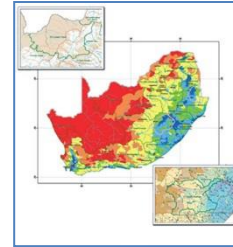


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Hydrological Analysis of the Nylsvlei A61 Tertiary Catchment

Draft Final Report

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1. Introduction

The Network diagrams for the catchments is given in Appendix A. There is an explanation of the diagrams at the start of the Appendix. This network diagram is used by the Water Resources Simulation Model referred to as WRSM/Pitman, WRSM2000 or the Pitman model (Pitman, 1973)

There were three previous studies that were used to extend the system as follows up to September 2021. It was important to include the high rainfall event of December 2020 so the hydrological year 2020 was required :

- The Water Resources of South Africa, 2012 Study (Bailey and Pitman, 2012), commonly referred to as WR2012 was used as a starting point for the system;
- The previous Volspruit Mine hydrological study completed in January 2014 “Nyl Riverr Hydrological Modelling” and
- The addendum study “Nyl River Hydrological Modelling – addendum following provincial non-acceptance of mining proposal”, completed in June 2016.

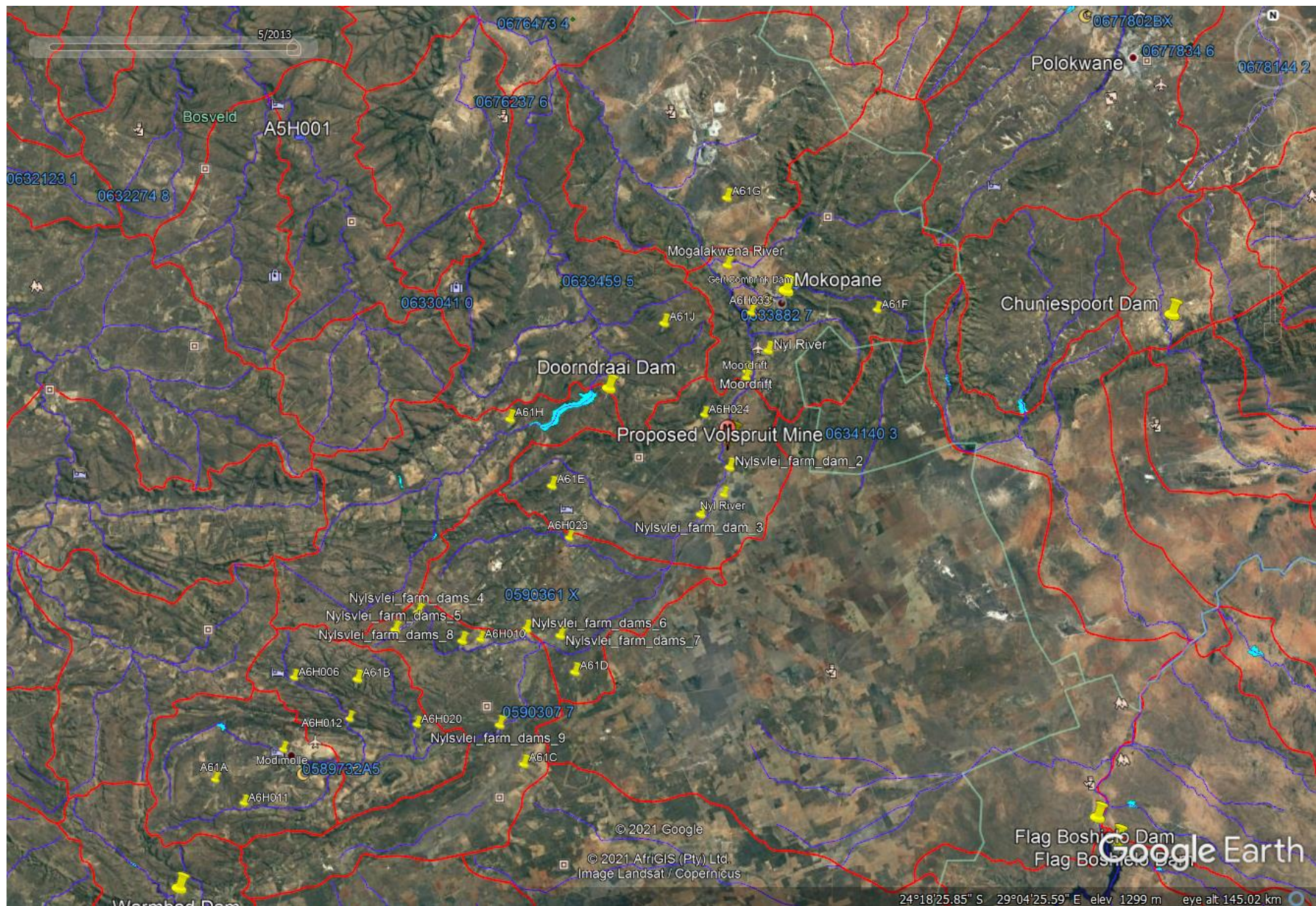


Figure 1: Study area

2. WRSMPitman hydrological model

The Water Resources Simulation Model (WRSMPitman) was initially developed about five decades ago by Dr Bill Pitman at the University of the Witwatersrand in South Africa. WRSMPitman is a modular water resources simulation program that runs on a monthly time step. The program features five different Module-types: The Runoff Module, the Channel Module, the Irrigation Module, the Reservoir Module and the Mining Module. Each of these Modules contains one (or offers a choice between more than one) hydrological models that simulate a particular hydrological aspect. The Modules are linked to one another by means of Routes. Multiple instances of the different Modules, together with the Routes, form a Network. By choosing and linking several modules judiciously, virtually any real-world hydrological system can be represented.

