DWS Report No. P WMA 09/00/00/0418/21/2

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Feasibility Bridging Study for Breede-Berg (Michell's Pass) Water Transfer Scheme (WP11389)

WATER RESOURCES ASSESSMENT REPORT (PARTIAL DELIVERABLE)

February 2024

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Department of Water and Sanitation
Directorate: Water Resource Development Planning

FEASIBILITY BRIDGING STUDY FOR BREEDE-BERG (MICHELL'S PASS) WATER TRANSFER SCHEME

DRAFT FOR APPROVAL

Title	:	Water Resources Assessment Report (Partial Deliverable)
DWS Report Number	:	P WMA DWS Report No. P WMA 09/00/00/0418/21/2
Consultants	:	Tlou Integrated Tech cc in association with Bigen Africa Services (Pty) Ltd
Report status	:	Draft
Date	:	February 2024

Study Team

Approved for Tlou Integrated Tech cc in association with Bigen Africa Services (Pty) Ltd:

L Kekana
Study Director

Dr A Le Grange
Study Leader

DEPARTMENT OF WATER AND SANITATION
Directorate Water Resource Development Planning

Approved for Department of Water and Sanitation

Dr M Mugumo
Chief Engineer: WRDP

C Fourie
Director: WRDP

ACKNOWLEDGEMENTS

The following contributions to the Feasibility Bridging Study for Breede - Berg (Michell's Pass) Water Transfer Scheme, and thereby to draft Water Resources Assessment Report (Partial Deliverable) are gratefully acknowledged:

- The guidance and general support given by the project management staff and other officials of the Department of Water and Sanitation;
- The invaluable contributions and direction given by members of the Project Steering Committee;
- Contributions and guidance received from officials of other Government Departments at national, provincial, and local level, as well as the representatives of relevant and affected organisations and members of the public for their active involvement and valuable comments.
- The dedication and high standard of professional work by the members of the project team.

DOCUMENT CONTROL RECORD

Document prepared by:

Tlou Integrated Tech cc

9 Ivy Street, Sunnyside
PO Box 12859
Hatfield
0028
Pretoria
South Africa

T: +27 12 343 7120
F: +27 12 343 7132
E: admin@tlouintegrated.co.za

Bigen Africa Services (Pty) Ltd
1999/010974/07

Avanti Building, 3rd Floor North Block,
Corner Carl Cronjé Drive and Bill
Bezuidenhout
Tyger Valley, Bellville
Cape Town
Suite 47, Private Bag X22
Tyger Valley
7536

T: +27 21 919 6976
F: +27 21 919 2508
E: capetown@bigengroup.com
W: bigengroup.com

Document prepared for:

Director: Water Resource Development Planning
Department of Water and Sanitation

Private Bag X313
Pretoria
0001
South Africa

Dr Menard Mugumo
Chief Engineer: Water Resources Development Planning (WRDP)

T: +27 82 804 5162
E: mugumom@dws.gov.za

This report is to be referred to in bibliographies as:

Department of Water and Sanitation, South Africa. 2024. *Water Resources Assessment Report (Partial Deliverable)*. Prepared by Tlou Integrated Tech cc, assisted by Bigen Africa Services (Pty) Ltd, as part of the Feasibility Bridging Study for Breede-Berg (Michell's Pass) Water Transfer Scheme.

Document control						
Report title		Feasibility Bridging Study for Breede-Berg (Michell's Pass) Water Transfer Scheme (WP11339) – Water Resources Assessment Report (Partial Deliverable)				
Document ID		P WMA 09/00/00/0418/21/2	**Project number**		3530	
File path						
Client		Department of Water and Sanitation	**Client contact**		Dr M Mugumo	
Rev	**Date**	**Revision details/status**	**Prepared by**	**Authors**	**Verifier**	**Approver**
1	17/02/24	Draft (Partial Deliverable)	PSP Team	Kornelius Riemann, Stephen Mallory, Gerald de Jager	-	-
Current Revision		**1**				

DOCUMENT INDEX

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Bold type indicates this report.

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ACRONYMS AND ABBREVIATIONS

Acronym	Description
BBTS	Breede-Berg (Michell's Pass) Transfer Scheme
BF	Baseflow
BGCMA	Breede-Gouritz Catchment Management Agency
Bigen	Bigen Africa Services (Pty) Ltd
CGS	Council for Geoscience
DT	Discharge Table
DWAF	Department of Water Affairs and Forestry (now DWS)
DWS	Department of Water and Sanitation
EWR	Ecological Water Requirement
IAP	Invasive Alien Plants
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
PSP	Professional Service Provider
SAWS	South African Weather Service
Tlou	Tlou Integrated Tech cc
WAAS	Water Availability Assessment Study
WCWSS	Western Cape Water Supply System
WMA	Water Management Area
WR2012	Water Resources of South Africa, 2012 Study
WRC	Water Research Commission
WRMF	Water Resources Modelling Framework
WRPM	Water Resources Planning Model
WRSM2000	Water Resources Simulation Model 2000
WRYM	Water Resources Yield Model
WUA	Water User Association

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1. INTRODUCTION

1.1. Background to study

Bid Number WP 11339 titled *Appointment of Professional Service Provider for a Feasibility Bridging Study for Breede-Berg (Michell's Pass) Water Transfer Scheme* (BBTS) was issued by the Department of Water and Sanitation (DWS) on 2 October 2020. This study is hereafter referred to as the Bridging Study.

The proposed BBTS comprises the diversion of winter water by a new diversion weir from the upper Breede River at the same site as that of the current Artois Canal diversion and transferring the water through a new pipeline to the upper reaches of the Klein Berg River, from where the water will be conveyed via the existing Klein Berg Canal into the Voëlvlei Dam, which is in the adjacent Berg River catchment area. The scheme would also supply the summer and winter irrigation requirements of the existing users of the Artois Canal, including the town of Wolseley, and the Ecological Water Requirement (EWR) of the Breede River downstream of the proposed weir.

Any transfer of water out of the Upper Breede River Basin will impact on downstream water users. In this case the yield of Brandvlei Dam would be reduced unless the capacity of the infrastructure to pump or supply water into the dam is increased. Therefore, allowance for maintaining the yield of Brandvlei Dam through an upgrade of the pump station at Papenkuils is required.

Tlou Integrated Tech cc (Tlou), supported by Bigen Africa Services (Pty) Ltd (Bigen) and other sub-consultants, has been appointed as Professional Service Provider (PSP) by the DWS to undertake the Bridging Study. The Service Level Agreement (SLA) between the DWS and the PSP stipulates a contractual project commencement date of 18 August 2021 and Contract Period of 30 months.

1.2. Scope of study

The main objectives of the Bridging Study are:

- Review and update the hydrology (water availability) and water requirements of the Upper Breede River catchment, as far downstream as the abstraction point for Brandvlei Dam near Worcester.
- Determine the stochastic yield of the Upper Breede River and the amount of water available for transfer to the Berg River, after providing for the EWR and existing users of the Breede River.

- Undertake a public participation process to engage with water users in the Upper Breede River and Klein Berg River catchments regarding the BBTS; and
- Review and update the layout, design and cost estimate of components required for the BBTS to feasibility level of detail, including an increased abstraction rate for Brandvlei Dam.

1.3. Overview of study area

The original BBTS study area comprised the Upper Breede catchment (H10A – H10L) as well as the Klein Berg River catchments (G10E and G10F). This comprises the upper part of the Breede River catchment area up to the Brandvlei Dam abstraction point at Papenkuils and part of the Berg River catchment contributing to the inflow into Voëlvlei Dam. However, this was extended for the water resource assessment tasks to include the whole of the Breede River catchment. Hence, the study area comprises of the Upper Breede River, Middle Breede River and Lower Breede River, as well as the Riviersonderend and all tributaries' catchment areas.

A map of the Breede River catchment is provided in **Figure 1.1** (white outlined area), with the extent of the BBTS study area as defined in the ToR (i.e., the Upper Breede River catchment) highlighted in colour.

As indicated in **Figure 1.2**, the extended study area includes the following quaternary catchments:

- H10A to H90E
- G10E (Boontjies River/Klein Berg River)
- G10F (including Voelvlei Dam)

Figure 1.1: Map of the Breede River catchment

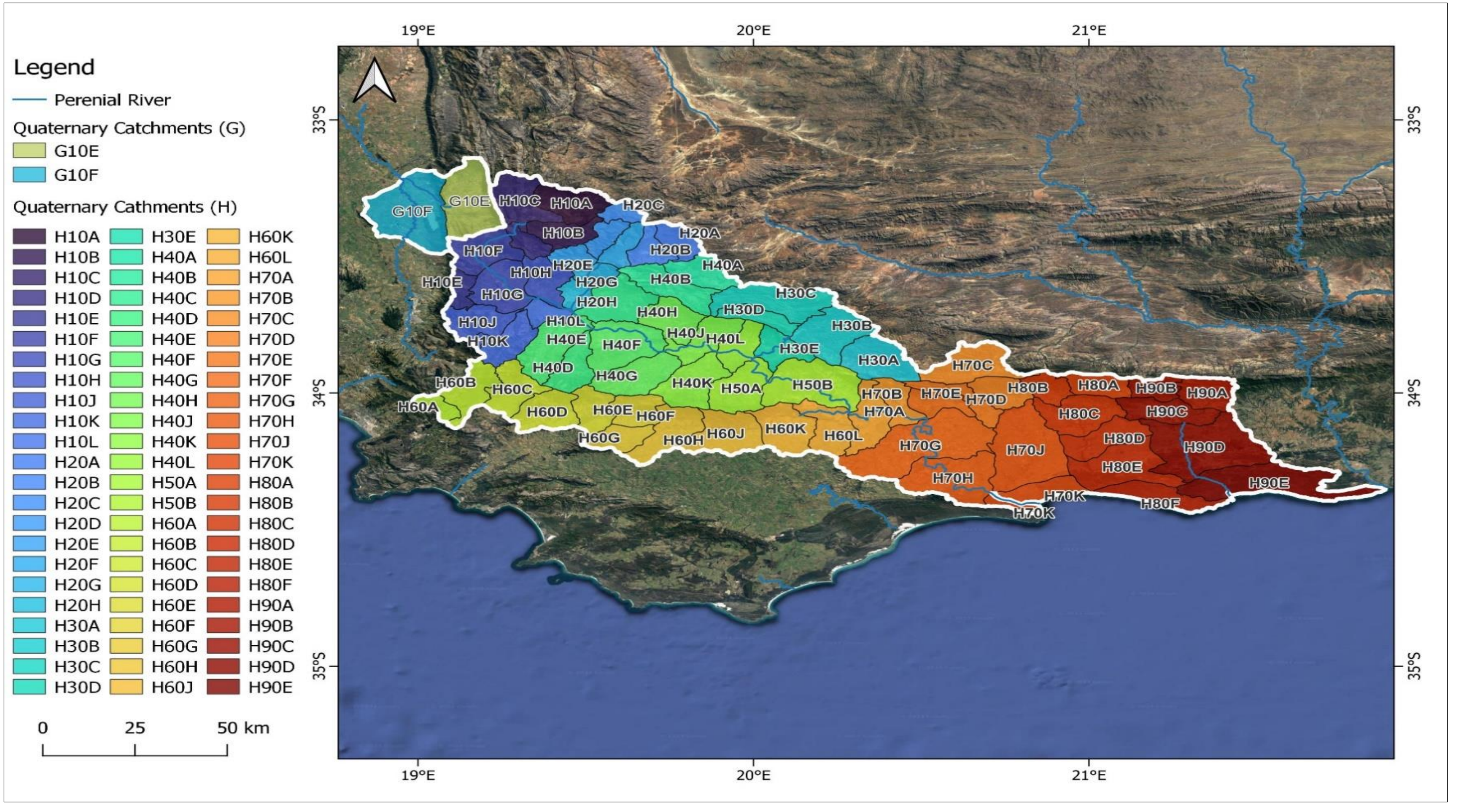

Figure 2.2: Extended study area considered in the groundwater resources assessment

1.4. Purpose of this Water Resources Assessment

The general objective of the BBTS Bridging Study can be stated to investigate and confirm the amount of water that can be transferred from the Upper Breede River to Voëlvlei Dam to augment the Western Cape Water Supply System (WCWSS), as well as undertake the feasibility design of the scheme components, i.e. the proposed abstraction of surplus winter water from the Breede River by means of the Michell's Pass Diversion Weir and transfer of the surplus water via a pipeline and discharged into a tributary of the Klein Berg River from where it will be abstracted via existing infrastructure.

The original main purpose of this water resources assessment was to:

- Review and update the hydrology (water availability) and water requirements of the Upper Breede River catchment, and as far downstream as the abstraction point for Brandvlei Dam (Worcester);
- Determine the stochastic yield of the Upper Breede River and the amount of water available for transfer to the Berg River, after providing for the environmental water requirements (EWR) in the Breede River;

Based on the outcome of consultations with various role players and stakeholders the most critical task, i.e. the water resources assessment to determine if sufficient water is available for the proposed abstraction of surplus winter water from the Breede River by means of the Michell's Pass Diversion Weir and transfer of this water to the Klein Berg River and eventually Voëlvlei Dam was extended by Variation Order No. 1 to include the middle and lower parts of the Breede River. These areas needed to be included in the water resources system models (Water Resources Yield Model (WRYM) and Water Resource Planning Model (WRPM)) and associated scenario analysis. However, it was only necessary to update the hydrology for the Breede River catchment upstream of Brandvlei Dam, to save costs.

1.5. Purpose and structure of this report

This report describes the initial outcomes of the Water Resources Assessment undertaken for the BBTS study. Note that several delays were experienced over the course of the study, with the result that the study reached its contracted termination date of 17 February 2024 before all technical work on the water resources assessment could be completed. As such, this report represents a *partial deliverable*, describing only the scope of work that had been completed up to 17 February 2024. This includes the relevant sources of information and datasets, methodologies, and results of the relevant sub-tasks, namely:

- Task 3.1.1: Updating rainfall data.
- Task 3.1.2: Updating evaporation data.
- Task 3.1.4: Updating streamflow data.
- Task 3.1.5: Groundwater resources (preliminary).
- Task 3.1.6: Water resources simulation model (preliminary).

Note that the updating of land use data and associated water requirements (under **Task 3.1.3**), pertaining to the original study area is discussed in a separate study report entitled *Water Requirements and Land Use* (April 2023). This includes historical and current (2019/20) land use and water requirements associated with small dams, commercial forestry, invasive alien plants (IAP), irrigation, point source abstractions and return flows.

This report is structured as follows:

Section 2 lists the sources of informationa and data used for the Water Resources Assessment Task.

Section 3 describes the water resources assessment undertaken as follows:

- Section 3.1: Rainfall data analysis
- Section 3.2: Updating evaporation data
- Section 3.3: Updating streamflow data
- Section 3.4: Groundwater resources
- Section 3.5: Water resources simulation model

Appendices are attached are as follows:

Appendix A: Representative catchment rainfall datasets

Appendix B: Rainfall stationarity tests

Appendix C: Streamflow and baseflow hydrographs

Appendix D: WRSM2000 model network designs

Appendix E: Preliminary WRSM2000 calibration results

2. SOURCES OF INFORMATION AND DATASETS

In the Inception Phase of the BBTS study (DWS, 2022), several key sources of information and datasets were identified for potential application in the Water Resources Assessment. A comprehensive list is provided in **Table 2.1**. It should be noted that, since this report represents a *partial deliverable* (as discussed in **Section 1.5**) only selected sources had been consulted for the work that had been completed up to 17 February 2024. Reference to these sources is provided in the relevant sections of this report.

Table 2.1: Sources of information for the water resources assessment

Source	Year	Client	PSP	Relevant information
Surface water				
Breede River Winter Surplus Water	2020	Central Breede River WUA	Aurecon.	Scheme configurations, system yields and operating rules, water requirements and projections
Water Resources of South Africa, 2012 Study (WR2012)	2016	Water Research Commission (WRC)	Various	Quaternary catchment Mean Annual Precipitations (MAPs), catchment isohyetal map, monthly average S-pan evaporation, preliminary Pitman catchment parameters, preliminary WRSM2000 model configurations.
Feasibility Studies. First Phase Augmentation of Voëlvlei Dam. Breede-Berg (Michell's Pass) Water Transfer Scheme	2012	DWA	WCWC JV	Scheme configurations, infrastructure characteristics, system yields and operating rules
Riverine Environmental Water Requirements	2012	DWA	WCWC JV	Riverine and estuarine EWRs for water resources systems analysis and assessing impacts on system yield and operations
Assessment of Water Availability in the Berg River Catchment: Summary Report (P WMA 19/000/00/0101)	2010	DWAF	Ninham Shand in association with Umvoto Africa	Catchment hydrology, scheme configurations and system yield and operations

Source	Year	Client	PSP	Relevant information
Assessment of Water Availability in the Berg River Catchment: Report 5 - Update of Catchment Hydrology – Vol 2: Upper Breede River (P WMA19/000/00/0407)	2009	DWAF	Ninham Shand in association with Umvoto Africa	Catchment hydrology
Breede River WMA: Overview of Water Resources and Utilization (P WMA 18/000/00/0203)	2003	DWAF	BKS	Catchment hydrology, scheme configurations, system yields, water requirements and projections
Breede River WMA: Water Resources Situation Assessment (P 18000/00/0101)	2002	DWAF	Ninham Shand in association with Jakoet and Associates	Catchment hydrology, scheme configurations, system yields and operating rules
Groundwater				
National Groundwater Archive (NGA)	2021	DWS	Various	Information related to current and historic groundwater resources within the project area.
The Assessment of Water Availability in the Berg Catchment (WMA 19) By Means of Water Resource Related Models – Groundwater Model Report Volume 1 Overview of Methodology and Results (P WMA 19/000/00/0408)	2010	DWAF	Ninham Shand in association with Umvoto Africa	IWRM assessment of the WCWSS in the Berg WMA.
The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models – Groundwater Model Report Volume 4 Breede River Alluvium Aquifer Model (P WMA 19/000/00/0408	2008	DWAF	Ninham Shand in association with Umvoto Africa	Assessment of water availability throughout the Berg WMA.

Source	Year	Client	PSP	Relevant information
The Assessment of Water Availability in the Berg Catchment (WMA 19) By Means of Water Resource Related Models – Groundwater Model Report Volume 8 Table Mountain Group (TMG) Aquifer, Witzenberg-Nuy Model (P WMA 19/000/00/0408)	2008	DWAF	Ninham Shand in association with Umvoto Africa	Assessment of groundwater availability in the Witzenberg – Nuy TMG Aquifer.
The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models – Groundwater Model Report Volume 9 Breede River Alluvium Aquifer Model (P WMA 19/000/00/0408)	2008	DWAF	Ninham Shand in association with Umvoto Africa	Assessment of groundwater availability in the Alluvial aquifer of the Breede River Valley.
The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models – Groundwater Model Report Volume 2 Data Availability and Evaluation (P WMA 19/000/00/0407)	2007	DWAF	Ninham Shand in association with Umvoto Africa	Data availability and evaluation report for the Berg water availability assessment study.
The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models – Groundwater Model Report Volume 3 Regional Conceptual Model (P WMA 19/000/00/0407)	2007	DWAF	Ninham Shand in association with Umvoto Africa	The conceptual groundwater model of the Berg WMA.
Groundwater Resource Assessment Phase 2 (GRA II) data sets	2003	DWAF	Various	National scale assessment of groundwater resources.
1:500 000 hydrogeological map 3317 Cape Town and information booklet	2001	DWAF	DWA	Regional hydrogeological conditions within the project area.
1:250 000 geological map 3319 Worcester and information booklet	1997	Council for Geoscience (CGS)	CGS	Regional Geological conditions within the project area.

Other sources of information				
Water Use Authorisation and Registration Management System (WARMS)	2021	DWS	Various	Registered NWA Section 21 (a) water users.
Water Management System (WMS)	2021	DWS	Various	Registered water users with water quality data.
Verification and validation (V&V)	2021	BGCMA	Various	Verified and validated water users within the project area.
Gazetted Resource Quality Objectives (RQOs)	2016	DWS	Various	Quaternary scale RQO's.
Support to the Implementation and Maintenance of Reconciliation Strategies for Towns in the Southern Planning Region	2015	DWS	Umvoto Africa	Water supply sources details, water balance calculations, water requirement projections for towns in the Berg and Breede catchments.

3. WATER RESOURCES ASSESSMENT

The assessment of the water resources of the Upper Breede River catchment was undertaken based on the accepted modelling methodologies and level of detail for a *Water Availability Assessment Study* (WAAS). As such, the quaternary catchment was adopted as the minimum spatial modelling resolution, but with sub-quaternary modelling undertaken in many cases based on the location of significant water resources infrastructure (dams, diversion weirs, canals, pipelines, etc.) and water use centres. Furthermore, the aim was to develop a comprehensive hydro-meteorological database extending over a period of 100 hydrological years from 1920 to 2019 (i.e. up to September 2020).

The following sub-sections describe the outcomes of the work that had been completed up to 17 February 2024 (as discussed earlier in **Section 1.5**). This includes the relevant sources of information and datasets, methodologies, and results of the tasks to update rainfall, evaporation, and streamflow data, the assessment of groundwater resources and the configuration and calibration of the Water Resources Simulation Model (WRSM) (not completed).

3.1. Rainfall data analysis

Rainfall records that accurately represent the rainfall in a catchment are essential for generating natural catchment runoffs using the *Water Resources Simulation Model 2000* (WRSM2000) rainfall-runoff model (as discussed later in **Section 3.5**). These records must be as long as possible so that the resulting hydro-meteorological database captures the true characteristic of the catchments in question – including natural periods of above and below average rainfall and, specifically, periods of drought. The process of updating rainfall data for the BBTS study included several sub-tasks, as detailed below:

3.3.1 Selection of rainfall stations

Monthly historical rainfall station data sets for all *South African Weather Service* (SAWS) rainfall stations are available from the DWS *Water Resources Modelling Framework* (WRMF). However, these data sets run only up to the 2011 hydrological year (September 2012), based on an existing Memorandum of Agreement (MoA) between the DWS and SAWS. Therefore, in the case of stations that were still open and being monitored at the end of 2011, data for the interim period up the present was acquired from SAWS for application in this study.

In the Inception Phase of the study, an initial assessment was made of the rainfall stations located within and/or in the proximity of the study area that were still open in 2011. A list of these stations is provided in **Table 3.1**. For each station monthly rainfall data was acquired from SAWS for the period 2010 to the present (if available).

Table 3.1: List of rainfall stations acquired from SAWS

Station		Location	
No.	**Name**	**Lat. (S.)**	**Long (E.)**
0006 361 A	S O S	-34° 1'	19°13'
0021 823 W	Paarl	-33°43'	18°58'
0021 879 W	Wellington-Mun	-33°39'	19° 0'
0022 005 W	Welbedacht	-33°35'	19° 1'
0022 009 D	G1E001 Wellington	-33°39'	19° 1'
0022 038 W	Vrugbaar	-33°38'	19° 3'
0022 116 D	Assegaaibos	-33°56'	19° 4'
0022 140 D	Zachariashoek @ Wemmershoek Dam	-33°50'	19°5'
0022 148 W	Robertsvlei-Bos	-33°56'	19° 5'
0022 440 W	Stettynskloof	-33°50'	19°15'
0022 504AW	Villiersdorp Welgegund	-33°54'	19°17'
0022 729 W	Worcester	-33°39'	19°25'
0022 803 W	Doorn River	-33°53'	19°27'
0022 825 W	Kwaggaskloof Dam	-33°46'	19°28'
0041 279 W	Moorreesburg-Pol	-33° 9'	18°40'
0041 347 W	Langgewens-Agr	-33°17'	18°42'
0041 388 W	Malmesbury E	-33°28'	18°43'
0041 418 W	Malmesbury Gevangenis	-33°28'	18°44'
0041 533 W	Lelyfontein	-33°23'	18°48'
0042 050 D	Vogel Vallij @ Voëlvlei Dam	-33°20'	19° 2'
0042 227 W	Tulbagh-Pol	-33°17'	19° 9'
0042 236 W	Watervalberg	-33°26'	19° 8'
0042 281AW	Remhoogte	-33°11'	19°10'
0042 326 W	Kluitjieskraal-Bos	-33°26'	19°11'

0042 355 W	Wolseley-Pol	-33°25'	19°12'
0042 357 D	Wolseley @ Experimental Farm	-33°27'	19°12'
0042 358 W	Dwars River TNK	-33°28'	19°12'
0042 532AW	Ceres-Mun	-33°22'	19°19'
0042 582 W	Bokveldskloof	-33°12'	19°20'
0042 588 W	Prince Alfred Hamlet - P	-33°18'	19°20'
0042 621 W	Warmbokveld	-33°21'	19°21'
0042 700 W	Die Erf	-33°10'	19°24'
0042 789 W	Odessa	-33° 9'	19°27'
0043 116 D	Roode Els Berg @ Roode Els Berg Dam	-33°26'	19°34'
0043 139 W	Klondyke	-33°19'	19°35'
0043 267 D	H2E001 De Doorns @ Hex Valley	-33°27'	19°39'
0043 329 W	De Doorns - Pol	-33°29'	19°40'

A map showing the location of rainfall stations is presented in **Figure 3.1**, with the stations that were still open after 2011 shown on blue.

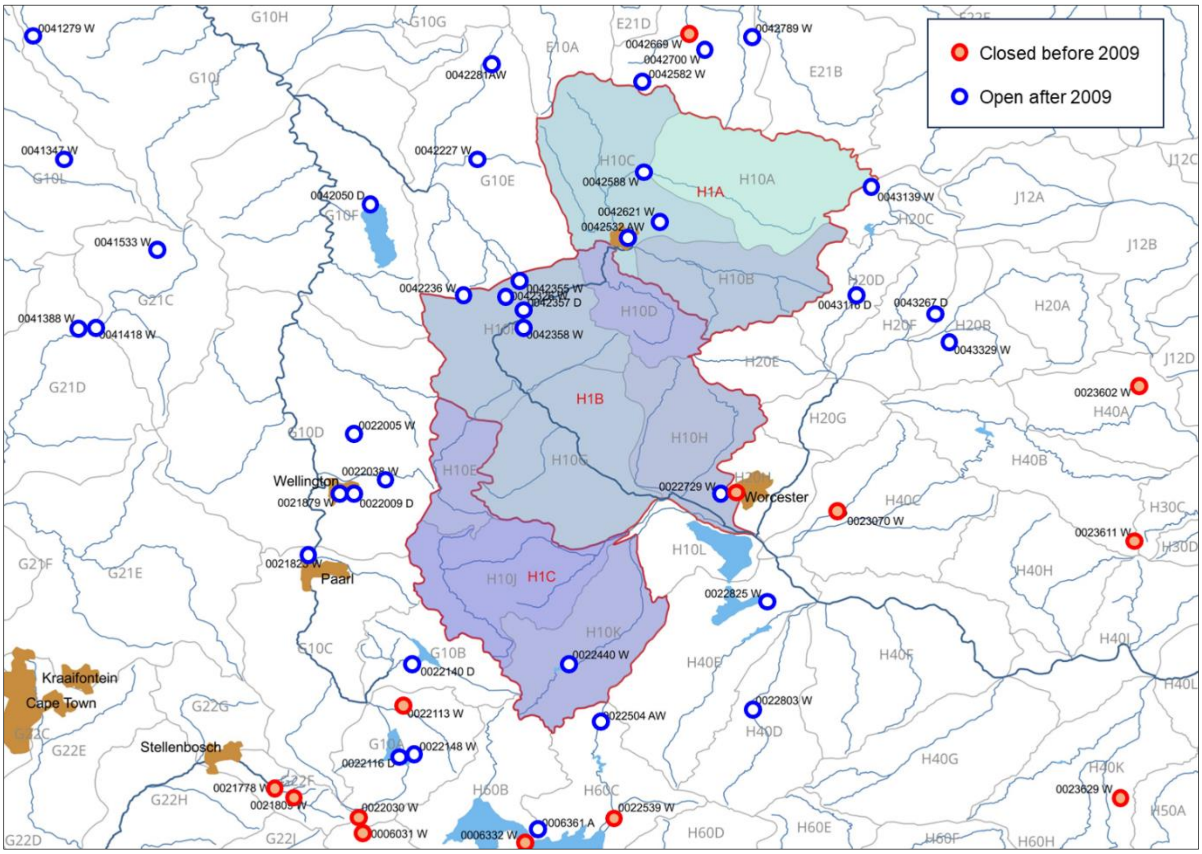

Figure 3.1: Location of rainfall stations

An assessment of the available datasets showed, however, that many of the stations still open after 2011 were also closed in the early 2010s, as shown in the bar chart below.

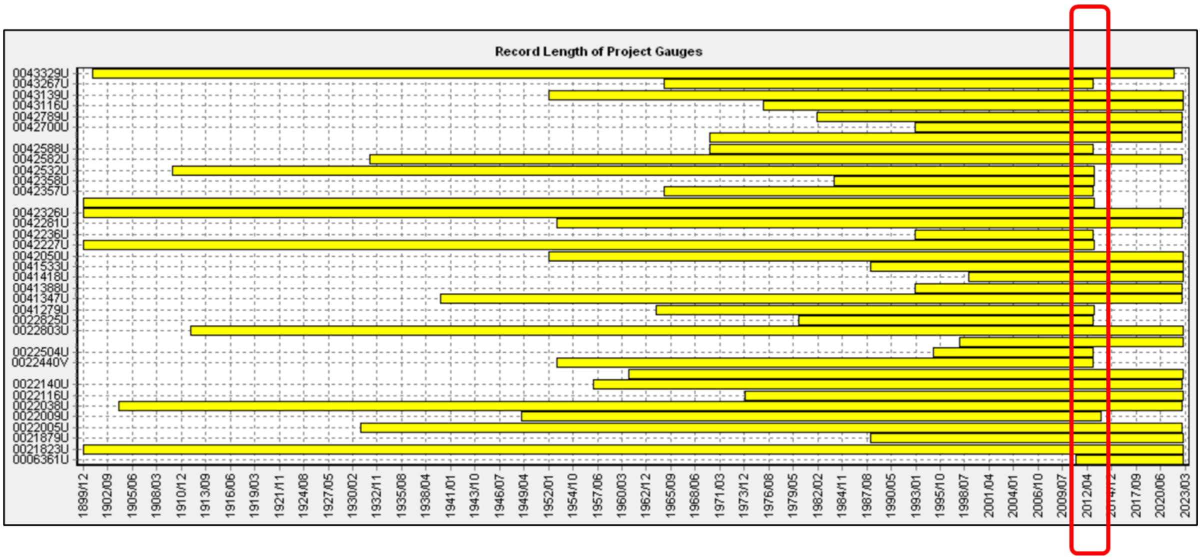

Figure 3.2: Evaluating rainfall station record lengths

Based on these considerations, as well as the physical location, record length and data quality, 11 stations were selected for extending catchment rainfall for the study area to the 2019 hydrological year. The location of these stations is shown in **Figure 3.3**, and more information on each station is provided in **Table 3.2**.

