○	○	○	○	○	○		0
39	Straight row and conservation tillage	High		●	○	○	○	○	○	○		0
40	Straight row and conservation tillage	Low		●	○	○	○	○	○	○		0
41	Planted on contour	High		●	○	○	○	○	○	○		0
42	Planted on contour	Low		●	○	○	○	○	○	○		0
43	Planted on contour and conservation tillage	High		●	○	○	○	○	○	○		0
44	Planted on contour and conservation tillage	Low		●	○	○	○	○	○	○		0
45	Planted on contour: Winter	Low		●	○	○	○	○	○	○		0
46	Conservation structures	High		●	○	○	○	○	○	○		0
47	Conservation structures	Low		●	○	○	○	○	○	○		0
48	Conservation structures and tillage	High		●	○	○	○	○	○	○		0
49	Conservation structures and tillage	Low		●	○	○	○	○	○	○		0

Figure 18: Initial weighted CN values

Lag time (T_L):

Cell Q18: Based on the values entered and results viewed in the previous steps, the appropriate option button contained in the lag time group box (*cell range Q18:X18*) must be selected by indicating either whether the T_C/T_L lag, SCS lag or SCS-SA lag methods must be used to estimate the lag time.

2.8.3 Calculation procedure

Runoff volume:

$$CN = \frac{25\,400}{(S+254)} \tag{26}$$

$$S = \frac{25\,400}{CN} - 254 \tag{27}$$

$$I_A = cS \tag{28}$$

$$Q_V = \frac{(P-I_A)^2}{P-I_A+S} \tag{29}$$

where:

c = seasonal soil moisture status coefficient,

CN = Curve Number,

I_A = initial losses/abstractions, normally 0.1S [mm],

P = 24-hour design rainfall depth for T-year return period [mm],

Q_V = stormflow depth [mm], and

S = potential maximum soil water retention [mm].

Note:

The total area distribution of CN (*cell range B17:L17*) must be equal to 100%. The following comment(s) will appear on screen if this cell range is accessed by clicking and holding the mouse cursor in position: "If the %-area distribution of CN (*cell range B17:L17*) equals "%-Error," check the sum-total of *cells K72 + W72* (%-area), since it must be equal to 100%."

Warning:

The initial CN values are not adjusted for any variations in the soil moisture status of the catchment.

Lag time (T_L):

$$T_{L1} = 0.6T_C \tag{30}$$

$$T_{L2} = \frac{L^{0.8}(S+25.4)^{0.7}}{7069S_{Avg}^{0.5}} \tag{31}$$

$$T_{L3} = \frac{A^{0.35}MAP^{1.1}}{41.67S_{Avg}^{0.3}\overline{I_{30}}^{0.87}} \tag{32}$$

where:

A = catchment area [km²],

$\overline{I_{30}}$ = 2-year return period 30-minute rainfall intensity [mm/h],

L = hydraulic length of catchment [m],

MAP = mean annual precipitation [mm],

S = potential maximum soil water retention [mm],

S_{Avg} = average catchment slope [%],

T_{L1} = lag time based on the T_C/T_L relationship [hours],

T_{L2} = lag time based on the SCS lag equation [hours],

T_{L3} = lag time based on the SCS-SA lag equation [hours], and

T_C = time of concentration [hours].

Peak flow:

$$Q_T = \frac{0.2083AQ_v}{\frac{T_C}{2}+T_L} \qquad (33)$$

where:

A = catchment area [km²],

Q_T = peak flow for T-year return period [m^3/s],

Q_V = stormflow depth [mm],

T_C = time of concentration [hours], and

T_L = lag time based on either Equations 30, 31 or 32 [hours].

The layout of the *SCS Method* worksheet, with specific reference to the procedural steps followed to estimate the peak flow, is shown in Figures 19 and 20, respectively.

	A	B	C–D	E–F	G–H	I–J	K	L
2	GENERAL CATCHMENT INFORMATION							
3	Secondary drainage region number	C5	PRINT	Main watercourse/river			Modder River	
4	Tertiary drainage region number	C52		Designed			OJ Gericke	
5	Quaternary drainage region number	C52A- G		Checked			JA du Plessis	
6	Catchment description	Krugersdrift Dam		Date			June 15, 2009	
7	RLMA-SAWS/TR102 24-hour DESIGN RAINFALL INFORMATION							
8	SAWS rainfall station number	Multiple station numbers		Thunder days/year (R)			62	
9	SAWs rainfall station name	Multiple stations		2-year 1-day maxima (mm)			48	
10	Rainfall region	Inland/summer		MAP (mm)			518	
11	Return period (T, years)	2	5	10	20	50	100	200
12	RLMA-SAWS/TR102 design rainfall depth (mm)	48	66	78	90	106	119	133
13	1' x 1' Grid RLMA&SI design rainfall depth (mm)							
14	RUNOFF VOLUME							
15	Return period (T, years)	2	5	10	20	50	100	200
16	Weighted Curve Number (CN)	75.146	75.146	75.146	75.146	75.146	75.146	75.146
17	Total area distribution of CN (%)	100.000	100.000	100.000	100.000	100.000	100.000	100.000
18	Potential maximum soil water retention (S, mm)	84.009	84.009	84.009	84.009	84.009	84.009	84.009
19	Initial losses/abstractions (I_a, mm)	8.401	8.401	8.401	8.401	8.401	8.401	8.401
20	Stormflow depth (Q_v, mm)	**12.936**	**23.121**	**31.197**	**39.880**	**52.477**	**62.855**	**74.040**
21	WARNING: The initial Curve Number (CN) values are not adjusted for any variations in the soil moisture status of the catchment							

Figure 19: General catchment, design rainfall and runoff volume information

	M	N	O–P	Q–R	S–T	U–V	W	X
2	PHYSICAL CATCHMENT CHARACTERISTICS							
3	NATURAL FLOW			ARTIFICIAL FLOW				
4	Size of catchment (A)	6331.000	km²	Street flow				
5	Overland flow distance (L_O)	0.000	km	Flow path length			0.000	km
6	Average overland slope (S_O)		m/m	Slope				m/m
7	Overland flow surface (r value) CHANNEL			Actual velocity				m/s
8	Longest main watercourse (L_{CH}) SLOPE	186.696	km	Canal flow				
9	Average channel slope (S_{CH}) CATCHMENT	0.00131	m/m	Canal length			0.000	km
10	Average catchment slope (S) SLOPE	0.04186	m/m	Actual velocity				m/s
11	TIME OF CONCENTRATION (T_C)							
12	Overland flow (T_{C1}, hours)	0.000		Defined main watercourse (T_{C2}, hours)				47.894
13	Artificial flow (T_{C3}, hours)	0.000		Total time of concentration (T_C ,hours)				**47.9**
14	LAG TIME (T_L)							
15	T_C-T_L relationship (T_{L1})			28.737				hours
16	SCS lag time (T_{L2})			30.478				hours
17	SCS-SA lag time (T_{L3}) (Schmidt and Schulze, 1984; 1987)			21.749				hours
18	PREFERRED METHOD FOR LAG TIME (T_L) ESTIMATION			○ TC/TL LAG		◉ SCS LAG	○ SCS-SA LAG	
19	PEAK FLOW (Q_T)							
20	Return period (T, years)	2	5	10	20	50	100	200
21	Peak flow (Q_T, m^3/s)	313	560	756	966	1272	1523	1794

Figure 20: Physical catchment characteristics, T_C, T_L and peak flow estimation

2.9 Standard Design Flood (SDF) Method

2.9.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Design Rainfall* worksheets are pre-requisite input for this worksheet. The *SDF Method* worksheet is also linked to the *Catchment Slope, Channel Slope, Design Tables* and *SDF TR102 Rainfall* worksheets, as well as the *SDF Map*. The latter worksheet and map can be accessed by clicking on the SDF TR102 RAINFALL and SDF MAP buttons, respectively.

2.9.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected) and option buttons. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

TR102 *n*-day design rainfall information:

Cell B7: Comment: "Enter the SDF basin number, between 1 and 29. Click on the *SDF Map* button to view the SDF regional map of South Africa."

Cell range D24:E24: Select the appropriate option button contained in the time of concentration group box by indicating either "Yes" or "No." If "Yes" is selected, the time of concentration in a defined main watercourse will be adjusted by a correction factor (τ, Table 1).

Cell A38: Click and hold the mouse cursor in position. The following comment box with instructions will appear on screen:

CLICK ON THE TABLE 8 BUTTON TO VIEW THE "DESIGN TABLES WORKSHEET".

THE (a) & (b) CONSTANTS ARE LISTED IN TABLE 8: SDF ADJUSTMENT FACTORS (F) (Van Bladeren, 2005).

ENTER THE (a) CONSTANTS OF THE SDF ADJUSTMENT FACTORS (F) APPLICABLE TO THE SELECTED SDF BASIN IN CELL RANGE B38: H38 (2- 200 years).

IF NO (a) & (b) CONSTANTS ARE DEFINED, ENTER THE SDF ADJUSTMENT FACTORS (F) IN CELL RANGE B38: H38.

LEAVE CELL RANGE B38: H38 EMPTY, IF NO ADJUSTMENTS ARE REQUIRED.

Cell A39: Click and hold the mouse cursor in position. The following comment box with instructions will appear on screen:

CLICK ON THE TABLE 8 BUTTON TO VIEW THE "DESIGN TABLES WORKSHEET".

THE (a) & (b) CONSTANTS ARE LISTED IN TABLE 8: SDF ADJUSTMENT FACTORS (F) (Van Bladeren, 2005).

ENTER THE (b) CONSTANTS OF THE SDF ADJUSTMENT FACTORS (F) APPLICABLE TO THE SELECTED SDF BASIN IN CELL RANGE B39: H39 (2- 200 years).

IF NO (a) & (b) CONSTANTS ARE DEFINED, ENTER A VALUE OF ONE (1) IN CELL RANGE B39: H39.

LEAVE CELL RANGE B38: H38 EMPTY, IF NO ADJUSTMENTS ARE REQUIRED.

Design notes:

Cell range
A44:A51: The user can enter any comments/design notes/recommendations in this cell range.

2.9.3 Calculation procedure

Time of concentration (T_C):

Refer to Section 2.7.3.

Design rainfall information:

Refer to Section 2.7.3.

Regionalised runoff coefficients:

$$C_T = \frac{C_2}{100} + \left(\frac{Y_T}{2.33}\right)\left(\frac{C_{100}}{100} - \frac{C_2}{100}\right) \tag{34}$$

Peak flow:

$$Q_T = 0.278 C_T I_{TAvg} A \tag{35}$$

$$Q_{SDF} = \frac{Q_T}{F} \tag{36}$$

where:

A = catchment area [km²],

C_2 = calibrated runoff coefficient for the 2-year return period,

C_{100} = calibrated runoff coefficient for the 100-year return period,

C_T = regionalised runoff coefficient,

F = adjustment factor (Van Bladeren, 2005),

I_{TAvg} = average design rainfall intensity [mm/h],

Q_{SDF} = adjusted peak flow for T-year return period [m^3/s],

Q_T = original peak flow for T-year return period [m^3/s], and

Y_T = return period factor.

The layout of the *SDF Method* worksheet is shown in Figure 21, while the location of the SDF basins is shown in Figure 22.

	A	B	C	D	E	F	G	H	I
1	HOME DESIGN TABLES	STANDARD DESIGN FLOOD METHOD					CATCHMENT INFORMATION	SDF TR102 RAINFALL	
2	Secondary drainage region number	C5		PRINT	Main watercourse/river			Modder River	
3	Tertiary drainage region number	C52			Designed			OJ Gericke	
4	Quaternary drainage region number	C52A- G			Checked			JA du Plessis	
5	Catchment description	Krugersdrift Dam			Date			June 15, 2009	
6	TR102 N-DAY DESIGN RAINFALL INFORMATION								
7	SDF Basin number SDF MAP		9		MAP (mm)			376	
8	SAWS rainfall station number		0258458W		Number of thunder days/year (R)			47	
9	SAWS rainfall station name		Jacobsdal (Police)		2-year 1-day maxima (M, mm)			43	
10	Duration (days)	Design rainfall depth (P_T, mm) and associated return period (T, years)							
11		2	5	10	20	50	100	200	
12	1	43	61	75	91	114	135	155	
13	2	54	78	98	119	151	179	210	
14	3	59	87	109	134	171	203	238	
15	7	70	104	131	160	203	240	280	
16	PHYSICAL CATCHMENT CHARACTERISTICS								
17	NATURAL FLOW				ARTIFICIAL FLOW				
18	Size of catchment (A)	6331.000	km²		Street flow			Canal flow	
19	Overland flow distance (L_O)		km		Flow path length (km)			Canal length (km)	
20	Average overland slope (S_O)		m/m		Slope (m/m)			Actual velocity (m/s)	
21	Longest main watercourse (L_{CH}) CHANNEL SLOPE	186.696	km		Actual velocity (m/s)			Max velocity (m/s)	
22	Average channel slope (S_{CH})	0.00131	m/m						
23	TIME OF CONCENTRATION (T_C)					TIME OF CONCENTRATION (T_C)			
24	Correction factor (τ) for defined main watercourse		0.956	YES	NO				
25	Overland flow (T_{C1})		Defined main watercourse (T_{C2})			Artificial flow (T_{C3})		Total T_C	
26	0.000	hours	47.894		hours	0.000	hours	47.9	hours
27	DESIGN RAINFALL INFORMATION								
28	Return period (T, years)	2	5	10	20	50	100	200	
29	Design point rainfall ($P_{T\ Hershfield,\ Tc \le 6\text{-}h}$, mm)	32.623	55.034	71.988	88.942	111.353	128.307	145.261	
30	Design point rainfall ($P_{T\ TR102/RLMA\text{-}SAWS,\ 6\text{-}h < Tc \le 168\text{-}h}$, mm)	53.951	77.925	97.899	118.877	150.837	178.806	209.757	
31	Design point rainfall intensity (I_T, mm/h)	1.126	1.627	2.044	2.482	3.149	3.733	4.380	
32	Areal reduction factor (ARF, %)	79.435	79.435	79.435	79.435	79.435	79.435	79.435	
33	Average design rainfall intensity ($I_{T\ Avg}$, mm/h)	0.895	1.292	1.624	1.972	2.502	2.966	3.479	
34	REGIONAL RUNOFF COEFFICIENTS								
35	Return period (T, years)	2	5	10	20	50	100	200	
36	Regional calibration factors	C_2	15		%	C_{100}	60		%
37	Regional runoff coefficient (C_T)	0.150	0.312	0.397	0.467	0.546	0.600	0.648	
38	Constant (a) TABLE 8	2.230	2.470	3.500	1.840	2.320	2.440	2.400	
39	Constant (b)	-0.090	-0.120	-0.200	-0.180	-0.170	-0.190	-0.210	
40	SDF Adjustment factor (F) (Van Bladeren, 2005)	1.014	0.864	0.608	0.381	0.524	0.462	0.382	
41	Original peak flow (Q_T, m^3/s)	236	710	1134	1618	2402	3129	3966	
42	Adjusted peak flow (Q_{SDF}, m^3/s)	233	821	1866	4251	4585	6766	10387	