The first step in simulating any hydrological system is to set up the Network of Modules and Routes to represent this system. WRSMPitman allows for interactive creation and editing of all Modules, Routes and Networks. The program supports the user by means of extensive error checking.

WRSMPitman has been enhanced many times over the years to be aligned to the latest water resource methodologies and computer science technology. About 15 years ago, a number of new methodologies were added with the most important being the groundwater-surface water interface. These new methodologies were added at the request of the Department of Water Affairs and Sanitation of South Africa who regard WRSMPitman as the preferred model in South Africa and have based most of their latest water resource allocation studies (for the purpose of water licensing) on it. It was also chosen by the Water Research Commission of South Africa as the preferred model for the “Water Resources of South Africa, 2012 Study (WR2012)” and its predecessors (WR2005 and WR90) which appraised the integrated water resources of South Africa, Lesotho and Swaziland.

WRSMPitman can be calibrated to obtain water resources statistics and graphs such as hydrographs, mean monthly flows, cumulative frequency of flows, etc. for simulated (modelled) flows that are as close as possible to observed flows.

WRSMPitman has been used for a number of diverse applications ranging from very small to very large catchments varying in complexity from being totally undeveloped to highly utilised. It has been used throughout South Africa, many other countries in Africa and a few countries outside Africa.

3. Rainfall

New resources of satellite observations like gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high resolution (0.05°) gridded precipitation (<https://www.chc.ucsb.edu/data/chirps>). When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias—a key technique in the production of the 1981 to near-present Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) data set. A scientific paper by Mr Allan Bailey and Dr Bill Pitman has recently been published by Water SA on the applicability of the CHIRPS dataset within South Africa. No patching is required as there are no missing values. Due to the fact that rainfall stations have closed down to quite an extent in the country, use was initially made of this USA based website system (CHIRPS).

A series of spreadsheets were established to set up the CHIRPS rainfall data and convert it from daily to monthly data in the correct format. The monthly values were also converted to percentage of MAP which is what is required by the WRSM/Pitman model. Use was made of the Water Resources of South Africa, 2012 (WR2012) (Bailey and Pitman, 2012) for the rainfall record from 1920 to 2009 (hydrological years, i.e. up to September 2010), the previous 2016 study and the CHIRPS data was added up to 2021. Comparisons of CHIRPS versus rainfall station data was made (see Figure 2 as an example). The following procedure was used:

- Using Google Earth, polygons were drawn to demarcate the WR2012 hydro zones which comprise a number of quaternary catchments;
- Save as a “.kmz” file
- Convert the kmz files to “GeoJson” files for use in CHIRPS (<https://mygeodata.cloud/converter/kmz-to-json>)
- Run CHIRPS with the GeoJson file and get a daily rainfall spreadsheet (1981 to 2020) (<https://climateserv.servirglobal.net/>)
- Convert to monthly rainfall in percentage of MAP (“.Ran” file)
- Compare the overlap period with rainfall station data
- Use in the WRSM/Pitman model. Mean annual precipitation (MAP) values for the quaternaries and runoff, reservoir, irrigation and channel modules were taken from the WR2012 study.

Comparisons were made from 1981 to 2014. There were three rainfall zones used in WR2012 as follows:

- A6A (used for quaternary catchments A61A to A61C);
- A6B (used for quaternary catchments A61D to A61E) and
- A6C (used for quaternary catchments A61F, A61G and A61J).

The graphs for the three zones have been shown in Figures 2 to 4. For A6A and A6B the comparison gets poorer from about 2007 onwards while for A6C the comparison is reasonably good over this period. It is thought that this coincides to some degree with the closing down of rainfall stations, i.e. the rainfall stations are probably less reliable over the last 10 to 15 years. The WR2012 data comes from the South African Weather Services (SAWS).