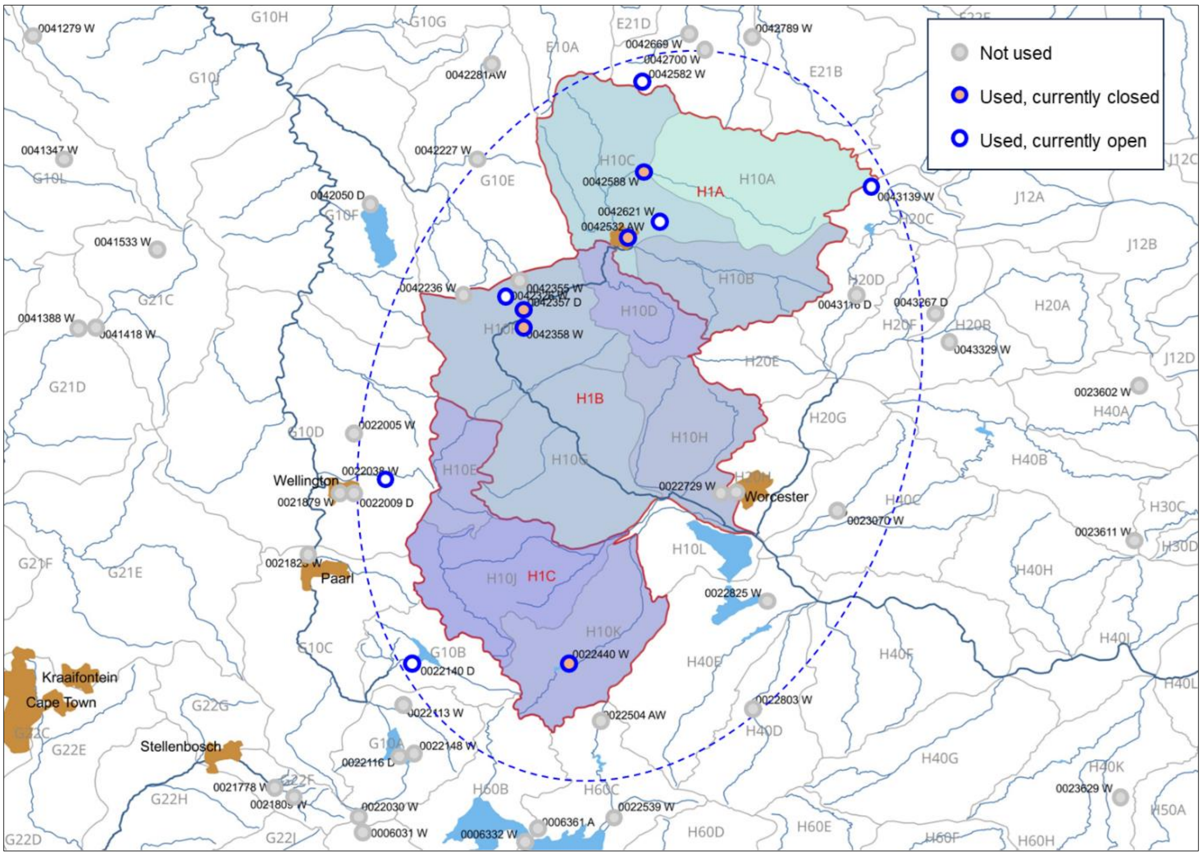

Figure 3.3: Location of selected rainfall stations

Table 3.2: List of selected rainfall stations

Station		Status	Location		Record period			Missing months	Notes
No.	Name		Lat. (S.)	Long (E.)	Start	End	Years		
0022038W	Vrugbaar	Open	33°38'	19° 3'	1903	2022	120	0.8%	Data OK
0022140D	G1e003 @ Wemmershoek Dam	Open	33°50'	19° 5'	1956	2022	67	1.5%	Data OK; Discard 1956/7
0022440W	Stettynskloof	Closed	33°50'	19°15'	1952	2012	61	1.6%	Data OK; Note: Only station in H1C
0042326W	Wolseley Kluitjieskraal	Open	33°26'	19°11'	1899	2022	124	0.8%	Inside catchment; Many flags in 2000s
0042357D	H1e002 Wolseley @ Exp. Farm	Closed	33°27'	19°12'	1964	2012	49	2.0%	Data OK; Discard 2013 hydro year
0042358W	Wolseley Dwarsrivier	Closed	33°28'	19°12'	1983	2012	30	3.3%	Inside catchment; Many flags
0042532A	Ceres - Tnk	Closed	33°22'	19°18'	1909	2012	104	1.0%	Suspect: Many flags, unflagged zeros
0042582W	Bokveldskloof	Open	33°11'	19°20'	1931	2022	92	1.1%	Suspect: Many unflagged zeros
0042588W	Prince Alfred Hamlet	Closed	33°18'	19°20'	1969	2012	44	2.3%	Inside catchment; Many flags
0042621W	Warmbokveld	Open	33°21'	19°21'	1969	2022	54	1.9%	Inside catchment; Many flags
0043139W	Klondyke Farm	Open	33°19'	19°35'	1951	2022	72	1.4%	Data OK; Some unflagged zeros

3.3.2 Rainfall data patching

While there are several rainfall stations in an around the upper Breede River catchment (as outlined in the preceding section), all contain missing and/or unreliable data values. The accepted practice to generate complete records is to patch and extend the rainfall records by analysing the statistical characteristics of each station record and grouping similar stations together for patching purposes.

Rainfall patching was undertaken using the DWS ClassR and PatchR suite of software. An example software screen is shown below, in this case to evaluate the record length of rainfall stations used for patching in an area referred to as 'Zone H1A'.

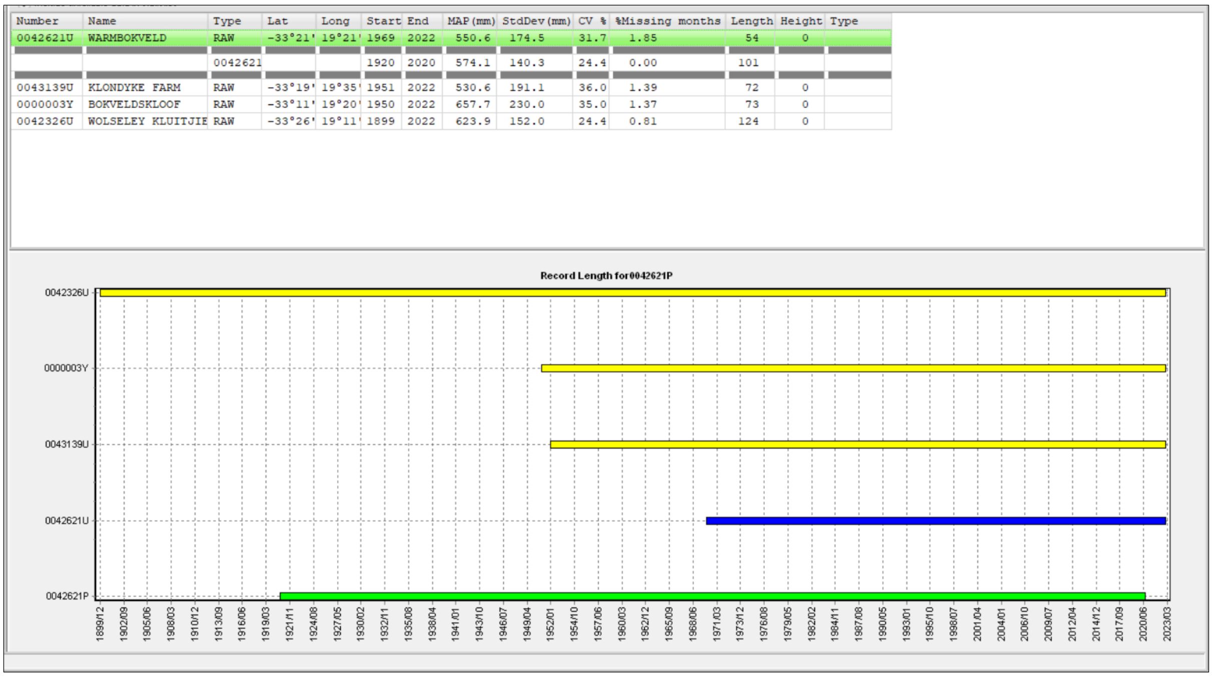

Figure 3.4: Example showing rainfall station record lengths (H1A)

3.3.3 Representative catchment rainfall

Patched station rainfall datasets were used to generate representative catchment rainfall time-series datasets for the BBTS study area, over the full 100-year study period from 1920 to 2019 (hydrological years). Note that the *Water Resources of South Africa, 2012 Study* (WR2012) (WRC, 2016) (and earlier studies) used defined 'Rainfall Zones' to represent rainfall for several selected quaternary catchments. These Rainfall Zones, which are numbered H1A, H1B and H1C, are shown earlier in **Figure 3.3** and were also adopted for developing representative catchment rainfall datasets in this study. An example is shown in **Figure 3.5** and datasets for all Rainfall Zones are provided in **Appendix A** of this report.

1920	5.44	1.47	3.81	4.19	6.47	3.85	7.23	2.77	59.16	31.66	15.92	6.30
1921	3.89	2.39	4.54	8.92	1.45	4.13	5.16	9.60	23.12	5.64	20.90	2.28
1922	2.55	1.90	0.99	3.05	0.79	0.82	7.47	16.15	26.36	15.51	11.88	8.59
1923	5.44	3.97	3.97	1.24	1.06	3.42	2.09	5.80	26.52	8.16	15.90	8.35
1924	9.63	5.78	0.00	2.15	1.02	0.95	1.02	8.05	46.09	20.91	5.96	3.47
1925	14.88	7.73	1.20	0.00	4.36	0.00	1.45	14.48	4.91	18.00	10.11	4.23
1926	14.55	5.41	0.00	2.83	5.93	0.00	7.51	13.06	11.27	4.32	21.48	6.07
1927	1.56	12.34	3.32	3.61	0.00	3.66	1.83	1.98	36.06	8.00	14.37	12.05
1928	3.97	3.97	1.54	0.00	1.20	2.15	13.89	12.32	12.29	20.95	16.37	3.70
1929	2.15	1.74	7.09	3.77	4.22	1.76	3.21	3.03	3.85	12.07	14.42	21.28
1930	4.13	4.18	1.59	0.00	2.20	0.83	10.73	18.52	5.86	7.89	30.58	11.68
1931	7.02	1.38	2.48	4.54	18.39	2.41	2.48	15.80	16.64	18.93	8.13	8.19
1932	2.53	0.95	2.15	2.85	3.70	2.46	1.24	13.24	26.03	26.02	11.78	6.02
1933	5.96	1.97	3.14	2.17	2.90	5.48	2.55	14.70	10.71	11.8		
1934	12.99	0.00	0.00	1.31	1.40	5.08	8.45	13.85	8.88	19.0		
1935	3.02	6.62	1.26	5.10	1.62	3.48	1.18	16.62	5.59	13.5		
1936	3.49	2.31	12.61	2.33	0.72	7.15	9.22	14.01	23.36	30.8		
1937	4.49	1.31	3.25	10.21	2.24	1.06	9.20	20.98	9.04	8.2		
1938	3.92	3.42	2.51	1.29	9.03	1.30	7.93	17.97	5.84	9.0		
1939	1.47	4.13	7.08	2.62	5.82	2.94	11.28	8.83	17.42	9.7		
1940	4.37	8.16	1.31	7.60	3.17	0.82	15.80	32.00	26.45	0.0		
…												
…												
2019	11.17	0.35	5.27	6.78	0.35	0.32	7.77	13.44	22.36	23.4		

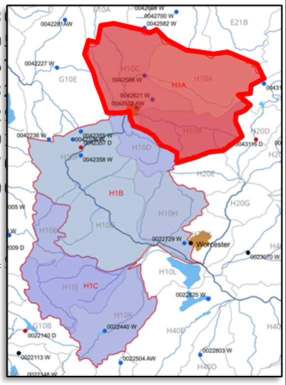

Figure 3.5: Example of representative catchment rainfall dataset (H1A)

Finally, standard tests were undertaken to ensure that the representative catchment rainfall datasets are statistically stationary. The results are presented in **Appendix B**, including plots of cumulative annual rainfall over time (or 'mass plots'), and cumulative deviation of annual rainfall from the means (or 'cusum plot').

3.2. Update evaporation data

Monthly and annual reference evaporation data was obtained from the WR2012 study (WRC, 2016). These were used to develop a quaternary catchment database of monthly Symons Pan (or 'S-pan') and lake evaporation for modelling catchment evapo-transpiration and evaporation from dams in later tasks. The results are presented in **Table 3.3**, **Table** 3.4 and **Table** 3.5.

Table 3.3: Quaternary catchment evaporation characteristics

Quaternary catchment	Catchment area (km²)	Evaporation Zone	MAE (S-pan) (mm)
H10A	234	23A	1 670
H10B	162	23A	1 650
H10C	260	23A	1 650
H10D	97	23A	1 640
H10E	85	23A	1 605
H10F	248	23A	1 625
H10G	270	23A	1 610
H10H	187	23A	1 620
H10J	214	23A	1 570
H10K	194	23A	1 545
H10L	96	23A	1 605
Total:	**2 047**	**Average:**	**1 619**

Table 3.4: Quaternary catchment monthly S-pan evaporation

Quaternary catchment	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
H10A	153	191	236	247	207	186	118	72	49	49	64	97
H10B	152	189	233	244	205	184	116	72	49	49	63	95
H10C	152	189	233	244	205	184	116	72	49	49	63	95
H10D	151	188	231	242	203	183	116	71	48	49	63	95
H10E	147	184	226	237	199	179	113	70	47	48	61	93
H10F	149	186	229	240	202	181	115	71	48	48	62	94
H10G	148	185	227	238	200	180	114	70	47	48	62	93
H10H	149	186	229	239	201	181	114	70	48	48	62	94
H10J	144	180	222	232	195	175	111	68	46	46	60	91
H10K	142	177	218	228	192	172	109	67	45	46	59	89
H10L	147	184	226	237	199	179	113	70	47	48	61	93
Average	**149**	**185**	**228**	**239**	**201**	**181**	**114**	**70**	**48**	**48**	**62**	**94**

Table 3.5: Quaternary catchment monthly lake evaporation

Quaternary catchment	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
H10A	124	157	196	207	182	164	104	63	42	41	52	78
H10B	123	155	193	205	180	162	102	62	41	41	51	77
H10C	123	155	193	205	180	162	102	62	41	41	51	77
H10D	122	154	192	204	179	161	102	62	41	40	51	77
H10E	119	151	188	199	175	158	100	61	40	39	50	75
H10F	121	153	190	202	177	160	101	61	41	40	50	76
H10G	120	151	189	200	176	158	100	61	40	40	50	75
H10H	121	152	190	201	177	159	101	61	40	40	50	76
H10J	117	148	184	195	171	154	97	59	39	39	49	74
H10K	115	145	181	192	169	152	96	58	39	38	48	72
H10L	119	151	188	199	175	158	100	61	40	39	50	75
Average	**120**	**152**	**190**	**201**	**177**	**159**	**100**	**61**	**40**	**40**	**50**	**76**

3.3. Update streamflow data

Observed streamflows are used in the process of calibrating the WRSM2000 rainfall-runoff model and subsequent development of naturalised streamflow records. Streamflow gauging station records were obtained from the online DWS Hydstra platform for stations located within the BBTS study area. A list of these stations is provided in **Table 3.6** and a map showing the location of each station in **Figure 3.6**.

Table 3.6: List of streamflow gauging stations in the study area

Quaternary	Latitude	Longitude	Station Number	Name/Description	Station Type	Open/Closed
H10L	-33.68482	19.33384	H1H002	Holsloot River @ Rawsonville	River	Closed
H10D	-33.38056	19.30167	H1H003	Bree River @ Ceres Toeken Geb.	River	Open
H10H	-33.56261	19.34079	H1H004	Jan Dutoits River @ De Breede River	River	Closed
H10H	-33.60871	19.31718	H1H005	Jan Dutoits River @ Goudiniweg	River	Closed
H10F	-33.42167	19.26722	H1H006	Bree River @ Ceres Toeken Geb.	River	Open
H10E	-33.56861	19.14500	H1H007	Wit River @ Drosterskloof	River	Open
H10L	-33.69427	19.31440	H1H008	Smalblaar River @ Rawsonville	River	Closed
H10K	-33.69361	19.32444	H1H009	Holsloot River @ Boontjies River	River	Open
H10L	-33.67232	19.33912	H1H010	Holsloot River @ Rawsonville	River	Closed
H10E	-33.64371	19.11134	H1H011	Wit River @ Oostenberg	River	Closed
H10K	-33.75676	19.32995	H1H012	Holsloot River @ Daschboch River	River	Closed
H10C	-33.35972	19.29833	H1H013	Koekedou River @ Ceres	River	Open
H10B	-33.43483	19.40412	H1H014	Vals River @ Ben Etive	River	Closed
H10H	-33.68427	19.42134	H1H015	Bree River @ Die Nekkies	River	Closed
H10B	-33.42095	19.47802	H1H016	Rooikloof River @ Ben Etive	River	Closed
H10J	-33.73343	19.11439	H1H017	Elands River @ Hawequas Forest Res.	River	Closed
H10J	-33.72472	19.16972	H1H018	Molenaars River @ Hawequas Forest Res.	River	Open
H10G	-33.58510	19.22467	H1H019	Slanghoek River @ Slanghoek	River	Closed
H10H	-33.55816	19.43551	H1H020	Hartbees River @ Brandwachtsberg	River	Closed
H10K	-33.83704	19.25273	H1H032	Holsloot River @ Haweqwas State For.	River	Closed
H10J	-33.73667	19.11472	H1H033	Elands River @ Hawequas Forest Res.	River	Open
H10L	-33.70185	19.45007	H1R001	Lower Brandvlei River @ Nekkies	Reservoir	Open
H10K	-33.83638	19.25176	H1R002	Holsloot River @ Haweqwas State For.	Reservoir	Open
H10C	-33.36321	19.27343	H1R003	Koekedou River @ Ceres	Reservoir	Closed

Available streamflow records were screened and evaluated for application in the study, based on the following considerations:

- Physical location of station and upstream catchment area.
- Record length.
- Reliability of streamflow data, considering aspects such as DWS evaluations, age of latest calibrated DWS discharge table (DT), number of missing and/or unreliable data values, etc.
- Selection of station for application in earlier studies.

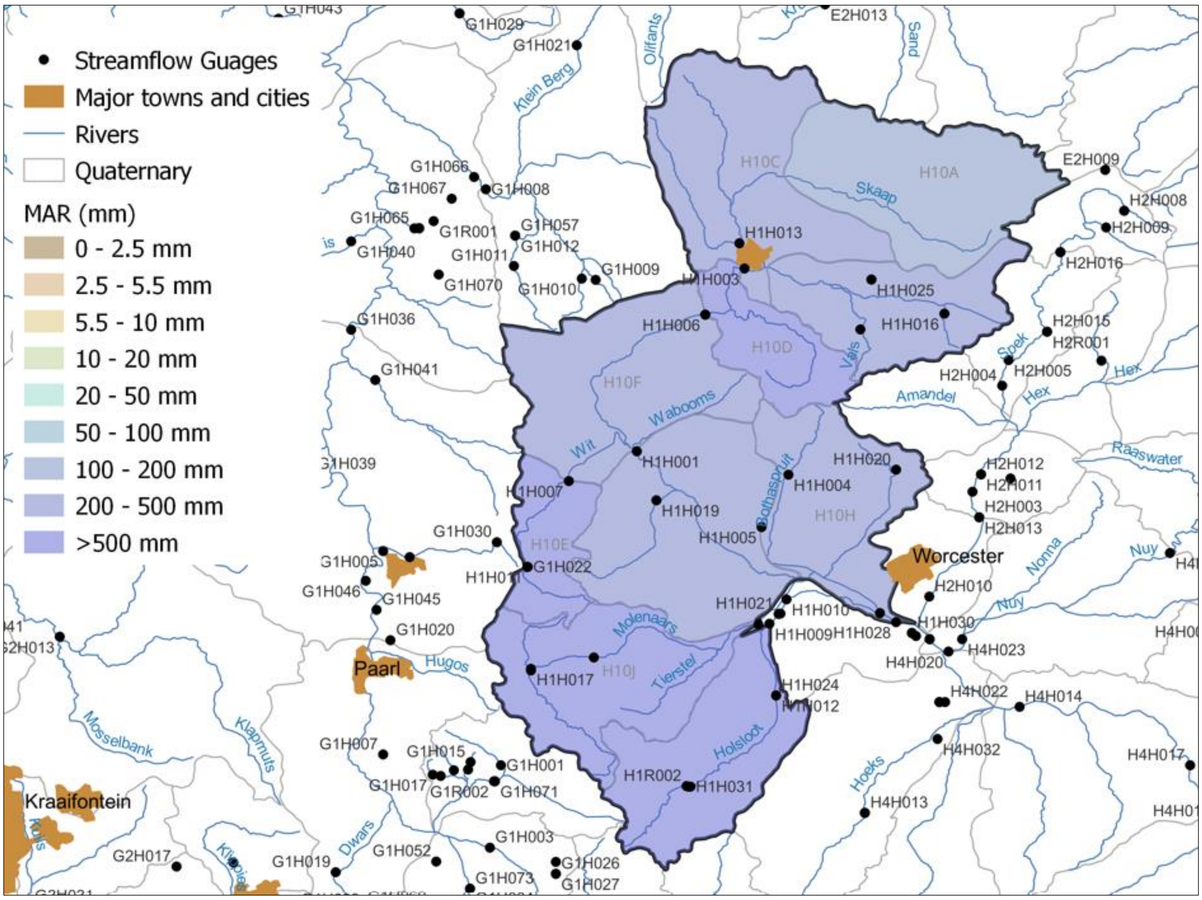

Figure 3.6: Location of streamflow gauging stations

Based on the consideration discussed above, seven gauging stations were selected for application in the assessment, as listed below.

Table 3.7: List of selected streamflow gauging stations

Station		Status	Location		Record period	
No.	Name		Lat. (S.)	Long (E.)	Start	End
H1H003	Bree River @ Ceres Toeken Geb.	Open	33.38	19.30	1923	-
H1H006	Bree River @ Ceres Toeken Geb.	Open	33.42	19.27	1950	-
H1H007	Wit River @ Drosterskloof	Open	33.57	19.15	1935	-
H1H012	Holsloot River @ Daschboch River	Closed	33.76	19.33	1963	1986
H1H013	Koekedou River @ Ceres	Open	33.36	19.30	1965	-

Station		Status	Location		Record period	
No.	Name		Lat. (S.)	Long (E.)	Start	End
H1H017	Elands River @ Hawequas Forest	Closed	33.73	19.11	1969	1992
H1H018	Molenaars River @ Hawequas Forest	Open	33.72	19.17	1969	-

For each of the selected stations, missing and unreliable data values were patched using simulated streamflows. These simulated values were generated using WRSM2000. For this purpose, the model was calibrated on a preliminary basis (as discussed later in **Section 3.5**). An example is shown in **Figure 3.7**, for gauge H1H013 (Koekedou River @ Ceres), with patched streamflow values highlighted in red.

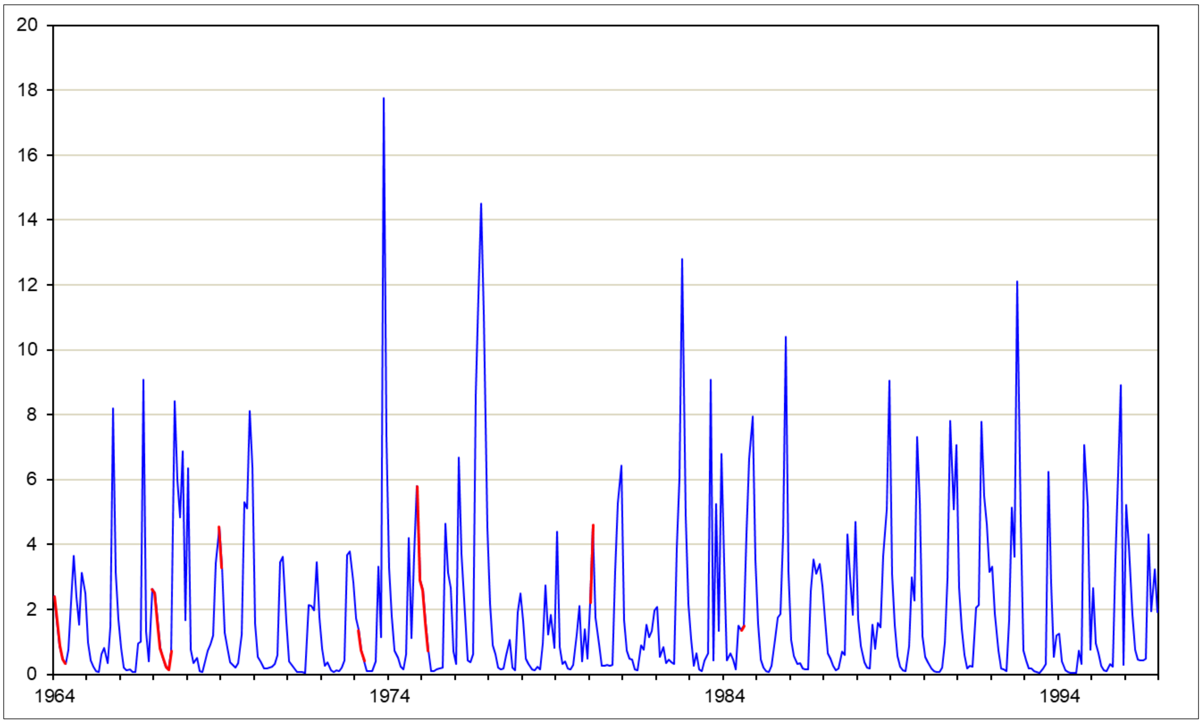

Figure 3.7: Example of patched observed streamflow record (H1H013)

3.4. Groundwater resources

3.4.1 Overview

The aim of the groundwater resources assessment was to provide relevant input into the streamflow hydrology and WRSM2000 modelling processes. Note that the original study area for the BBTS comprised of the Upper Breede catchment (H10A – H10L) as well as the Klein Berg River catchments (G10E and G10F). However, this was extended for the water resource assessment tasks to include the whole of the Breede River catchment. Hence, the groundwater resources assessment presented here comprises of the Upper Breede River, Middle Breede River and Lower Breede River, as well as the Riviersonderend and all its tributary catchment areas, as shown in Error! Reference source not found..

The assessment was focused on determining the groundwater resources of the catchment, its current use, and its interaction with the surface water of the catchment, to correctly model the hydrology of the catchment. Hence, the output of the assessment comprises of baseflow hydrographs as input to the WRSM2000 model, either to confirm or calibrate the Sami Module output or to replace it, where required.

The aquifers present within the Breede River catchment are the fractured Peninsula Aquifer, the Fractured Nardouw Aquifer (consistent of the Skurweberg and Rietvlei Formations), the intergranular-fractured aquifer (consistent of the basement Malmesbury Group formations) and the intergranular aquifer (mainly consistent of the alluvial deposits along the river systems within the study area).

3.4.2 Baseflow separation methods

Baseflow separation is a fundamental aspect of hydrological analysis, serving to dissect streamflow into its constituent components of baseflow and surface runoff. The accurate delineation of baseflow is crucial for various water resource management applications, including flood forecasting, water quality assessment, and ecosystem management. To select the most appropriate method, a total of four baseflow separation methods were assessed and reviewed. These include Recursive Digital Filter methods such as Lyne & Hollick (1979); Chapman (1991); Chapman & Maxwell (1996); and Furey and Gupta (2001), as described below:

Lyne and Hollick (1979) Method

The Lyne and Hollick method hinges on the principle that baseflow exhibits slower variations compared to surface runoff. This method typically involves fitting a recession curve to the hydrograph's recession limb, which represents the baseflow component. By delineating the recession period and isolating the baseflow contribution from the total flow, this method enables the estimation of baseflow under varying hydrological conditions.