Figure 21: *SDF Method* worksheet

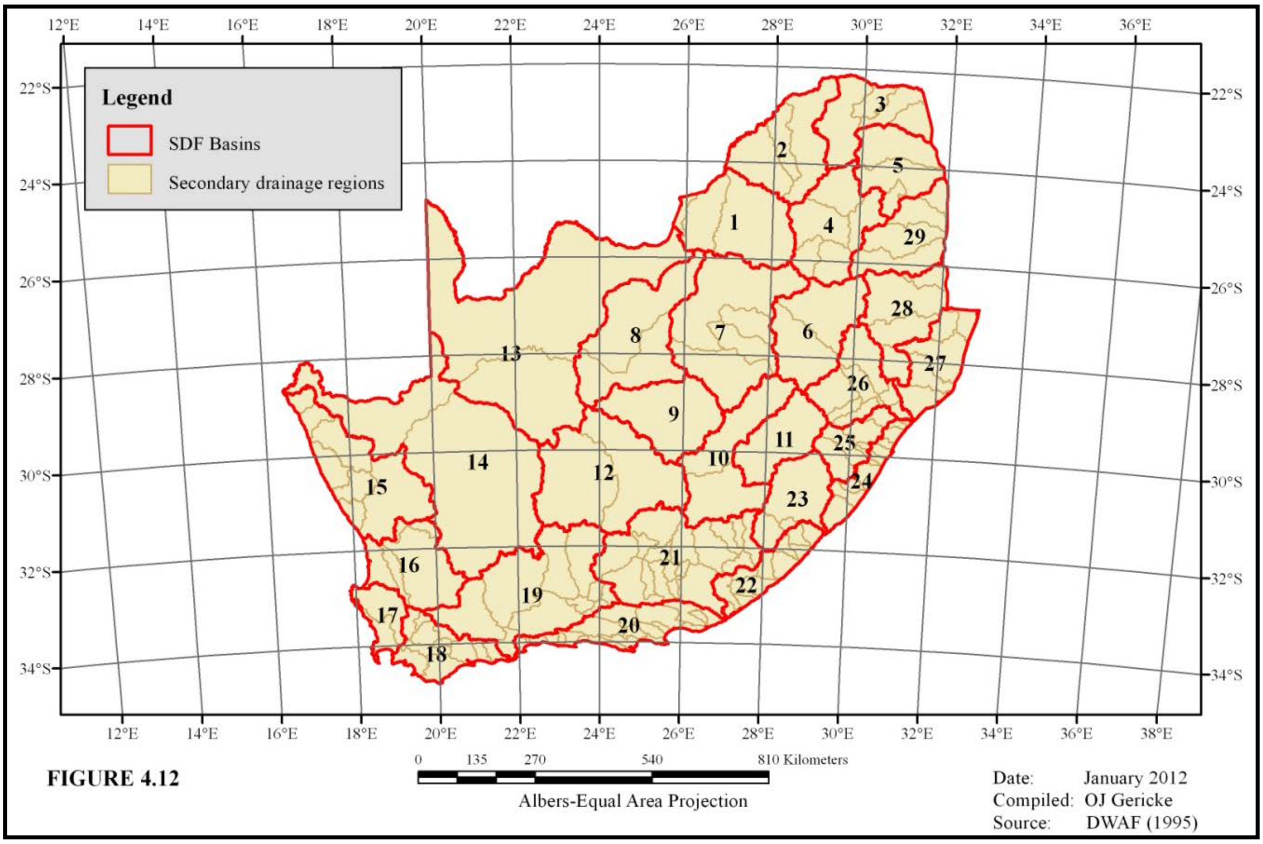


Figure 22: SDF regional map of South Africa (Alexander, 2002)

2.10 Synthetic Unit Hydrograph (SUH) Method

2.10.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Design Rainfall* worksheets are pre-requisite input for this worksheet. The *Synthetic Unit Hydrograph Method* worksheet is also linked to the *Catchment Slope*, *Channel Slope*, *SUH Runoff Factors*, *Q/Q_P Information* and *SUH S-curve Lag* worksheets.

2.10.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected) and spinner buttons which enable the user to increase or decrease the veld-type number associated with a specific veld-type region. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Physical catchment characteristics:

Cell range

B9:B11: Enter the area distribution (%) associated with the veld-type region number in *cell range D9:D11*. Use the spinner button to increase or decrease the veld region number in the latter cell range.

Click on the **VELD-TYPE MAP** button to view the "*General Veld-type Region*" map to enable the selection of the appropriate region.

<u>*Note:*</u> The sum of *cell range B9:B11* must be equal to 100%.

Design rainfall information:

Cells

D15 & H15: Select the appropriate return period (years) from the group box (drop-down list, 7 options available, *e.g.* 100) to be used in the design rainfall and flood estimation. Repeat this process until all the return periods were evaluated.

Cell A17: Click and hold the mouse cursor in position. The following comment box with instructions will appear on screen:

RLMA-SAWS/TR102 DESIGN RAINFALL:
5 GROUPED USER-DEFINED STORM DURATIONS RELATED TO THE TIME OF CONCENTRATION (T_C) AND/OR LAG TIME (T_L), *e.g.* 0.25, 0.5, 1, 1.5 and 2 T_C or T_L COULD BE USED IN CELL RANGE C17: G17.

1' x 1' GRID RLMA&SI DESIGN RAINFALL (Smithers & Schulze, 2003):
5 GROUPED USER-DEFINED STORM DURATIONS OF BETWEEN 0.250 hour (15 minutes) & 168 hour (7 days) COULD BE USED IN CELL RANGE C17: G17, BUT THESE DURATIONS MUST CORRESPOND WITH THE DURATIONS ENTERED IN THE DESIGN RAINFALL WORKSHEET.

THE DECIMAL ACCURACY OF THE STORM DURATIONS IS TO THE NEAREST 0.125 hour. HOWEVER, THE DECIMAL ACCURACY OF THE SELECTED DURATIONS MUST ALSO CORRESPOND WITH THE INCREMENTAL TIME INTERVAL (*e.g.* 0.25, 0.5 or 1 hour) SELECTED IN CELL E55.

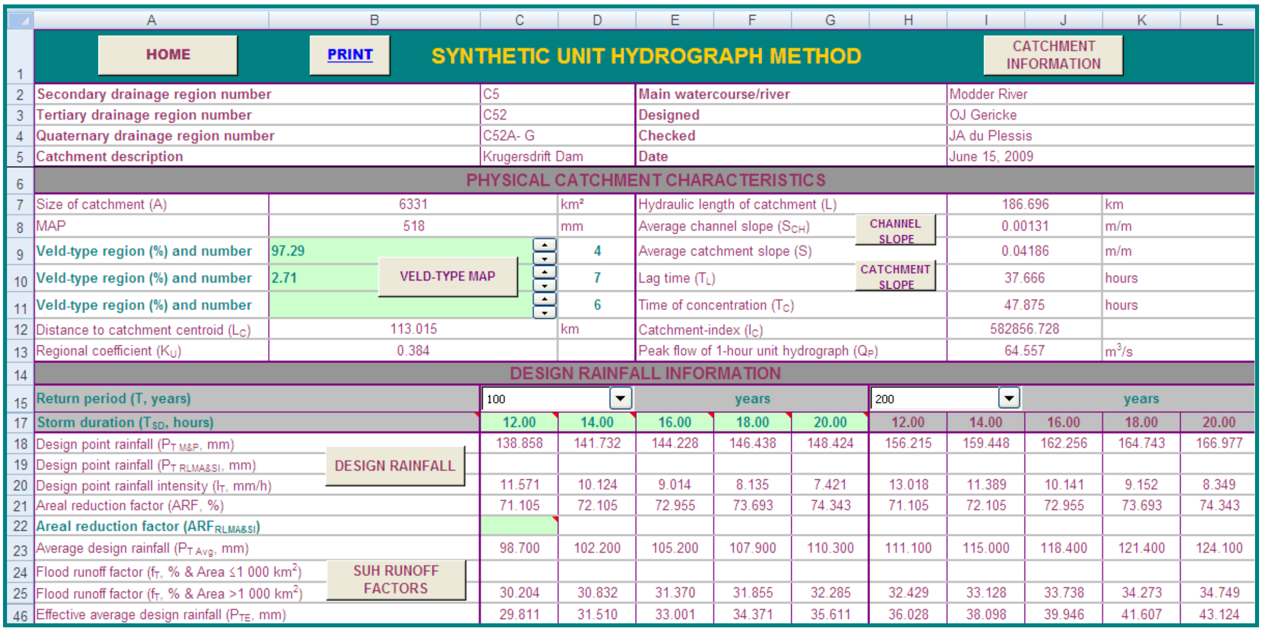
Cell range

C17:G17: Comment: "Storm duration range (0.25-168 hours): Use the same incremental time interval (0.25, 0.5 or 1 hour) as selected in *cell E55*."

Cell C22: Only applicable if the 1' x 1'Grid RLMA&SI design rainfall method was selected at the *Catchment Information* worksheet.

Comment: "Enter a user-defined ARF or an ARF equal to the default ARF in *cell C21*. To exclude the use of an ARF, enter a value of 100 (recommended)."

An example of the SUH method design rainfall information screen is shown in Figure 23.



	A	B	C	D	E	F	G	H	I	J	K	L
1	HOME	PRINT	SYNTHETIC UNIT HYDROGRAPH METHOD						CATCHMENT INFORMATION			
2	Secondary drainage region number		C5		Main watercourse/river				Modder River			
3	Tertiary drainage region number		C52		Designed				OJ Gericke			
4	Quaternary drainage region number		C52A- G		Checked				JA du Plessis			
5	Catchment description		Krugersdrift Dam		Date				June 15, 2009			
6	PHYSICAL CATCHMENT CHARACTERISTICS											
7	Size of catchment (A)	6331		km²	Hydraulic length of catchment (L)				186.696		km	
8	MAP	518		mm	Average channel slope (S_{CH})			CHANNEL SLOPE	0.00131		m/m	
9	Veld-type region (%) and number	97.29		4	Average catchment slope (S)				0.04186		m/m	
10	Veld-type region (%) and number	2.71	VELD-TYPE MAP	7	Lag time (T_L)			CATCHMENT SLOPE	37.666		hours	
11	Veld-type region (%) and number			6	Time of concentration (T_C)				47.875		hours	
12	Distance to catchment centroid (L_C)	113.015		km	Catchment-index (I_C)				582856.728			
13	Regional coefficient (K_U)	0.384			Peak flow of 1-hour unit hydrograph (Q_P)				64.557		m^3/s	
14	DESIGN RAINFALL INFORMATION											
15	Return period (T, years)		100			years		200			years	
17	Storm duration (T_{SD}, hours)		12.00	14.00	16.00	18.00	20.00	12.00	14.00	16.00	18.00	20.00
18	Design point rainfall ($P_{T\ M\&P}$, mm)		138.858	141.732	144.228	146.438	148.424	156.215	159.448	162.256	164.743	166.977
19	Design point rainfall ($P_{T\ RLMA\&SI}$, mm)	DESIGN RAINFALL										
20	Design point rainfall intensity (I_T, mm/h)		11.571	10.124	9.014	8.135	7.421	13.018	11.389	10.141	9.152	8.349
21	Areal reduction factor (ARF, %)		71.105	72.105	72.955	73.693	74.343	71.105	72.105	72.955	73.693	74.343
22	Areal reduction factor ($ARF_{RLMA\&SI}$)											
23	Average design rainfall ($P_{T\ Avg}$, mm)		98.700	102.200	105.200	107.900	110.300	111.100	115.000	118.400	121.400	124.100
24	Flood runoff factor (f_T, % & Area ≤1 000 km^2)	SUH RUNOFF FACTORS										
25	Flood runoff factor (f_T, % & Area >1 000 km^2)		30.204	30.832	31.370	31.855	32.285	32.429	33.128	33.738	34.273	34.749
46	Effective average design rainfall (P_{TE}, mm)		29.811	31.510	33.001	34.371	35.611	36.028	38.098	39.946	41.607	43.124

Figure 23: SUH method design rainfall information

SUH S-curve lagging:

Cell E55: Comment: "An incremental time interval (t) of 0.25, 0.5 or 1 hour can be used to represent the storm duration (T_{SD})."

Click on the SUH S-CURVE LAG button to access the *SUH S-curve Lag* worksheet. The following applies:

SUH S-curve lag (1 hour):

Only applicable if *cell E55* (*SUH Method* worksheet) equals 1 hour. Time intervals ranging from zero to 168 hours (7 days) can be evaluated.

Cell FS11: Click and hold the mouse cursor in position. The following comment box with the S-curve lag instructions will appear on screen:

THE BEGINNING OF ANY S-CURVE LAG IN COLUMNS FT to FX IS WHERE THE TIME-VALUE (t, hours) IN COLUMN A12: A179 EQUALS THE NUMERICAL VALUE, *e.g.* 12.0 IN THE FT, FU, FV, FW & FX COLUMN HEADINGS.

SET THE BEGINNING OF THE S-CURVE LAG (BASED ON A SPECIFIC STORM DURATION) IN COLUMNS FT, FU, FV, FW & FX EQUAL TO CELL FS11 BY ENTERING THE FOLLOWING FORMULA, =FS11.

USE COPY & PASTE FORMULAS TO COPY THIS FORMULA UP UNTIL THE END OF EACH COLUMN IN CELL RANGE FT12: FX179.

SUH S-curve lag (0.5 hour):

Only applicable if *cell E55* (*SUH Method* worksheet) equals 0.5 hour. Time intervals ranging from zero to 84 hours (3½ days) can be evaluated.

Cell FS186: Click and hold the mouse cursor in position. The following comment box with the S-curve lag instructions will appear on screen:

THE BEGINNING OF ANY S-CURVE LAG IN COLUMNS FT to FX IS WHERE THE TIME-VALUE (t, hours) IN COLUMN A187: A354 EQUALS THE NUMERICAL VALUE, *e.g.* 12.0 IN THE FT, FU, FV, FW & FX COLUMN HEADINGS.

SET THE BEGINNING OF THE S-CURVE LAG (BASED ON A SPECIFIC STORM DURATION) IN COLUMNS FT, FU, FV, FW & FX EQUAL TO CELL FS186 BY ENTERING THE FOLLOWING FORMULA, =FS186.

USE COPY & PASTE FORMULAS TO COPY THIS FORMULA UP UNTIL THE END OF EACH COLUMN IN CELL RANGE FT187: FX354.

<u>SUH S-curve lag (0.25 hour):</u>

Only applicable if *cell E55* (*SUH Method* worksheet) equals 0.25 hour. Time intervals ranging from zero to 42 hours (1¾ days) can be evaluated.

Cell FS361: Click and hold the mouse cursor in position. The following comment box with the S-curve lag instructions will appear on screen:

> **THE BEGINNING OF ANY S-CURVE LAG IN COLUMNS FT to FX IS WHERE THE TIME-VALUE (t, hours) IN COLUMN A362: A529 EQUALS THE NUMERICAL VALUE, e.g. 12.0 IN THE FT, FU, FV, FW & FX COLUMN HEADINGS.**
>
> **SET THE BEGINNING OF THE S-CURVE LAG (BASED ON A SPECIFIC STORM DURATION) IN COLUMNS FT, FU, FV, FW & FX EQUAL TO CELL FS361 BY ENTERING THE FOLLOWING FORMULA, =FS361.**
>
> **USE COPY & PASTE FORMULAS TO COPY THIS FORMULA UP UNTIL THE END OF EACH COLUMN IN CELL RANGE FT362: FX529.**

Figure 24 displays an extract of the S-curve lagging results as obtained using above-listed instructions.