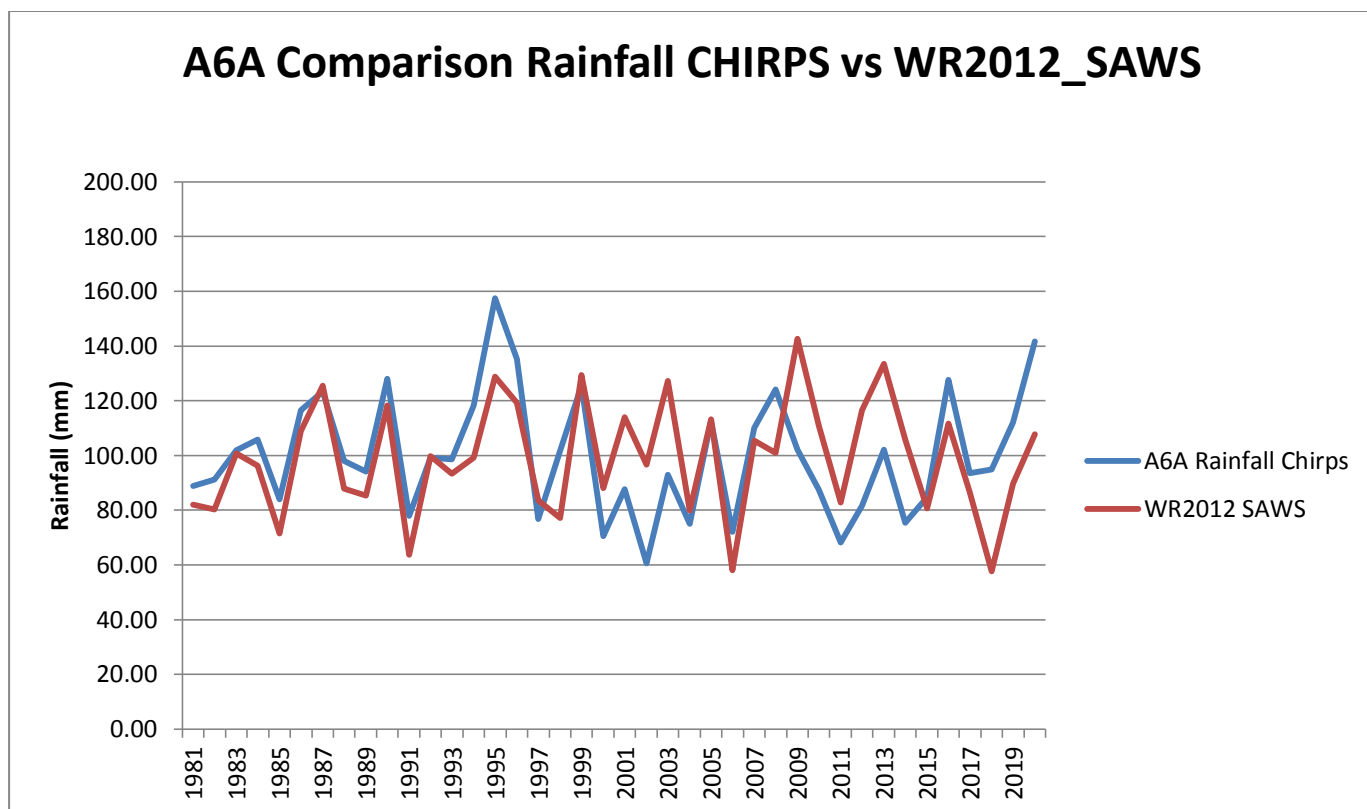


Figure 2: CHIRPS versus rainfall stations for hydro zone A6A

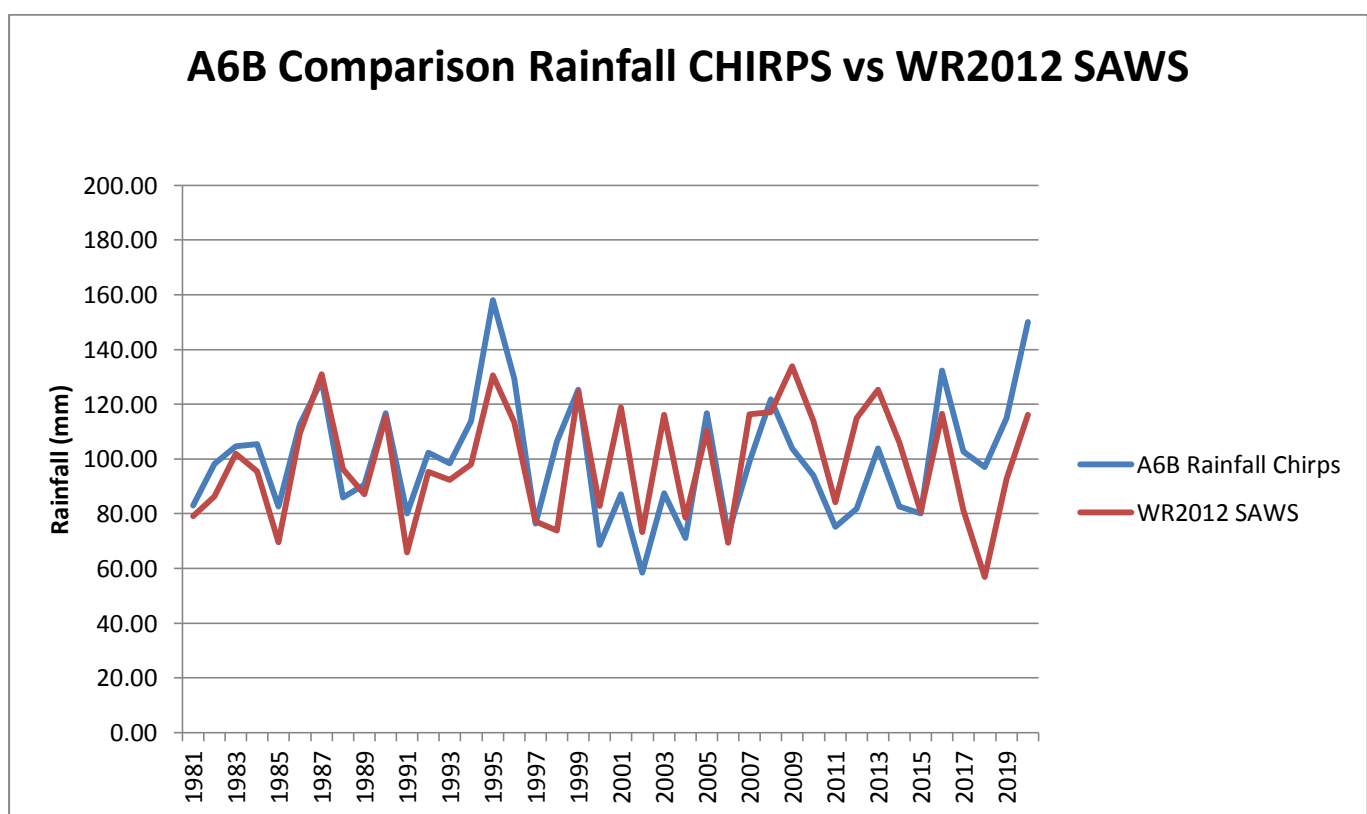


Figure 3: CHIRPS versus rainfall stations for hydro zone A6B

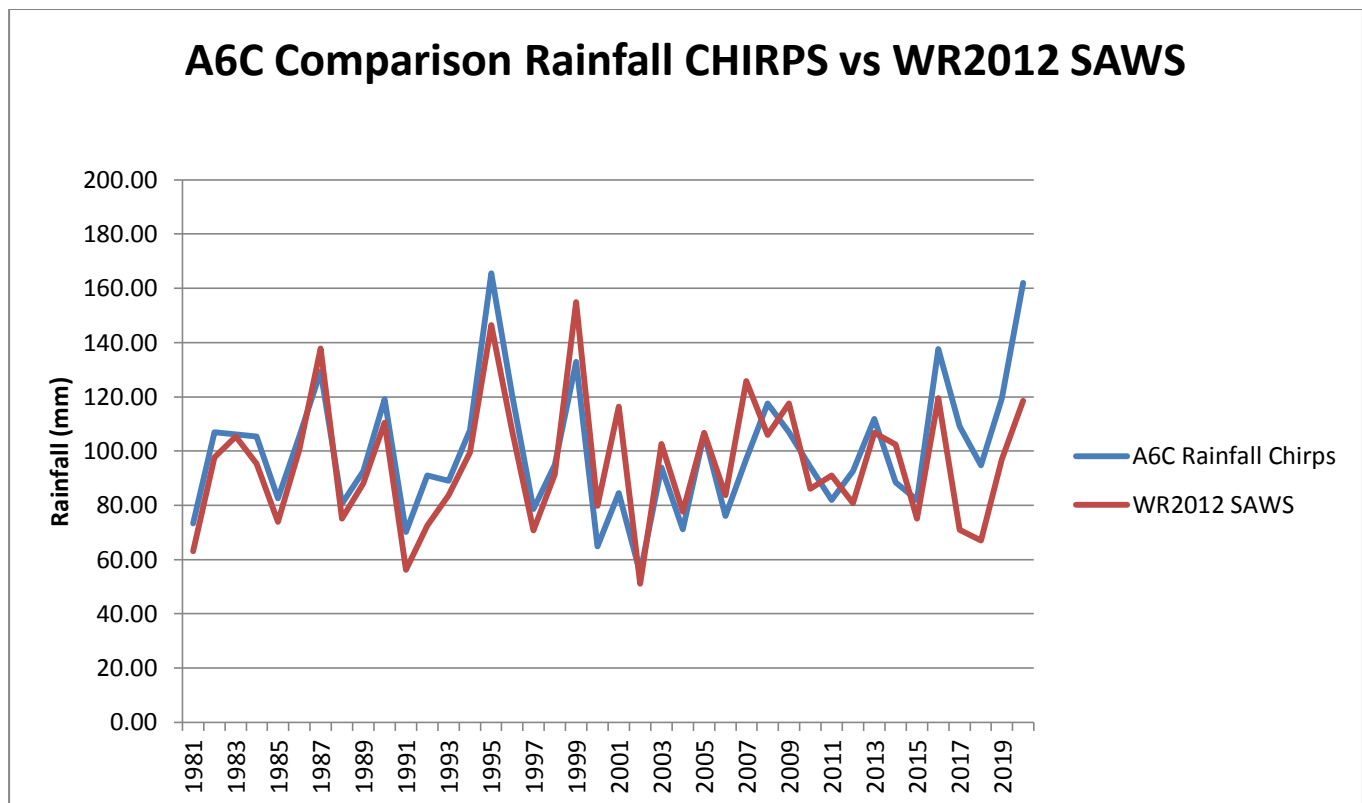


Figure 4: CHIRPS versus rainfall stations for hydro zone A6C

It was noticed in all the calibrations at streamflow gauges and reservoirs that the simulated flow in particular for January, February and March 2017 was much higher than observed. This was assumed to be a rainfall problem and therefore it was decided to obtain the South African Weather Services (SAWS) rainfall data for the following four rainfall stations. Details of any missing values have been given in which case they were patched:

- 0589732 A5 : Missing data from June – December 2020 and April 2021 not available yet.
- 0590307 7 : Some missing days in 2020 and for 2021.
- 0590361 x : Missing data for March 2018, 2020 and April 2021 not available yet.
- 0633796 A8 : No missing data.