This method assumes that high frequency signals represent direct runoff, whereas low frequency signals indicate the baseflow component. The method calculates the surface runoff component, which, when combined with streamflow, can be used to determine the baseflow component.

$$qt = a \times q_{t-1} + \frac{(1-a)}{2} \times (Qt - Q_{t-1})$$

with

q - surface or quick runoff (m3/s)

Q - streamflow (m3/s)

t - the time (e.g., day) for which the surface runoff is calculated

α - catchment constant (values between 0 and 1); default set to 0.750

Chapman (1991) Method

In contrast, the Chapman & Maxwell method employs digital filtering techniques, such as the Eckhardt filter, to partition streamflow into its baseflow and surface runoff constituents. By applying a mathematical filter to the streamflow time series, high-frequency fluctuations associated with surface runoff are attenuated, leaving behind the low-frequency baseflow component.

$$bt = \frac{(3 \times a - 1)}{(3 - a)} \times bt - 1 + \frac{(1-a)}{(3-a)} \times (Qt - Q_{t-1})$$

with

b - baseflow (m3/s)

Q - streamflow (m3/s)

t - the time (e.g., day) for which the baseflow is calculated

α - hydrological recession constant (values between 0 and 1); default set to 0.500

Chapman & Maxwell (1996) Method

The Chapman and Maxwell hydrograph separation digital filter, introduced in 1996, can be viewed as a simplified method that aims to partition streamflow into its baseflow and surface runoff constituents. This method utilizes a mathematical filter to remove rapidly varying components of the hydrograph, leaving behind the low frequency baseflow component.

$$\boldsymbol{bt} = \frac{\boldsymbol{k}}{\boldsymbol{2+C}} \times \boldsymbol{b_{t-1}} + \frac{\boldsymbol{1-\ k}}{\boldsymbol{2-\ k}} \times \boldsymbol{Qt}$$

with

b - baseflow (m3/s)

Q - streamflow (m3/s)

t - the time (e.g., day) for which the baseflow is calculated

k - groundwater recession constant [values between 0 and 1]; set to 0.100

Furey and Gupta (2001) Method

This hydrograph separation filter, introduced in 2001, is a relatively recent approach for baseflow separation that combines elements of recession curve analysis with digital filtering techniques. This method aims to improve upon the limitations of traditional techniques by integrating both empirical and mathematical aspects for more robust baseflow estimation. It is based on a mass balance equation for baseflow through a hillside, and its construction is founded on a physical-statistical theory of low streamflow's developed by Furey and Gupta.

$$\boldsymbol{bt} = (1-y)\ \times \boldsymbol{b_{t-1}} + \mathrm{y}\,\frac{\mathbf{c3}}{\mathbf{c1}} \times (\boldsymbol{Q_{t-d-1}} - \boldsymbol{b_{t-d-1}})$$

with

b - baseflow [m3/s].

Q - streamflow [m3/s].

t - the time (e.g. day) for which the baseflow is calculated.

γ - recession constant [values between 0 and 1].

c1 - ratio of overland flow to precipitation.

c3 - ratio of groundwater recharge to precipitation.

d - time-delay between precipitation and groundwater recharge [d]*.

(Note: *d is assumed to be equal to zero, however the user can change this value during method selection.)

Based on the review of these methods against available data and knowledge of the different catchments, the Lyne and Hollick (1979) method and the Chapman (1991) method were selected for application in the analysis and for providing baseflow timeseries per catchment.

3.4.3 Data collection and processing

The datasets used to generate baseflow values comprise of monthly streamflow data under naturalised and current (developed) conditions. Naturalization of streamflow data involves adjusting the observed flow values to account for anthropogenic influences such as dams, diversions, and withdrawals, thus providing a more representative depiction of the natural hydrological regime. Developed streamflow data refers to existing developed catchment runoff.

The naturalised streamflow data for the catchments H20A to H90E, as well as G30E and G30F were acquired from the WR2012 database which provides streamflow and rainfall data from 1920 to 2011 (hydrological years) for all quaternary catchments. Updated naturalised streamflow and current (developed) streamflow data for catchments H10A – H10L (data from 1920 to 2019) were provided from the surface water team after initial analysis of more recent streamflow and rainfall data.

The application of the Lyne and Hollick (1979) and Chapman (1991) equations to these data sets involved preliminary processing and restructuring of the datasets to produce catchment specific spreadsheets. The two respective equations were then applied to partition stream flow time series data into base flow and direct run off. This involves setting:

- An initial baseflow value for Month 1; usually set equal to minimum threshold baseflow.
- A minimum threshold baseflow value to avoid calculated zero or negative values; based of an assessment of the minimum observed flow in the datasets; and
- The catchment specific variable per method.

This was performed to produce a representative spread of minimum baseflow values that could occur across the time period relative to respective catchment flow records. This is an iterative process, as the selection of these values impact on the outcome, e.g. a higher catchment variable (e.g. 0.9) would minimize the number of months with minimum baseflow but also lead to a lower annual baseflow, while a lower catchment variable (such as the default) would increase the total baseflow, but also increase the number of months with minimum baseflow.

Graphical results of the hydrographs were used to compare the base flow separation results visually between different seasons and years. These are presented in **Appendix C** of this report.

3.4.4 Results

The implemented methodologies were applied to the time series flow data, and the resulting baseflow values were scrutinized for consistency and accuracy. Statistical measures were computed to assess the agreement between the extracted baseflow values from each method. An example is shown in **Table 3.8**.

Table 3.8: Example of statistical data computed for each method and catchment

Statistic	Lyne & Hollick		Chapman	
	million m3	% of total	million m3	% of total
SUM: Flow	3862.73	-	3862.73	-
SUM: Runoff	3737.56	97%	3757.63	97%
SUM: Baseflow	125.17	3%	105.10	3%
Count: Data points	1200	-	1200	-
Count: Minimum BF	525	-	639	-
Annual Average BF	1.25	M m3/a	1.05	M m3/a
Annual Average Flow	38.63	M m3/a	38.63	M m3/a

Variations in the extracted baseflow values were observed and compared to other baseflow data such as Schultz, Hughes and Pitman values derived from the WR2012 dataset, and the recently gazetted Reserve for the Breede River catchments. The results are shown in **Table 3.9**.

Statistical analyses provide quantitative measures of the agreement between the two methods, facilitating a comprehensive evaluation of their performance across different hydrological regimes and environmental settings.

A comparison of naturalized baseflow versus current (developed) baseflow for the H10 catchments shows that a slight decrease in baseflow can be expected, depending upon the degree of land use changes and increase of other water uses, such as surface water and groundwater abstraction.

Considerations such as hydrogeological variability, and the applicability of underlying assumptions play a pivotal role in shaping the outcomes of baseflow separation analyses. Therefore, the results of **Table 3.9** are considered interim results and must be used with caution as the baseflows reported therein are simplified numeric calculations that do not account for natural variability in the system. The final step in the iterative process to compute groundwater contribution to baseflow time series data is still outstanding; viz. evaluation of the baseflow time series against geological and hydrogeological settings in the relevant catchments and deriving the catchment specific variable per catchment to better align to observations and expected groundwater flows.

Table 3.9: Interim results of groundwater contribution to baseflow (BF)

Quaternary catchment	Annual Average Flow (Mm3/a)	BF Schultz (Mm3/a)	BF Pitman (Mm3/a)	BF Hughes (Mm3/a)	BF Gazetted* (Mm3/a)	Naturalised BF L&H (Mm3/a)	Naturalised BF Chap (Mm3/a)	Developed BF L&H (Mm3/a)	Developed BF Chap (Mm3/a)
G10F	53.23	2.22	8.19	19.50		2.03	1.66	N/a	N/a
G10E	76.38	2.28	9.42	21.84		3.21	2.76	N/a	N/a
H10A	38.63	0.84	4.84	11.80	0.76	1.25	1.05	1.25	1.05
H10B	26.77	1.08	5.95	14.25	0.48	1.71	1.55	0.94	0.79
H10C	70.7	1.56	8.74	21.31	2.00	2.37	1.94	2.01	1.65
H10D	134	1.13	6.33	15.78	2.05	5.02	4.08	4.63	3.74
H10E	126.9	4.55	12.72	31.86	3.20	4.94	4.12	4.56	3.87
H10F	75.97	1.92	10.86	27.05	1.39	3.13	2.6	2.59	2.09
H10G	83.93	2.15	11.93	29.88	0.44	3.83	3.24	2.64	2.05
H10H	47.71	1.78	9.91	24.89	2.80	1.83	1.48	1.44	1.13
H10J	196.33	9.32	25.66	64.67	7.94	8.12	6.69	6.78	5.48
H10K	120.34	6.20	15.99	39.22	7.40	4.05	3.25	3.95	3.19
H10L	8.13	0.00	0.00	0.88	0.00	0.34	0.29	0.34	0.29
H20A	4.07	0.00	0.00	0.00	0.47	0.2	0.17	N/a	N/a
H20B	6.31	0.12	0.47	1.18	0.17	0.29	0.25	N/a	N/a

Quaternary catchment	Annual Average Flow (Mm3/a)	BF Schultz (Mm3/a)	BF Pitman (Mm3/a)	BF Hughes (Mm3/a)	BF Gazetted* (Mm3/a)	Naturalised BF L&H (Mm3/a)	Naturalised BF Chap (Mm3/a)	Developed BF L&H (Mm3/a)	Developed BF Chap (Mm3/a)
H20C	8.32	0.29	0.39	1.03	0.05	0.31	0.26	N/a	N/a
H20D	30.35	0.99	3.59	8.74	2.11	1.24	1.05	N/a	N/a
H20E	33.5	1.47	5.21	12.92	2.01	1.97	1.15	N/a	N/a
H20F	13.5	0.24	0.97	3.36	0.32	0.54	0.47	N/a	N/a
H20G	6.29	0.12	0.48	1.33	0.47	0.29	0.26	N/a	N/a
H20H	1.94	0.00	0.00	0.02	0.07	0.12	0.1	N/a	N/a
H30A	16.35	0.00	0.00	1.85	0.33	0.78	0.68	N/a	N/a
H30B	10.59	0.00	0.00	0.81	0.16	0.44	0.38	N/a	N/a
H30C	17.15	0.03	0.00	3.15	0.07	0.75	0.65	N/a	N/a
H30D	3.78	0.00	0.00	0.24	0.06	0.19	0.17	N/a	N/a
H30E	3.87	0.09	0.00	1.58	0.31	0.19	0.17	N/a	N/a
H40A	7.34	0.00	0.00	0.46	0.87	0.31	0.26	N/a	N/a
H40B	3.9	0.42	0.87	1.51	0.87	0.16	0.14	N/a	N/a
H40C	17.43	0.00	0.00	1.26	0.86	0.7	0.59	N/a	N/a
H40D	20.55	0.00	0.00	3.29	1.85	0.74	0.62	N/a	N/a
H40E	26.45	0.00	0.00	4.93	0.20	1.09	0.96	N/a	N/a

Quaternary catchment	Annual Average Flow (Mm3/a)	BF Schultz (Mm3/a)	BF Pitman (Mm3/a)	BF Hughes (Mm3/a)	BF Gazetted* (Mm3/a)	Naturalised BF L&H (Mm3/a)	Naturalised BF Chap (Mm3/a)	Developed BF L&H (Mm3/a)	Developed BF Chap (Mm3/a)
H40F	8.59	0.00	0.00	0.51	0.58	0.34	0.28	N/a	N/a
H40G	17.18	0.21	0.00	3.37	0.23	0.68	0.6	N/a	N/a
H40H	15.48	0.00	0.00	2.04	0.13	0.63	0.55	N/a	N/a
H40J	10.76	0.09	0.00	1.86	0.18	0.46	0.4	N/a	N/a
H40K	8.55	0.12	0.00	2.17	0.24	0.39	0.34	N/a	N/a
H40L	5.29	0.03	0.00	0.88	0.42	0.26	0.23	N/a	N/a
H50A	2.58	0.03	0.00	0.94	0.26	0.13	0.11	N/a	N/a
H50B	15.58	0.12	0.00	2.84	0.78	0.62	0.53	N/a	N/a
H60A	111.92	3.48	11.81	30.38	2.49	4.02	3.38	N/a	N/a
H60B	159.36	4.23	15.14	39.49	7.28	5.48	4.56	N/a	N/a
H60C	63.39	3.07	11.18	27.97	1.64	2.13	1.71	N/a	N/a
H60D	34.81	1.38	5.15	13.34	0.95	1.22	1.02	N/a	N/a
H60E	24.27	0.93	3.72	9.41	0.71	0.87	0.73	N/a	N/a
H60F	19.07	0.66	2.89	7.27	0.66	0.69	0.58	N/a	N/a
H60G	10.63	0.51	1.48	3.83	0.64	0.45	0.39	N/a	N/a
H60H	18.06	0.87	2.48	6.49	1.14	0.64	0.54	N/a	N/a

Quaternary catchment	Annual Average Flow (Mm3/a)	BF Schultz (Mm3/a)	BF Pitman (Mm3/a)	BF Hughes (Mm3/a)	BF Gazetted* (Mm3/a)	Naturalised BF L&H (Mm3/a)	Naturalised BF Chap (Mm3/a)	Developed BF L&H (Mm3/a)	Developed BF Chap (Mm3/a)
H60J	20.18	0.99	2.78	7.28	1.31	0.7	0.6	N/a	N/a
H60K	11.3	0.45	1.39	3.65	1.04	0.4	0.34	N/a	N/a
H60L	9.27	0.36	1.13	3.00	0.87	0.36	0.31	N/a	N/a
H70A	12.18	0.51	1.61	4.25	1.47	0.5	0.44	N/a	N/a
H70B	35.07	8.83	6.32	22.59	4.17	1.22	1.06	N/a	N/a
H70C	19.24	0.00	0.00	0.84	0.23	0.91	0.8	N/a	N/a
H70D	36.19	7.98	5.98	21.01	5.53	1.27	1.1	N/a	N/a
H70E	44.17	10.59	7.33	26.17	5.16	1.56	1.35	N/a	N/a
H70F	19.2	4.53	3.55	12.27	2.31	0.93	0.83	N/a	N/a
H70G	12.06	0.54	1.43	3.53	1.26	0.64	0.56	N/a	N/a
H70H	8.48	0.42	1.08	2.64	1.89	0.37	0.31	N/a	N/a
H70J	10.1	0.54	1.38	3.45	1.43	0.57	0.51	N/a	N/a
H70K	3.35	0.36	0.83	2.09	1.21	0.15	0.13	N/a	N/a
H80A	26.07	5.91	4.71	16.02	7.21	1.27	1.1	N/a	N/a
H80B	36.68	9.82	6.49	22.68	6.45	1.59	1.37	N/a	N/a
H80C	12.74	0.78	1.25	3.23	0.61	0.58	0.5	N/a	N/a

Quaternary catchment	Annual Average Flow (Mm3/a)	BF Schultz (Mm3/a)	BF Pitman (Mm3/a)	BF Hughes (Mm3/a)	BF Gazetted* (Mm3/a)	Naturalised BF L&H (Mm3/a)	Naturalised BF Chap (Mm3/a)	Developed BF L&H (Mm3/a)	Developed BF Chap (Mm3/a)
H80D	8.2	0.33	0.69	1.86	1.23	0.35	0.29	N/a	N/a
H80E	5.63	0.57	1.42	3.45	2.11	0.38	0.34	N/a	N/a
H80F	5.04	0.60	1.18	3.40	2.72	0.21	0.18	N/a	N/a
H90A	51.13	9.06	6.48	21.20	9.04	2.26	1.98	N/a	N/a
H90B	34.25	6.36	4.48	14.84	6.02	1.55	1.36	N/a	N/a
H90C	7.99	0.57	0.89	2.19	1.93	0.32	0.28	N/a	N/a
H90D	12.1	0.93	1.93	5.18	3.29	0.43	0.36	N/a	N/a
H90E	11	1.11	2.33	6.34	4.88	0.4	0.34	N/a	N/a

Note: Using Lyne and Hollick (1979) and Chapman (1991), compared to WR2012 Baseflow data for calibration and Baseflow values obtained from the determination of water resource classes in the Breede-Gouritz WMA, (DWS 2017).

3.4.5 Conclusion

The application of baseflow separation methods, namely the Lyne and Hollick (1979) and Chapman (1991) techniques, provides valuable insights into the hydrological processes governing streamflow dynamics in the BBTS study area. Through the utilization of these methodologies, baseflow time series data are provided as input to and use in WRSM2000.

Both methods, albeit employing different mathematical approaches, offer viable means of partitioning streamflow into baseflow and surface runoff constituents. The Lyne and Hollick method relies on recession curve analysis, leveraging the principle of slower variations in baseflow compared to surface runoff, while the Chapman method utilizes digital filtering techniques to separate high-frequency fluctuations associated with surface runoff from the low-frequency baseflow component.

It is noted that the provided datasets are interim results, as evaluating of the baseflow time series against geological and hydrogeological settings in the relevant catchments and deriving the catchment specific variable per catchment to better align to observations and expected groundwater flows still need to be performed as final step in the iterative process.

3.5. Water resources simulation model

3.5.1 Overview

The *Water Resources Simulation Model 2000* (WRSM2000) rainfall-runoff model (also known as the 'Pitman Model') is used for developing monthly time-series of natural incremental catchment runoff. These time-series are then applied in the groundwater resources assessment and stochastic streamflow, yield, and planning analysis processes. However, because the study reached its contracted termination date before the WRSM2000 configuration, testing and calibration could be fully completed, the task description provided here represents a *partial deliverable* of the relevant scope of work. More information in this regard is provided earlier in **Section 1.5**).

3.5.2 Model network design

Prior to the termination of study on 17 February 2024, refined WRSM2000 model network designs were developed, based largely on the existing model configurations obtained from the WR2012 study (WRC, 2016). The designs were refined based on the following considerations:

- As noted at the beginning of **Section 3**, the intention was to undertake the hydrological analysis of the BBTS on the level of detail adopted for a *Water Availability Assessment Study* (WAAS). As such, the model design was based on quaternary catchments as its minimum spatial modelling resolution, but with sub-quaternary modelling undertaken in many cases based on the location of significant water resources infrastructure (dams, diversion weirs, canals, pipelines, etc.) and water use centres.
- As far as possible the design reflects the source of water for users, such as whether they have access to water from the main stem of the river, or from tributaries only, and whether they are abstracting from farm dams or directly from the river.
- It was noted that there are a very large number farm dams in the study area, many of which were developed off-channel and filled by pumping or canals from the main stem of the Breede River or its tributaries.

The resulting model network designs are presented in **Appendix D** of this report.

3.5.3 Preliminary model calibration results

At the time of the termination of study on 17 February 2024 the study team had not yet used the refined model network designs (discussed in the preceding section) to develop new WRSM2000 model configurations. However, at an earlier stage in the study, preliminary model calibrations were undertaken for the purpose of supporting the groundwater resources assessment (as discussed in **Section 3.4**). The preliminary calibrations were undertaken using the following:

- Existing model configurations obtained from the WR2012 study (WRC, 2016).
- Representative catchment rainfall time-series datasets developed in this study, covering the full 100-year study period from 1920 to 2019 (hydrological years).
- Observed streamflows at selected streamflow gauging stations, after preliminary patching of missing and unreliable data values (as discussed in **Section 3.3**).

An example of a preliminary WRSM2000 calibration result plot is presented below, for gauge H1H013 (Koekedou River @ Ceres), with observed monthly flows shown in red, and simulated flows in blue.

Results of all preliminary calibrations are provided in **Appendix E** of this report.

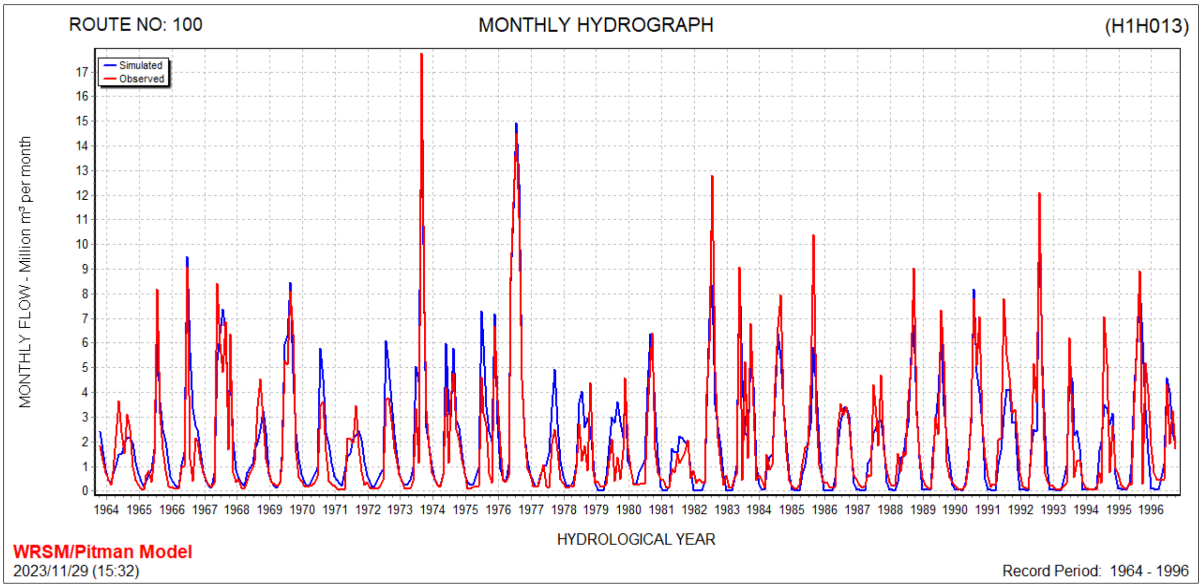

Figure 3.8: Example of preliminary WR2012 calibration (H1H013)

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Appendix A

Representative catchment rainfall datasets

Rainfall Zone H1A representative catchment rainfall (% MAP)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1920	5.44	1.47	3.81	4.19	6.47	3.85	7.23	2.77	59.16	31.66	15.92	6.30	148.27
1921	3.89	2.39	4.54	8.92	1.45	4.13	5.16	9.60	23.12	5.64	20.90	2.28	92.02
1922	2.55	1.90	0.99	3.05	0.79	0.82	7.47	16.15	26.36	15.51	11.88	8.59	96.06
1923	5.44	3.97	3.97	1.24	1.06	3.42	2.09	5.80	26.52	8.16	15.90	8.35	85.92
1924	9.63	5.78	0.00	2.15	1.02	0.95	1.02	8.05	46.09	20.91	5.96	3.47	105.03
1925	14.88	7.73	1.20	0.00	4.36	0.00	1.45	14.48	4.91	18.00	10.11	4.23	81.35
1926	14.55	5.41	0.00	2.83	5.93	0.00	7.51	13.06	11.27	4.32	21.48	6.07	92.43
1927	1.56	12.34	3.32	3.61	0.00	3.66	1.83	1.98	36.06	8.00	14.37	12.05	98.78
1928	3.97	3.97	1.54	0.00	1.20	2.15	13.89	12.32	12.29	20.95	16.37	3.70	92.35
1929	2.15	1.74	7.09	3.77	4.22	1.76	3.21	3.03	3.85	12.07	14.42	21.28	78.59
1930	4.13	4.18	1.59	0.00	2.20	0.83	10.73	18.52	5.86	7.89	30.58	11.68	98.19
1931	7.02	1.38	2.48	4.54	18.39	2.41	2.48	15.80	16.64	18.93	8.13	8.19	106.39
1932	2.53	0.95	2.15	2.85	3.70	2.46	1.24	13.24	26.03	26.02	11.78	6.02	98.97
1933	5.96	1.97	3.14	2.17	2.90	5.48	2.55	14.70	10.71	11.80	10.67	14.05	86.10
1934	12.99	0.00	0.00	1.31	1.40	5.08	8.45	13.85	8.88	19.05	14.52	10.18	95.71
1935	3.02	6.62	1.26	5.10	1.62	3.48	1.18	16.62	5.59	13.57	18.11	11.39	87.56
1936	3.49	2.31	12.61	2.33	0.72	7.15	9.22	14.01	23.36	30.82	7.39	2.88	116.29
1937	4.49	1.31	3.25	10.21	2.24	1.06	9.20	20.98	9.04	8.29	13.77	13.19	97.03
1938	3.92	3.42	2.51	1.29	9.03	1.30	7.93	17.97	5.84	9.01	19.23	8.68	90.13
1939	1.47	4.13	7.08	2.62	5.82	2.94	11.28	8.83	17.42	9.70	7.24	6.23	84.76
1940	4.37	8.16	1.31	7.60	3.17	0.82	15.80	32.00	26.45	0.00	15.84	28.41	143.93
1941	9.08	2.18	1.98	1.27	0.00	1.20	2.66	22.38	48.29	7.11	10.93	2.43	109.51
1942	5.38	0.00	5.00	5.79	1.74	4.78	4.54	6.83	14.89	28.42	24.63	12.66	114.66
1943	4.38	7.57	0.00	1.34	0.00	3.32	7.00	18.81	39.67	5.39	13.67	9.71	110.86
1944	4.04	6.91	1.55	0.00	0.00	1.14	8.14	24.40	32.89	19.36	16.47	2.91	117.81
1945	2.77	3.32	1.51	0.90	0.88	3.32	6.24	6.40	5.96	8.24	12.76	21.50	73.80
1946	5.29	1.42	1.61	0.00	0.00	7.93	3.33	7.98	5.67	30.90	10.41	5.17	79.71
1947	6.89	1.88	0.00	1.06	2.40	12.25	10.66	16.70	12.14	22.80	5.46	19.25	111.49
1948	6.89	2.51	1.54	1.41	0.00	1.21	8.15	10.30	11.69	15.43	14.28	15.58	88.99
1949	8.16	10.53	2.07	0.79	0.72	1.25	21.08	3.80	5.97	32.56	2.20	14.27	103.40
1950	5.97	9.70	4.15	3.72	0.00	0.00	9.83	7.76	29.47	17.86	11.94	5.63	106.03
1951	7.90	15.87	0.38	0.00	1.70	1.89	3.51	25.79	9.89	17.95	24.73	8.79	118.40
1952	2.67	9.54	2.55	0.23	2.15	0.24	22.41	19.96	6.69	28.32	16.43	0.58	111.77
1953	11.17	3.81	3.21	0.82	0.53	1.94	17.36	34.13	11.29	35.94	16.26	5.57	142.03
1954	7.28	4.77	3.03	0.07	8.41	2.44	3.11	1.72	12.99	16.02	20.81	3.61	84.26
1955	7.07	3.49	2.12	0.78	3.39	2.03	1.38	16.66	21.45	19.58	14.95	2.13	95.03
1956	1.49	0.27	1.76	0.36	10.99	4.30	2.72	35.62	26.21	24.98	13.89	8.11	130.70
1957	14.04	1.29	1.77	0.77	3.80	1.25	7.15	16.17	10.95	1.03	16.78	5.52	80.52
1958	5.92	1.64	1.86	0.72	4.65	3.41	14.68	35.78	3.61	2.28	19.43	10.81	104.79
1959	10.29	0.04	2.33	0.06	0.97	6.92	3.91	18.69	21.54	1.49	6.49	3.43	76.16
1960	1.18	0.09	4.30	5.46	1.63	4.64	7.58	9.16	16.97	11.69	15.11	18.71	96.52
1961	2.43	0.31	1.29	3.31	2.23	3.86	8.93	5.67	33.91	12.40	26.73	6.57	107.64
1962	18.90	7.85	0.17	2.71	0.68	0.28	0.93	2.75	15.38	17.53	35.15	3.96	106.29
1963	3.86	6.74	5.47	0.00	3.01	0.88	5.71	6.04	22.16	12.82	18.19	8.78	93.66
1964	6.51	7.97	0.32	1.75	4.83	11.08	8.13	11.27	5.21	5.69	9.95	5.46	78.17
1965	5.28	1.20	4.66	0.18	0.37	7.87	3.49	3.76	15.39	24.45	8.14	7.10	81.89
1966	0.28	1.46	1.16	1.00	1.30	0.01	14.45	9.57	35.95	12.48	10.26	5.81	93.73
1967	11.27	4.99	0.00	1.16	0.46	0.10	10.27	28.49	23.22	20.29	16.50	2.14	118.89
1968	21.28	1.52	3.58	2.77	2.42	0.09	10.13	1.43	8.07	3.52	10.41	12.97	78.19
1969	14.91	0.26	0.62	0.18	1.12	0.04	0.26	15.38	26.82	18.66	23.54	9.08	110.87
1970	3.04	0.19	2.35	0.73	0.71	3.56	0.30	3.30	8.14	27.80	11.61	2.28	64.01
1971	2.47	2.98	0.00	5.24	1.20	0.94	10.70	11.55	7.55	8.63	8.74	9.92	69.92
1972	2.19	0.00	4.07	0.00	0.00	4.00	0.27	4.06	3.72	28.82	15.99	10.72	73.84
1973	4.45	1.47	3.78	0.00	3.16	3.04	0.55	9.91	27.13	13.89	44.87	9.48	121.73
1974	8.41	9.17	2.37	1.27	1.76	1.41	8.92	30.44	7.13	14.20	20.04	0.48	105.60
1975	13.66	1.63	0.62	1.26	2.56	2.14	6.12	5.65	34.26	15.52	8.33	3.59	95.34
1976	4.43	29.48	12.74	3.04	4.79	2.20	12.55	37.55	32.27	34.02	26.17	6.81	206.05
1977	2.50	2.69	5.25	3.79	0.42	3.73	7.60	4.35	4.59	1.18	22.08	18.33	76.51
1978	4.34	1.37	6.20	2.23	5.99	1.68	0.94	10.70	25.55	13.63	5.90	12.67	91.20
1979	8.91	0.70	0.03	3.92	2.45	0.52	7.76	16.73	18.94	2.54	16.34	3.11	81.95
1980	7.40	22.06	5.04	14.96	1.31	7.14	5.71	2.27	9.95	23.98	21.57	17.88	139.27
1981	4.42	5.55	0.05	6.47	0.00	10.00	16.80	4.59	9.59	9.22	4.02	2.15	72.86
1982	8.42	2.32	3.02	0.25	7.13	4.01	1.95	26.83	24.82	23.29	6.49	5.96	114.49
1983	1.51	1.03	1.36	0.53	1.16	13.38	7.35	38.22	3.21	10.27	5.65	23.81	107.48
1984	12.69	0.14	10.42	7.88	2.11	16.51	9.21	8.43	19.24	19.94	14.54	8.89	130.00
1985	1.45	1.72	6.51	1.90	1.37	8.97	4.88	6.31	15.76	12.46	24.23	8.10	93.66
1986	2.20	2.37	0.00	3.62	0.41	0.27	7.12	16.98	18.39	11.28	12.55	9.35	84.54
1987	0.98	0.09	4.77	0.43	0.30	6.76	12.52	5.76	17.68	8.26	13.48	10.34	81.37
1988	2.06	0.90	3.34	1.63	2.47	15.55	10.21	5.45	15.94	11.53	19.77	19.53	108.38
1989	5.07	9.32	1.18	0.98	4.61	1.96	15.72	19.37	16.22	18.02	5.33	0.53	98.31
1990	0.70	3.10	3.62	2.21	0.55	1.67	4.51	11.41	20.08	28.82	8.58	15.20	100.45
1991	7.53	1.35	0.20	0.00	2.15	3.67	12.56	11.71	20.72	14.84	12.53	3.85	91.11
1992	13.47	3.71	0.00	0.42	2.96	1.12	18.29	16.98	13.16	31.77	4.96	1.33	108.17
1993	0.16	1.82	2.36	0.49	0.13	0.87	7.28	6.64	33.16	7.79	2.49	11.18	74.37
1994	3.32	0.56	3.53	4.40	2.37	4.18	3.20	15.54	12.46	18.23	11.99	2.99	82.77
1995	17.31	2.53	9.37	0.17	2.45	3.75	4.40	7.38	28.07	21.75	20.75	16.49	134.42
1996	10.03	9.97	7.60	2.32	0.91	1.92	7.18	7.42	30.24	5.31	6.58	0.99	90.47
1997	0.81	11.24	4.72	6.52	0.01	1.14	4.28	39.36	14.93	18.01	6.89	5.68	113.59
1998	5.28	15.96	3.55	0.45	1.76	0.00	6.71	8.78	12.21	5.41	8.39	13.85	82.35
1999	0.12	3.33	2.62	1.11	0.00	0.52	0.96	1.51	7.09	16.57	8.84	14.10	56.77
2000	1.28	0.00	1.55	1.08	5.22	0.30	7.95	16.68	7.73	37.98	20.79	12.27	112.83
2001	4.93	2.91	2.04	6.18	2.00	1.59	4.00	20.72	10.99	33.27	20.71	5.16	114.50
2002	8.21	2.77	3.88	2.67	0.56	6.75	4.55	2.58	2.56	4.32	29.74	9.07	77.66
2003	6.58	0.13	5.86	2.74	0.00	1.10	10.80	1.09	12.36	12.06	8.46	4.80	65.98
2004	10.20	2.19	2.44	1.54	0.26	1.07	16.32	7.34	17.75	8.70	24.29	7.42	99.52
2005	2.84	4.70	0.28	0.49	0.16	0.75	8.61	29.45	11.52	13.90	13.67	7.27	93.64
2006	4.33	11.03	1.58	0.00	2.25	3.35	11.91	10.63	32.76	34.12	14.81	4.57	131.34
2007	7.61	6.08	5.08	0.77	6.75	1.47	1.55	10.72	15.31	38.41	22.74	28.43	144.92
2008	1.87	10.09	3.53	0.01	4.41	3.10	9.14	25.13	39.85	11.59	15.09	6.78	130.59
2009	4.51	11.12	0.13	0.01	3.86	1.05	2.44	25.15	15.96	7.15	16.07	4.11	91.56
2010	4.11	4.11	4.74	4.11	4.11	2.36	4.44	17.60	19.81	16.80	16.46	9.21	107.86
2011	4.74	6.52	3.44	1.60	1.34	3.54	14.57	5.66	24.62	11.67	26.50	6.29	110.49
2012	3.64	3.31	1.99	1.77	1.75	4.77	10.03	15.77	25.31	14.26	36.22	13.44	132.26
2013	7.08	9.83	1.07	8.18	0.91	7.90	3.02	17.98	24.00	19.07	18.50	7.82	125.36
2014	0.69	8.01	0.15	2.45	0.10	1.99	0.05	4.30	19.71	16.74	3.85	0.49	58.53
2015	0.48	1.66	0.93	2.49	1.82	5.05	13.04	2.47	27.45	21.10	10.90	6.43	93.82
2016	0.67	0.82	1.39	1.26	0.04	0.24	3.29	0.94	22.16	4.88	9.95	2.59	48.23
2017	9.74	3.19	1.10	0.10	2.27	2.87	6.09	17.20	30.38	6.17	16.10	11.69	106.90
2018	3.02	2.73	6.07	1.69	3.20	4.96	2.60	7.17	14.08	22.13	5.75	6.24	79.64
2019	11.17	0.35	5.27	6.78	0.35	0.32	7.77	13.44	22.36	23.49	23.12	7.25	121.67