HOME | PRINT | **SYNTHETIC UNIT HYDROGRAPH METHOD** | CATCHMENT INFORMATION

Secondary drainage region number	C5	Main watercourse/river	Modder River
Tertiary drainage region number	C52	Designed	OJ Gericke
Quaternary drainage region number	C52A- G	Checked	JA du Plessis
Catchment description	Krugersdrift Dam	Date	June 15, 2009

S-CURVE LAGGING

Q/QP INFORMATION

SUH S-CURVE LAG

Time (t, hours)	t/T_L	T_{SD} =	1.000	UNIT HYDROGRAPHS (hours)				
		Q/Q_P	S-curve (S_1)	12.0	14.0	16.0	18.0	20.0
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.027	0.006	0.006	0.000	0.000	0.000	0.000	0.000
2	0.053	0.011	0.017	0.001	0.001	0.001	0.001	0.001
3	0.080	0.018	0.035	0.003	0.003	0.002	0.002	0.002
4	0.106	0.025	0.060	0.005	0.004	0.004	0.003	0.003
5	0.133	0.033	0.093	0.008	0.007	0.006	0.005	0.005
6	0.159	0.038	0.131	0.011	0.009	0.008	0.007	0.007
7	0.186	0.040	0.171	0.014	0.012	0.011	0.010	0.009
8	0.212	0.047	0.218	0.018	0.016	0.014	0.012	0.011
9	0.239	0.062	0.281	0.023	0.020	0.018	0.016	0.014
10	0.265	0.075	0.356	0.030	0.025	0.022	0.020	0.018
11	0.292	0.085	0.440	0.037	0.031	0.028	0.024	0.022
12	0.319	0.096	0.537	0.045	0.038	0.034	0.030	0.027
13	0.345	0.107	0.644	0.053	0.046	0.040	0.036	0.032
14	0.372	0.122	0.766	0.062	0.055	0.048	0.043	0.038
15	0.398	0.136	0.902	0.072	0.064	0.056	0.050	0.045
16	0.425	0.154	1.056	0.083	0.074	0.066	0.059	0.053
17	0.451	0.174	1.231	0.095	0.085	0.077	0.068	0.062
18	0.478	0.198	1.428	0.108	0.098	0.088	0.079	0.071
19	0.504	0.229	1.657	0.124	0.112	0.101	0.092	0.083
20	0.531	0.299	1.956	0.145	0.130	0.118	0.108	0.098
21	0.558	0.403	2.359	0.173	0.156	0.142	0.129	0.118
22	0.584	0.576	2.936	0.215	0.194	0.175	0.160	0.146
23	0.611	0.755	3.691	0.271	0.244	0.220	0.200	0.183
24	0.637	0.900	4.591	0.338	0.303	0.273	0.248	0.227
25	0.664	0.980	5.571	0.411	0.366	0.331	0.300	0.274
26	0.690	0.993	6.563	0.483	0.430	0.388	0.353	0.322
27	0.717	0.995	7.558	0.555	0.494	0.445	0.404	0.369
28	0.743	0.988	8.546	0.624	0.556	0.501	0.455	0.416
29	0.770	0.947	9.494	0.689	0.614	0.553	0.503	0.461
30	0.796	0.896	10.389	0.747	0.667	0.601	0.547	0.502
31	0.823	0.835	11.224	0.797	0.714	0.645	0.588	0.539
32	0.850	0.767	11.990	0.836	0.754	0.683	0.624	0.573
33	0.876	0.721	12.711	0.863	0.790	0.718	0.656	0.603
34	0.903	0.674	13.385	0.871	0.816	0.747	0.685	0.631
35	0.929	0.628	14.013	0.860	0.832	0.772	0.710	0.656

Figure 24: SUH S-curve lagging results

Click on the SYNTHETIC UNIT HYDROGRAPH button to return to the *SUH Method* worksheet. The following applies:

Summary of peak flows:

Cell B54: Comment: "The SUH method can only estimate peak flows for two return periods at a time. After every two return period selections, the results must be entered in the applicable cell within *cell range C54:K54*, before proceeding to the next analysis."

The peak flow adjustment calculations and summary of peak flows are illustrated in Figure 25.

	A	B	C	D	E	F	G	H	I	J	K	L
1	HOME	PRINT	SYNTHETIC UNIT HYDROGRAPH METHOD							CATCHMENT INFORMATION		
2	Secondary drainage region number		C5		Main watercourse/river				Modder River			
3	Tertiary drainage region number		C52		Designed				OJ Gericke			
4	Quaternary drainage region number		C52A- G		Checked				JA du Plessis			
5	Catchment description		Krugersdrift Dam		Date				June 15, 2009			
47	PEAK FLOW ADJUSTMENTS	Return period (T)	100			years		200			years	
48		Storm duration (T_{SD}, hours)	12.00	14.00	16.00	18.00	20.00	12.00	14.00	16.00	18.00	20.00
49		SUH peak (Q_{PT}, m^3/s)	56.215	53.775	51.632	49.576	47.577	56.215	53.775	51.632	49.576	47.577
50		Peak flow (Q_T, m^3/s)	1675.843	1694.479	1703.925	1703.991	1694.230	2025.330	2048.723	2062.503	2062.721	2051.692
51		$Q_{PT}/Q_P<1$	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995
52		Adjusted peak flow (Q_{TA}, m^3/s)	1667	1685	1695	1695	1685	2014	2038	2051	2052	2041
53	SUMMARY OF PEAK FLOWS	Return period (T, years)	2	5	10	20	50		100		200	
54		Adjusted peak flow (Q_{TA}, m^3/s)	236	393	572	804	1222		1695		2052	

Figure 25: Peak flow adjustments and summary

2.10.3 Calculation procedure

Physical catchment characteristics:

$$I_C = \frac{L\,L_C}{\sqrt{S_{CH}}} \qquad (37)$$

$$T_L = C_T I_C^{\,0.36} \qquad (38)$$

$$Q_P = K_U \frac{A}{T_L} \qquad (39)$$

where:

A = catchment area [km²],

C_T = regional SUH veld-type coefficient [Table 2],

I_C = catchment-index,

K_U = regional SUH coefficient,

L = hydraulic length of catchment [km],

L_C = distance to catchment centroid [km],

Q_P = peak flow of 1-hour unit hydrograph [m^3/s]

S_{CH} = average main watercourse slope [m/m], and

T_L = lag time [hours].

Table 2: Generalised regional SUH veld-type coefficients (HRU, 1972)

Veld region	Veld-type description	C_T
1	Coastal tropical forest	0.99
2	Schlerophyllous bush	0.62
3	Mountain sourveld	0.35
4	Grassland of interior plateau	0.32
5	Highland sourveld and Dohne sourveld	0.21
5A	Zone 5, soils weakly developed	0.53
6	Karoo	0.19
7	False Karoo	0.19
8	Bushveld	0.19
9	Tall sourveld	0.13

Design rainfall information:

The following DDF relationships (based on user-defined critical storm durations related to T_C and T_L using a trail-and-error approach) of averaged design rainfall information are possible options in the SUH method:

(a) Midgley and Pitman (M&P) DDF relationship based on LEV1 distributions (Midgley and Pitman, 1978); and

(b) DDF relationship based on the RLMA&SI approach.

Design point rainfall ($P_{T\ M\&P}$):

Refer to Section 2.6.3.

Design point rainfall ($P_{T\ RLMA\&SI}$):

Refer to Section 2.6.3.

Design point rainfall intensity (I_T):

Refer to Section 2.6.3.

Areal reduction factors:

Refer to Section 2.6.3.

Average and effective design rainfall:

$$P_{T\,Avg} = \frac{ARF}{100} P_T \tag{40}$$

$$P_{TE} = \frac{f_T}{100} P_{T\,Avg} \tag{41}$$

where:

ARF = areal reduction factor [%],

f_T = flood runoff factor [%, Figure 26],

P_T = design point rainfall [mm],

$P_{T\,Avg}$ = average design rainfall [mm], and

P_{TE} = effective average design rainfall [mm].

Peak flow and adjusted peak flow:

$$Q_{PT} = Q_P * UH_{Max\,(n\text{-}hour)} \tag{42}$$

$$Q_T = P_{TE} * Q_{PT} \tag{43}$$

$$Q_{TA} = Q_T \frac{Q_{PT}}{Q_P} \tag{44}$$

where:

Q_P = peak flow of 1-hour unit hydrograph [m^3/s],

Q_{PT} = peak flow of *n*-hour unit hydrograph [m^3/s],

Q_T = peak flow for *T*-year return period [m^3/s],

Q_{TA} = adjusted peak flow for *T*-year return period [m^3/s],

P_{TE} = effective average design rainfall [mm], and

UH_{Max} = maximum *n*-hour unit hydrograph value.

Figure 26 shows the average storm losses chart normally used to estimate the flood runoff factors manually. However, in the DFET, this chart is included numerically and no user input is required, except for the area distribution (%) associated with the different veld-type regions (Figure 27) when the catchment under consideration extends over more than one veld-type region.

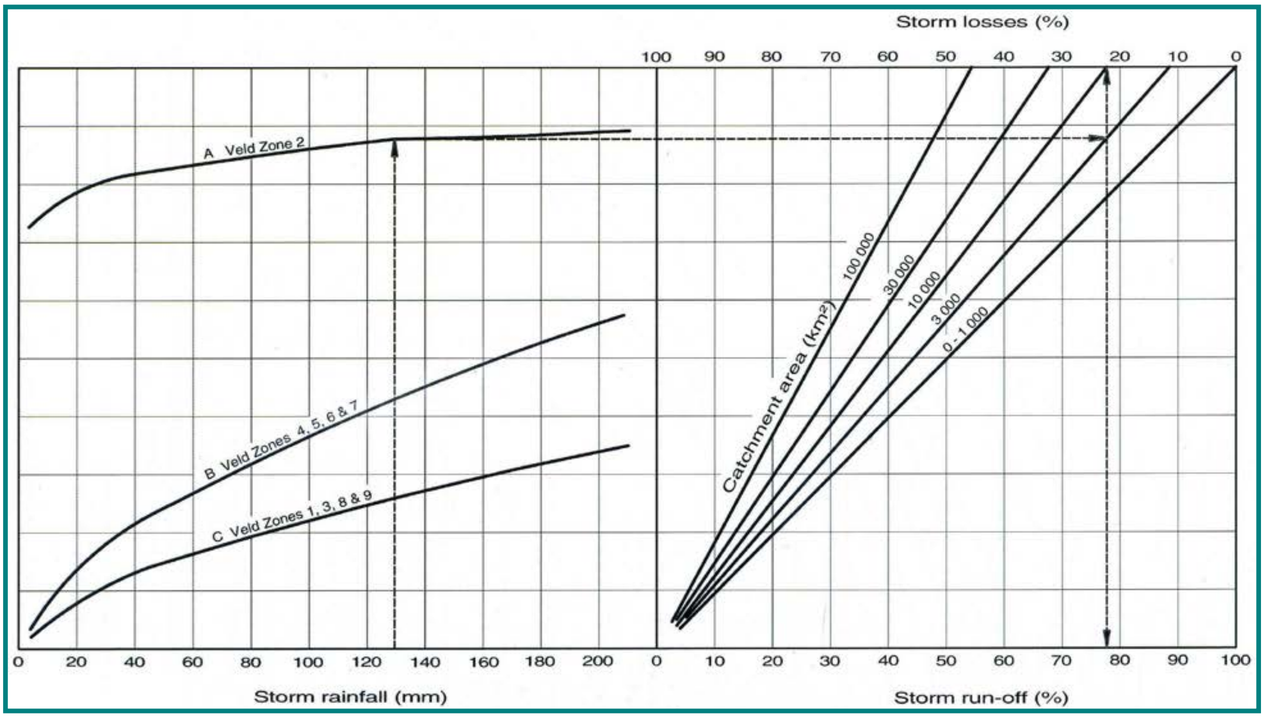


Figure 26: Average storm losses (SANRAL, 2006)

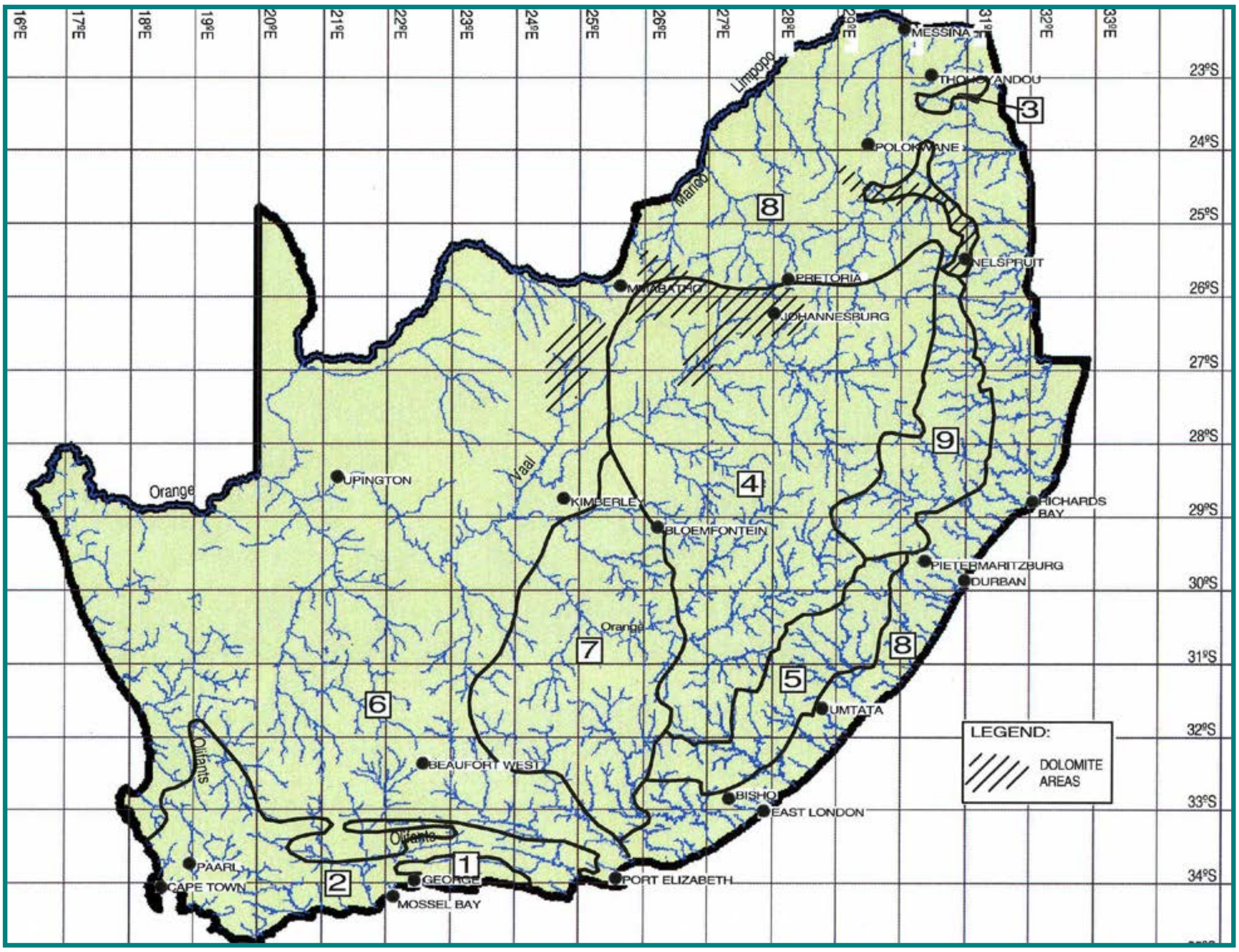


Figure 27: Regions with generalised veld-types in South Africa (SANRAL, 2006)

2.11 Lag-routed Hydrograph (LRH) Method

2.11.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Design Rainfall* worksheets are pre-requisite input for this worksheet. This worksheet is also linked to the *Channel Slope, LRH Runoff Factors* and *Rainfall Distribution* worksheets. The *Rainfall distribution over Time* chart can be viewed by clicking on the RAINFALL DISTRIBUTION button.

2.11.2 Input ranges and comments

Input range identifier:

Single cell entries (light-green shaded and unprotected), option buttons and spinner buttons which enable the user to increase or decrease the veld-type number associated with a specific veld-type region. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Physical catchment characteristics:

Cell range

B9:B11: Enter the area distribution (%) associated with the veld-type region number in *cell range D9:D11*. Use the spinner button to increase or decrease the veld region number in the latter cell range.

Click on the VELD-TYPE MAP button to view the "*General Veld-type Region*" map to enable the selection of the appropriate region.

<u>*Note:*</u> The sum of *cell range B9:B11* must be equal to 100%.

Cell I12: Select the appropriate option button contained in the Muskingum routing factor group box by indicating either "Veld-type based" or "T_C based". If "Veld-type based" is selected, the routing factor (K) contained in *cell I11* will be used. By selecting "T_C based," the routing factor (K) contained in *cell I10* will be used.

Design rainfall information:

Cell C21: Only applicable if the 1' x 1'Grid RLMA&SI design rainfall method was selected at the *Catchment Information* worksheet.

Comment: "Enter a user-defined ARF or an ARF equal to the default ARF in *cell range C20:J20*. To exclude the use of an ARF, enter a value of 100 (recommended)."