The data for the above 4 stations was obtained and missing and/or unreliable months were patched. Use was also made of 2 other stations in the study area. The rainfall stations selected for appending the years 2014 to 2021 were as follows:

0633796 in quaternary catchment A61E

0590307 in quaternary catchment A61C

0590361 in quaternary catchment A61D

0589732 in quaternary catchment A61A

0634050 in quaternary catchment B51E close to A61E and A61F

0676237 in quaternary catchment A62A close to A61J

For the period October 2014 to May 2021 the following groupings were decided on:

A61A to C 0589732, 0590307 and 0590361

A61D to E 0590361, 0633796 and 0590307

A61F,G,J 0676237, 0634050 and 0633796

For rainfall station 0590307, the value for December 2016 looked unrealistically high and gave rise to a simulated flow that was out of sync with all the streamflow gauging stations. It was accordingly patched and a value of 148.5 mm was used instead of 340.5 mm. The % of MAR value for December 2016 determined as above was taken from the patched rainfall file and used in the final “.RAN” file. Furthermore a comparison was made from 2013 to 2020 between CHIRPS and the SAWS rainfall stations (above) and it was concluded that over 2013 and 2014 the CHIRPS representation gave simulated streamflow more in line with the streamflow gauges so it was decided to use CHIRPS for these two years and SAWS stations thereafter. To summarise, the three catchment based rainfall files “.RAN” files were determined as follows:

- From 1920 to 2012 (as for the previous study using SAWS rainfall stations)
- For 2013 and 2014 use CHIRPS
- For 2015 to 2020 use the SAWS rainfall stations (as above) with 0590307 having a patched value for Dec 2016
- For the months May to September (April to September for A61F,G,J) CHIRPS was used as it is available right up to the end of September and SAWS was not.

The WRSM/Pitman system ultimately used is in folder WRSM_SAWS (note for authors for future reference)

The “.RAN” files were determined from these groupings and the hydrological years 2013 to 2020 were appended to the previous “.RAN” files.

One of the focus points of the latest study was the high rainfall event around November, December 2020 and January, February 2021. From analysis of rainfall data and previous high rainfall events, it appears that this was in the same ballpark as high rainfall events for other years. It is be noted in the comparison below that for the 2009 hydrological year, March and April were also extremely high rainfall months which gave rise to annual streamflow at the gauges considerably higher than for 2016 and 2020. Table 2 shows comparisons with two previous events.

Table 2: Comparisons of high rainfall events (mm)

Event	SAWS station 0590307	SAWS station 0589732	SAWS station 0590361	SAWS station 0633796	CHIRPS A61A to C	CHIRPS A61D to E	CHIRPS A61F to J
November 2020	112+	117+	114	58	154	122	102
December 2020	142+	149+	144	128	148	150	167
January 2021	192+	118	189	157	166	157	194
February 2021	123+	63	124	233	190	216	249
Total	569+	447+	571	576	658	645	712
November 2016	209	102	159	119	112	107	98
December 2016	341	155+	151	201	112	114	147
January 2017	70	164+	159	155	260	244	236
February 2017	64	79	66	55	91	82	83
Total	682	500	534	530	575	547	564
November 2009	26	96	205	154	85	82	92
December 2009	209	181	105	100	104	95	95
January 2010	157	175	88	125	136	129	120
February 2010	36	50	56	28	45	39	41
Total	428	502	454	406	370	345	348

Note: A + symbol indicates it was missing and had to be patched

4. Irrigation

Irrigation data is one of the most difficult data sets to obtain. For this study use was made of the following two datasets:

- WR2012 and
- WARMS data from the Department of Water and Sanitation (DWS) .

For WR2012 areas and volumes supplied were obtained from the systems and summed for each quaternary catchment.

For the WARMS data, the DWS spreadsheet was manipulated to give irrigation volumes (areas were not given) for streams and rivers per quaternary catchment and were summed to give totals for each quaternary catchment. Table 3 below gives the comparison. From this comparison, the irrigation areas in each quaternary catchment were adopted for this. From an inspection of Google earth and the map in Figure 1, it was decided which irrigation blocks in the WRSM/Pitman model to either increase or decrease the irrigation area to give volumes of irrigation water comparable with WARMS.

Table 3: Comparison of land use/water use for irrigation, urban and industrial between WARMS and WR2012 extended

Quaternary Catchment	Total Volume WARMS (million m3/a)	Included in Total Volume Non-irrigation WARMS (million m3/a)	WR2012 Extended Irrigation (million m3/a)	WR2012 Extended Urban (million m3/a)	WR2012 Extended total (million m3/a)	Adopted (approximate as the area changes from year to year) (million m3/a)
A61A	1.35		2.79	0.79	3.58	2.79
A61B	1.42		2.01		2.01	2.01
A61C	1.42		0.32		0.32	1.00
A61D	4.75	0.82 (water supply service)	1.19		1.19	3.00
A61E	6.91	4.38 (urban from Doorndraai Dam)	2.65		2.65	2.65
A61F	7.98		2.28	0.42	2.70	5.00
A61G	2.92	1.090 (mining)	3.45		3.45	3.45
A61H	7.96	2.160 (mining)	5.87 4.63 (Doorndraai Dam)	1.20	11.70	11.70
A61J	6.25	4.340 (mining)	9.44		9.44	9.44
TOTAL	40.66	12.700	34.63	2.41	37.04	41.04

5. Reservoirs

Reservoir records were obtained from DWS from which the total releases, urban abstractions and irrigation releases were obtained.