Rainfall Zone H1B representative catchment rainfall (% MAP)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1920	5.83	1.18	3.92	4.36	7.05	3.96	7.92	1.19	42.67	30.45	16.45	6.24	131.22
1921	4.01	2.25	4.77	9.93	1.15	4.31	5.49	9.12	21.22	5.53	22.21	1.56	91.55
1922	2.46	1.68	0.61	3.02	0.37	0.41	8.20	16.70	23.14	14.98	11.77	8.88	92.22
1923	5.83	3.07	3.07	0.90	0.69	3.47	1.91	4.72	23.24	7.95	15.20	7.41	77.46
1924	10.74	6.23	0.00	1.96	0.65	0.57	0.66	7.32	34.89	20.15	4.90	2.96	91.03
1925	16.89	8.52	0.85	0.00	4.56	0.00	1.16	14.76	10.38	17.37	9.71	3.84	88.04
1926	16.48	5.80	0.00	2.76	6.41	0.00	8.24	13.12	14.17	4.26	22.88	5.96	100.08
1927	1.29	13.93	3.35	3.68	0.00	3.74	1.61	0.43	28.92	7.79	14.64	12.89	92.27
1928	7.41	3.07	1.25	0.00	0.85	1.96	15.72	12.25	14.78	20.20	16.96	3.22	97.67
1929	1.98	1.50	7.78	3.87	4.41	1.51	3.23	1.50	9.76	11.68	14.70	23.61	85.53
1930	4.31	4.35	1.32	0.00	2.04	0.42	12.03	19.45	10.95	7.69	33.43	12.47	108.46
1931	7.69	1.07	2.37	4.77	21.02	2.29	2.38	16.31	17.36	18.26	7.41	8.43	109.36
1932	2.42	0.57	1.96	2.78	3.78	2.33	0.91	13.34	22.96	25.06	11.63	5.91	93.65
1933	6.43	1.76	3.13	2.00	2.84	5.87	2.46	15.01	13.84	11.43	10.35	15.22	90.34
1934	14.66	0.00	0.00	0.98	1.10	5.41	9.35	14.03	12.75	18.38	14.80	10.73	102.19
1935	3.00	7.23	0.92	5.43	1.35	3.54	0.84	17.26	10.80	13.12	18.99	12.14	94.62
1936	3.56	2.16	14.23	2.18	0.29	7.83	10.25	14.22	21.36	29.66	6.56	2.26	114.56
1937	4.70	0.98	3.26	11.43	2.07	0.69	10.24	22.29	12.84	8.07	13.94	14.21	104.72
1938	4.05	3.47	2.40	0.96	10.03	0.96	8.74	18.82	10.94	8.75	20.27	9.01	98.40
1939	1.19	4.31	7.76	2.52	6.28	2.90	12.67	8.23	17.83	9.42	6.38	6.15	85.64
1940	4.58	9.03	0.98	8.37	3.16	0.41	17.95	35.08	23.20	0.00	16.35	31.87	150.98
1941	9.32	1.86	1.63	0.87	0.00	0.78	2.39	22.10	33.42	6.40	9.84	1.60	90.21
1942	5.33	0.00	4.91	5.77	1.38	4.67	4.41	5.45	15.08	25.26	24.51	12.57	109.34
1943	4.46	8.06	0.00	1.01	0.00	3.24	7.41	19.17	29.67	5.10	13.43	9.87	101.42
1944	4.07	7.30	1.25	0.00	0.00	0.78	8.70	25.43	25.77	18.01	16.56	2.27	110.14
1945	2.64	3.24	1.20	0.52	0.50	3.24	6.55	5.30	10.31	7.72	12.40	23.07	76.69
1946	5.49	1.11	1.31	0.00	0.00	8.47	3.27	7.08	10.16	28.66	9.78	4.79	80.12
1947	7.29	1.62	0.00	0.69	2.22	13.35	11.53	16.82	13.86	21.19	4.25	20.54	113.36
1948	7.29	2.33	1.23	1.09	0.00	0.87	8.71	9.65	13.60	14.36	14.11	16.43	89.67
1949	8.72	11.41	1.84	0.38	0.31	0.91	23.31	2.40	10.32	30.20	0.62	14.97	105.39
1950	6.25	10.47	4.18	7.60	0.00	0.00	13.14	10.10	23.44	14.89	9.98	7.94	107.99
1951	7.82	13.40	0.38	0.00	3.24	3.65	4.03	22.98	13.43	12.33	26.15	10.94	118.35
1952	6.39	9.13	0.00	0.38	0.45	1.02	22.00	25.20	11.19	22.28	11.44	0.54	110.02
1953	1.92	8.72	4.36	1.58	0.74	1.34	14.07	28.11	13.45	28.12	21.16	9.60	133.17
1954	5.39	1.44	6.05	0.00	12.27	1.12	5.28	3.30	17.06	22.40	37.27	3.73	115.31
1955	12.38	9.25	2.90	1.88	3.11	2.00	2.90	13.45	20.10	13.86	15.39	4.01	101.23
1956	3.79	0.00	1.11	0.94	18.48	7.38	4.03	26.22	24.95	26.65	18.53	7.84	139.92
1957	19.35	0.94	0.00	1.00	7.05	1.25	4.26	18.23	13.81	4.71	21.81	5.63	98.04
1958	4.84	4.91	0.00	1.28	3.41	1.78	14.38	44.95	10.37	3.16	17.03	4.71	110.82
1959	12.73	0.42	2.27	0.72	1.26	3.90	7.22	19.21	19.07	3.87	3.96	3.71	78.34
1960	2.45	0.60	2.25	5.85	0.45	1.19	6.85	14.04	14.36	10.00	14.12	18.68	90.84
1961	2.09	0.00	1.63	2.38	5.22	5.71	7.78	5.37	30.43	11.83	25.30	6.08	103.82
1962	16.52	6.30	0.00	1.56	0.00	0.82	1.50	2.02	13.65	16.23	33.76	2.68	95.04
1963	1.87	6.23	2.84	2.84	9.13	0.00	7.27	9.90	20.90	11.00	25.80	5.05	102.83
1964	5.98	9.56	1.34	3.07	7.11	11.63	8.77	8.59	7.78	4.38	6.72	2.93	77.86
1965	4.76	1.07	4.82	0.02	0.34	9.03	6.94	2.95	13.97	24.38	6.37	9.76	84.41
1966	0.33	0.52	1.13	3.10	0.77	0.02	10.05	6.87	33.26	9.48	7.38	5.27	78.18
1967	8.03	7.41	0.24	1.85	0.87	0.00	12.05	24.77	17.23	17.76	13.82	0.96	104.99
1968	22.01	2.55	2.81	0.64	1.54	0.87	7.97	3.22	7.43	4.24	11.22	10.50	75.00
1969	12.35	1.55	0.59	0.52	1.87	0.33	0.24	14.64	22.90	16.79	17.40	8.32	97.50
1970	4.07	2.53	2.06	0.51	0.39	8.51	0.21	5.46	7.39	15.79	16.87	1.22	65.01
1971	1.19	0.92	1.19	1.42	1.95	0.60	11.46	14.70	9.52	7.88	7.53	7.39	65.75
1972	5.37	0.00	4.57	0.05	0.00	5.18	0.33	6.43	3.15	27.13	15.40	11.31	78.92
1973	4.22	1.00	4.54	0.05	0.06	0.79	0.00	16.21	22.37	10.49	51.17	10.26	121.16
1974	12.52	8.88	0.66	3.06	2.00	1.09	7.87	29.02	6.58	12.76	17.11	1.03	102.58
1975	12.23	2.89	0.75	0.00	2.88	2.60	7.05	4.68	35.67	16.14	6.27	2.86	94.02
1976	1.91	25.34	11.91	3.60	4.15	1.38	11.55	34.40	25.24	28.40	21.15	6.10	175.13
1977	2.56	1.81	6.98	0.89	1.51	5.02	6.98	8.32	2.70	0.12	20.01	9.42	66.32
1978	1.47	0.46	2.50	3.31	7.64	0.96	1.47	10.85	18.27	10.69	9.36	10.32	77.30
1979	11.71	0.25	0.00	4.37	1.96	0.12	8.50	13.25	14.29	2.48	15.48	2.03	74.44
1980	4.77	20.77	13.26	15.97	0.00	4.24	4.65	1.81	10.64	22.21	18.79	16.28	133.39
1981	3.03	2.00	0.58	6.31	0.27	4.69	16.88	7.31	10.37	10.86	5.72	0.67	68.69
1982	10.89	2.17	3.83	0.00	4.81	4.01	1.81	27.36	21.96	22.84	5.67	6.15	111.50
1983	0.31	1.77	0.62	0.46	0.05	15.55	5.50	40.27	6.50	10.73	6.40	19.99	108.15
1984	13.15	0.18	10.41	6.38	2.83	20.32	8.96	9.43	17.71	17.75	19.82	8.18	135.12
1985	2.49	0.57	1.18	1.49	2.20	7.36	6.43	9.36	17.28	14.71	25.80	8.77	97.64
1986	2.22	2.23	0.00	3.56	1.22	1.40	7.86	24.41	22.02	14.77	16.78	9.67	106.14
1987	0.51	0.21	4.26	0.05	0.00	1.34	13.23	7.99	17.70	7.34	14.38	10.55	77.56
1988	1.44	0.93	1.67	0.18	3.54	12.61	10.08	8.01	18.00	14.35	19.85	18.06	108.72
1989	6.83	6.00	0.30	0.83	5.04	2.34	22.53	16.79	17.82	24.82	6.53	0.66	110.49
1990	0.49	2.95	4.75	0.94	0.80	1.85	5.97	11.21	23.56	30.63	7.72	16.81	107.68
1991	5.91	2.58	0.71	0.00	4.29	5.81	12.58	7.96	30.82	16.81	9.99	4.63	102.09
1992	14.77	3.60	0.79	0.92	3.23	0.91	19.17	24.17	13.37	31.22	7.67	3.64	123.46
1993	0.10	1.31	3.55	0.49	0.00	1.02	9.09	7.77	37.06	10.25	2.77	15.31	88.72
1994	4.13	0.99	1.28	0.85	1.39	2.28	0.84	14.44	16.68	19.33	12.67	2.29	77.17
1995	19.18	1.00	16.70	0.22	4.59	4.61	3.74	13.70	37.39	27.03	24.20	22.06	174.42
1996	7.44	12.73	7.96	0.84	0.48	1.97	3.99	8.05	32.61	5.25	12.04	0.44	93.80
1997	1.05	10.10	2.99	7.79	0.00	0.38	3.80	43.52	11.26	15.72	6.64	2.50	105.75
1998	4.22	14.17	13.59	3.50	1.59	0.00	8.41	11.59	17.76	3.21	8.05	6.86	92.95
1999	0.04	1.18	3.71	1.32	0.36	2.15	0.68	5.91	8.22	21.06	10.90	13.37	68.90
2000	0.65	3.76	0.91	0.94	1.34	0.04	9.40	16.37	8.08	39.07	17.58	14.08	112.22
2001	5.55	4.39	0.50	12.41	4.61	2.68	8.94	22.23	14.63	33.98	19.13	5.09	134.14
2002	6.85	4.97	3.87	1.99	0.13	4.12	3.96	3.71	1.41	5.71	26.79	12.38	75.89
2003	7.62	0.00	9.95	2.99	0.37	0.81	10.80	0.78	16.63	17.51	9.26	6.76	83.48
2004	12.14	1.23	0.20	1.60	0.54	0.35	15.01	7.98	19.81	11.71	25.60	7.17	103.34
2005	2.10	2.82	0.00	0.02	0.21	0.55	8.45	25.80	9.00	13.91	11.76	5.41	80.03
2006	4.83	13.35	2.36	0.00	2.07	3.31	9.68	9.41	30.72	29.12	13.17	2.44	120.46
2007	3.00	6.06	4.94	2.03	6.68	1.05	1.38	10.00	19.21	42.01	20.11	22.34	138.81
2008	2.12	6.96	6.81	0.00	1.36	0.21	2.11	29.39	31.26	13.80	13.60	8.30	115.92
2009	6.13	21.75	0.11	0.00	1.66	2.28	2.86	39.85	15.42	9.48	9.14	4.18	112.86
2010	8.97	6.07	4.13	1.68	0.00	1.70	14.36	12.02	25.39	5.89	7.99	5.89	94.09
2011	5.46	4.57	3.43	1.46	2.68	3.77	10.78	5.98	18.99	15.69	15.69	10.01	98.51
2012	7.65	1.41	1.16	1.25	1.91	3.86	7.90	20.26	18.92	20.92	40.21	15.88	141.33
2013	6.02	7.47	0.00	5.71	0.34	8.50	3.19	16.44	20.34	14.50	16.69	7.55	106.75
2014	0.92	7.62	0.00	2.23	0.41	1.09	0.46	2.67	17.31	16.13	6.44	2.79	58.07
2015	7.65	6.41	0.85	1.83	0.41	5.49	11.92	4.42	21.21	18.31	12.08	4.90	95.48
2016	0.38	1.16	3.17	0.30	0.34	0.63	1.01	1.11	19.66	4.50	9.35	2.42	44.03
2017	7.98	6.69	0.95	1.13	0.43	1.66	5.53	21.59	20.04	8.15	14.79	10.67	99.61
2018	1.92	0.00	2.66	0.59	0.92	3.56	0.52	6.05	16.69	24.11	6.46	1.78	65.26
2019	12.12	0.95	3.51	1.91	0.29	0.59	6.47	9.73	12.85	23.67	27.68	6.84	106.61

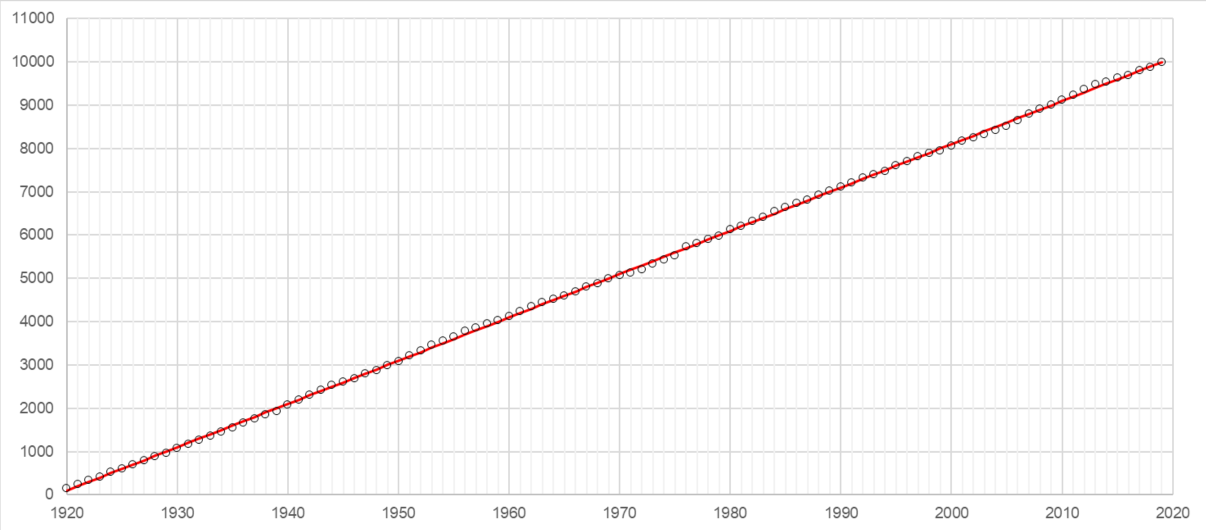
Rainfall Zone H1C representative catchment rainfall (% MAP)

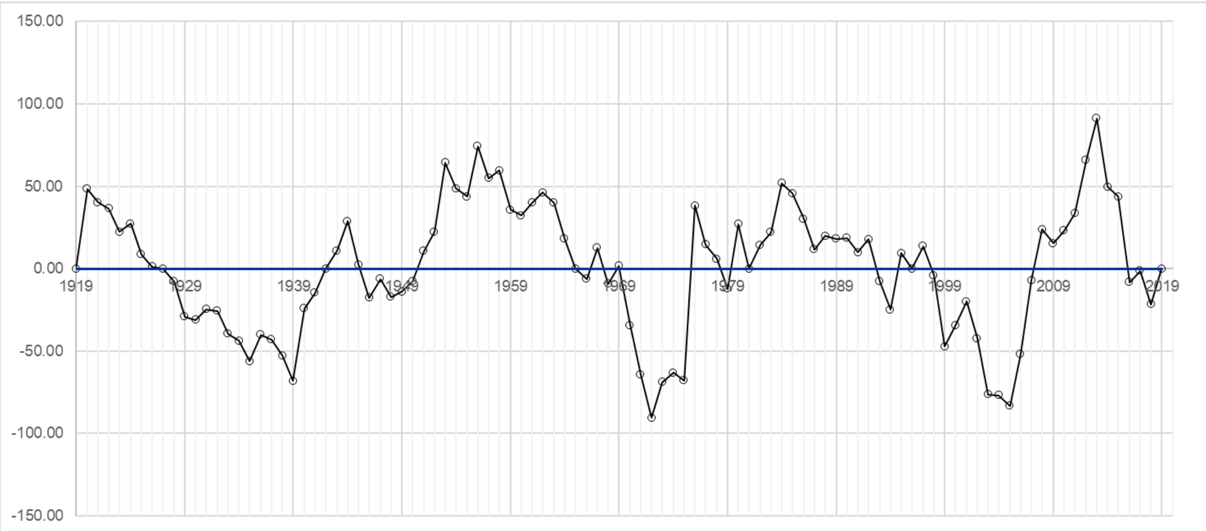
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1920	7.38	4.54	5.30	3.64	6.30	1.47	8.62	2.38	39.76	19.24	16.91	5.57	121.11
1921	3.84	2.91	5.84	8.23	2.91	5.82	6.28	11.35	20.97	10.47	20.66	3.65	102.93
1922	2.70	3.00	0.22	2.38	0.19	1.07	11.50	28.92	26.44	16.42	16.13	9.25	118.22
1923	4.79	13.84	3.67	2.82	0.25	2.75	2.66	8.24	21.54	10.69	19.96	8.34	99.55
1924	8.18	8.96	0.22	3.10	0.90	0.69	1.41	9.29	41.45	26.20	8.28	3.91	112.59
1925	10.37	6.43	1.32	0.84	4.72	0.00	2.20	18.66	4.86	17.76	11.40	4.68	83.24
1926	15.66	2.43	0.00	0.96	5.82	0.08	7.51	11.30	13.59	10.94	20.23	3.67	92.19
1927	0.68	9.11	2.45	3.41	0.00	3.64	2.18	1.40	22.06	9.95	12.21	9.65	76.74
1928	2.85	1.64	2.91	0.00	0.38	2.68	9.10	20.92	13.07	22.35	11.72	4.88	92.50
1929	2.32	2.58	4.50	2.64	3.36	2.57	4.72	1.28	2.32	14.46	14.45	18.56	73.76
1930	4.51	5.10	1.61	0.00	4.21	0.08	13.36	13.58	7.06	10.75	22.69	14.91	97.86
1931	8.74	0.35	2.72	4.04	15.83	2.68	1.94	19.67	17.75	12.28	14.10	9.53	109.63
1932	2.49	1.28	3.03	2.48	2.30	2.00	1.82	10.95	31.10	19.55	12.46	3.11	92.57
1933	8.51	1.87	1.82	0.15	2.40	8.52	2.22	15.97	6.62	13.06	10.19	8.65	79.98
1934	5.96	7.81	0.69	0.28	1.25	4.51	10.34	13.68	7.58	19.01	17.53	10.20	98.84
1935	3.43	5.80	0.51	7.49	1.67	3.73	0.71	11.62	6.58	12.68	13.83	10.97	79.02
1936	2.99	2.41	6.54	1.16	0.30	13.98	7.35	12.37	25.90	22.04	9.44	3.82	108.30
1937	4.44	1.00	0.48	3.91	2.70	0.94	16.05	15.66	9.31	13.23	11.59	11.35	90.66
1938	3.87	3.02	1.33	0.42	4.75	1.09	7.28	15.49	7.21	12.84	19.23	7.35	83.88
1939	2.22	4.70	2.56	0.68	5.66	4.07	9.42	13.92	17.41	10.01	8.54	11.03	90.22
1940	4.27	8.13	2.01	7.10	3.09	1.00	18.57	23.79	26.38	15.19	20.51	21.31	151.35
1941	5.10	2.19	4.95	1.20	0.22	0.25	2.30	26.51	34.46	11.04	19.94	3.79	111.95
1942	5.03	0.49	1.10	7.33	3.40	6.24	4.51	5.49	11.14	19.74	20.64	11.54	96.65
1943	3.92	6.49	0.00	2.52	0.02	1.25	6.11	19.84	29.82	14.70	18.89	8.39	111.95
1944	8.62	6.11	6.33	0.00	0.03	0.85	7.94	23.48	29.32	22.31	17.41	1.88	124.28
1945	4.52	3.07	1.20	1.03	0.08	4.67	10.91	14.32	10.32	15.96	15.10	16.06	97.24
1946	10.64	3.37	1.98	0.00	0.00	8.81	3.88	11.42	8.38	23.68	14.72	5.27	92.15
1947	3.56	2.86	0.43	0.78	1.22	6.28	5.66	11.99	10.97	23.37	13.76	11.38	92.26
1948	10.39	1.61	3.84	0.79	0.05	1.08	11.92	9.09	12.17	18.15	19.39	8.30	96.78
1949	6.82	8.32	1.71	0.26	0.04	1.48	16.70	3.27	10.28	34.19	5.20	13.60	101.87
1950	4.28	9.04	4.54	3.45	0.14	0.00	4.58	14.46	28.35	17.79	14.30	5.91	106.84
1951	5.33	8.62	0.00	0.05	1.32	3.10	5.58	15.10	11.41	17.68	30.74	19.27	118.20
1952	5.62	13.44	0.88	0.66	0.79	1.70	26.79	25.65	6.09	19.07	16.27	1.86	118.82
1953	3.95	6.09	1.92	0.90	1.39	4.29	13.97	29.93	15.91	32.99	21.04	6.57	138.95
1954	7.42	0.98	5.09	0.07	11.58	1.25	5.18	4.12	14.87	24.00	32.69	3.76	111.01
1955	10.26	4.58	2.36	0.92	0.99	2.35	3.50	11.89	26.49	19.07	18.81	5.58	106.80
1956	4.54	0.75	5.75	1.03	10.31	3.74	5.80	25.54	28.46	31.33	14.44	7.04	138.73
1957	17.18	0.89	0.00	0.98	3.06	2.12	3.21	16.39	8.34	1.57	16.39	3.73	73.86
1958	4.49	4.39	0.08	2.29	1.58	2.05	10.34	39.24	3.22	2.63	11.43	3.68	85.42
1959	5.76	0.12	1.49	0.78	0.59	4.13	5.14	11.40	19.50	3.21	3.47	5.75	61.34
1960	2.17	0.61	2.89	4.40	1.83	2.33	5.75	8.93	15.64	10.62	11.91	15.53	82.61
1961	2.34	0.04	1.81	1.11	2.38	4.09	7.72	3.11	41.97	12.05	28.12	6.55	111.29
1962	18.69	2.53	0.58	3.68	0.22	1.63	2.47	3.01	8.84	20.28	25.66	4.55	92.14
1963	1.51	4.04	4.83	0.07	11.28	0.92	2.31	5.07	25.29	12.33	17.36	4.00	89.01
1964	6.28	6.00	0.78	2.84	5.50	11.69	8.94	11.59	9.12	7.11	14.04	6.02	89.91
1965	3.58	2.51	6.37	0.70	0.53	12.98	5.49	4.12	17.80	21.13	8.79	8.11	92.11
1966	0.39	1.06	1.41	1.55	0.29	0.33	12.17	10.57	26.44	12.50	8.38	9.31	84.40
1967	5.92	6.25	1.23	2.52	1.27	0.44	11.75	25.37	19.83	17.19	13.45	2.69	107.91
1968	19.42	2.11	3.62	2.57	1.76	1.79	8.33	1.24	9.53	8.98	14.23	15.26	88.84
1969	12.33	1.04	0.31	0.35	3.97	0.34	0.43	18.92	22.84	18.80	18.27	8.48	106.08
1970	4.21	2.55	2.85	0.58	0.60	3.68	0.82	8.52	9.15	21.85	19.76	1.67	76.24
1971	1.52	1.01	3.70	3.09	1.93	1.85	8.45	15.18	9.53	7.37	9.74	6.57	69.94
1972	2.28	0.31	4.57	0.24	0.08	3.00	1.42	4.50	2.75	22.64	11.96	11.79	65.54
1973	5.00	2.42	6.63	0.79	1.10	1.85	0.82	11.17	23.00	12.90	64.82	8.61	139.11
1974	11.11	2.68	1.85	2.83	2.22	0.47	10.19	26.24	12.68	19.21	14.40	2.29	106.17
1975	10.28	2.79	0.51	0.13	0.67	3.75	2.30	9.49	43.15	28.75	6.99	5.76	114.57
1976	3.37	22.65	14.47	3.65	5.17	2.06	12.28	36.81	28.94	32.71	43.64	6.40	212.15
1977	2.88	2.96	4.46	2.23	2.29	6.09	5.82	5.95	2.35	4.08	25.62	9.56	74.29
1978	3.79	1.15	4.37	3.16	6.28	1.45	0.71	17.70	20.57	9.47	13.51	10.21	92.37
1979	11.61	0.21	0.08	3.16	1.14	0.61	6.35	18.41	13.56	5.86	12.41	3.47	76.87
1980	4.00	15.15	11.06	11.52	0.03	5.07	5.02	2.63	4.99	24.20	15.45	21.04	120.16
1981	1.71	2.78	1.68	3.95	0.05	1.92	12.01	9.54	14.97	10.27	6.33	2.85	68.06
1982	6.76	2.33	3.89	0.45	6.21	5.03	1.39	24.34	24.22	20.27	7.04	13.96	115.89
1983	0.93	1.38	1.71	0.93	0.88	7.45	6.18	34.29	8.20	16.76	8.60	20.46	107.77
1984	12.90	0.44	7.11	4.04	3.87	14.46	8.34	6.73	14.65	16.61	18.01	7.31	114.47
1985	3.26	0.78	2.49	1.22	1.36	6.12	5.64	6.39	21.98	15.17	23.10	6.70	94.21
1986	1.55	3.39	0.06	1.58	1.40	1.03	5.54	20.38	14.20	10.56	12.79	4.16	76.64
1987	0.46	0.29	4.90	0.14	0.32	2.74	13.60	8.41	8.26	9.87	17.18	6.94	73.11
1988	1.37	1.08	2.95	0.60	2.95	11.75	7.19	10.01	13.71	13.35	14.99	11.65	91.60
1989	5.18	2.95	0.26	1.13	4.85	1.21	19.13	11.11	15.00	22.55	7.30	2.88	93.55
1990	1.27	3.21	4.78	1.38	0.55	1.06	3.88	19.52	23.66	27.60	8.29	18.47	113.67
1991	4.08	1.59	0.40	0.02	4.68	3.64	8.08	7.98	38.63	17.36	9.75	5.15	101.36
1992	15.47	1.71	0.17	0.77	2.44	0.68	24.88	14.10	13.31	49.02	6.56	2.37	131.48
1993	0.33	1.47	3.08	0.73	1.02	0.78	5.05	4.18	43.62	12.00	3.24	10.12	85.62
1994	2.30	0.40	2.53	0.90	1.28	1.84	0.98	13.34	18.28	23.43	13.80	2.93	82.01
1995	10.86	1.52	7.49	0.57	3.80	2.80	2.89	10.12	41.42	17.49	18.44	17.84	135.24
1996	11.29	9.69	5.92	0.48	0.12	0.65	4.18	7.20	32.26	7.32	12.00	0.63	91.74
1997	0.72	9.76	3.20	4.53	0.87	1.46	5.33	29.22	8.84	21.29	7.15	4.75	97.12
1998	1.54	11.29	4.43	0.30	0.10	0.08	8.47	10.40	23.41	7.82	9.97	7.68	85.49
1999	1.74	3.40	7.13	2.39	0.21	3.44	0.90	18.75	14.24	29.75	13.19	17.61	112.75
2000	0.93	1.59	0.90	2.36	1.06	0.25	7.51	26.52	8.40	51.81	32.07	25.12	158.52
2001	6.28	2.92	1.37	16.06	2.50	2.37	10.00	23.42	14.63	42.19	30.36	6.76	158.86
2002	10.56	7.32	5.93	2.09	0.65	12.60	4.33	3.82	1.23	10.74	21.78	10.62	91.67
2003	5.87	0.08	4.46	1.04	0.00	1.71	6.78	0.62	11.49	10.24	11.17	4.33	57.79
2004	9.20	0.16	1.32	4.83	0.46	1.07	11.85	11.21	16.11	10.15	20.71	4.98	92.05
2005	2.56	4.12	0.01	0.00	0.73	0.75	6.42	16.10	9.75	9.29	15.59	3.09	68.41
2006	2.61	6.73	2.82	0.00	2.20	2.97	6.50	19.47	20.74	21.76	12.12	2.01	99.93
2007	4.08	9.53	3.40	0.97	1.39	0.43	0.74	11.08	12.44	28.22	15.71	22.93	110.92
2008	2.34	15.96	2.65	0.00	1.27	0.23	3.75	13.62	25.90	10.97	10.26	8.49	95.44
2009	6.46	12.26	0.42	0.00	2.76	1.82	1.61	26.76	11.67	5.02	10.96	2.33	82.07
2010	8.24	6.50	3.02	1.02	0.28	0.68	6.30	15.01	19.85	4.02	10.87	7.27	83.06
2011	4.14	4.50	2.81	0.26	0.57	2.63	7.46	5.91	12.47	14.27	26.33	9.98	91.33
2012	3.72	2.71	0.22	1.36	2.36	2.63	5.38	12.07	32.47	15.17	46.65	16.94	141.68
2013	13.48	21.49	0.07	4.75	0.27	7.66	4.93	13.66	28.21	23.40	20.79	5.62	144.33
2014	0.73	3.45	0.63	2.42	0.57	0.44	0.37	4.98	13.18	22.65	10.29	4.97	64.68
2015	1.38	2.19	2.45	2.96	0.97	6.68	9.38	3.44	21.58	20.28	11.49	8.90	91.70
2016	1.67	0.90	2.15	0.08	0.00	0.25	1.92	0.98	19.22	10.32	13.11	4.57	55.17
2017	5.46	7.37	1.17	1.08	1.85	3.51	12.62	18.61	27.04	10.50	12.86	14.32	116.39
2018	1.42	1.44	3.18	3.24	1.13	3.32	3.10	8.62	19.43	26.35	7.05	3.31	81.59
2019	10.48	0.73	3.33	2.00	0.00	0.18	4.75	6.61	20.37	25.04	22.98	14.14	110.61