2.11.3 Calculation procedure

Physical catchment characteristics:

$$\Delta t = 0.05T_C \tag{45}$$

$$K_1 = 0.6T_C \tag{46}$$

$$K_2 = C_T A^{0.318} \tag{47}$$

$$C_0 = -\frac{K_n}{\Delta t}(1 - C_2) + 1 \tag{48}$$

$$C_1 = \frac{K_n}{\Delta t}(1 - C_2) - C_2 \tag{49}$$

$$C_2 = e^{-\frac{\Delta t}{Kn}} \tag{50}$$

where:

A = catchment area [km²],

C_T = regional LRH veld-type coefficient [Table 3],

C_0 = Muskingum routing coefficient,

C_1 = Muskingum routing coefficient,

C_2 = Muskingum routing coefficient,

K_n = Muskingum routing factor, either T_C based or veld-type based,

K_1 = Muskingum routing factor, T_C based,

K_2 = Muskingum routing factor, veld-type based,

Δt = incremental time step [hours], and

T_C = time of concentration [hours].

Table 3: Regional LRH veld-type coefficients (Bauer and Midgley, 1974)

Veld region	Veld-type description	C_T
1	Coastal tropical forest	1.83
2	Schlerophyllous bush	1.30
3	Mountain sourveld	1.10
4	Grassland of interior plateau	0.97
5	Highland sourveld and Dohne sourveld	0.79
6	Karoo	0.86
7	False Karoo	0.48
8	Bushveld	0.45
9	Tall sourveld	0.55

An example of the physical catchment characteristics screen illustrating above-listed instructions and calculation procedures is shown in Figure 28.

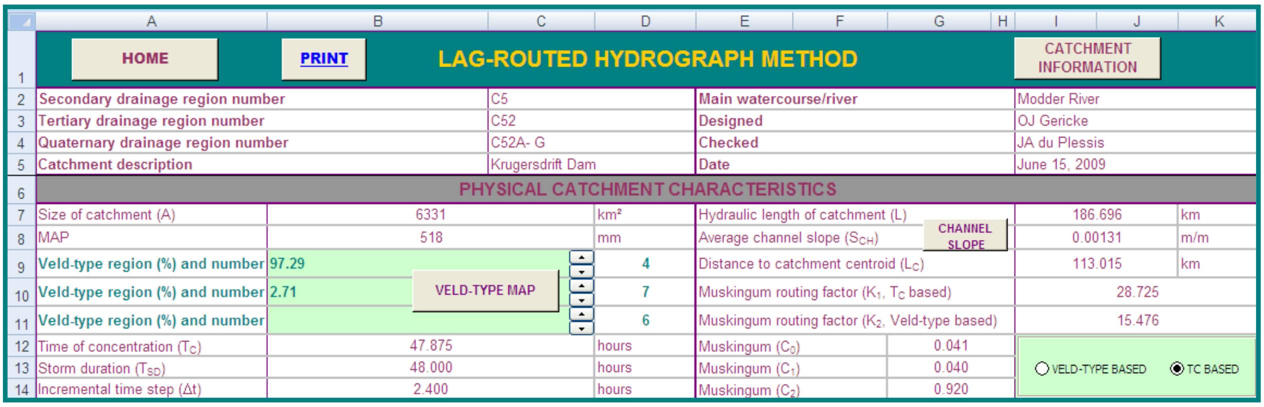


Figure 28: LRH veld-type regions and Muskingum routing factors

Design point rainfall ($P_{T\ M\&P}$):

Refer to Section 2.10.3.

Design point rainfall ($P_{T\ RLMA\&SI}$):

Refer to Section 2.10.3.

Design point rainfall intensity (I_T):

Refer to Section 2.10.3.

Areal reduction factors:

Refer to Section 2.10.3.

Average and effective design rainfall:

Refer to Section 2.10.3.

Rainfall distribution over time:

The estimation of effective average design rainfall is followed by the estimation of rainfall distribution over time. In other words, the excess/effective rainfall as a percentage of the critical storm duration must be estimated. Figure 29 shows the rainfall distribution over time curves used for these estimations.

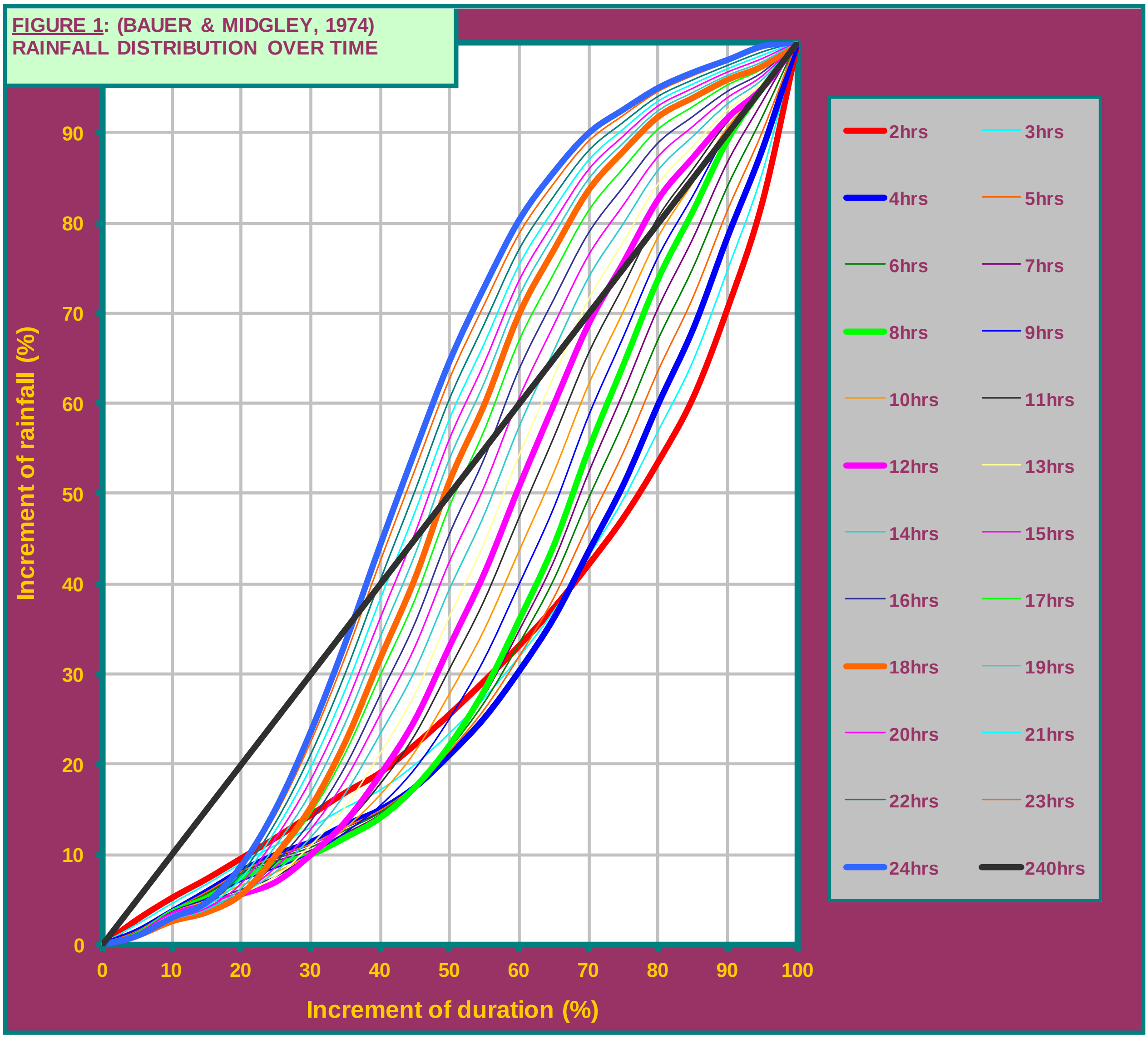


Figure 29: Rainfall distribution over time curves (Bauer and Midgley, 1974)

In the DFET, these curves are included numerically and no user input is required, thus the hyetographs used to derive the hydrographs are determined automatically.

Muskingum routing:

$$Q_{out(N)} = C_0 Q_{in(N)} + C_1 Q_{in(N-1)} + C_2 Q_{out(N-1)} \tag{51}$$

where:

$C_{0,\,1,\,2}$ = Muskingum routing coefficients,

$Q_{in(N)}$ = routed peak inflow at current time interval [m^3/s],

$Q_{in(N-1)}$ = routed peak inflow at previous time interval [m^3/s],

$Q_{out(N)}$ = routed peak outflow at current time interval [m^3/s], and

$Q_{out(N-1)}$= routed peak outflow at previous time interval [m^3/s].

Peak flows:

$$Q_T = Max\ Q_{out\ (N,T)} \tag{52}$$

where:

Q_T = peak flow for T-year return period [m^3/s], and

$Max\ Q_{out\ (N,T)}$ = maximum routed outflow associated with a specific incremental duration and rainfall distribution for the T-year return period [m^3/s].

Figure 30 is illustrative of the rainfall distribution over time and Muskingum routing results screen.

HOME | PRINT | **LAG-ROUTED HYDROGRAPH METHOD** | CATCHMENT INFORMATION

Secondary drainage region number	C5	Main watercourse/river	Modder River
Tertiary drainage region number	C52	Designed	OJ Gericke
Quaternary drainage region number	C52A- G	Checked	JA du Plessis
Catchment description	Krugersdrift Dam	Date	June 15, 2009

RAINFALL DISTRIBUTION OVER TIME		MUSKINGUM ROUTING						
Duration-increment used	5% RAINFALL DISTRIBUTION	1: 2 year	1: 5 year	1: 10 year	1: 20 year	1: 50 year	1: 100 year	1: 200 year
Increment of duration (%)	Increment of precipitation (%)	Routed (Out_i)	Routed (Out_i)	Routed (Out_i)	Routed (Out_i)	Routed (Out_i)	Routed (Out_i)	Routed (Out_i)
0	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.44	2.861	4.678	6.851	9.621	14.531	20.383	24.769
10	3.78	10.036	16.408	24.031	33.750	50.973	71.500	86.885
15	5.84	17.820	29.134	42.670	59.926	90.507	126.955	154.274
20	10.04	28.693	46.909	68.702	96.487	145.726	204.410	248.396
25	16.29	46.853	76.598	112.185	157.555	237.958	333.785	405.610
30	24.40	71.193	116.392	170.466	239.406	361.579	507.189	616.327
35	33.76	99.644	162.905	238.588	335.077	506.074	709.873	862.625
40	43.91	129.795	212.199	310.784	436.471	659.210	924.679	1123.652
45	53.71	158.367	258.911	379.197	532.551	804.322	1128.228	1371.002
50	63.16	183.260	299.607	438.800	616.258	930.747	1305.565	1586.498
55	71.00	202.303	330.739	484.397	680.295	1027.462	1441.229	1751.355
60	78.13	215.328	352.035	515.585	724.097	1093.618	1534.026	1864.119
65	83.40	222.242	363.339	532.141	747.348	1128.734	1583.283	1923.976
70	87.78	223.246	364.979	534.543	750.722	1133.829	1590.431	1932.662
75	90.64	219.463	358.795	525.486	738.001	1114.618	1563.482	1899.914
80	93.33	212.720	347.771	509.341	715.327	1080.373	1515.447	1841.542
85	95.40	204.943	335.056	490.719	689.175	1040.874	1460.041	1774.214
90	97.20	196.063	320.538	469.455	659.311	995.770	1396.774	1697.333
95	99.09	187.556	306.631	449.087	630.706	952.567	1336.173	1623.692
100	100.00	177.966	290.952	426.124	598.456	903.860	1267.851	1540.669
PEAK FLOWS		Return period (T, years)						
		2	5	10	20	50	100	200
Peak flow (Q_T, m^3/s)		223	365	535	751	1134	1590	1933

Figure 30: Rainfall distribution over time and Muskingum routing results

2.12 Empirical Methods

2.12.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Design Rainfall* worksheets are pre-requisite input for this worksheet. This worksheet is also linked to the *Catchment Slope, Channel Slope* and *Design Tables* worksheets.

2.12.2 Input ranges and comments

Input range identifier:

Single cell entries (light-green shaded and unprotected), group box (drop-down list), option buttons and spinner buttons.

Physical catchment characteristics:

Cell range

A10:A12: Enter the Kovács region %-distribution associated with the Kovács region number selected from the group box (drop-down list, 8 options available). Click on the KOVÁCS MAP button to view the *"Kovács Region"* map to enable the selection of the appropriate region(s).

<u>*Note:*</u> The sum of *cell range B10:B12* must be equal to 100%.

Cell range

F10:F12: Enter the area distribution (%) associated with the veld-type region number in *cell range G10:G12*. Use the spinner button to increase or decrease the veld region number in the latter cell range.

Click on the VELD-TYPE MAP button to view the "*General Veld-type Region*" map to enable the selection of the appropriate region.

<u>*Note:*</u> The sum of *cell range F10:F12* must be equal to 100%.

Cell G13: Select the appropriate option button contained in the veld- type/rainfall group box by indicating either "Winter" or "All year". If "Winter" is selected, the regional distribution coefficient (K_T) used in the MIPI method will be based on the above selected veld-type regions and winter rainfall, while "All year" will reflect the chosen veld-type regions and summer/all year rainfall.

Design notes:

Cell range

A79:A86: The user can enter any comments/design notes/recommendations in this cell range.

2.12.3 Calculation procedure

Physical catchment characteristics:

$$C = \frac{A\sqrt{S_{CH}}}{LL_C} \tag{53}$$

where:

C = catchment response time parameter,

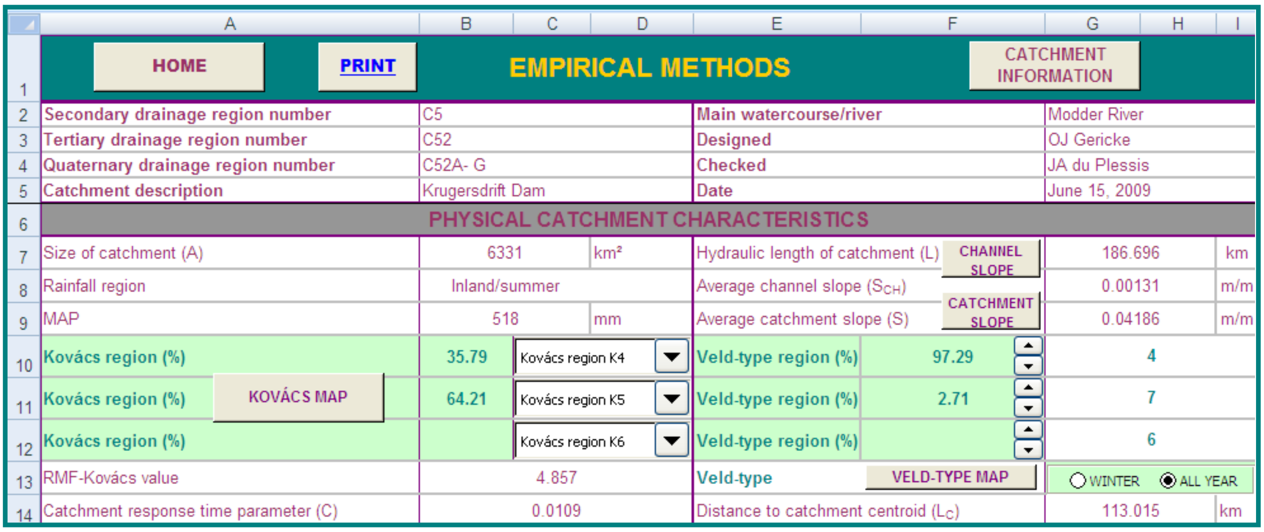
A = catchment area [km²],

L = hydraulic length of catchment [km],

L_C = distance to catchment centroid [km], and

S_{CH} = average main watercourse slope [m/m].

An example of the physical catchment characteristics screen illustrative of above-listed instructions and estimation procedures is shown in Figure 31.