6. Observed streamflow

Observed streamflow data was obtained from the DWS hydrology website for the following streamflow gauges.

- A6H006
- A6H011
- A6H012
- A6H010
- A6H033
- A6R001 and
- A6H027

7. Catchment area

Catchment areas were taken from WR2012

8. Groundwater Abstractions

Groundwater abstractions were obtained from the hydro-census in 2010 and 2011 and entered into the runoff modules for the relevant quaternary catchments. All but one were entered as annual values but in A61E the monthly values were known and entered.

9. WRSMPitman Networks and Calibration of Runoff Modules

The WRSMPitman network was set up as shown in Appendix A. Used by the WRSMPitman model, the hexagons represent runoff modules, the rectangles are irrigation modules, the circles are channel reaches and the triangles are reservoirs or grouped farm dams or dummy dams. Lines with arrows (called routes) represent the flow of water from one module to the next. These routes can also go out of the system (consumed water) or enter the system (return flow). River names have been shown for the larger rivers. Gauging stations where flows are measured (Observed flows) are shown with a dash across the route and have a name that ends in ".OBS". Outflows and inflows have names that are used in the WRSMPitman model, e.g. "A61.ABS" is the urban demand from Donkerpoort Dam for Modimolle. Major dams have been named. The calibration process involves the adjustment of certain model parameters until a satisfactory fit is obtained between the observed and simulated time series of monthly and annual flows. It involves not only the attempt to match simulated and observed flows as far as possible but also to obtain an acceptable comparison between observed and simulated flow records for a selection of statistics. These statistics are compared in Table 4.

Table 4 – Statistics of observed and simulated streamflow records

Gauge	Period	MAR (10 ⁶ m ³)		Std. dev. (10 ⁶ m ³)		Seasonal Index (%)	
		Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
A6H006	1969 - 2020	5.99	5.86	6.66	6.03	33.24	36.64
A6H011	1967 - 2020	4.42	3.87	4.44	2.85	30.45	32.84
A6H012	1966 - 2020	6.68	6.36	5.91	6.93	43.47	38.31
A6H010	1964 - 2020	2.37	2.24	2.71	2.37	43.89	42.58
A6H033 (vlei ouput)	2005 - 2020	5.08	5.20	12.10	17.20	65.85	61.85
A6R001	1953 - 2020	20.54	20.63	19.96	18.16	35.06	36.18
A6H027	1952 - 2020	8.64	9.87	13.37	15.12	35.76	41.61

The following plots were produced by the WRSMPitman model.