Appendix B

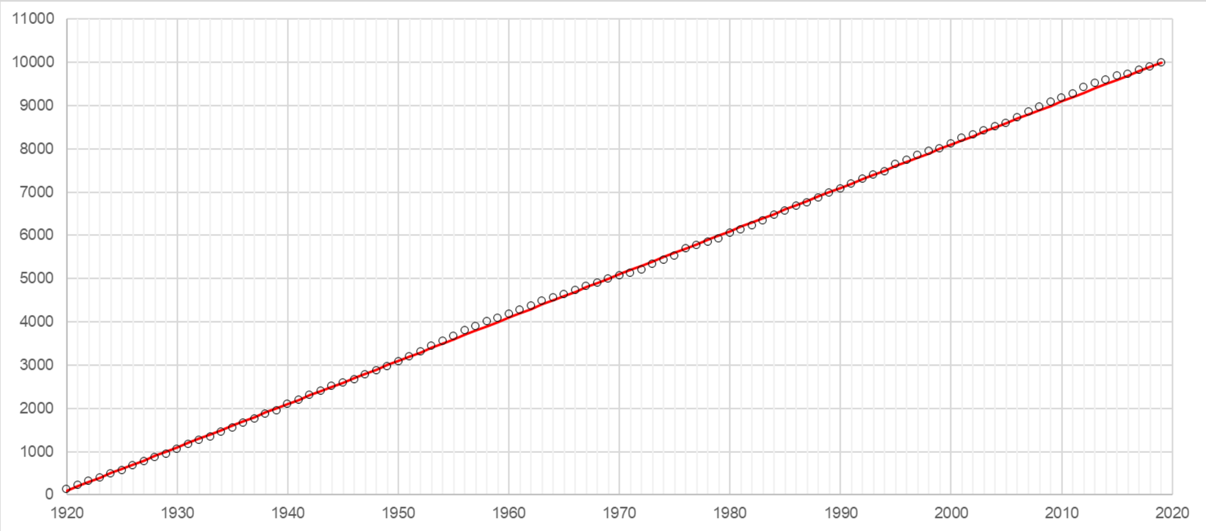
Rainfall stationarity tests

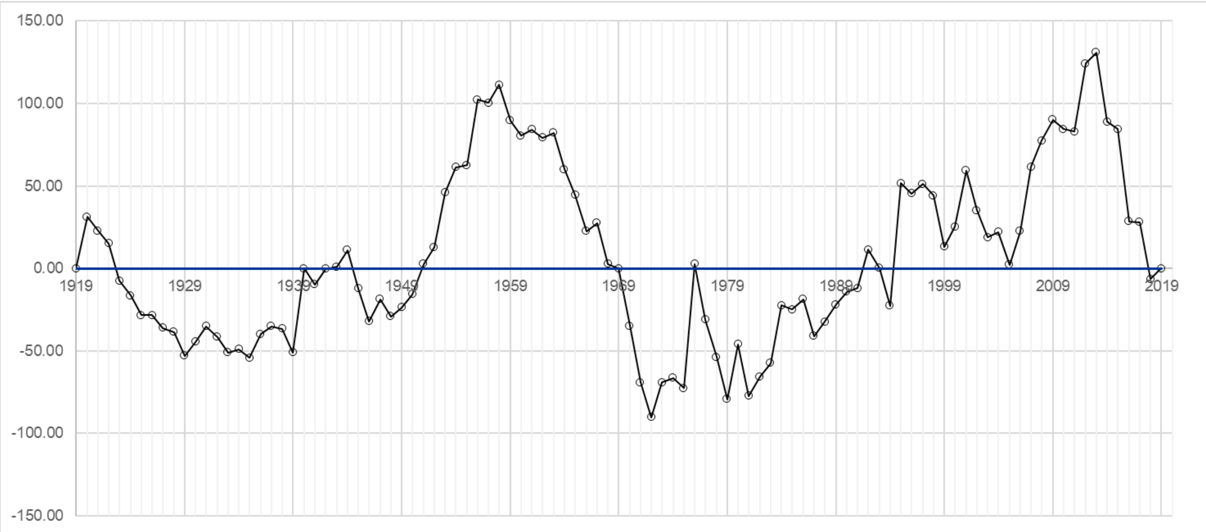
Rainfall Zone H1A representative catchment rainfall stationarity tests



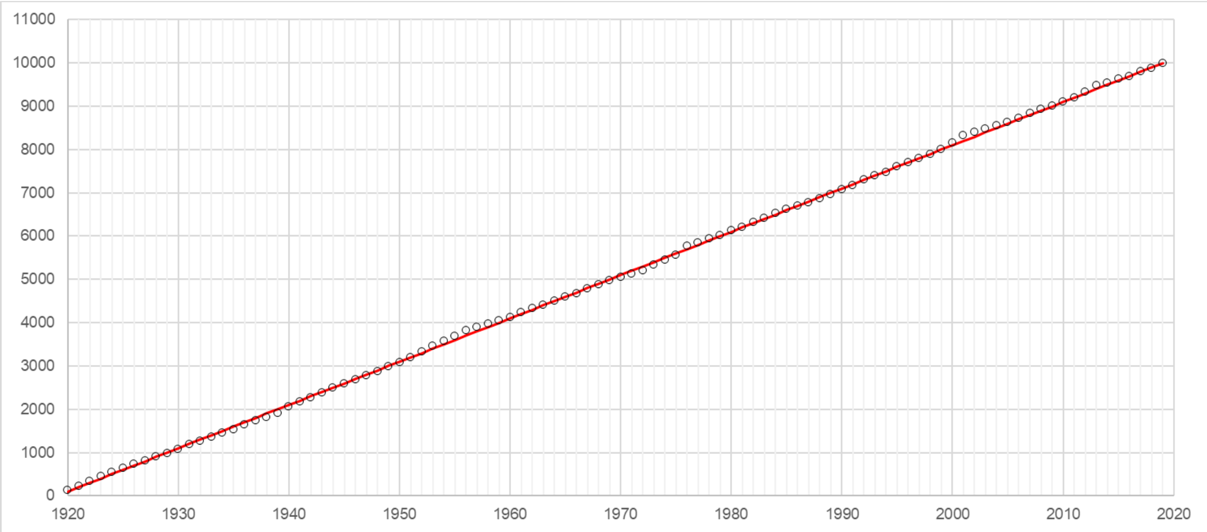


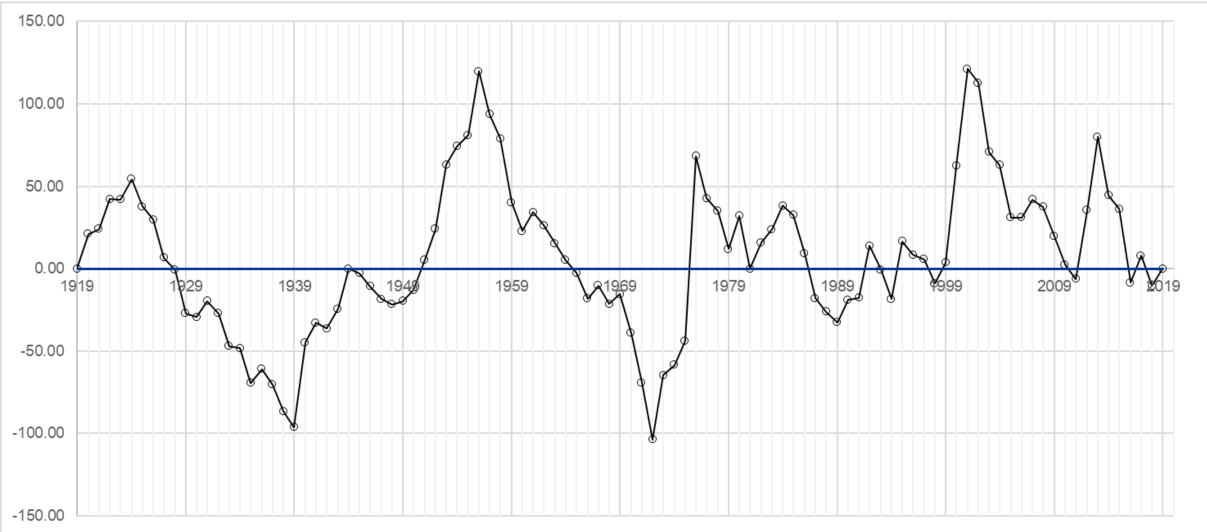
Rainfall Zone H1B representative catchment rainfall stationarity tests





Rainfall Zone H1C representative catchment rainfall stationarity tests

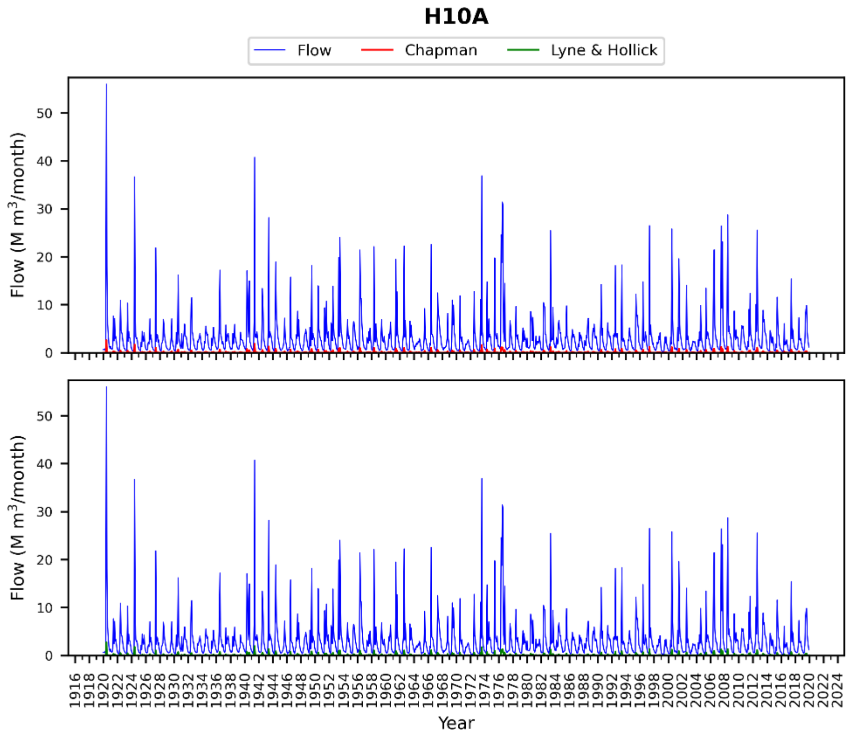


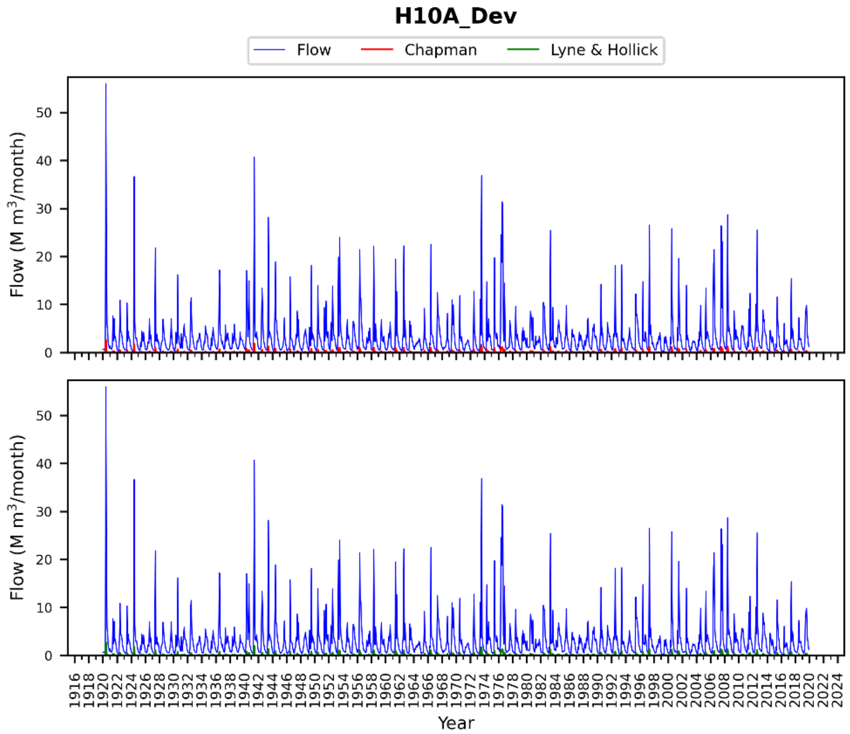


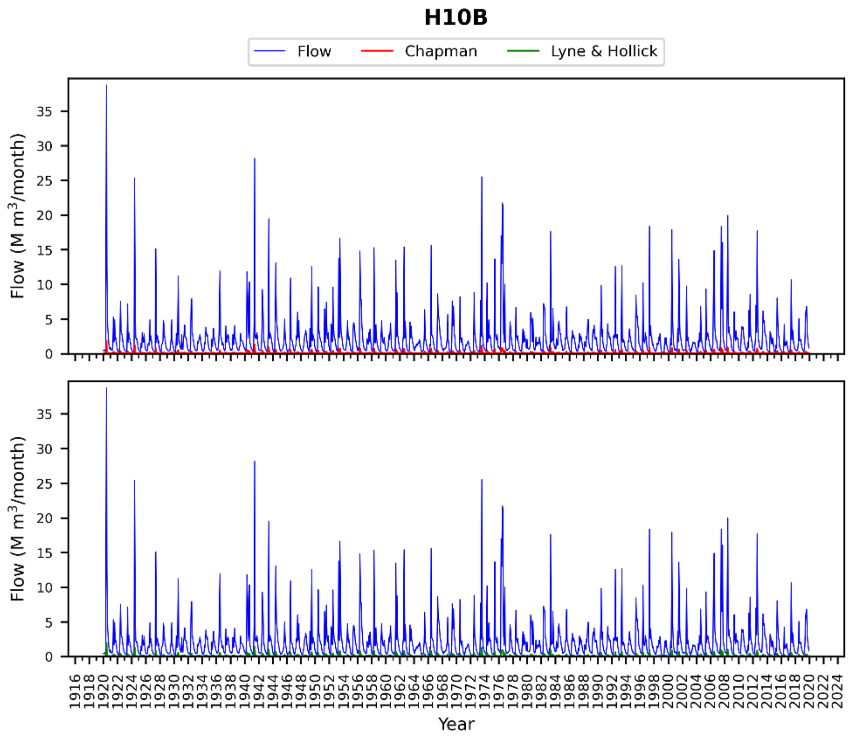
Appendix C

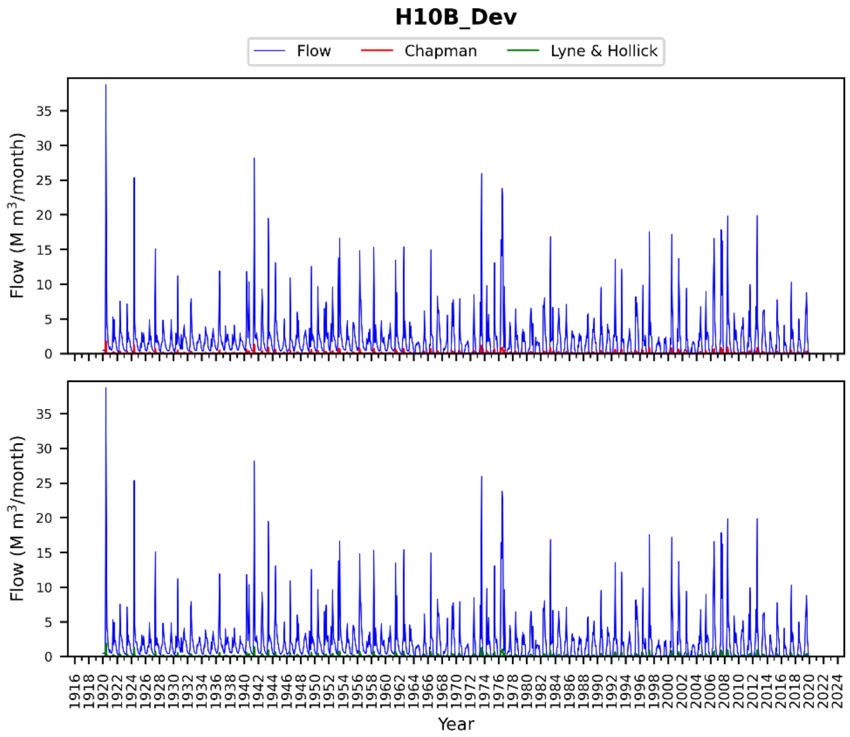
Streamflow and baseflow hydrographs

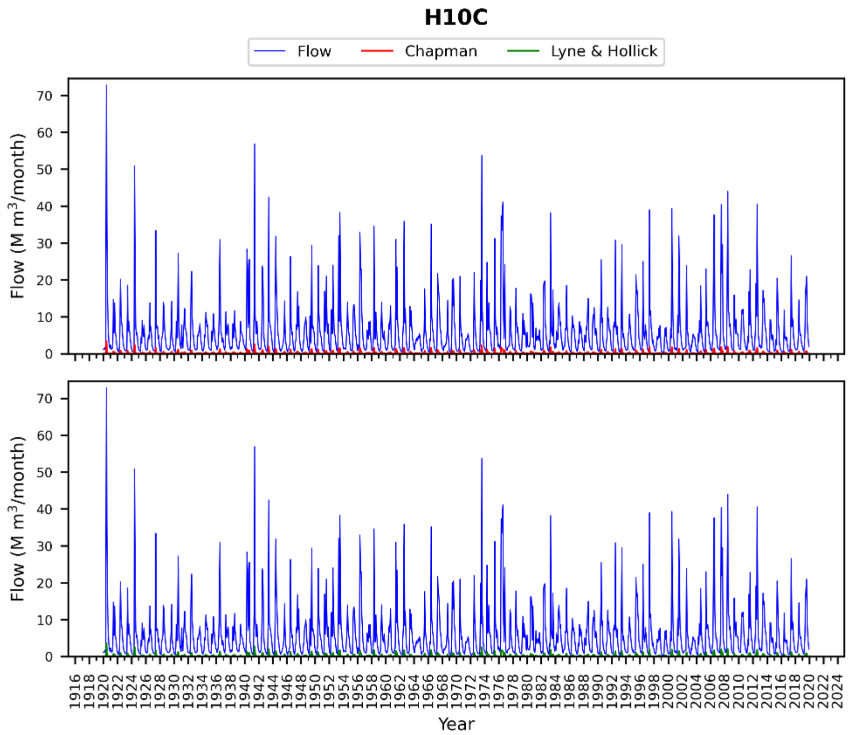
Hydrographs with streamflow and baseflow for quaternary catchments H10A to H10L in the BBTS study area using Lyne & Hollick (1979), and Chapman (1991) methods, with comparison of naturalised flow vs current (developed) flow. Hydrographs for all catchments are provided in digital data set.