	A		B	C	D	E	F	G	H
1	HOME	PRINT	EMPIRICAL METHODS					CATCHMENT INFORMATION	
2	Secondary drainage region number		C5			Main watercourse/river		Modder River	
3	Tertiary drainage region number		C52			Designed		OJ Gericke	
4	Quaternary drainage region number		C52A- G			Checked		JA du Plessis	
5	Catchment description		Krugersdrift Dam			Date		June 15, 2009	
6	PHYSICAL CATCHMENT CHARACTERISTICS								
7	Size of catchment (A)		6331	km²		Hydraulic length of catchment (L)	CHANNEL SLOPE	186.696	km
8	Rainfall region		Inland/summer			Average channel slope (S_{CH})		0.00131	m/m
9	MAP		518	mm		Average catchment slope (S)	CATCHMENT SLOPE	0.04186	m/m
10	Kovács region (%)		35.79	Kovács region K4		Veld-type region (%)	97.29	4	
11	Kovács region (%)	KOVÁCS MAP	64.21	Kovács region K5		Veld-type region (%)	2.71	7	
12	Kovács region (%)			Kovács region K6		Veld-type region (%)		6	
13	RMF-Kovács value		4.857			Veld-type	VELD-TYPE MAP	WINTER / ALL YEAR	
14	Catchment response time parameter (C)		0.0109			Distance to catchment centroid (L_C)		113.015	km

Figure 31: Physical catchment characteristics screen of Empirical methods

Midgley and Pitman (MIPI) method:

$$Q_T = 0.0377 K_T MAP\, A^{0.6}\, C^{0.2} \qquad (54)$$

where:

Q_T = peak flow for T-year return period [m^3/s],

A = catchment area [km²],

C = catchment response time parameter,

K_T = regional distribution coefficient, and

MAP = mean annual precipitation [mm].

Catchment Parameter (CAPA) method:

$$M = MAP\left(\sqrt{\frac{100SA^{0.5}}{L}}\right) \qquad (55)$$

$$K_P = x\log(MAP)^y \qquad (56)$$

$$MAF = 10^{(a+0.61\log A)} \qquad (57)$$

$$Q_T = K_P MAF \qquad (58)$$

where:

A = catchment area [km²],

K_P = exceedance probability constant,

L = hydraulic length of catchment [km],

M = lumped catchment parameter,

MAF = mean annual flood [m^3/s],

MAP = mean annual precipitation [mm],

Q_T = peak flow for T-year return period [m^3/s],

S = average catchment slope [m/m],

T = return period [years],

a $= -0.9414 + 1.08073(\log(M) - 2.0163)^{0.7384}$,

x $= 99.51\log\left(\frac{1}{T}\right)^4 - 5.95\log\left(\frac{1}{T}\right)^2 + 0.722$, and

y $= 0.28\log\left(\frac{1}{T}\right)^4 + 2.22\log\left(\frac{1}{T}\right)^3 + 6.82\log\left(\frac{1}{T}\right)^2 + 10.92\log\left(\frac{1}{T}\right) + 2.73$

Regional Maximum Flood (RMF) method:

$$Q_{RMF1} = 10^6\left(\frac{A}{10^8}\right)^{1-0.1K} \quad (59)$$

Table 4 presents all the Q_{RMF2} equations as proposed by Kovács (1988) for the different Kovács regions in Southern Africa.

Table 4: RMF regional classification in Southern Africa (SANRAL, 2006)

Regional constant (K)	Transition zone		Flood zone	
	Q_{RMF2} (m³/s)	Areal range (km²)	Q_{RMF2} (m³/s)	Areal range (km²)
2.8	$30A^{0.262}$	1 - 500	$1.74A^{0.720}$	500 - 500 000
3.4	$50A^{0.265}$	1 - 300	$5.25A^{0.660}$	300 - 500 000
4	$70A^{0.340}$	1 - 300	$15.9A^{0.600}$	300 - 300 000
4.6	$100A^{0.380}$	1 - 100	$47.9A^{0.540}$	100 - 100 000
5	$100A^{0.500}$	1 - 100	$100A^{0.500}$	100 - 100 000
5.2	$100A^{0.560}$	1 - 100	$145A^{0.480}$	100 - 30 000
5.4	$100A^{0.620}$	1 - 100	$209A^{0.460}$	100 - 20 000
5.6	$100A^{0.680}$	1 - 100	$302A^{0.440}$	100 - 10 000

where:

A = catchment area [km²],

K = Kovács regional constant,

Q_{RMF1} = RMF based on the Francou-Rodier methodology [Equation 59, m³/s], and

Q_{RMF2} = RMF based on the Kovács methodology [Equations in Table 4, m³/s].

The layout of the *Empirical Methods* worksheet containing the design flood estimation results is shown in Figure 32, while Figure 33 is illustrative of the maximum flood peak regions in Southern Africa, in other words, the Kovács regions.

	A	B	C	D	E	F	G	H
1	HOME / PRINT		EMPIRICAL METHODS				CATCHMENT INFORMATION	
2	Secondary drainage region number	C5			Main watercourse/river		Modder River	
3	Tertiary drainage region number	C52			Designed		OJ Gericke	
4	Quaternary drainage region number	C52A- G			Checked		JA du Plessis	
5	Catchment description	Krugersdrift Dam			Date		June 15, 2009	
15	MIDGLEY AND PITMAN METHOD (MIPI, HRU 1/71)							
16	Return period (T, years)	10			20	50	100	
17	Regional distribution coefficient (K_T)	0.592			0.686	0.958	1.211	
18	Peak flow (Q_T, m^3/s)	894			1037	1448	1829	
19	CATCHMENT PARAMETER (CAPA) METHOD							
20	Return period (T, years)	2	5	10	20	50	100	200
21	Lumped catchment parameter (M)	692.502	692.502	692.502	692.502	692.502	692.502	692.502
25	Probability of exceedance constant (K_P)	1.000	2.247	3.449	4.965	7.486	9.511	11.504
26	Mean annual flood (MAF, $Q_{50\%}$, m^3/s)	206.243	206.243	206.243	206.243	206.243	206.243	206.243
27	Peak flow (Q_T, m^3/s)	206	463	711	1024	1544	1962	2373
28	REGIONAL MAXIMUM FLOOD (RMF) METHOD							
29	Peak flow (Q_{RMF1}, m^3/s, Francou-Rodier)	6928						
30	KOVÁCS REGIONALISATION	Transition zone <	100 km^2			Flood zone ≤	100000 km^2	
31	Peak flow (Q_{RMF2}, m^3/s)	6105				7045		
32	MIPI/RMF RATIOS (Q_T/Q_{RMF})							
33	Return period (T, years)	2	5	10	20	50	100	200
34	Weighted $Q_{T/RMF}$ ratio: A ≤ 10 km²	DESIGN TABLES						
35	Weighted $Q_{T/RMF}$ ratio: 10 < A ≤ 3 000 km²							
36	Weighted $Q_{T/RMF}$ ratio: 3 000 < A ≤ 100 000 km²					0.492	0.591	0.692
77	Q_T/Q_{RMF} ratio peak flow (Q_T, m^3/s)					3409	4097	4796

Figure 32: Empirical flood estimation results

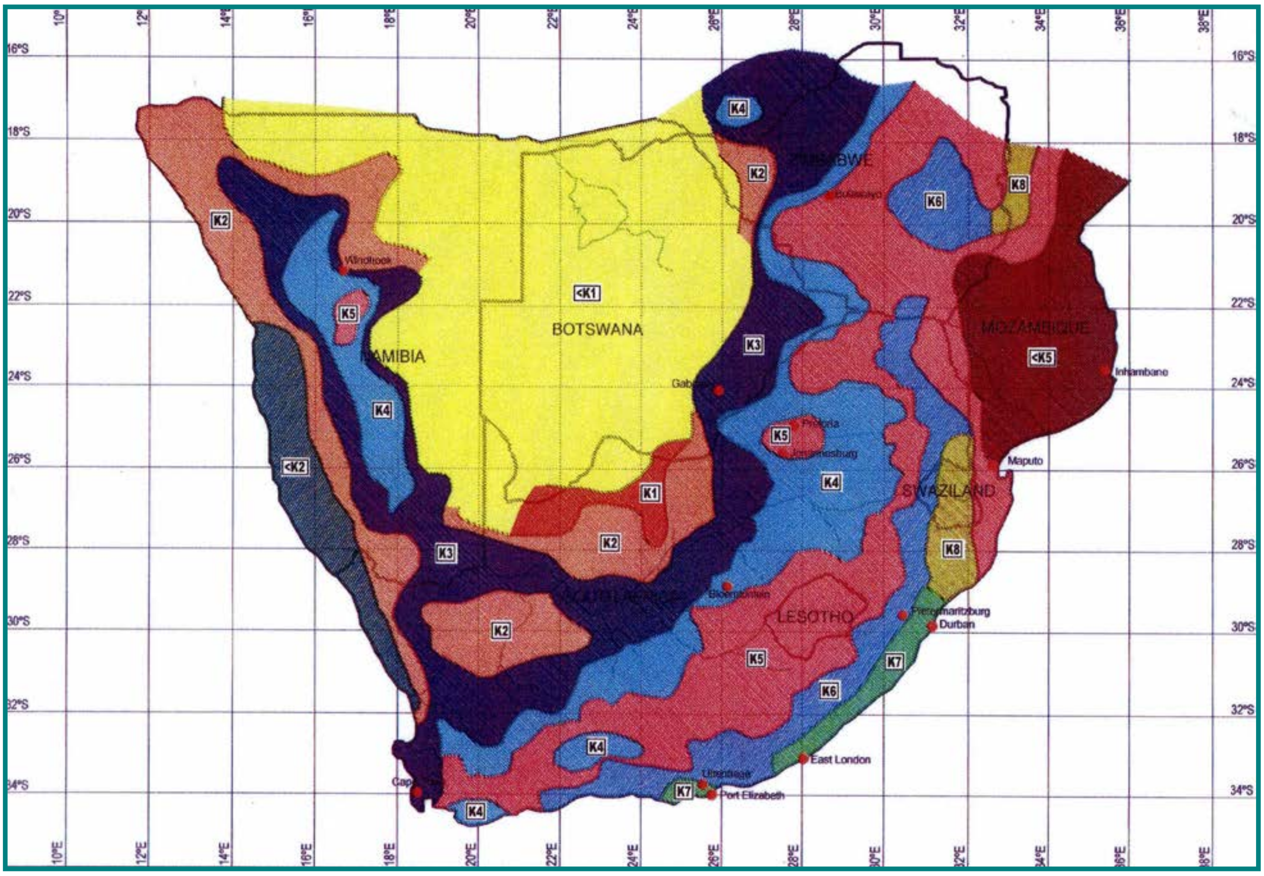


Figure 33: Maximum flood peak (Kovács) regions in Southern Africa (SANRAL, 2006)

3. PROBABILISTIC METHODS

3.1 Annual Maximum Series (AMS)

3.1.1 Pre-requisite input and linked worksheets

The *Catchment Information* worksheet is a pre-requisite input for this worksheet. The *Annual Maximum Series* worksheet is also linked to the *Probabilistic Methods (AMS)* worksheet.

3.1.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected). Click and hold the mouse cursor in position to read any comment box (cells with red flags).

<u>Note:</u>

The annual maximum series as obtained from the Department of Water Affairs (DWA) monthly flood peak database must be copied into *cell ranges D14:D213, F14:F213* and *G14:G213*, if applicable. Use *Copy & Paste values* to retain the cell format. A maximum period of 200 years can be used. Enter the start date (year) of the data period in *cell A14*.

Base flow-gauging station:

Cell D7: Compulsory.
Enter the flow-gauging station name, *e.g.* Krugersdrift Dam. It can either be a dam or a river flow-gauging station.

Cell D8: Compulsory.
Enter the flow-gauging station number, *e.g.* C5R004.

Cell D10: Compulsory.
Enter the structural limit (m^3/s) of the flow-gauging station. If the structural limit is unknown, enter the peak flow as estimated with the RMF method.

Cell A14: Click and hold the mouse cursor in position.
<u>Comment:</u> "Enter the start date (year) of data period."

Cell range

D14:D213: Copy the annual maximum peak flow data into this cell range or a part thereof. Use *Copy & Paste values* to retain the cell format.

Additional station 1/2 (US/DS):

Cell F6/G6: Click and hold the mouse cursor in position. The following comment box related to the use of additional stations will appear on screen:

> **THE ANNUAL MAXIMUM SERIES (m^3/s) OF THE ADDITIONAL STATIONS ARE USED TO SUPPLEMENT/EXTEND THE RECORD LENGTH OF THE BASE STATION.**
>
> **COPY THE ANNUAL MAXIMUM SERIES INTO THE "REQUIRED PART" OF CELL RANGE F14: F213 (STATION 1) or G14:G213 (STATION 2).**
>
> **THE "REQUIRED PART" REFERS TO THE BASE STATION DATA PERIOD CHARACTERISED BY MISSING DATA.**
>
> **CELL ENTRIES IN THE SAME ROW OF COLUMNS D, F and G ARE NOT ALLOWED.**
>
> **IN ALL CASES, USE COPY & PASTE VALUES FOR MULTIPLE ENTRIES.**

Cell F7/G7: Compulsory, if applicable.
Enter the flow-gauging station name, *e.g.* Modder River at Stoomhoek. It can either be a dam or a river flow-gauging station.

Cell F8/G8: Compulsory, if applicable.
Enter the flow-gauging station number, *e.g.* C5H015.

Cell
F11/G11: Compulsory, if applicable.
Enter the catchment area (km²) contributing to the specific flow-gauging station.

Cell range(s)
F14:F213 or
G14:G213: Refer to above-listed comment box.

3.1.3 Calculation procedure

Square root area method (SRAM):

In the SRAM (Equation 60), the AMS or PDS at single sites up- or downstream from one another (in close proximity) could be combined, based on the assumption that the temporal and spatial variability of the flood producing mechanisms in the two or more catchment under consideration are near homogeneous. The SRAM is especially useful to supplement the record length at dams using data from a flow-gauging station just downstream or upstream from the dam, which might have been operational prior the construction of the dam. However, the homogeneity in these catchments under consideration must be 80% or more (Rademeyer, 2010).

$$Q_{DS} = Q_{US}\left(\frac{\sqrt{A_{DS}}}{\sqrt{A_{US}}}\right) \tag{60}$$

where:

Q_{DS} = AMS or PDS at downstream flow-gauging station [m^3/s],

A_{DS} = catchment area contributing to downstream flow-gauging station [km²],

A_{US} = catchment area contributing to upstream flow-gauging station [km²], and

Q_{US} = AMS or PDS at upstream flow-gauging station [m^3/s].

The AMS worksheet illustrative of above-listed instructions and SRAM is shown in Figure 34.

	A	B	C	D	E	F	G
1	HOME		PRINT	SQUARE ROOT AREA METHOD (SRAM)			PROBABILISTIC METHODS (AMS)
2	NOTE:						
3	THE ANNUAL MAXIMUM SERIES AS OBTAINED FROM THE DEPARTMENT OF WATER AFFAIRS (DWA) MONTHLY FLOOD PEAK DATABASE						
4	MUST BE COPIED INTO CELL RANGES D14:D213, F14:F213 & G14: G213, IF APPLICABLE. USE COPY & PASTE VALUES TO RETAIN THE CELL FORMAT.						
5	A MAXIMUM PERIOD OF 200 YEARS CAN BE USED. ENTER THE START DATE (YEAR) OF THE DATA PERIOD IN CELL A14.						
6	BASE FLOW-GAUGING STATION					ADDITIONAL STATION 1 (US/DS)	ADDITIONAL STATION 2 (US/DS)
7	Station name (Dam/River)			Krugersdrift Dam		Modder River at Stoomhoek	
8	Station number (R/H)			C5R004		C5H015	
9	Structural limit (H, m)						
10	Structural limit (Q, m³/s)			3000			
11	Catchment area (A, km²)			6331.000		6009.000	
12	Square root area factor			1.000		1.026	
13	Year:Start	/	Year: End	Annual Maximum Q (m³/s)		Annual Maximum Q (m³/s)	Annual Maximum Q (m³/s)
14	1948	/	1949		137.543	134.000	
15	1949	/	1950		773.938	754.000	
16	1950	/	1951		240.188	234.000	
17	1951	/	1952		339.753	331.000	
18	1952	/	1953		1090.083	1062.000	
19	1953	/	1954		187.839	183.000	
20	1954	/	1955		570.703	556.000	
21	1955	/	1956		1642.310	1600.000	
22	1956	/	1957		86.221	84.000	
23	1957	/	1958		56.454	55.000	
24	1958	/	1959		362.335	353.000	
25	1959	/	1960		374.652	365.000	
26	1960	/	1961		153.967	150.000	
27	1961	/	1962		60.560	59.000	
28	1962	/	1963		636.395	620.000	
29	1963	/	1964		985.386	960.000	
30	1964	/	1965		482.428	470.000	
31	1965	/	1966		1087.004	1059.000	
32	1966	/	1967		555.306	541.000	
33	1967	/	1968		537.856	524.000	
34	1968	/	1969		366.440	357.000	
35	1969	/	1970		162.178	158.000	

Figure 34: *Annual Maximum Series* worksheet with SRAM functionality

3.2 Probabilistic Methods (AMS)

3.2.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Annual Maximum Series* worksheets are pre-requisite input for this worksheet. The *Probabilistic Methods (AMS)* worksheet is also linked to the *Probabilistic Methods (PDS)* and *Probabilistic Plotting* worksheets.