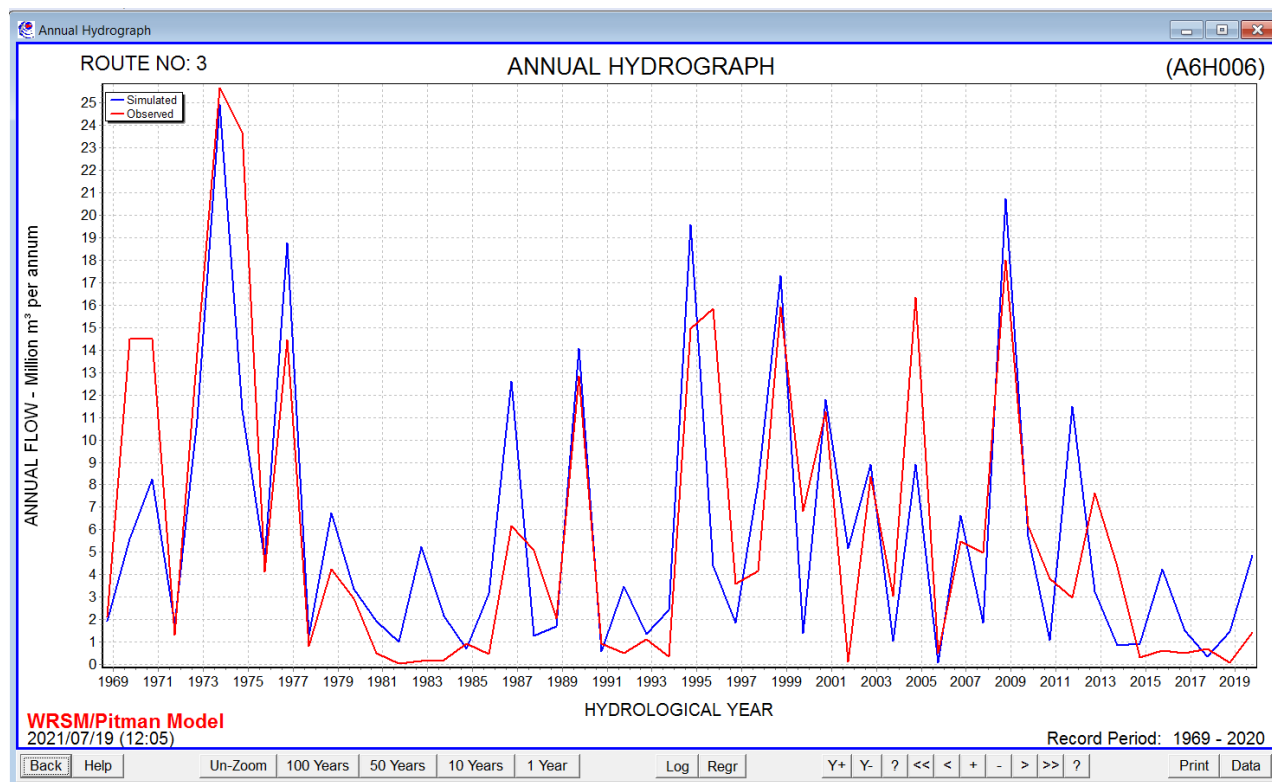


Figure 5: Annual hydrograph for A6H006

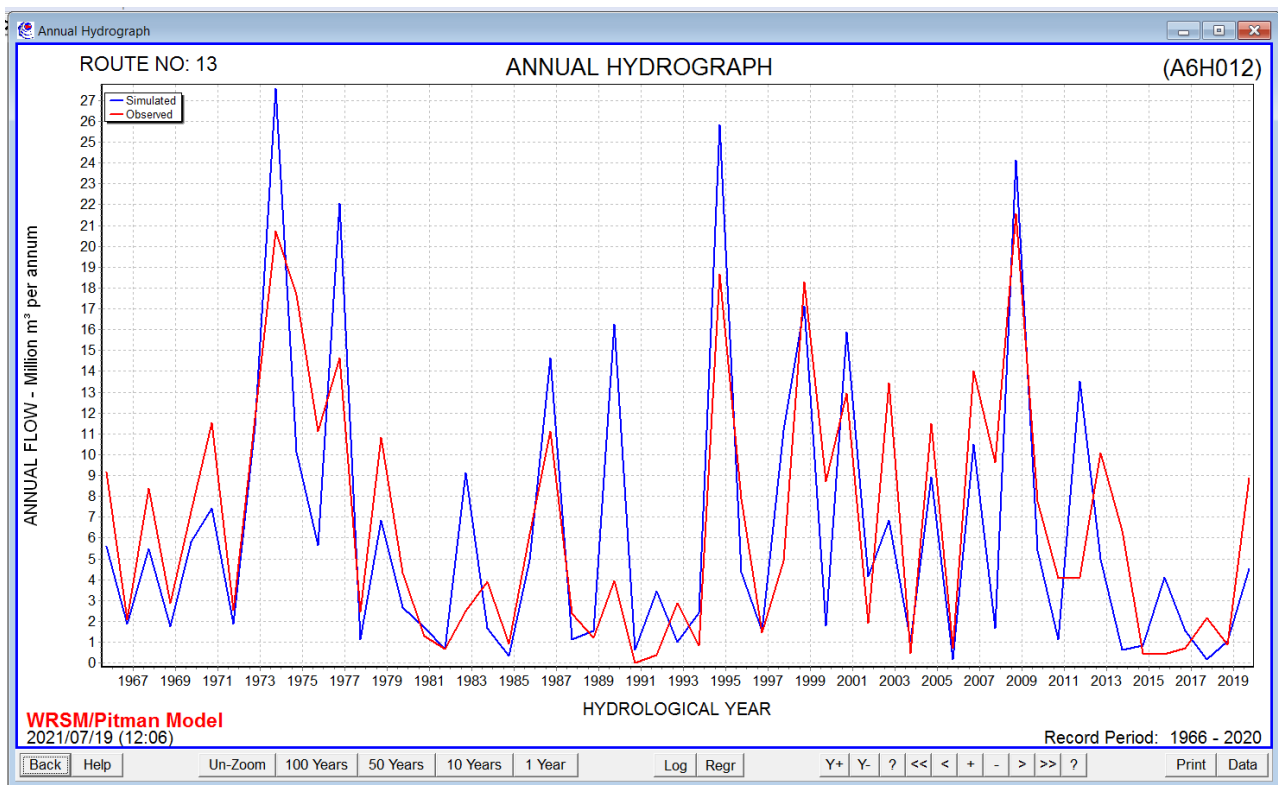


Figure 6: Annual hydrograph for A6H012