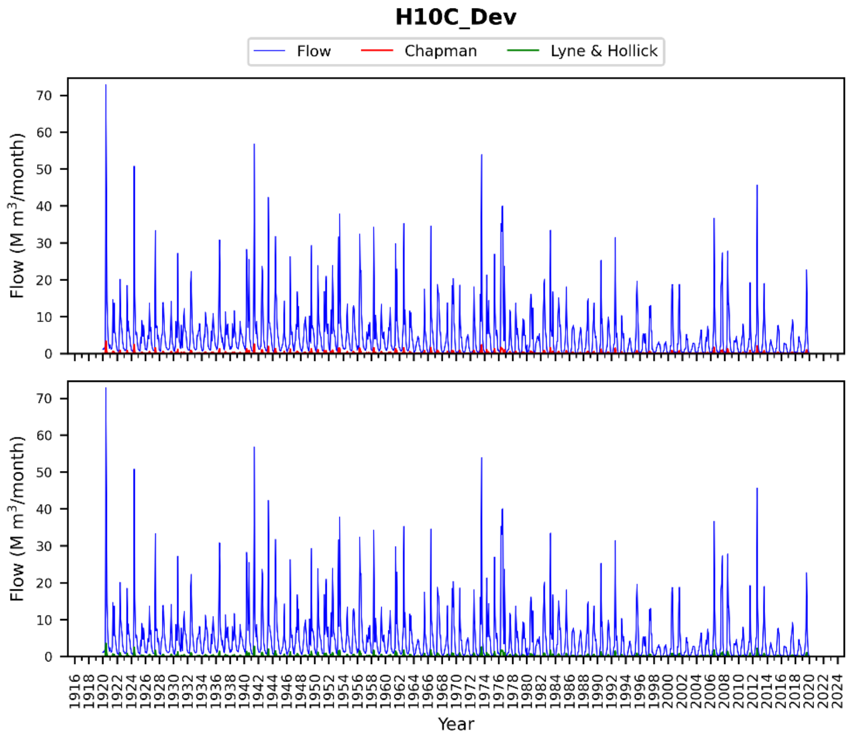


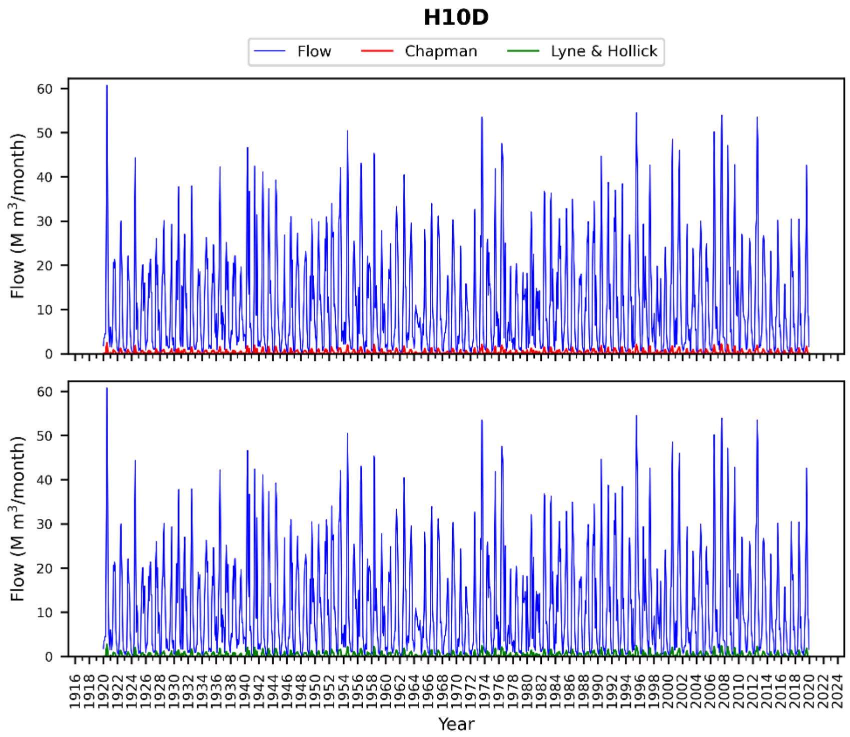


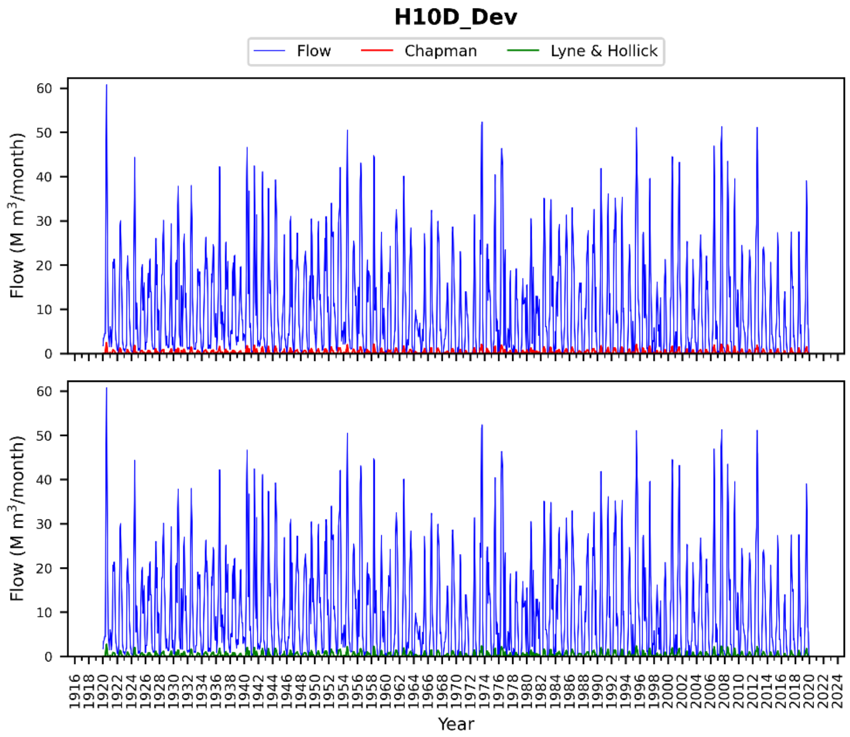

H10B
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Year

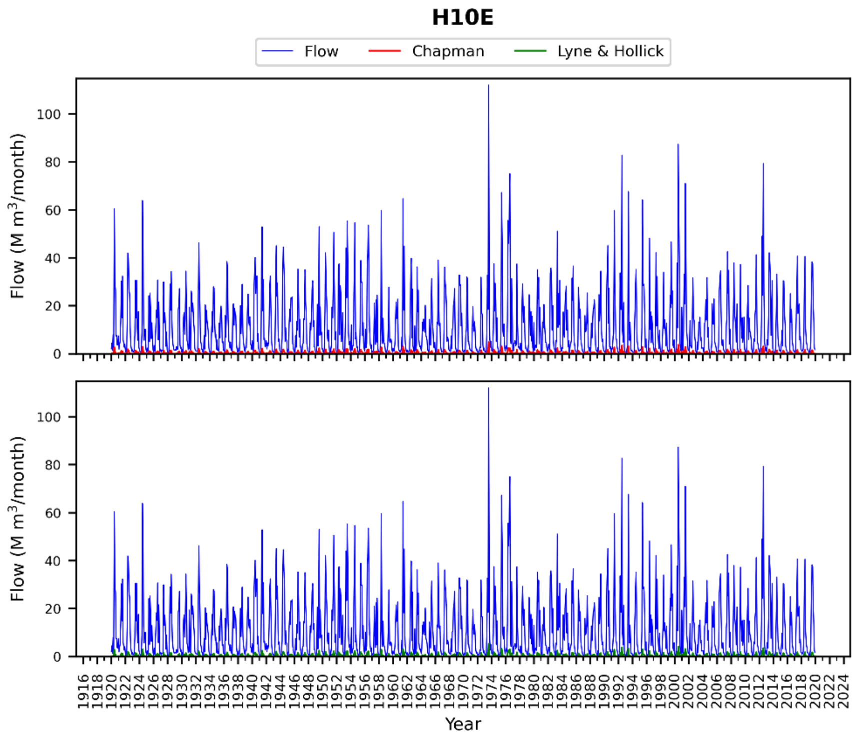

H10B_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Year

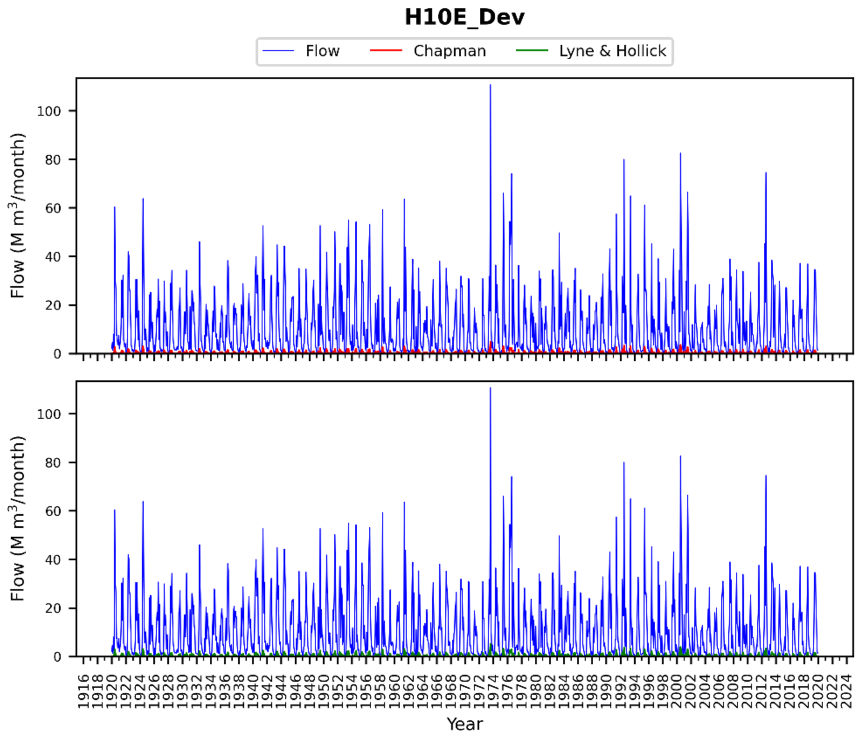

H10C
Flow
Chapman
Lyne & Hollick
Flow (M m³/month)
Year

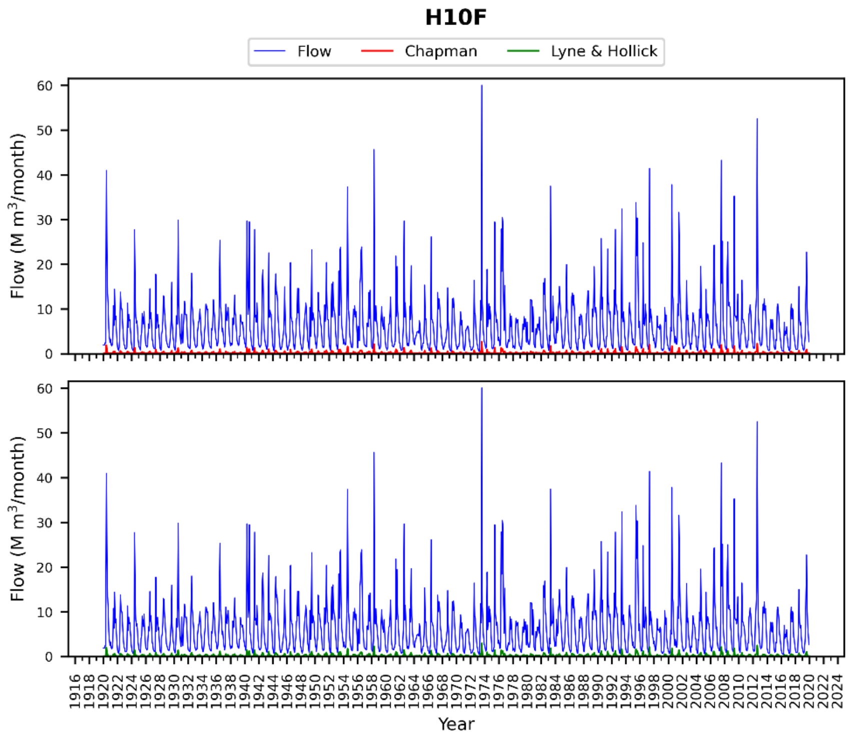

H10C_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m³/month)
Year

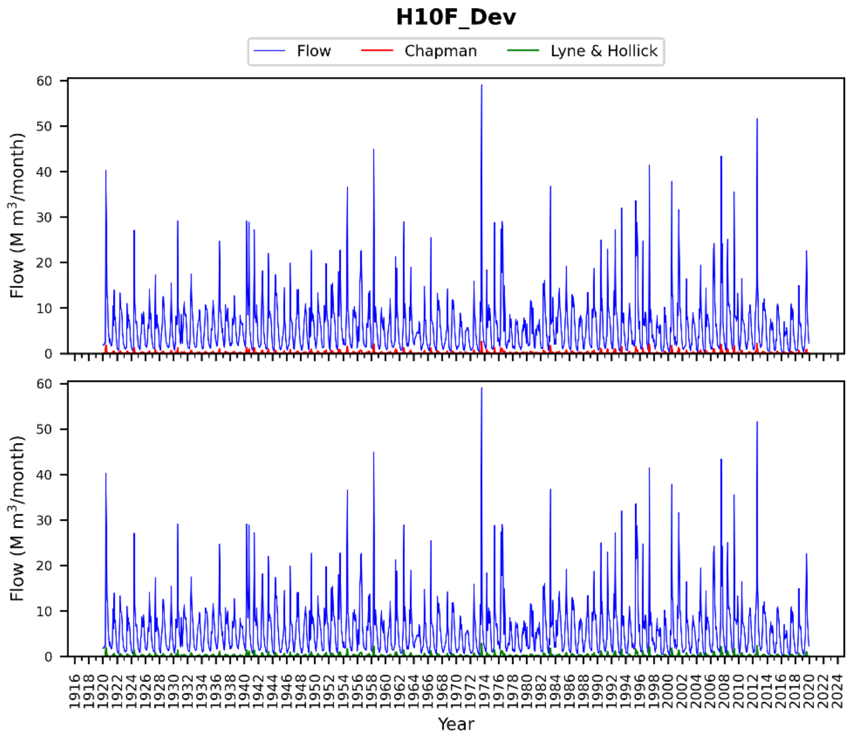

H10D
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
0
10
20
30
40
50
60
Year
1916 1918 1920 1922 1924 1926 1928 1930 1932 1934 1936 1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024

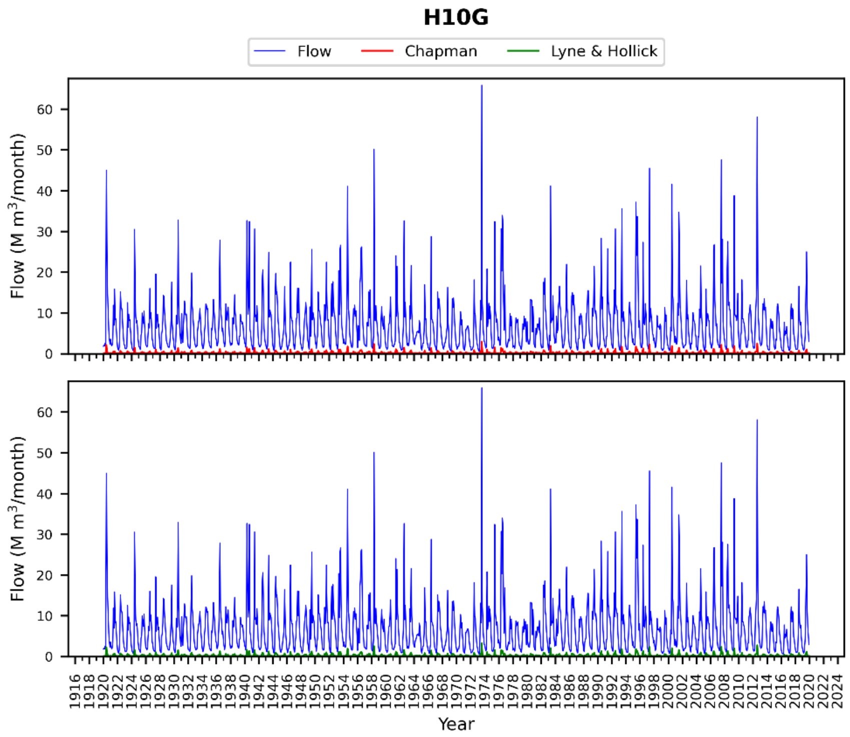

H10D_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
0
10
20
30
40
50
60
Year
1916 1918 1920 1922 1924 1926 1928 1930 1932 1934 1936 1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024

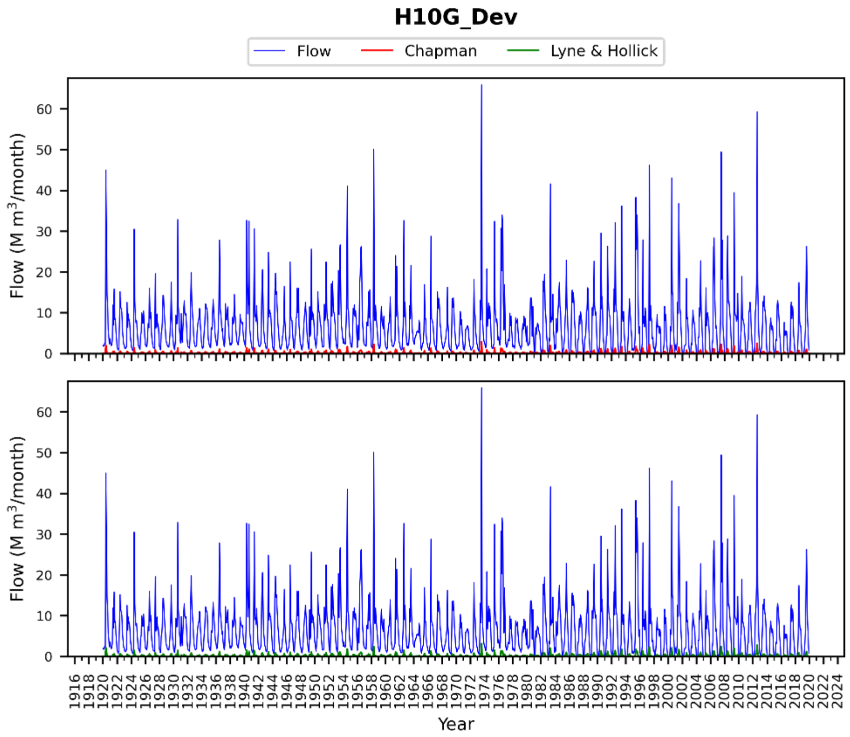

H10E
Flow
Chapman
Lyne & Hollick
Flow (M m^3/month)
Year

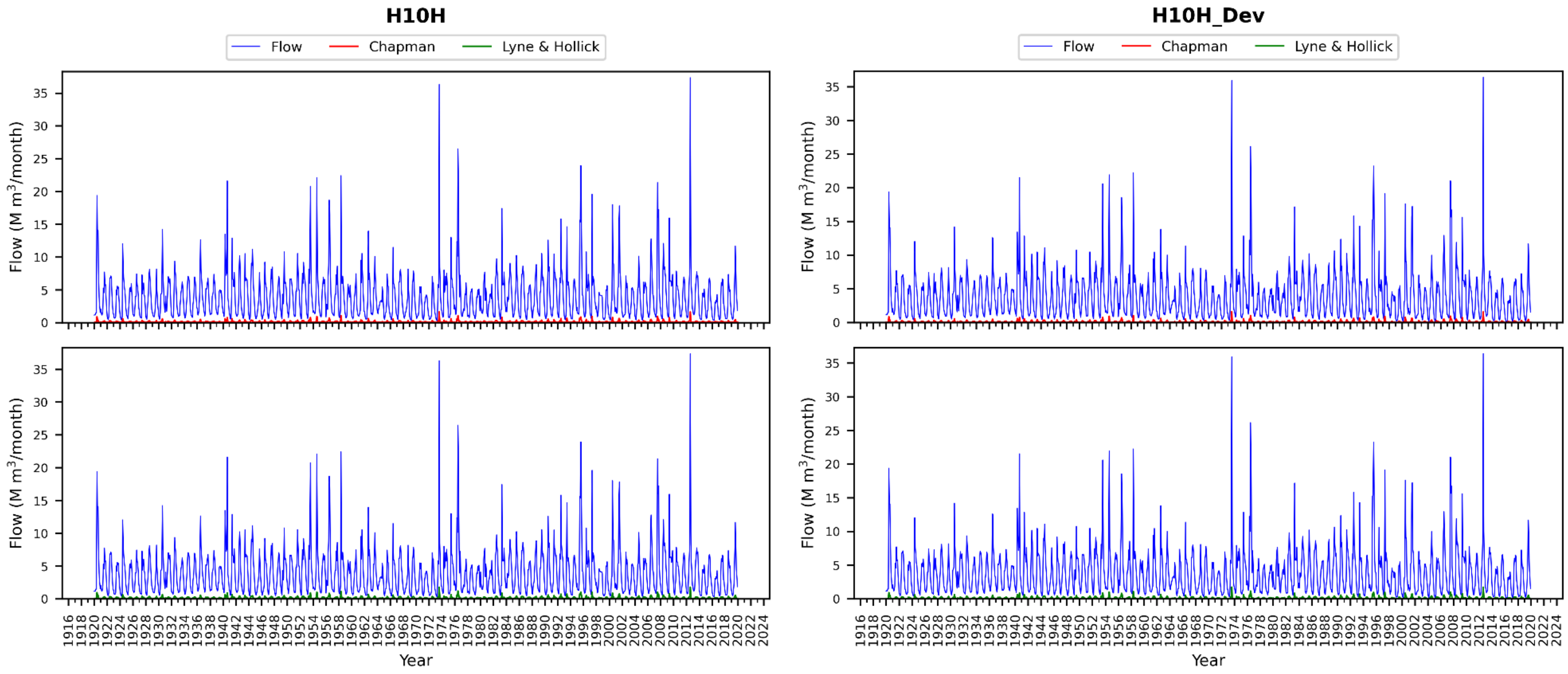

H10E_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m^3/month)
Year

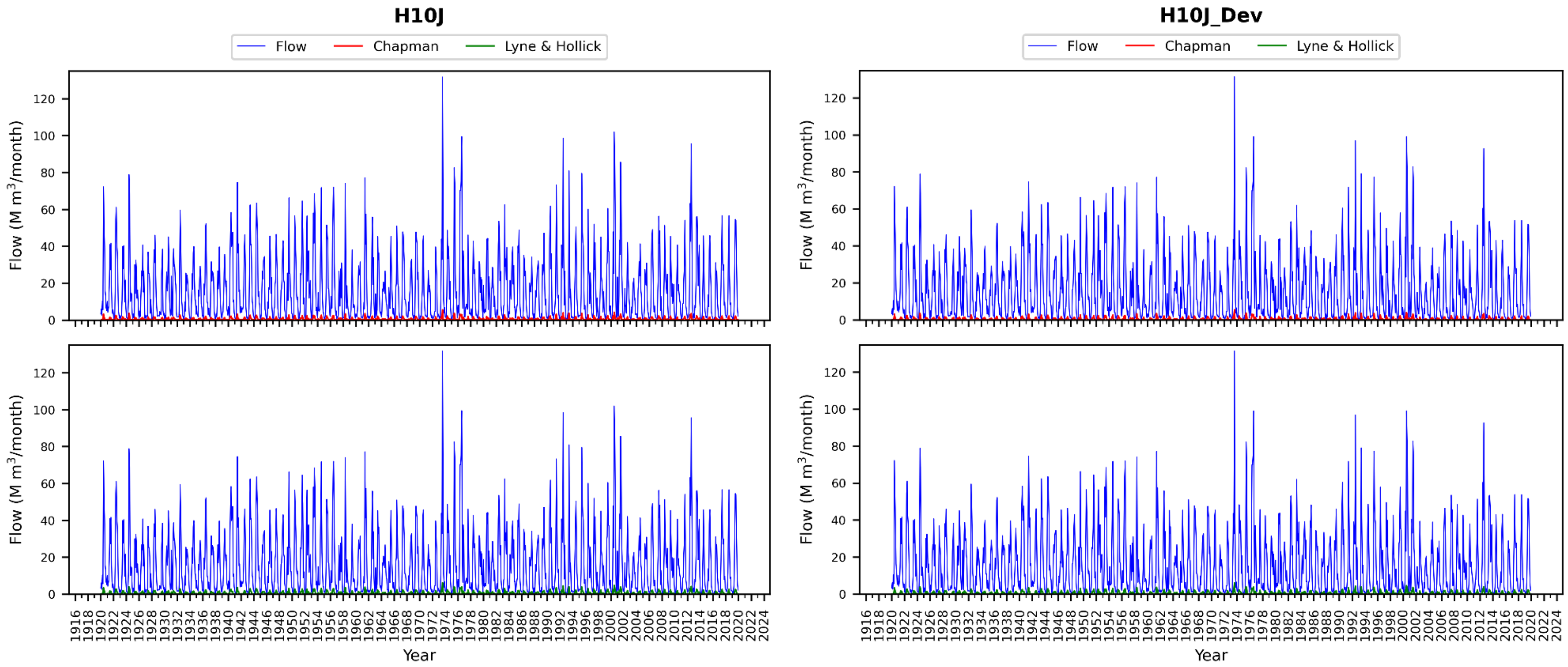

H10F
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Year

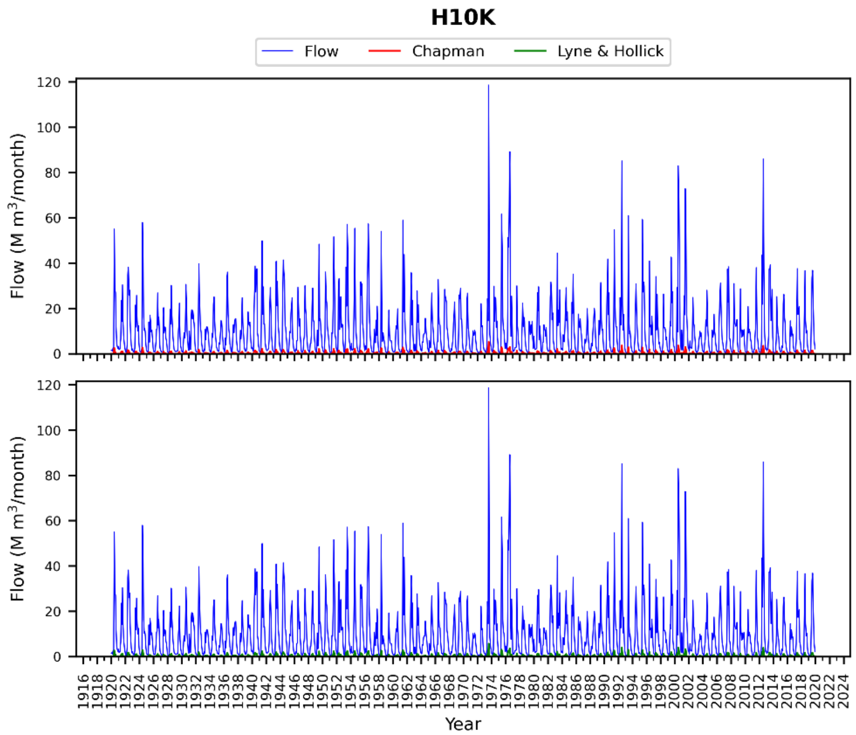

H10F_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Year

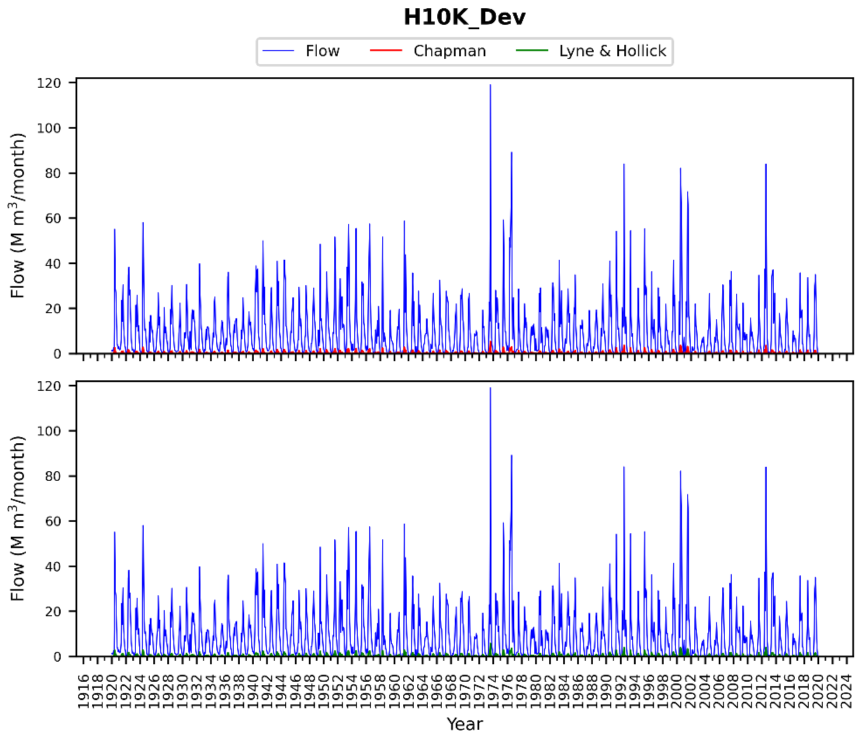

H10G
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Year

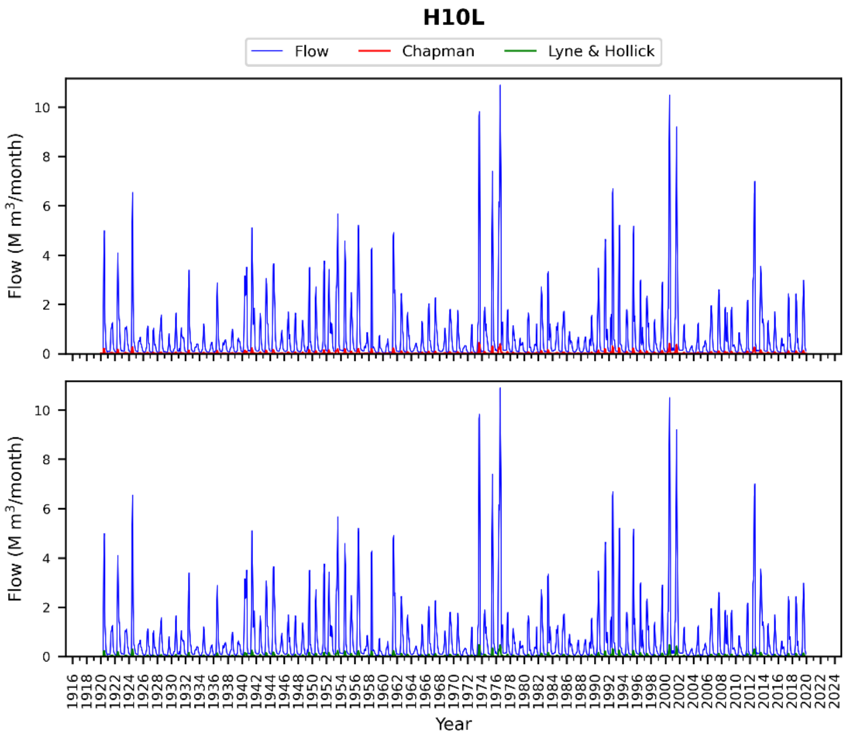

H10G_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Year

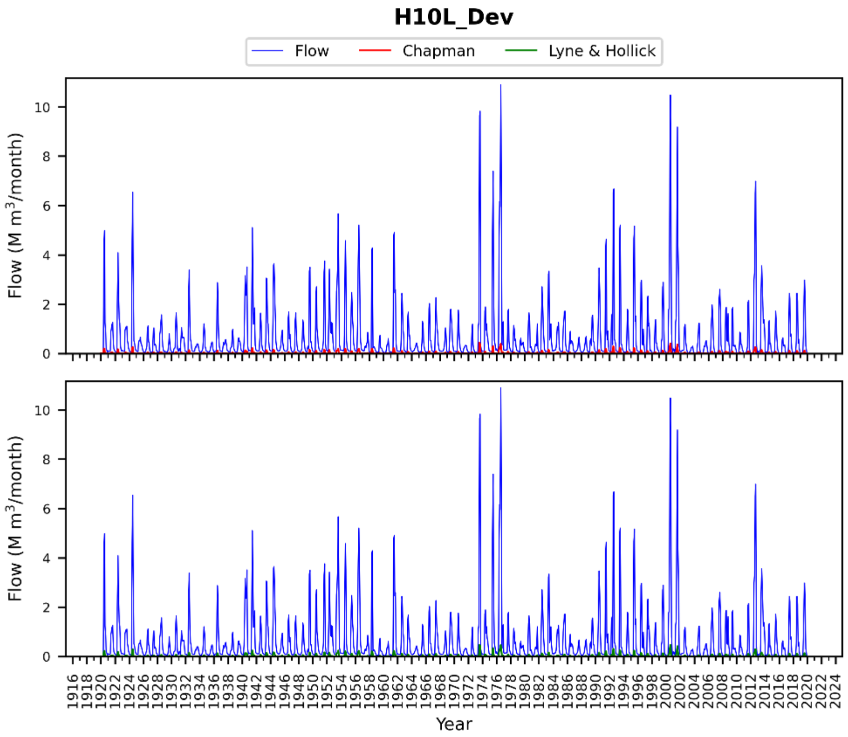

H10H
H10H_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m³/month)
Year


H10J
H10J_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m³/month)
Year


H10K
Flow
Chapman
Lyne & Hollick
Flow (M m³/month)
0 20 40 60 80 100 120
1916 1918 1920 1922 1924 1926 1928 1930 1932 1934 1936 1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024
Year

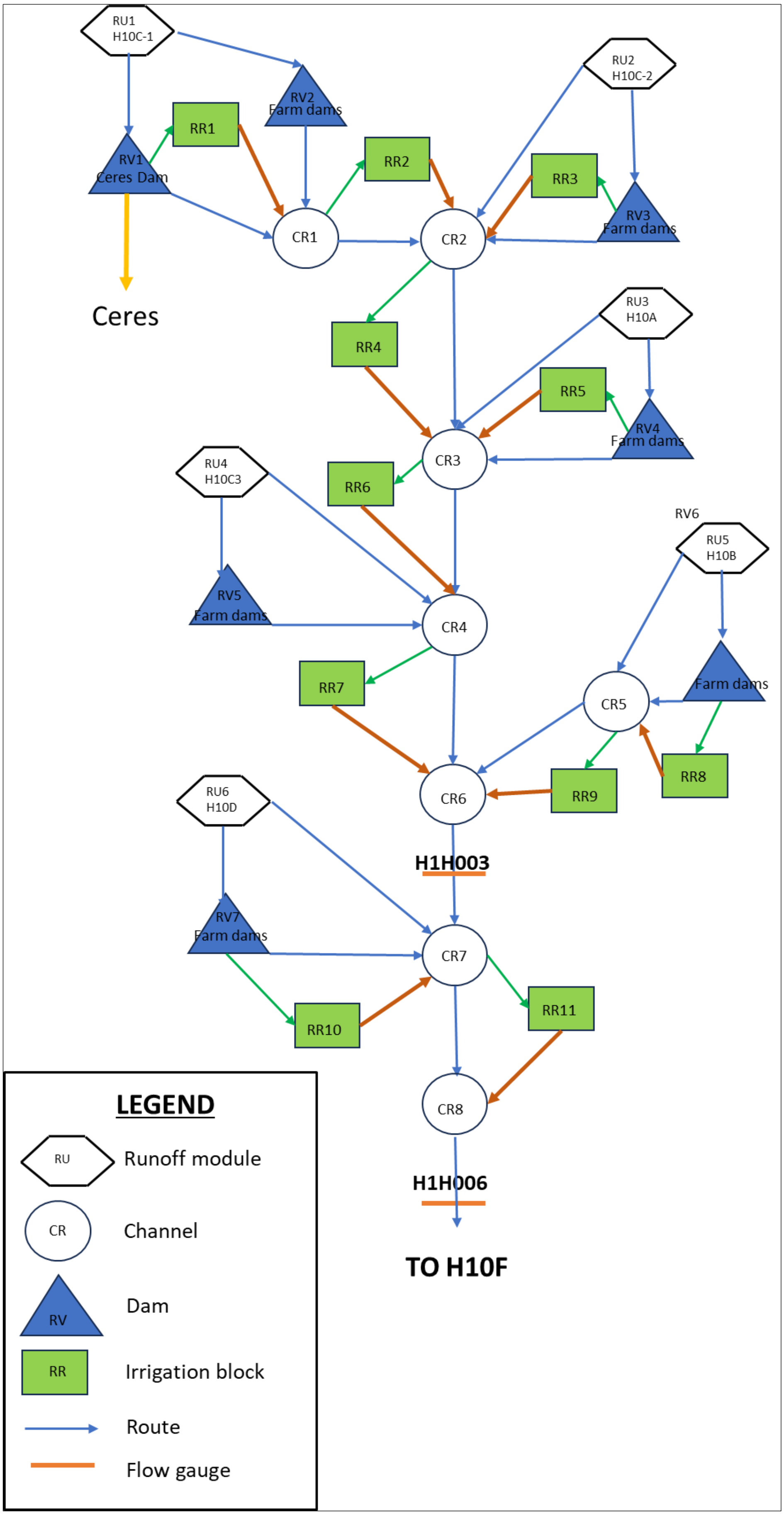

H10K_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m³/month)
0 20 40 60 80 100 120
1916 1918 1920 1922 1924 1926 1928 1930 1932 1934 1936 1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024
Year