3.2.2 Input ranges and comments

Input range identifier:

Not applicable, since this worksheet is only used for calculations.

3.2.3 Calculation procedure

Conservation statistics (Missing data excluded):

Normal and $\log_{10}$-transformed data:

$$\bar{x} = \frac{\sum x}{N} \tag{61}$$

$$\overline{\log x} = \frac{\sum \log(x)}{N} \tag{62}$$

$$s = \left[\frac{\sum (x-\bar{x})^2}{N-1}\right]^{0.5} \tag{63}$$

$$s_{log} = \left[\frac{\sum \left(\log(x)-\overline{\log(x)}\right)^2}{N-1}\right]^{0.5} \tag{64}$$

$$c_v = \frac{s}{\bar{x}} \tag{65}$$

$$c_v = \frac{s_{\log}}{\overline{\log(x)}} \tag{66}$$

$$g = \left(\frac{N}{(N-1)(N-2)}\right)\left(\frac{\sum (x-\bar{x})^3}{s^3}\right) \tag{67}$$

$$g_{log} = \left(\frac{N}{(N-1)(N-2)}\right)\left(\frac{\sum\left(\log(x)-\overline{\log(x)}\right)^3}{s_{\log}{}^3}\right) \tag{68}$$

where:

c_v = coefficient of variation,

c_{vlog} = coefficient of variation of the observed value logarithms,

g = skewness coefficient,

g_{log} = skewness coefficient of the observed value logarithms,

N = total number of observations (sample size),

s = standard deviation of observed values [m^3/s],

s_{log} = standard deviation of the observed value logarithms [m^3/s],

x = observed values [m^3/s],

$\overline{x}$ = mean of observed values [m^3/s], and

$\overline{\log x}$ = mean of observed value logarithms [m^3/s].

Conservation statistics (Missing data included; historically weighted variables):

Normal and log$_{10}$-transformed data:

$$\overline{x_h} = \frac{\left((W_T)\sum x_b + \sum x_a\right)}{\left(Y_T - (W_T)(L_W)\right)} \tag{69}$$

$$s_h = \left[\frac{\left((W_T)\sum d_b{}^2 + \sum d_a{}^2\right)}{\left(Y_T - (W_T)(L_W) - 1\right)}\right]^{0.5} \tag{70}$$

$$g_h = \left[\frac{\dfrac{\left(Y_T - (W_T)(L_W)\right)\left((W_T)\sum d_b{}^3 + \sum d_a{}^3\right)}{s^3}}{\left(Y_T - (W_T)(L_W) - 1\right)\left(Y_T - (W_T)(L_W) - 2\right)}\right] \tag{71}$$

where:

d_a, d_b = deviations of $x_a + x_b$ from $\overline{x_h}$,

g_h = historically weighted skewness coefficient,

L_W = low outliers including zero flows,

N_A = floods equal to or above high threshold,

N_B = floods between high and low thresholds,

N_C = missing data,

s_h = historically weighted standard deviation [m^3/s],

W_T = weight applied to data, $\frac{(Y_T - N_A)}{N_B}$

x_a = peak flows equal to or above the high threshold [m^3/s],

x_b = peak flows below the high threshold [m^3/s],

$\overline{x_h}$ = historically weighted mean [m^3/s], and

Y_T = total time span, N_A+N_B+N_C [years].

An example of the *Probabilistic Methods (AMS)* worksheet containing the conservation statistics and historically weighted variables is shown in Figure 35.

	A–C		D–E		F–G		H
1	HOME	ANNUAL MAXIMUM SERIES	PROBABILISTIC METHODS (AMS)			PROBABILISTIC METHODS (PDS)	
2	Secondary drainage region number		C5	PRINT	Main watercourse/river		Modder River
3	Tertiary drainage region number		C52		Designed		OJ Gericke
4	Quaternary drainage region number		C52A- G		Checked		JA du Plessis
5	Catchment description		Krugersdrift Dam		Date		June 15, 2009
6	Flow-gauging station name		Krugersdrift Dam		Flow-gauging station number		C5R004
7	CONSERVATION STATISTICS				PROBABILISTIC PLOTTING		
8	MISSING DATA EXCLUDED				MISSING DATA INCLUDED		
9	Variable	Normal data	Log$_{10}$-transformed data		Variable	Normal data	Log$_{10}$-transformed data
10	Mean (x_{mean})/Log (x_{mean}) (m^3/s)	398.322	2.351		Mean (x_h)/Log ($x_{h\text{-}mean}$) (m^3/s)	398.322	2.351
11	Total time span (Y_T, years)	60	60		Total time span (Y_T, years)	60	60
12	Missing data (N_C, years)	0	0		Missing data (N_C, years)	0	0
13	Standard deviation (s)/(s_{log}) (m^3/s)	421.917	0.543		Standard deviation (s_h)/(s_{hlog}) (m^3/s)	421.917	0.543
14	Coefficient of variation (c_v)/(c_{vlog})	1.059	0.231		Coefficient of variation (c_{vh})/(c_{vhlog})	1.059	0.231
15	Skewness (g)/(g_{log})	2.571	-0.814		Skewness (g_h)/(g_{hlog})	2.571	-0.814
16	HISTORICALLY WEIGHTED VARIABLES						
17	Weight applied to data (W_T)		1.000		Sum of peaks equal to or above the high threshold (Σx_a)		
18	Floods equal to or above the high threshold (N_A)		0		Sum of peaks below the high threshold (Σx_b)		23899.327
19	Floods between high and low thresholds (N_B)		60		Sum of the deviations of x_a (Σd_a)		
20	Low outliers including zero flows (L_W)		0		Sum of the deviations of x_b (Σd_b)		3240.806

Figure 35: *Probabilistic Methods (AMS)* worksheet and conservation statistics

Theoretical probability distributions:

The theoretical probability distributions available in the DFET are either based on Mean Moments (MM) and/or Linear Moments (LM) parameter estimators. The following theoretical probability distributions are based on MM parameter estimation:

Normal (N/MM) distribution:

$$Q_T = \bar{x} - sy \tag{72}$$

Extreme Value Type I (EV1/MM) distribution:

$$Q_T = \bar{x} + s(0.781 W_T - 0.451) \tag{73}$$

Extreme Value Type II (EV2/MM) distribution:

$$Q_T = \bar{x} + \sqrt{\frac{s^2}{\mathrm{var}(y)}}\left(1 - E(y) - kW_T\right) \tag{74}$$

Extreme Value Type III (EV3/MM) distribution:

$$Q_T = \bar{x} + \sqrt{\frac{s^2}{\mathrm{var}(y)}}\left(-1 + E(y) + kW_T\right) \tag{75}$$

Log-Normal (LN/MM) distribution:

$$Q_T = anti\log\left[\overline{\log(x)} + s_{\log} W_T\right] \tag{76}$$

Log-Extreme Value Type I (LEV1/MM) distribution:

$$Q_T = anti\log\left[\overline{\log(x)} + s_{\log}(0.781 W_T - 0.451)\right] \tag{77}$$

Log-Pearson Type III (LP3/MM) distribution:

$$Q_T = anti\log\left[\overline{\log(x)} + s_{\log} W_T\right] \tag{78}$$

The following theoretical probability distribution is based on LM parameter estimation. It is not included in the *Probabilistic Methods (AMS)* worksheet, but available as an option in the *Probabilistic Plotting* worksheet for comparison purposes:

Generalised Logistic (GLO/LM) distribution:

$$Q_T = Q_{Med}\left[1 + \frac{\beta}{k}\left(1 - (T-1)^{-k}\right)\right] \tag{79}$$

with:

$$\beta = \frac{t_2 k \sin(\pi k)}{k\pi(k+t_2) - t_2 \sin(\pi k)} \quad (79a)$$

$$k = -t_3 \quad (79b)$$

$$t_2 = \frac{2\left[\frac{1}{N}\sum_{m=2}^{N}\frac{(m-1)}{(N-1)}Q_m\right] - \bar{x}}{\bar{x}} \quad (79c)$$

$$t_3 = \frac{6\left[\frac{1}{N}\sum_{m=3}^{N}\frac{(m-1)(m-2)}{(N-1)(N-2)}Q_m\right] - 6\left[\frac{1}{N}\sum_{m=2}^{N}\frac{(m-1)}{(N-1)}Q_m\right] + \bar{x}}{2\left[\frac{1}{N}\sum_{m=2}^{N}\frac{(m-1)}{(N-1)}Q_m\right] - \bar{x}} \quad (79d)$$

where:

$E(y)$ = mean of the standardised variate,

k = shape parameter,

m = number, in ascending order, of the ranked events (peak flows),

N = number of observations/record length [years],

Q_m = ranked annual maximum flood peak [m^3/s],

Q_{Med} = median annual maximum flood peak [m^3/s],

Q_T = peak flow for T-year return period [m^3/s],

s = standard deviation of observed values [m^3/s],

s_{log} = standard deviation of the observed value logarithms [m^3/s],

T = return period [years],

$var(y)$ = variance of the standardised variate,

W_T = frequency factor for T-year return period or LN standard variate,

$\bar{x}$ = mean of observed values [m^3/s], and

y = standardised variate.

An example of the *Probabilistic Methods (AMS)* worksheet containing the theoretical probability distribution results is shown in Figure 36.

HOME	ANNUAL MAXIMUM SERIES	PROBABILISTIC METHODS (AMS)		PROBABILISTIC METHODS (PDS)
Secondary drainage region number	C5	PRINT	Main watercourse/river	Modder River
Tertiary drainage region number	C52		Designed	OJ Gericke
Quaternary drainage region number	C52A- G		Checked	JA du Plessis
Catchment description	Krugersdrift Dam		Date	June 15, 2009
Flow-gauging station name	Krugersdrift Dam		Flow-gauging station number	C5R004

THEORETICAL PROBABILITY DISTRIBUTIONS (m^3/s)						
Return period	MISSING DATA EXCLUDED					
(T, years)	N/MM	EV1/MM	EV2/MM	LN/MM	LEV1/MM	LP3/MM
1.25	43	51	88	78	80	84
2	398	329	302	225	183	266
5	753	702	637	643	553	654
10	939	949	893	1114	1149	961
20	1092	1187	1168	1755	2321	1266
50	1265	1494	1571	2925	5764	1654
100	1380	1724	1913	4112	11393	1933
200	1485	1953	2293	5617	22476	2195
500	1613	2256	2859	8197	55069	2515
1000	1702	2484	3343	10685	108319	2736
Return period	MISSING DATA INCLUDED					
(T, years)	N/MM	EV1/MM	EV2/MM	LN/MM	LEV1/MM	LP3/MM
1.25	43	51	88	78	80	84
2	398	329	302	225	183	266
5	753	702	637	643	553	654
10	939	949	893	1114	1149	961
20	1092	1187	1168	1755	2321	1266
50	1265	1494	1571	2925	5764	1654
100	1380	1724	1913	4112	11393	1933
200	1485	1953	2293	5617	22476	2195
500	1613	2256	2859	8197	55069	2515
1000	1702	2484	3343	10685	108319	2736

Figure 36: Theoretical probability distribution results based on the AMS

3.3 Raw Flow Data (Partial Duration Series)

3.3.1 Pre-requisite input and linked worksheets

The *Annual Maximum Series* worksheet is a pre-requisite input for this worksheet. The *Raw Flow Data* worksheet is also linked to the *Partial Duration Series* and *Probabilistic Methods (PDS)* worksheets.

3.3.2 Input ranges and comments

Input range identifier:

Single cell entry (light-green shaded and unprotected) and cell range entries (no defined cell format). Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Note:

The maximum monthly peak flows as obtained from the Department of Water Affairs (DWA) monthly flood peak database must be copied into *cell range D9:O208.* A maximum period of 200 years can be used. Use *Copy & Paste values* to retain the cell format. Enter the start date (year) of the data period in *cell A9*.

Cell A9: Click and hold the mouse cursor in position.
Comment: “Enter the start date (year) of data period.”

Cell range D9:O208: Copy the maximum monthly peak flows into this cell range or a part thereof. Use *Copy & Paste values* to retain the cell format.

3.3.3 Calculation procedure

Not applicable, since this worksheet is only used for data management.

3.4 Partial Duration Series (PDS)

3.4.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Raw Flow Data* worksheets are pre-requisite input for this worksheet. The *Partial Duration Series* worksheet is also linked to the *Probabilistic Methods (AMS & PDS)* worksheets.

3.4.2 Input ranges and comments

Input range identifier:

Single cell entry (light-green shaded and unprotected) and a group box (drop-down list). The group box contains the various plotting position methods and associated theoretical probability distributions. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Cell B9: Click and hold the mouse cursor in position. The following comment box related to the use of threshold exceedance values will appear on screen:

IF THE NUMBER OF PEAK YEARS (CELL B9) IS LEFT EMPTY, THE NUMBER OF PEAKS EQUAL TO THE NUMBER OF DATA YEARS (CELL B8) WILL BE USED FOR THE CALCULATIONS.

IN ORDER TO MAKE USE OF A THRESHOLD EXCEEDANCE VALUE (EXCLUSION OF PEAKS ABOVE THE STRUCTURAL LIMIT, CELLS B7 or D7), THE USER CAN ENTER A NUMBER OF PEAK YEARS (CELL B9) LESS THAN THE NUMBER OF DATA YEARS (CELL B8).

Cell A10: Select the appropriate plotting position method from the group box (drop-down list, 6 options available) to establish the plotting constants in *cells D8* (a) and *D9* (b) respectively.

3.4.3 Calculation procedure

The calculation procedure used to establish the return period of each ranked peak flow within *N*-years will be discussed in Section 3.6.

An example of the *Partial Duration Series* worksheet illustrative of above-listed instructions is shown in Figure 37.

	A	B	C	D
1	HOME	RAW FLOW DATA	PARTIAL DURATION SERIES	PROBABILISTIC METHODS (PDS)
2	Secondary drainage region number	C5	Main watercourse/river	Modder River
3	Tertiary drainage region number	C52	Designed	OJ Gericke
4	Quaternary drainage region number	C52A- G	Checked	JA du Plessis
5	Catchment description	Krugersdrift Dam	Date	June 15, 2009
6	Flow-gauging station name	Krugersdrift Dam	Flow-gauging station number	C5R004
7	Structural limit (H, m)		Structural limit (Q, m^3/s)	3000
8	Number of data years (N)	60	Plotting constant (a)	0.200
9	User-input: Number of peak years (N)	35	Plotting constant (b)	0.400
10	Plotting position method	CUNNANE (General purpose)		
11	Rank (m)	Peak flow (m^3/s)	Ranked peak flow (m^3/s) within N-years	Return period (T, years)
12	1	2456.000	2456.000	58.667
13	2	1642.297	1642.297	22.000
14	3	1090.075	1090.075	13.538
15	4	1086.996	1086.996	9.778
16	5	985.378	985.378	7.652
17	6	836.000	836.000	6.286
18	7	792.000	792.000	5.333
19	8	773.933	773.933	4.632
20	9	741.000	741.000	4.093
21	10	687.000	687.000	3.667
22	11	636.390	636.390	3.321
23	12	625.000	625.000	3.034
24	13	616.000	616.000	2.794
25	14	570.698	570.698	2.588
26	15	555.302	555.302	2.411

Figure 37: *Partial Duration Series* worksheet

3.5 Probabilistic Methods (PDS)

3.5.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Partial Duration Series* worksheets are pre-requisite input for this worksheet. The *Probabilistic Methods (PDS)* worksheet is also linked to the *Probabilistic Methods (AMS)* and *Probabilistic Plotting* worksheets.

3.5.2 Input ranges and comments

Input range identifier:

Single cell or cell range entries (light-green shaded and unprotected) in the case of "Design Notes," otherwise not applicable. This worksheet is mainly used for calculations.

Design notes:

Cell range

F9:F14: The user can enter any comments/design notes/recommendations in this cell range.

3.5.3 Calculation procedure

Conservation statistics:

Refer to Section 3.2.3.

Theoretical probability distributions:

Refer to Section 3.2.3.

The layout of the *Probabilistic Methods (PDS)* worksheet is shown in Figure 38.

HOME	PARTIAL DURATION SERIES	PROBABILISTIC METHODS (PDS)	PROBABILISTIC METHODS (AMS)

Secondary drainage region number	C5	PRINT	Main watercourse/river	Modder River
Tertiary drainage region number	C52		Designed	OJ Gericke
Quaternary drainage region number	C52A- G		Checked	JA du Plessis
Catchment description	Krugersdrift Dam		Date	June 15, 2009
Flow-gauging station name	Krugersdrift Dam		Flow-gauging station number	C5R004

CONSERVATION STATISTICS			PROBABILISTIC PLOTTING
MISSING DATA EXCLUDED			DESIGN NOTES
Variable	Normal data	Log_{10}-transformed data	
Mean (x_{mean})/Log (x_{mean}) (m^3/s)	613.268	2.717	
Total time span (Y_T, years)	35	35	
Standard deviation (s)/(s_{log}) (m^3/s)	437.606	0.234	
Coefficient of variation (c_v)/(c_{vlog})	0.714	0.086	
Skewness (g)/(g_{log})	2.698	0.871	

THEORETICAL PROBABILITY DISTRIBUTIONS (m^3/s)						
Return period	MISSING DATA EXCLUDED					
(T, years)	N/MM	EV1/MM	EV2/MM	LN/MM	LEV1/MM	LP3/MM
1.25	245	253	294	331	334	328
2	613	541	512	521	477	482
5	982	929	857	820	768	790
10	1174	1185	1122	1040	1054	1072
20	1333	1431	1408	1265	1427	1415
50	1512	1749	1831	1577	2113	1990
100	1631	1988	2192	1826	2835	2540
200	1740	2226	2595	2089	3800	3215
500	1873	2540	3199	2459	5593	4347
1000	1966	2777	3719	2757	7489	5427

Figure 38: Layout of the *Probabilistic Methods (PDS)* worksheet

3.6 Probabilistic Plotting

3.6.1 Pre-requisite input and linked worksheets

The *Catchment Information* and *Probabilistic Methods (AMS & PDS)* worksheets are pre-requisite input for this worksheet. The *Probabilistic Plotting* worksheet is also linked to the *Probabilistic Plot (AMS & PDS)* charts.

These charts can be viewed by clicking on either the PROBABILISTIC PLOT (AMS) or PROBABILISTIC PLOT (PDS) buttons.

3.6.2 Input ranges and comments

Input range identifier:

Single cell and cell range entries (light-green shaded and unprotected), check boxes and group boxes (drop-down lists). Each group box (Probabilistic methods, AMS or PDS) contains the various plotting position methods and associated theoretical probability distributions. Click and hold the mouse cursor in position to read any comment box (cells with red flags).

Design notes:

Cell range

G3:G8: The user can enter any comments/design notes/recommendations in this cell range.

Probabilistic methods (AMS):

Cell G11: Select the appropriate plotting position method from the group box (drop-down list, 6 options available) to establish the plotting constants in *cells F7* (a) and *F8* (b) respectively.

Cell C11: Click and hold the mouse cursor in position. The following comment box related to the source data range ("Ranked AMS" series) will appear on screen:

CLICK ON "PROBABILISTIC PLOT (AMS)".

RIGHT-CLICK ON THE RELEVANT CHART.

SELECT "SELECT DATA" FROM THE LIST.

SELECT THE "RANKED AMS" SERIES FROM THE LEGEND ENTRIES (SOURCE DATA).

CLICK ON "EDIT".

EDIT THE END X (E) and Y (B) DATA RANGE VALUES ACCORDING TO THE END-VALUE AS INDICATED IN CELL C11 (*e.g.* "62").

THE DEFINED DATA RANGE (Ending at *e.g.* "62") WILL BE AS FOLLOWS:

SERIES X VALUES: E3: E62
SERIES Y VALUES: B3: B62

Figure 39 is illustrative of the Edit Series window that will appear on screen after the steps contained in the above-listed comment box were followed.

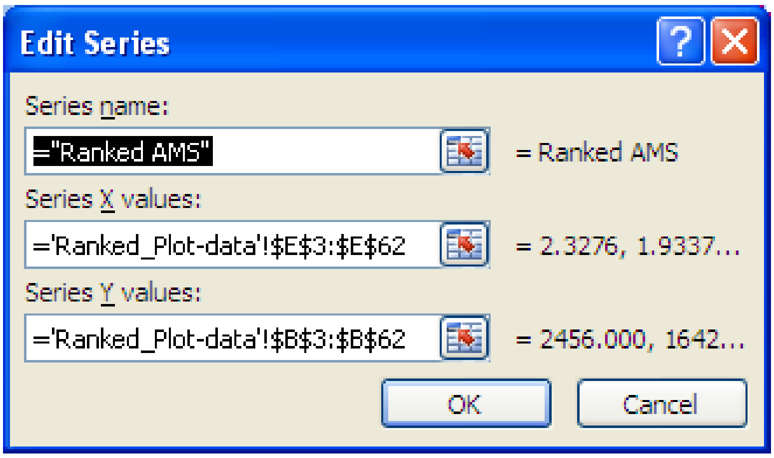


Figure 39: Edit Series window (*Probabilistic Plot, AMS*)

Hydrological literature frequently emphasises that a regional approach should be adopted when the observed flood peak data at a single site are insufficient for frequency analysis. However, in recognition of the practising engineers' possible time and human resource constraints to implement an extensive regional approach, two single-site approaches were included to assist the focus user group of the DFET. These two approaches are respectively referred to as the SRAM (*c.f.* Section 3.1.3) and the Mean Logarithm Value Approach (MLVA).

The MLVA (Equation 82, Section 3.6.3) is based on the combination of the mean values of the logarithms of two or more probability distributions at a single site and could be used to establish the applicability of theoretical probability distributions to specific return period ranges, *e.g.* the LP3 fits the lower recurrence interval values better and the GEV the rest. It could also improve design flood estimations based on the AMS at a single site characterised by insufficient record lengths *e.g.* missing data, low outliers and flood peaks exceeding the hydraulic capacity of flow-gauging structures. These insufficient record lengths are likely to make it impossible to conclusively select a **single** probability distribution that could consistently provide flood frequency estimates for return periods much greater than the period of record.

The DFET procedure to establish and select the most applicable theoretical probability distribution(s) to specific return period ranges, is highlighted in following paragraphs:

Cell range D12:I12: The check boxes "Included" enable the user to select or exclude a particular theoretical probability distribution (*cell range D15:I15*, column headings) from being included in Equation 82 and subsequently plotted on the *Probabilistic Plot (AMS)* chart.

Cell range D13:I13: The user must enter the maximum return period in which a particular theoretical probability distribution must be taken into consideration. The following applies:

Cell D13: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the EV1/MM must be taken into consideration."

Cell E13: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the EV2/MM or EV3/MM must be taken into consideration."

Cell F13: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the LN/MM must be taken into consideration."

Cell G13: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the LEV1/MM must be taken into consideration."

Cell H13: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the LP3/MM must be taken into consideration."

Cell I13: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the GLO/LM must be taken into consideration."

Cell range D14:I14: The user must enter the minimum return period in which a particular theoretical probability distribution must be taken into consideration. The following applies:

Cell D14: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the EV1/MM must be taken into consideration."

Cell E14: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the EV2/MM or EV3/MM must be taken into consideration."

Cell F14: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the LN/MM must be taken into consideration."

Cell G14: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the LEV1/MM must be taken into consideration."

Cell H14: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the LP3/MM must be taken into consideration."

Cell I14: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the GLO/LM must be taken into consideration."

Probabilistic methods (PDS):

Cell G29: Select the appropriate plotting position method from the group box (drop-down list, 6 options available) to establish the plotting constants in *cells F7* (a) and *F8* (b) respectively.

Cell C29: Click and hold the mouse cursor in position. The following comment box related to the source data range ("Ranked PDS" series) will appear on screen:

CLICK ON "PROBABILISTIC PLOT (PDS)".

RIGHT-CLICK ON THE RELEVANT CHART.

SELECT "SELECT DATA" FROM THE LIST.

SELECT THE "RANKED PDS" SERIES FROM THE LEGEND ENTRIES (SOURCE DATA).

CLICK ON "EDIT".

EDIT THE END X (E) and Y (B) DATA RANGE VALUES ACCORDING TO THE END-VALUE AS INDICATED IN CELL C29 (*e.g.* "37").

THE DEFINED DATA RANGE (Ending at *e.g.* "37") WILL BE AS FOLLOWS:

SERIES X VALUES: R3: R37
SERIES Y VALUES: O3: O37

Figure 40 is illustrative of the Edit Series window that will appear on screen after the steps contained in the above-listed comment box were followed.

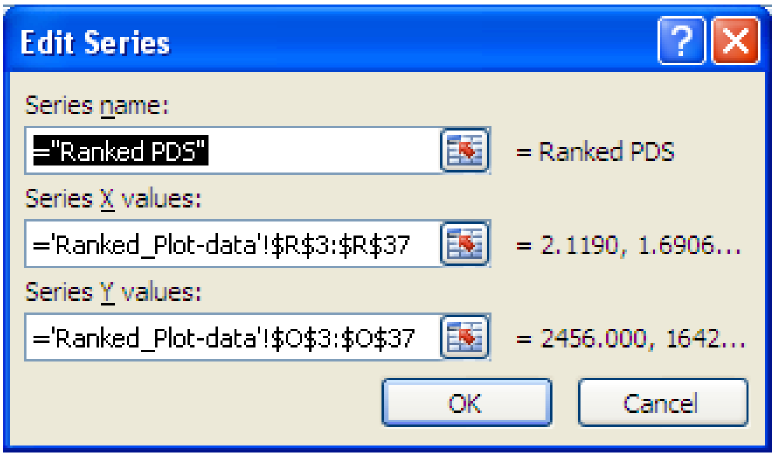


Figure 40: Edit Series window (*Probabilistic Plot, PDS*)

The DFET procedure to establish and select the most applicable theoretical probability distribution(s) to specific return period ranges, is highlighted in following paragraphs:

Cell range D30:I30: The check boxes "Included" enable the user to select or exclude a particular theoretical probability distribution (*cell range D33:I33*, column headings) from being included in Equation 82 and subsequently plotted on the *Probabilistic Plot (PDS)* chart.

Cell range D31:I31: The user must enter the maximum return period in which a particular theoretical probability distribution must be taken into consideration. The following applies:

Cell D31: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the EV1/MM must be taken into consideration."

Cell E31: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the EV2/MM or EV3/MM must be taken into consideration."

Cell F31: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the LN/MM must be taken into consideration."

Cell G31: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the LEV1/MM must be taken into consideration."

Cell H31: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the LP3/MM must be taken into consideration."

Cell I31: Comment: "Enter the maximum return period (1.25- 1 000 years) in which the GLO/LM must be taken into consideration."

Cell range D32:I32: The user must enter the minimum return period in which a particular theoretical probability distribution must be taken into consideration. The following applies:

Cell D32: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the EV1/MM must be taken into consideration."

Cell E32: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the EV2/MM or EV3/MM must be taken into consideration."

Cell F32: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the LN/MM must be taken into consideration."

Cell G32: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the LEV1/MM must be taken into consideration."

Cell H32: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the LP3/MM must be taken into consideration."

Cell I32: Comment: "Enter the minimum return period (1.25- 1 000 years) in which the GLO/LM must be taken into consideration."

3.6.3 Calculation procedure

Plotting position methods:

$$T = \frac{n+a}{m-b} \qquad (80)$$

where:

T = return period [years],

a = constant [Table 5],

b = constant [Table 5],

m = number, in descending order, of the ranked events (peak flows), and

n = number of observations/record length [years].

Table 5: Common plotting position methods (SANRAL, 2006)

Method		Plotting position	Theoretical probability distribution
Beard	(1962)	a = 0.40 and b = 0.30	Pearson Type 3
Blom	(1958)	a = 0.25 and b = 0.375	Normal
Cunnane	(1978)	a = 0.20 and b = 0.40	General purpose
Greenwood	(1979)	a = 0.00 and b = 0.35	GEV and Wakeby
Gringorten	(1963)	a = 0.12 and b = 0.44	Extreme Value Type 1, GEV and Exponential
Weibull	(1939)	a = 1.00 and b = 0.00	Normal and Pearson Type 3

Probabilistic methods and plotting (AMS & PDS):

$$P = \frac{1}{T} \tag{81}$$

$$Q_P = 10\exp\left[\frac{\log[(Q_i)(Q_{i+1}).....(Q_N)]}{N}\right] \tag{82}$$

where:

Q_P = probabilistic peak flow based on the MLVA [m^3/s],

P = probability of annual exceedance [fraction],

N = number of probability distributions used,

$Q_{i\,,\,i+1}$ = peak flows based on a recognised theoretical probability distribution, with a minimum of two probability distributions used in combination [m^3/s], and

T = return period [years].

The individual peak flows (Q_i) in Equation 82 can either be based on the combination of two or more theoretical probability distributions, *e.g.* LN, LP3, GEV and/or GLO distributions. The DWA, Directorate: Flood Studies recommends and use Equation 82 in their flood studies and safety evaluation of dams (Van der Spuy and Rademeyer, 2010).

Examples of the *Probabilistic Plotting* worksheet illustrative of above-listed instructions and calculation procedures applicable to the AMS and PDS are shown in Figures 41 and 42 respectively, while the AMS and PDS probabilistic charts (plotting results) are shown in Figures 43 and 44, respectively.