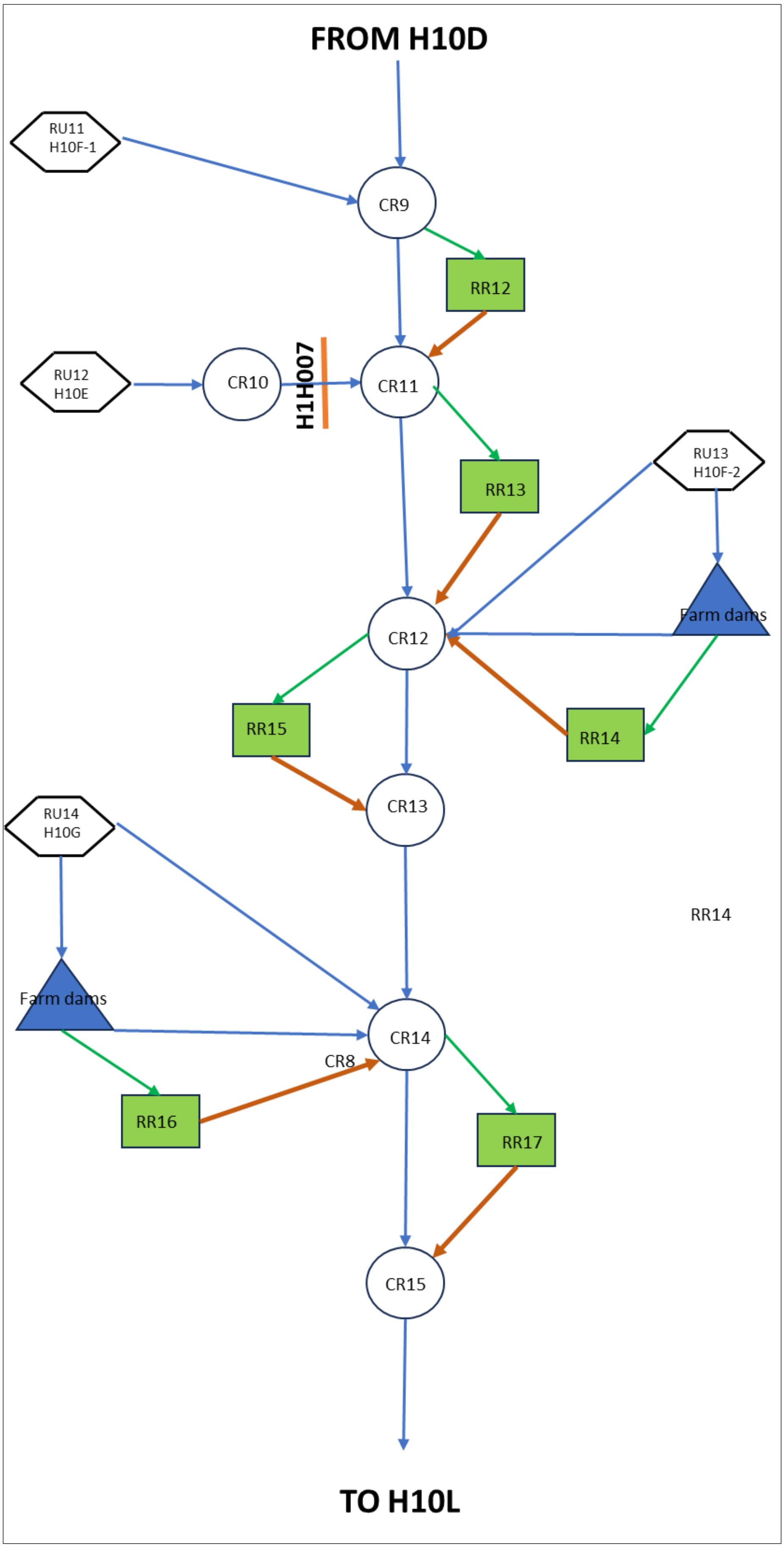

H10L
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Flow (M m3/month)
Year

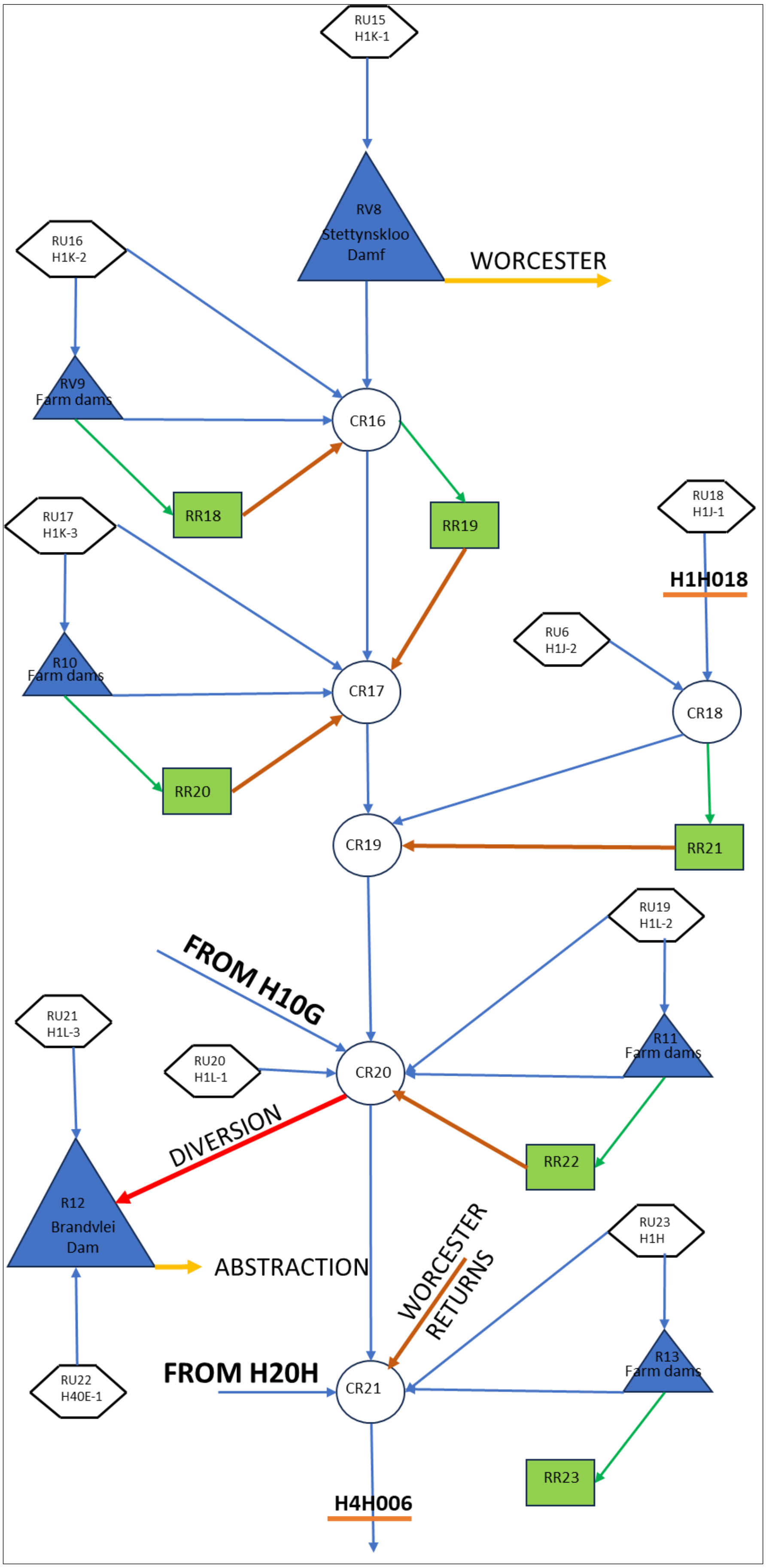

H10L_Dev
Flow
Chapman
Lyne & Hollick
Flow (M m3/month)
Flow (M m3/month)
Year

Appendix D

WRSM2000 model network designs


RU1 H10C-1
RV2 Farm dams
RU2 H10C-2
RR1
RV1 Ceres Dam
RR2
RR3
RV3 Farm dams
CR1
CR2
Ceres
RU3 H10A
RR4
RR5
RV4 Farm dams
CR3
RU4 H10C3
RR6
RV6
RU5 H10B
RV5 Farm dams
CR4
Farm dams
RR7
CR5
RR8
RR9
CR6
RU6 H10D
H1H003
RV7 Farm dams
CR7
RR11
RR10
CR8
H1H006
TO H10F
LEGEND
RU Runoff module
CR Channel
RV Dam
RR Irrigation block
Route
Flow gauge

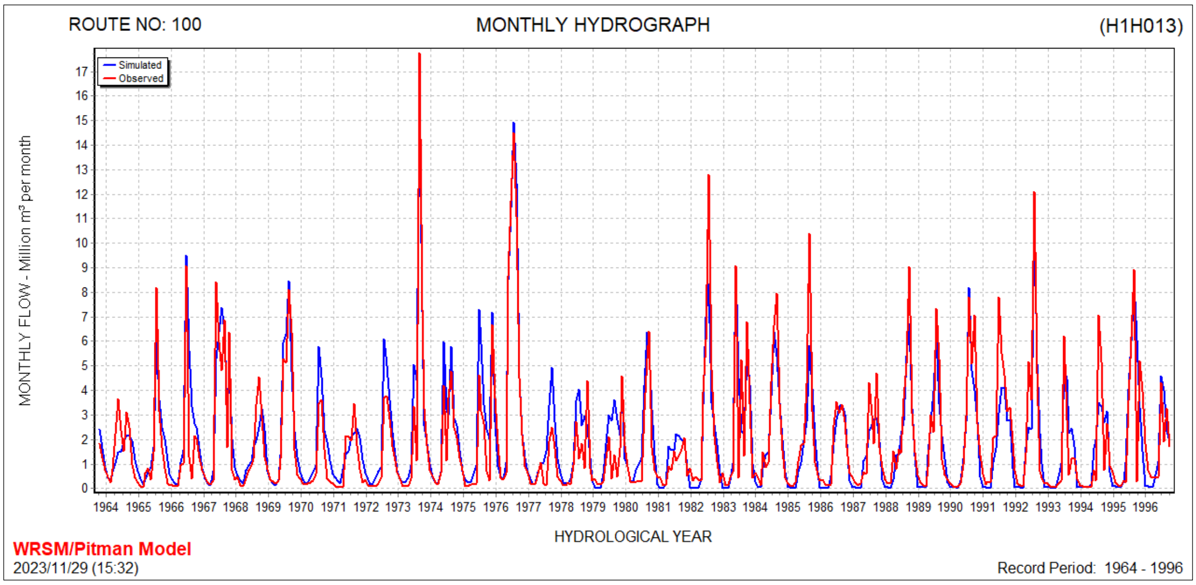

FROM H10D
RU11
H10F-1
CR9
RR12
RU12
H10E
CR10
H1H007
CR11
RR13
RU13
H10F-2
Farm dams
CR12
RR15
RR14
CR13
RU14
H10G
RR14
Farm dams
CR14
CR8
RR16
RR17
CR15
TO H10L

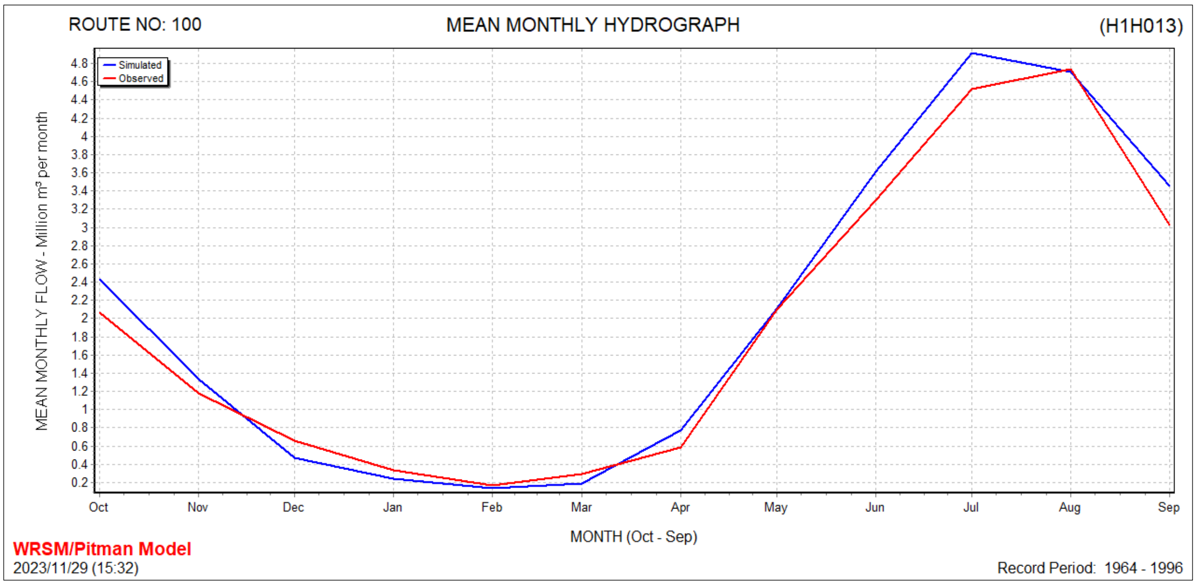

RU15
H1K-1
RV8
Stettynskloo
Damf
WORCESTER
RU16
H1K-2
RV9
Farm dams
CR16
RR18
RR19
RU17
H1K-3
RU18
H1J-1
H1H018
RU6
H1J-2
R10
Farm dams
CR17
CR18
RR20
CR19
RR21
RU19
H1L-2
FROM H10G
RU21
H1L-3
R11
Farm dams
RU20
H1L-1
CR20
DIVERSION
RR22
R12
Brandvlei
Dam
WORCESTER
RETURNS
RU23
H1H
ABSTRACTION
R13
Farm dams
FROM H20H
CR21
RU22
H40E-1
RR23
H4H006

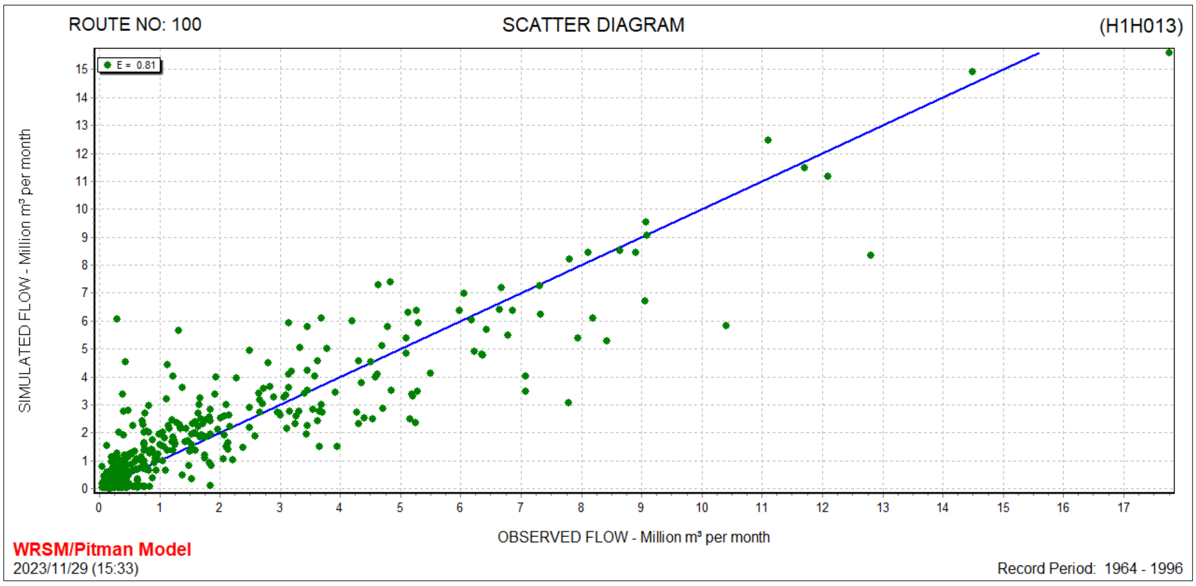
Appendix E

Preliminary WRSM2000 calibration results

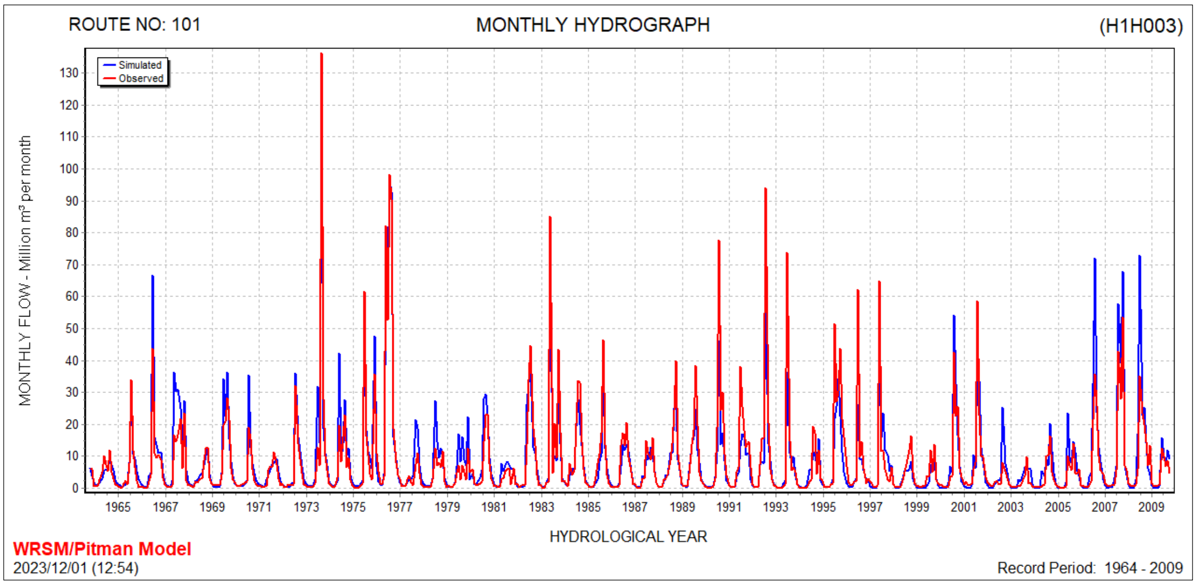
Preliminary WRSM2000 calibration results for H1H013

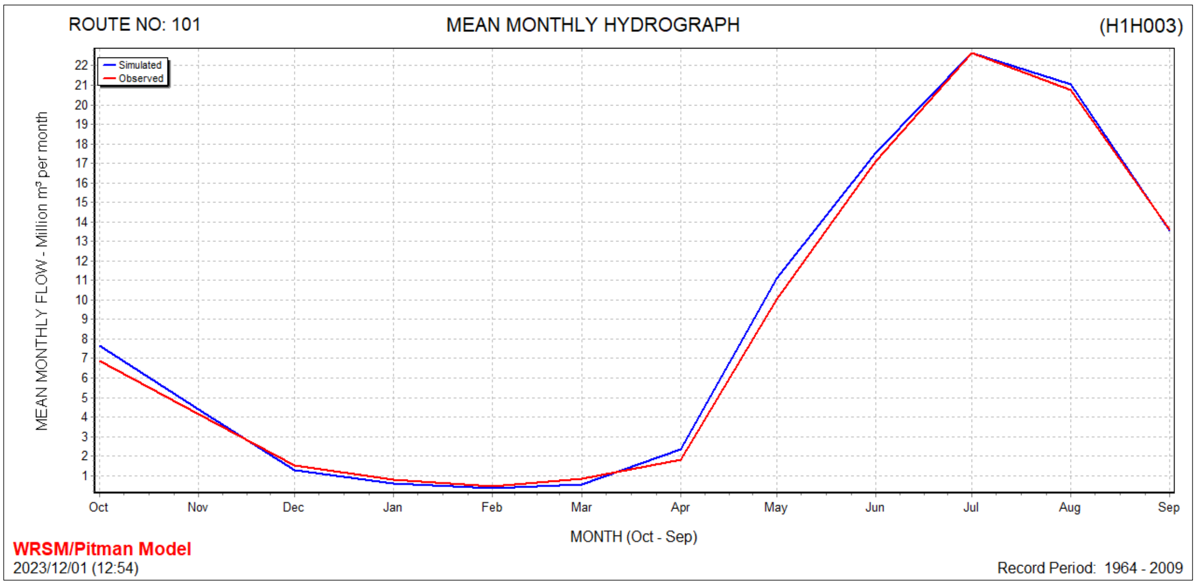


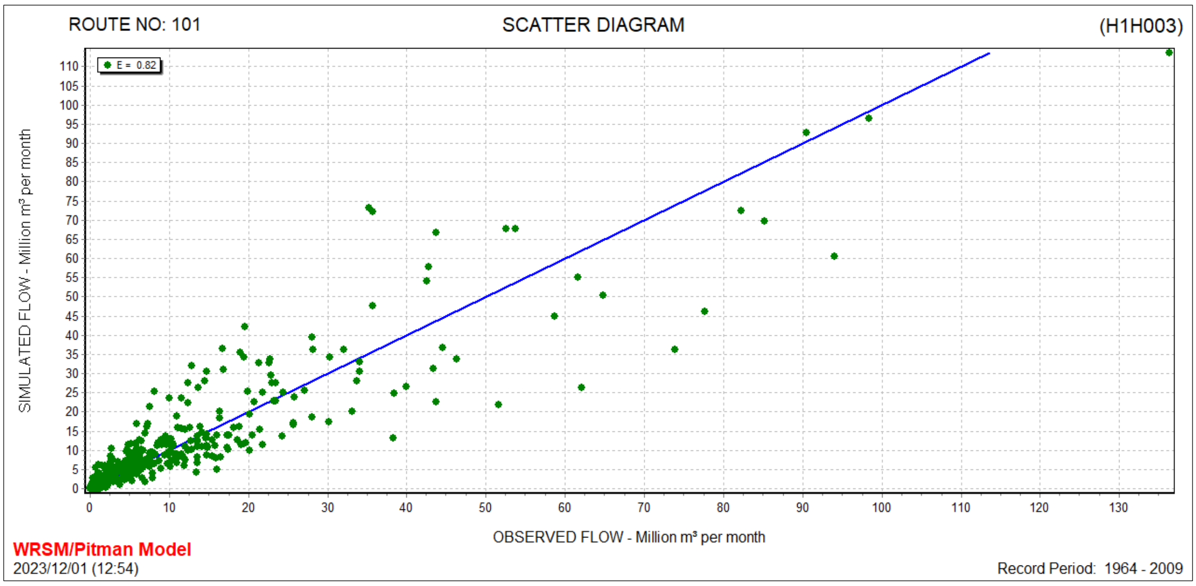




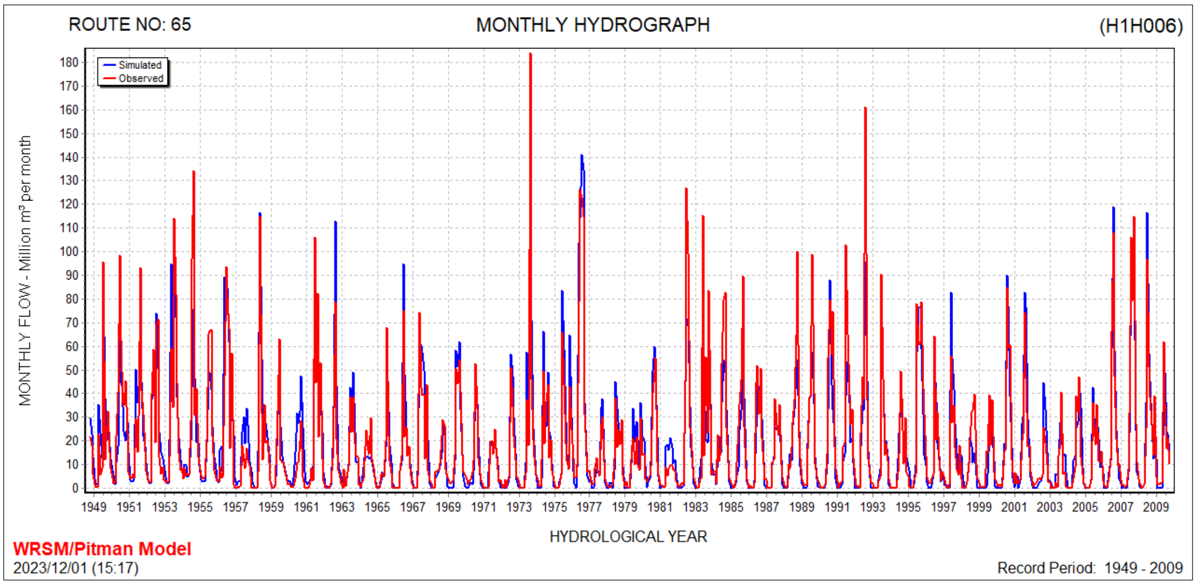
Preliminary WRSM2000 calibration results for H1H003

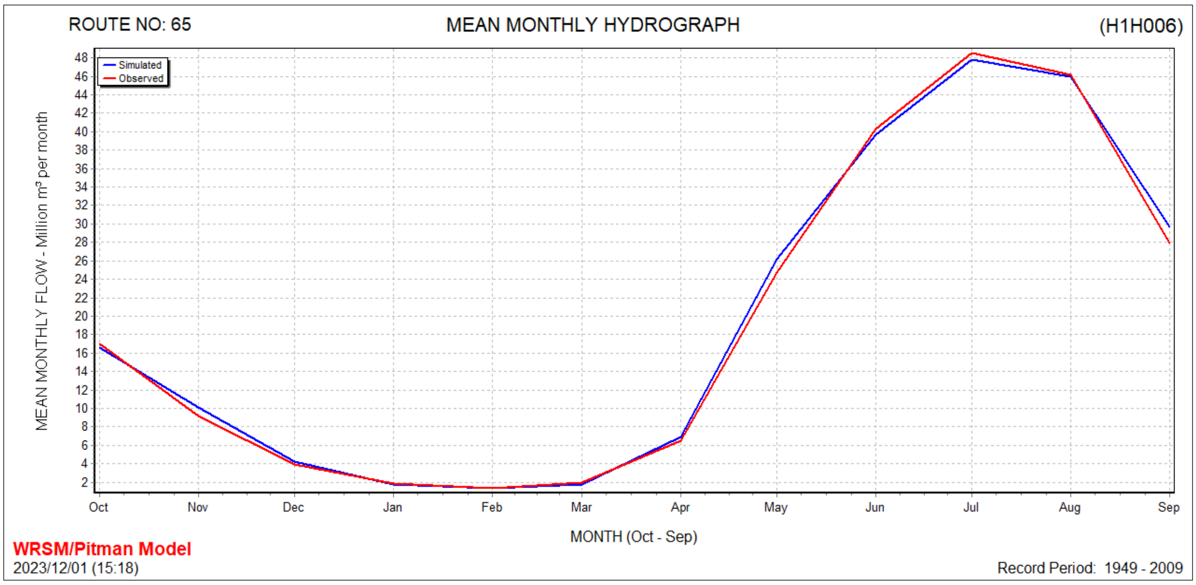


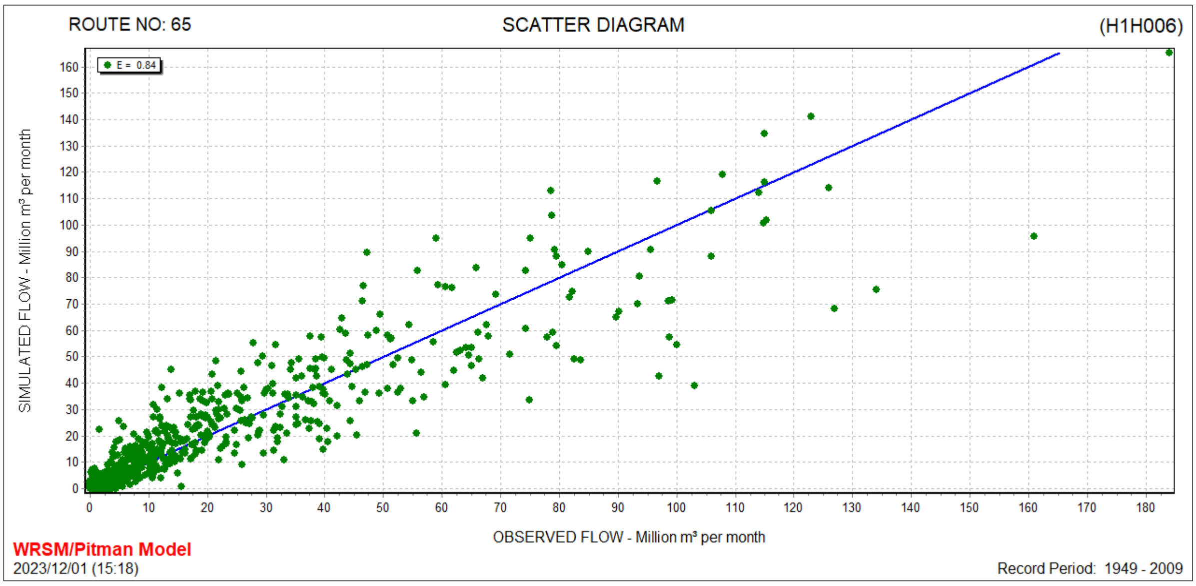




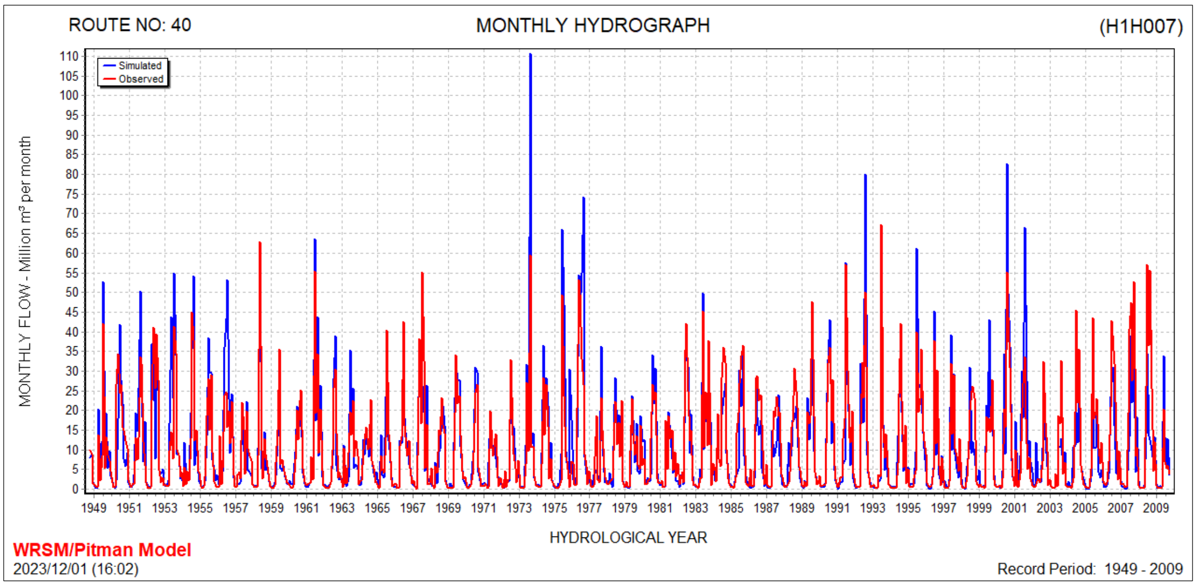
Preliminary WRSM2000 calibration results for H1H006