	A	B	C	D	E	F	G	H	I	J
1	HOME	PRINT	PROBABILISTIC PLOTTING METHODS AND INFORMATION							
2	Secondary drainage region number		C5	Main watercourse/river		Modder River	DESIGN NOTES			
3	Tertiary drainage region number		C52	Designed		OJ Gericke				
4	Quaternary drainage region number		C52A- G	Checked		JA du Plessis				
5	Catchment description		Krugersdrift Dam	Date		June 15, 2009				
6	DATA RECORD LENGTH (N, years) and PLOTTING CONSTANTS (a & b)									
7	Annual maximum series: Record length (N)		60	Plotting constant (a)		0.200				
8	Partial duration series: Record length (N)		35	Plotting constant (b)		0.400				
9	PROBABILISTIC METHODS (ANNUAL MAXIMUM SERIES)									
10	SOURCE DATA RANGE ["Ranked AMS" series (B3:B202,E3:E202)]			MEAN LOGARITHM VALUE APPROACH (MLVA)			Plotting position method			
11	END-VALUE OF DATA PLOT RANGE (B, E):		62	PROBABILISTIC ANALYSIS (AMS)		PROBABILISTIC PLOT (AMS)	CUNNANE (General purpose)			
12	Return period	PROBABILITY DISTRIBUTION(S) TO BE INCLUDED		☐ INCLUDED	☐ INCLUDED	☐ INCLUDED	☐ INCLUDED	☑ INCLUDED	☑ INCLUDED	MLVA Q_P (m^3/s)
13		PROBABILITY DISTRIBUTION RANGE (T, years)	MAXIMUM	1000	1000	1000	1000	20	1000	
14			MINIMUM	1.25	1.25	1.25	1.25	1.25	20	
15	(T, years)	Exceedance probability	Log-Normal	EV1/MM	EV2/MM	LN/MM	LEV1/MM	LP3/MM	GLO/LM	
16		(decimal)	Standard variate (W_{TLN})	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	
17	1.25	0.800	-0.842	51	104	78	80	84	119	**84**
18	2	0.500	0.000	329	302	225	183	266	317	**266**
19	5	0.200	0.842	702	637	643	553	654	637	**654**
20	10	0.100	1.282	949	893	1114	1149	961	910	**961**
21	20	0.050	1.645	1187	1168	1755	2321	1266	1241	**1253**
22	50	0.020	2.054	1494	1571	2925	5764	1654	1807	**1807**
23	100	0.010	2.326	1724	1913	4112	11393	1933	2366	**2366**
24	200	0.005	2.576	1953	2293	5617	22476	2195	3075	**3075**
25	500	0.002	2.878	2256	2859	8197	55069	2515	4317	**4317**
26	1000	0.001	3.090	2484	3343	10685	108319	2736	5559	**5559**

Figure 41: Example illustrating the MLVA based on Equation 82 (AMS)

	A	B	C	D	E	F	G	H	I	J
1	HOME	PRINT	PROBABILISTIC PLOTTING METHODS AND INFORMATION							
2	Secondary drainage region number		C5	Main watercourse/river		Modder River	DESIGN NOTES			
3	Tertiary drainage region number		C52	Designed		OJ Gericke				
4	Quaternary drainage region number		C52A- G	Checked		JA du Plessis				
5	Catchment description		Krugersdrift Dam	Date		June 15, 2009				
6	DATA RECORD LENGTH (N, years) and PLOTTING CONSTANTS (a & b)									
7	Annual maximum series: Record length (N)		60	Plotting constant (a)		0.200				
8	Partial duration series: Record length (N)		35	Plotting constant (b)		0.400				
27	PROBABILISTIC METHODS (PARTIAL DURATION SERIES)									
28	SOURCE DATA RANGE ["Ranked PDS" series (O3:O2402,R3:R2402)]			MEAN LOGARITHM VALUE APPROACH (MLVA)			Plotting position method			
29	END-VALUE OF DATA PLOT RANGE (O, R):		37	PROBABILISTIC ANALYSIS (PDS)		PROBABILISTIC PLOT (PDS)	CUNNANE (General purpose)			
30	Return period	PROBABILITY DISTRIBUTION(S) TO BE INCLUDED		☐ INCLUDED	☐ INCLUDED	☐ INCLUDED	☐ INCLUDED	☑ INCLUDED	☑ INCLUDED	MLVA Q_P (m^3/s)
31		PROBABILITY DISTRIBUTION RANGE (T, years)	MAXIMUM	1000	1000	1000	1000	20	1000	
32			MINIMUM	1.25	1.25	1.25	1.25	1.25	1.25	
33	(T, years)	Exceedance probability	Log-Normal	EV1/MM	EV2/MM	LN/MM	LEV1/MM	LP3/MM	GLO/LM	
34		(decimal)	Standard variate (W_{TLN})	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	
35	1.25	0.800	-0.842	253	321	331	334	328	319	**323**
36	2	0.500	0.000	541	512	521	477	482	466	**474**
37	5	0.200	0.842	929	857	820	768	790	733	**761**
38	10	0.100	1.282	1185	1122	1040	1054	1072	981	**1026**
39	20	0.050	1.645	1431	1408	1265	1427	1415	1301	**1357**
40	50	0.020	2.054	1749	1831	1577	2113	1990	1886	**1886**
41	100	0.010	2.326	1988	2192	1826	2835	2540	2504	**2504**
42	200	0.005	2.576	2226	2595	2089	3800	3215	3332	**3332**
43	500	0.002	2.878	2540	3199	2459	5593	4347	4882	**4882**
44	1000	0.001	3.090	2777	3719	2757	7489	5427	6533	**6533**

Figure 42: Example illustrating the MLVA based on Equation 82 (PDS)

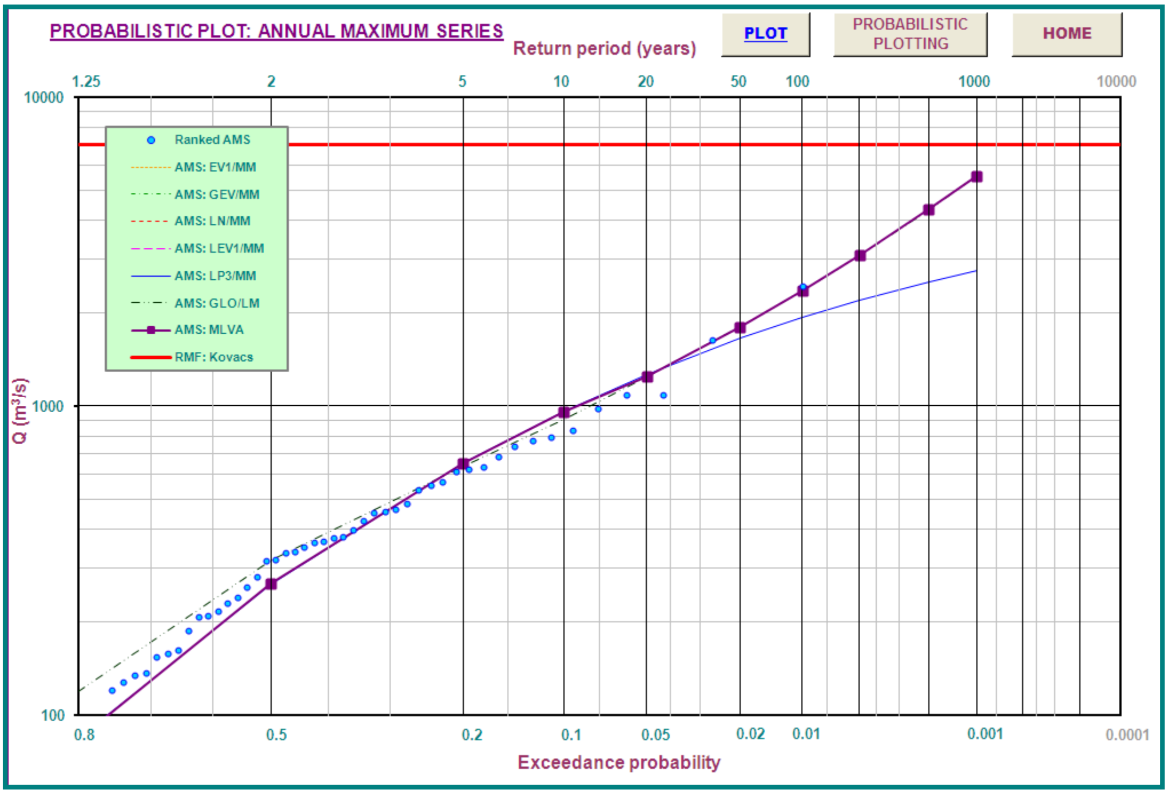


Figure 43: Probabilistic plot based on the ranked AMS and Cunnane plotting position

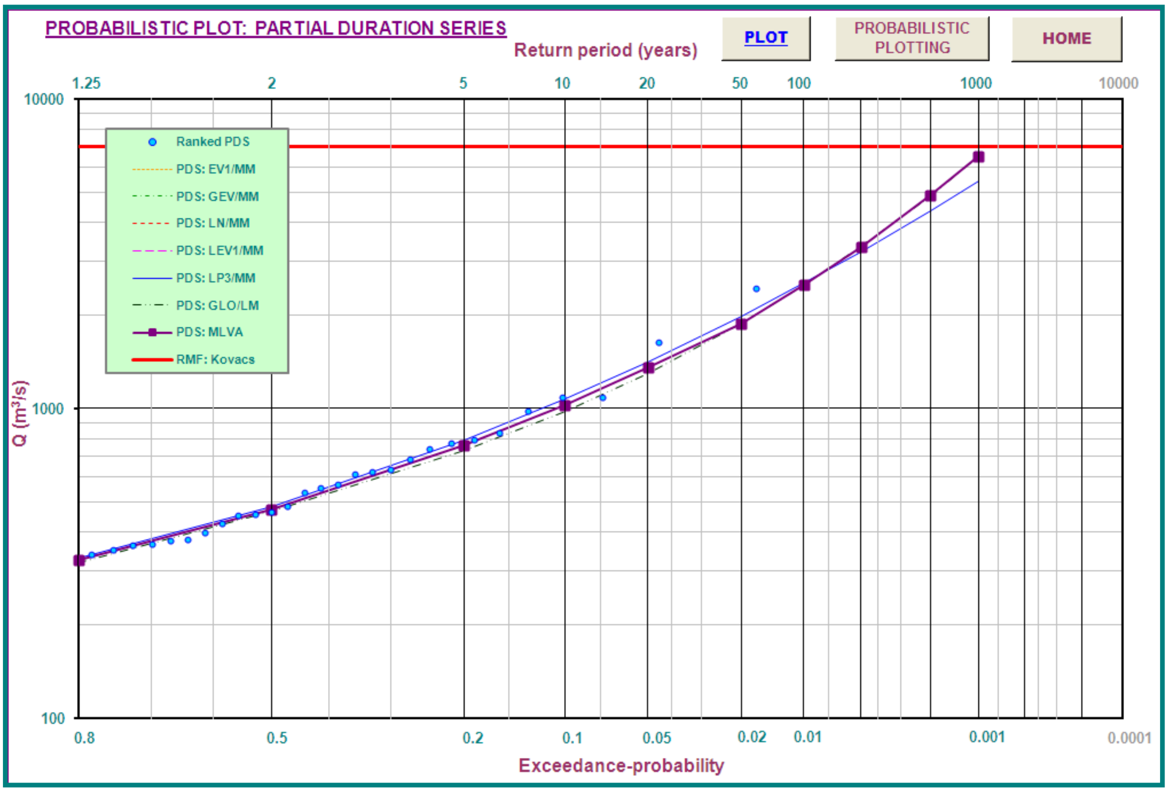


Figure 44: Probabilistic plot based on the ranked PDS and Cunnane plotting position

4. SUMMARY

4.1 Summary Report

The SUMMARY and SUMMARY PLOT buttons can be used to view and examine the design flood estimation results summarised in both a tabular and graphical format. The summary in tabular format is shown in Figure 45, while the summary plot (chart) is illustrated in Figure 46.

HOME | SUMMARY PLOT | **SUMMARY OF RESULTS** | PRINT

Catchment description	Krugersdrift Dam	MAP (mm)	518
Catchment classification	Inland/summer rainfall and flat & permeable	Flow-gauging station	C5R004
Size of catchment (A, km^2)	6331.0	Designed	OJ Gericke
Main watercourse/river	Modder River	Date	JA du Plessis

DESIGN FLOOD ESTIMATION RESULTS

DETERMINISTIC METHODS							DESIGN NOTES
Return period	Peak flow (m^3/s)						
(T, years)	RM	ARM	SCS	SDF	SUH	LRH	
2	245	308	313	236	236	223	
5	363	451	560	710	393	365	
10	497	576	756	1134	572	535	
20	678	735	966	1618	804	751	
50	1075	1057	1272	2402	1222	1134	
100	1576	1409	1523	3129	1695	1590	
200	2108	1891	1794	3966	2052	1933	

EMPIRICAL METHODS						
Return period	Peak flow (m^3/s)					
(T, years)	MIPI	CAPA	Q_T/Q_{RMF} ratio	RMF		
				Francou-Rodier	Kovács	
2		206				
5		463				
10	894	711				
20	1037	1024		6928	7045	
50	1448	1544	3409			
100	1829	1962	4097			
200		2373	4796			

PROBABILISTIC METHODS (AMS)								
Return period	Peak flow (m^3/s)							
(T, years)	N/MM	EV1/MM	EV2/MM	LN/MM	LEV1/MM	LP3/MM	GLO/LM	MLVA Q_P
2	398	329	302	225	183	266	317	266
5	753	702	637	643	553	654	637	654
10	939	949	893	1114	1149	961	910	961
20	1092	1187	1168	1755	2321	1266	1241	1253
50	1265	1494	1571	2925	5764	1654	1807	1807
100	1380	1724	1913	4112	11393	1933	2366	2366
200	1485	1953	2293	5617	22476	2195	3075	3075

PROBABILISTIC METHODS (PDS)								
Return period	Peak flow (m^3/s)							
(T, years)	N/MM	EV1/MM	EV2/MM	LN/MM	LEV1/MM	LP3/MM	GLO/LM	MLVA Q_P
2	613	541	512	521	477	482	466	474
5	982	929	857	820	768	790	733	761
10	1174	1185	1122	1040	1054	1072	981	1026
20	1333	1431	1408	1265	1427	1415	1301	1357
50	1512	1749	1831	1577	2113	1990	1886	1886
100	1631	1988	2192	1826	2835	2540	2504	2504
200	1740	2226	2595	2089	3800	3215	3332	3332

Figure 45: Summary of results (tabular format)

4.2 Summary Plot

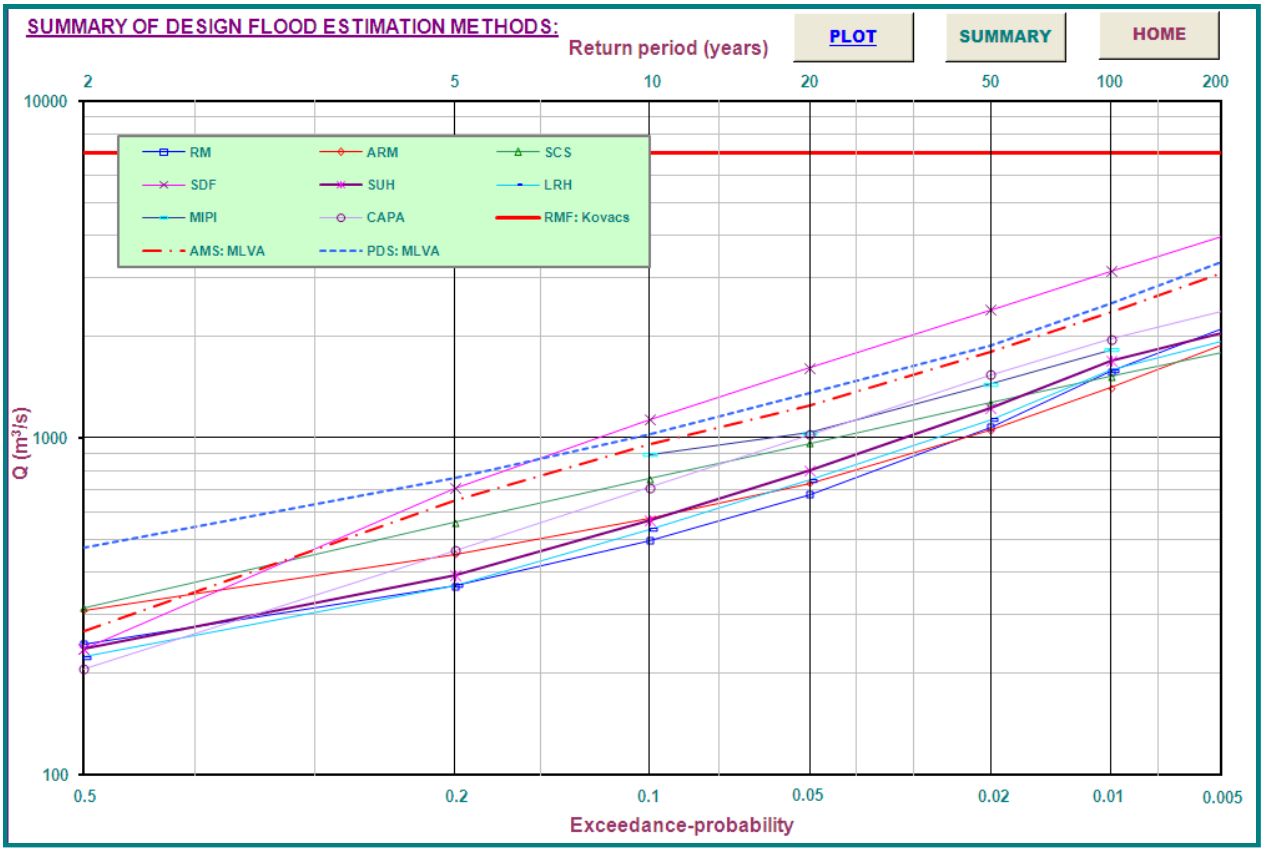


Figure 46: Summary of results (chart)

5. REFERENCES

The following list of references reflects the most prominent sources used during the development of the DFET:

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