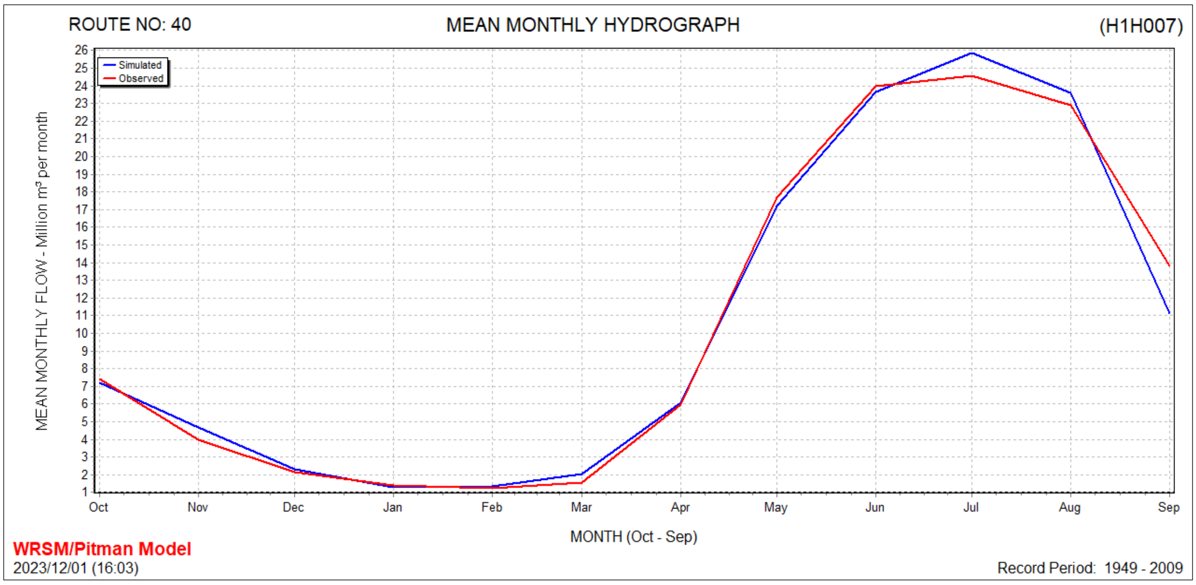


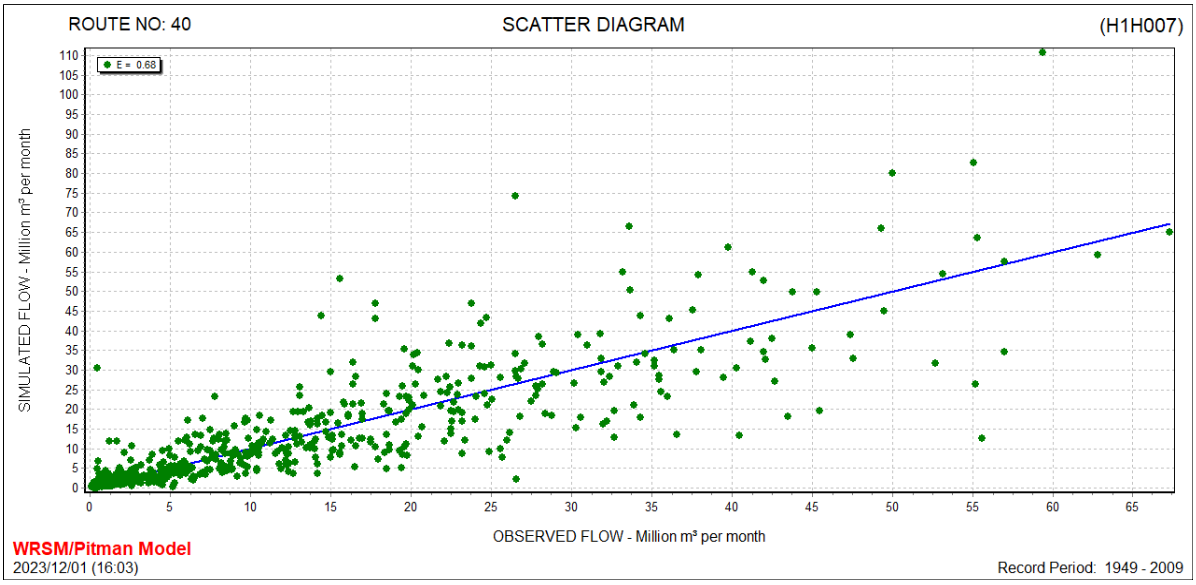




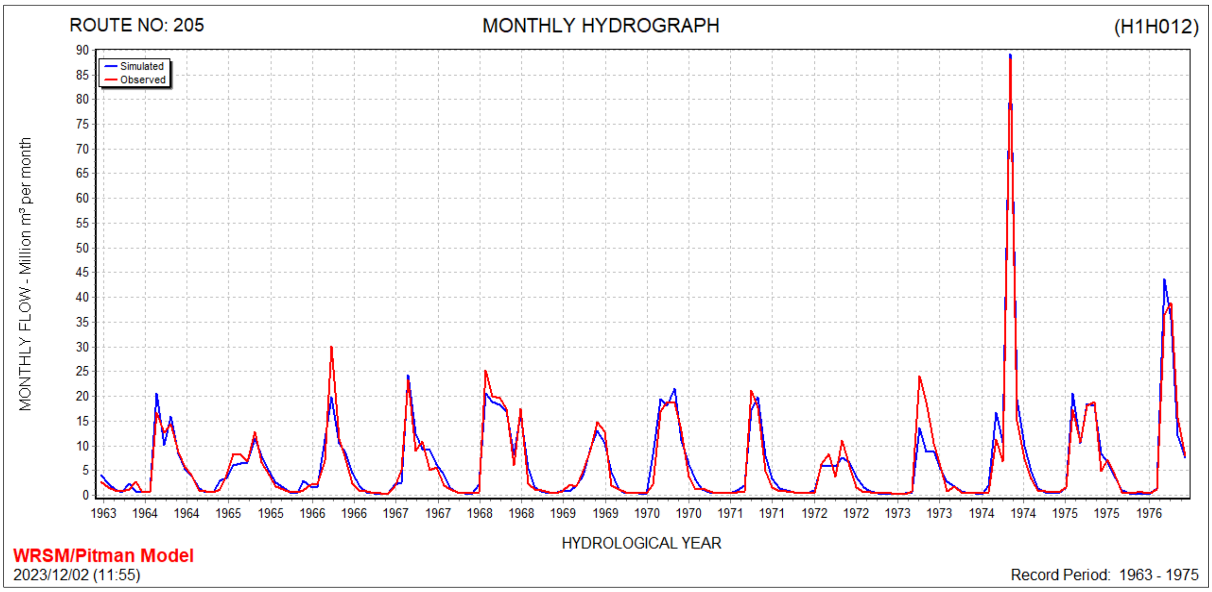
Preliminary WRSM2000 calibration results for H1H007

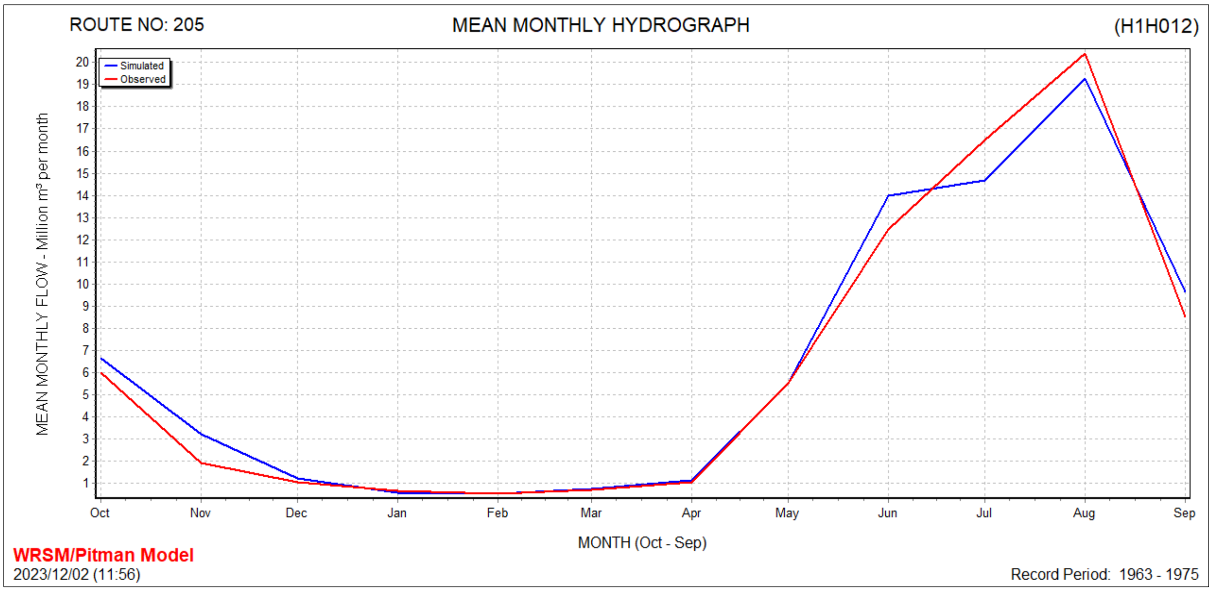


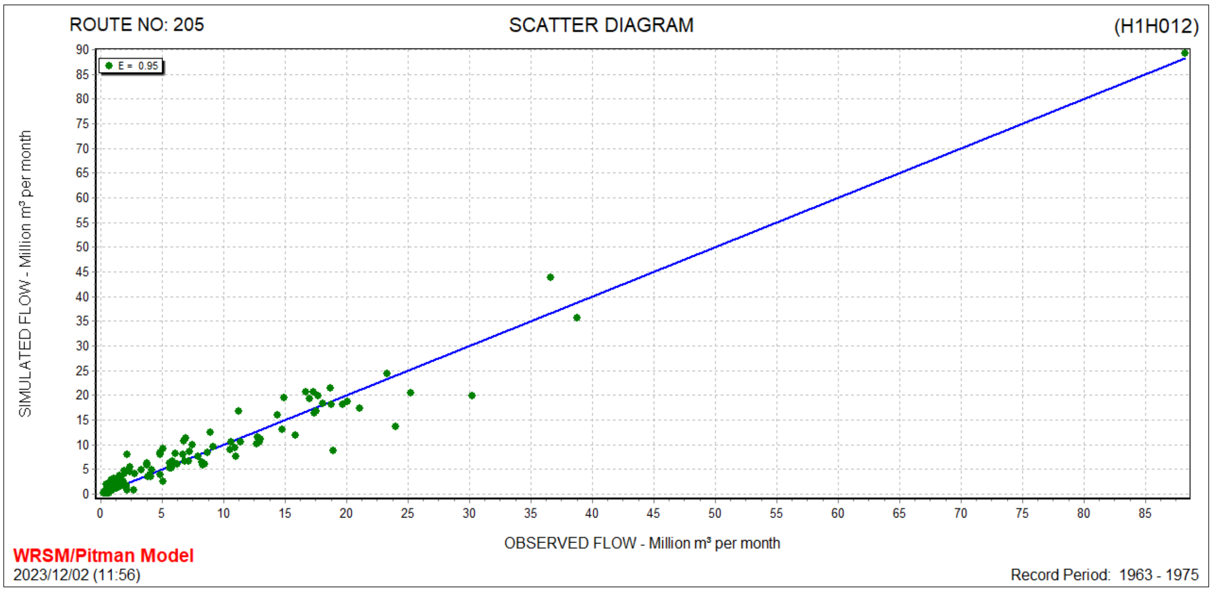




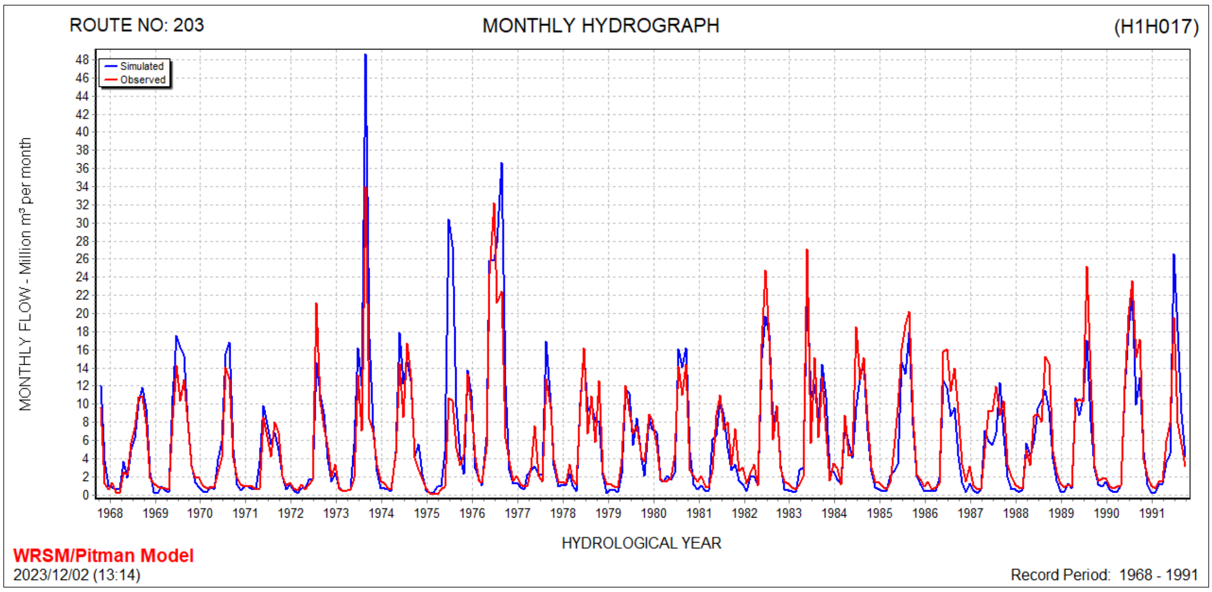
Preliminary WRSM2000 calibration results for H1H012

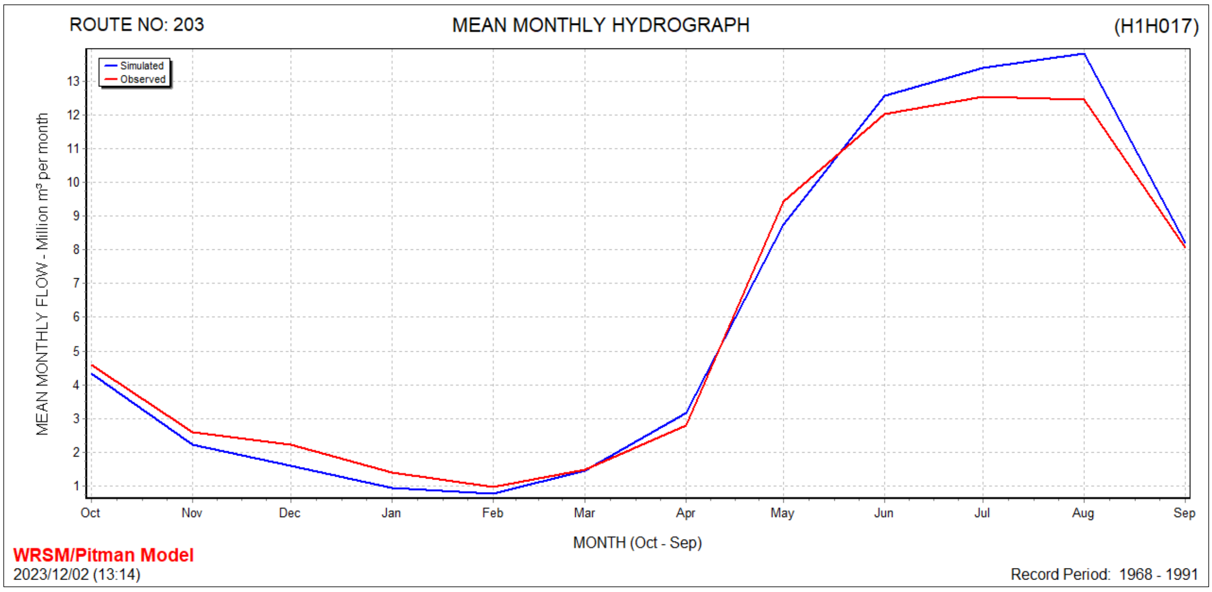


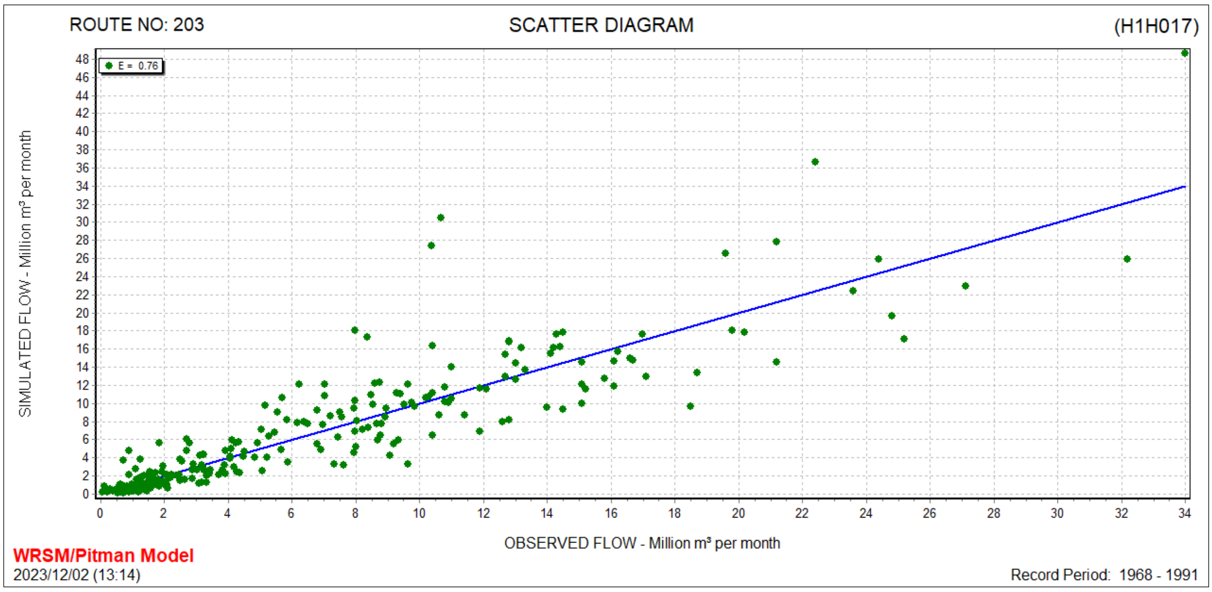




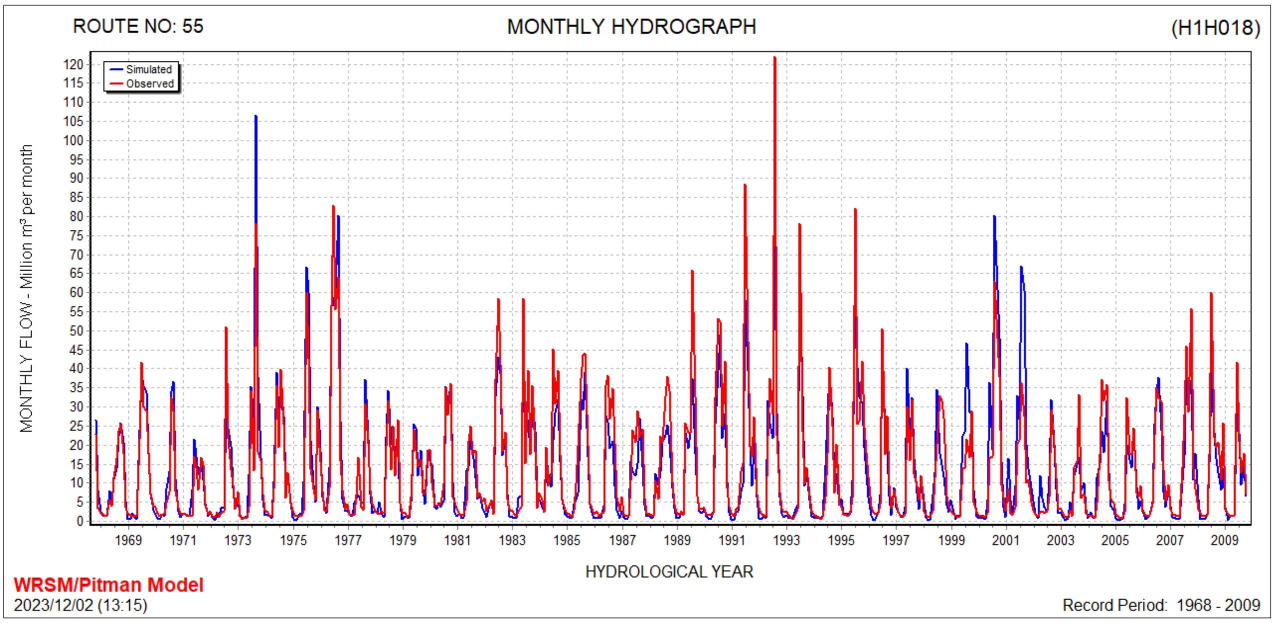
Preliminary WRSM2000 calibration results for H1H017

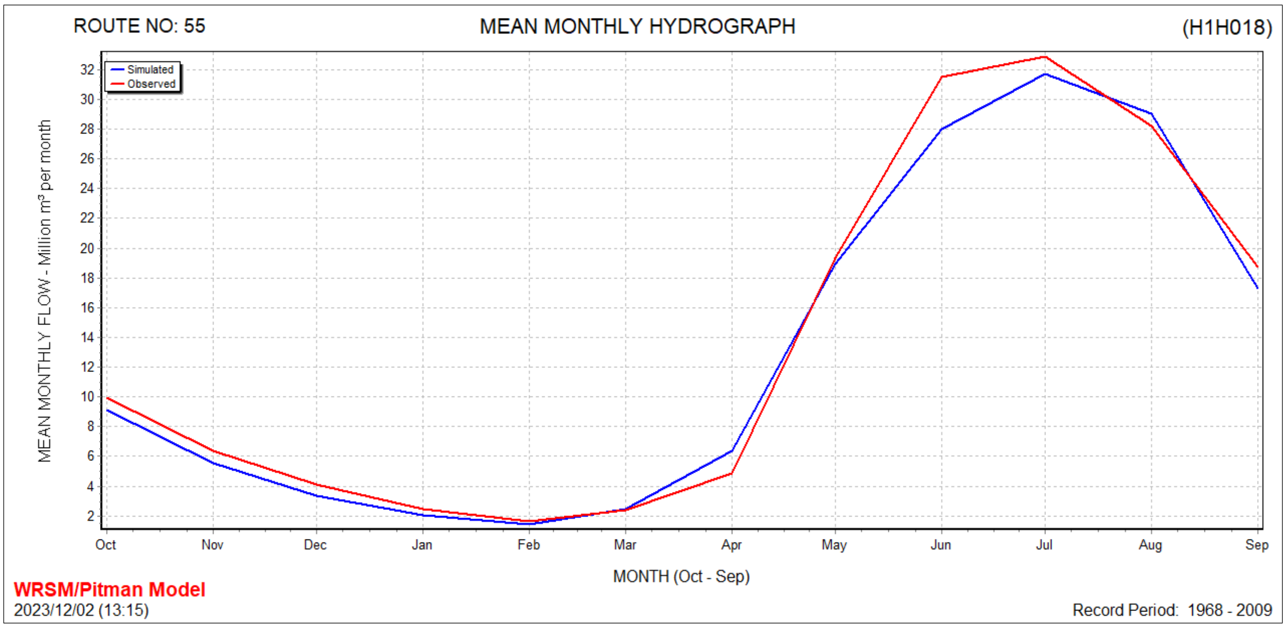


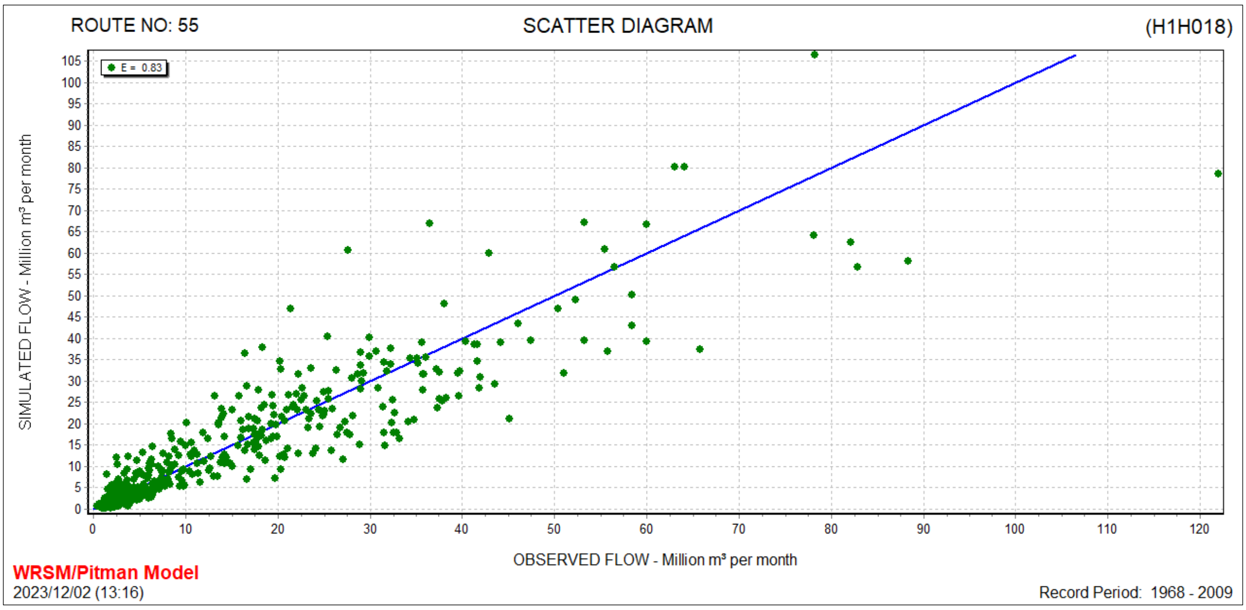




Preliminary WRSM2000 calibration results for H1H018


ROUTE NO: 55
MONTHLY HYDROGRAPH
(H1H018)
Simulated
Observed
MONTHLY FLOW - Million m³ per month
HYDROLOGICAL YEAR
WRSM/Pitman Model
2023/12/02 (13:15)
Record Period: 1968 - 2009


ROUTE NO: 55
MEAN MONTHLY HYDROGRAPH
(H1H018)
Simulated
Observed
MEAN MONTHLY FLOW - Million m³ per month
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
MONTH (Oct - Sep)
WRSM/Pitman Model
2023/12/02 (13:15)
Record Period: 1968 - 2009


ROUTE NO: 55
SCATTER DIAGRAM
(H1H018)
E = 0.83
SIMULATED FLOW - Million m³ per month
OBSERVED FLOW - Million m³ per month
WRSM/Pitman Model
2023/12/02 (13:16)
Record Period: 1968 - 2009