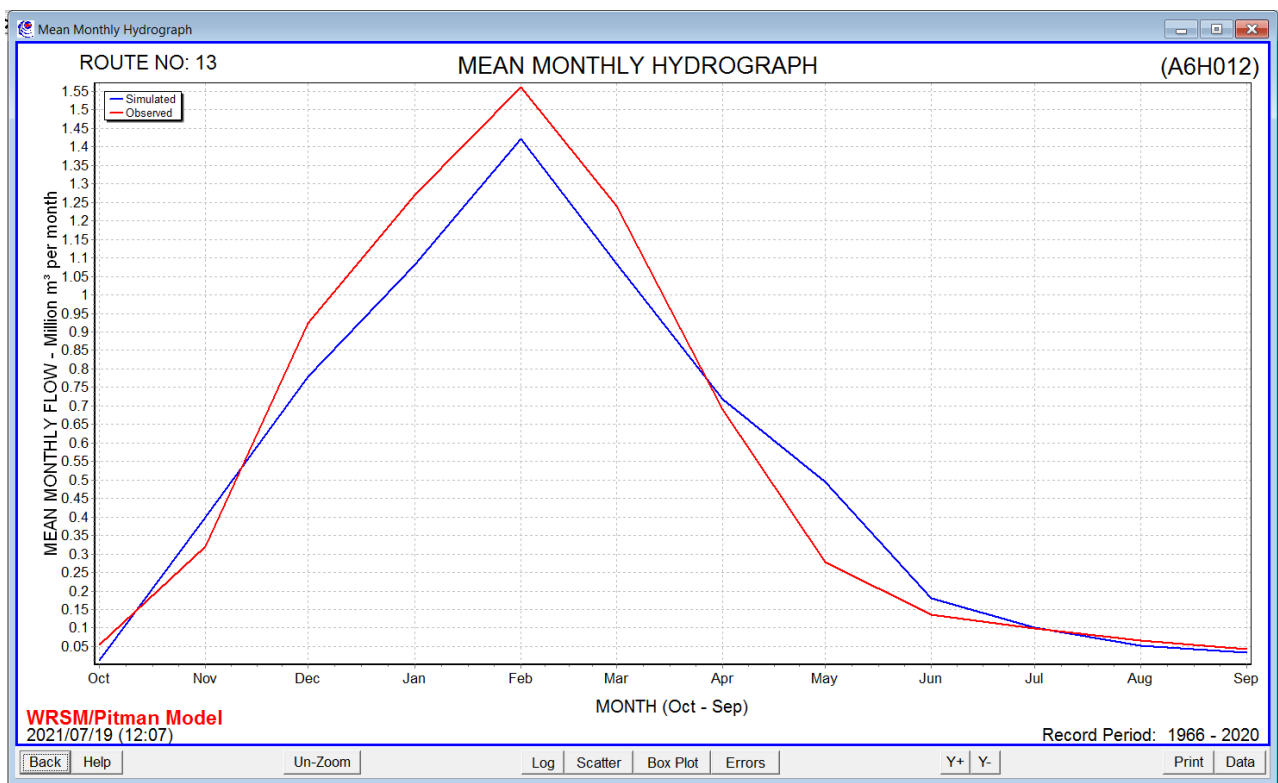


Figure 7: Mean monthly flows for A6H012

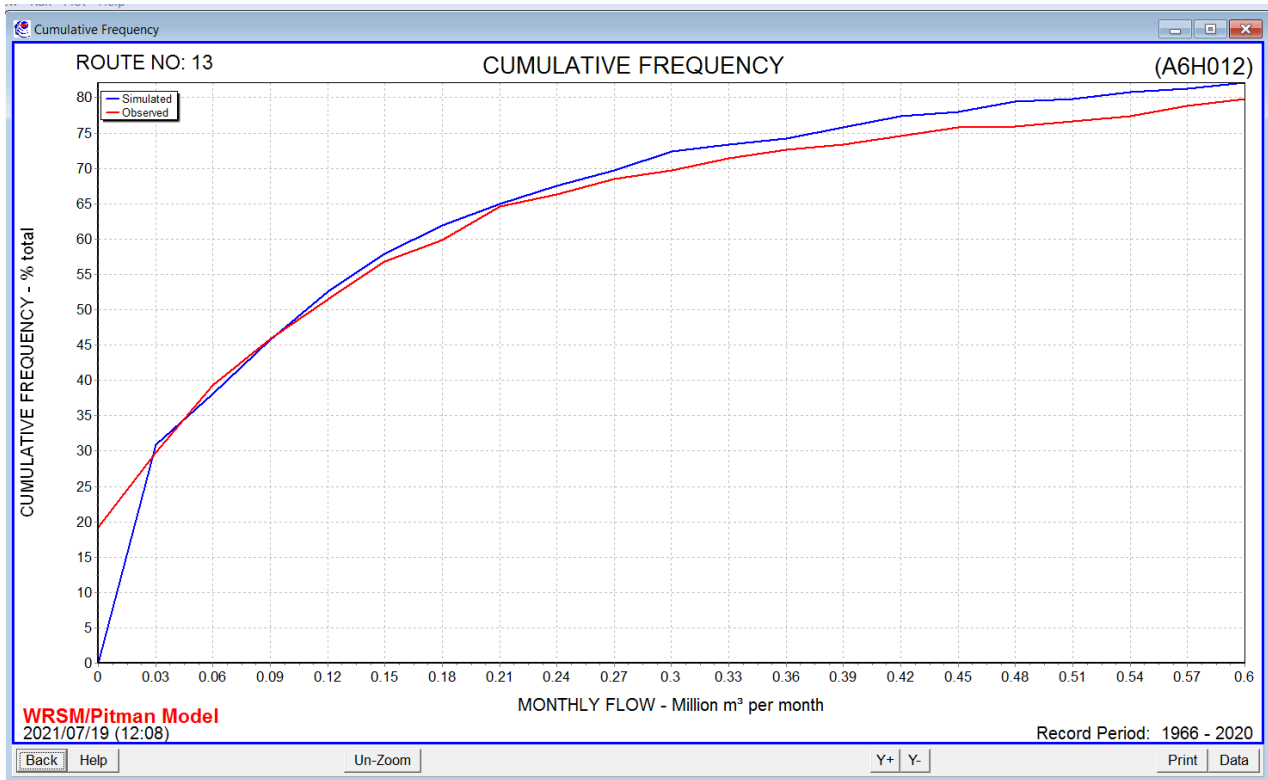


Figure 8: Cumulative frequency for A6H012

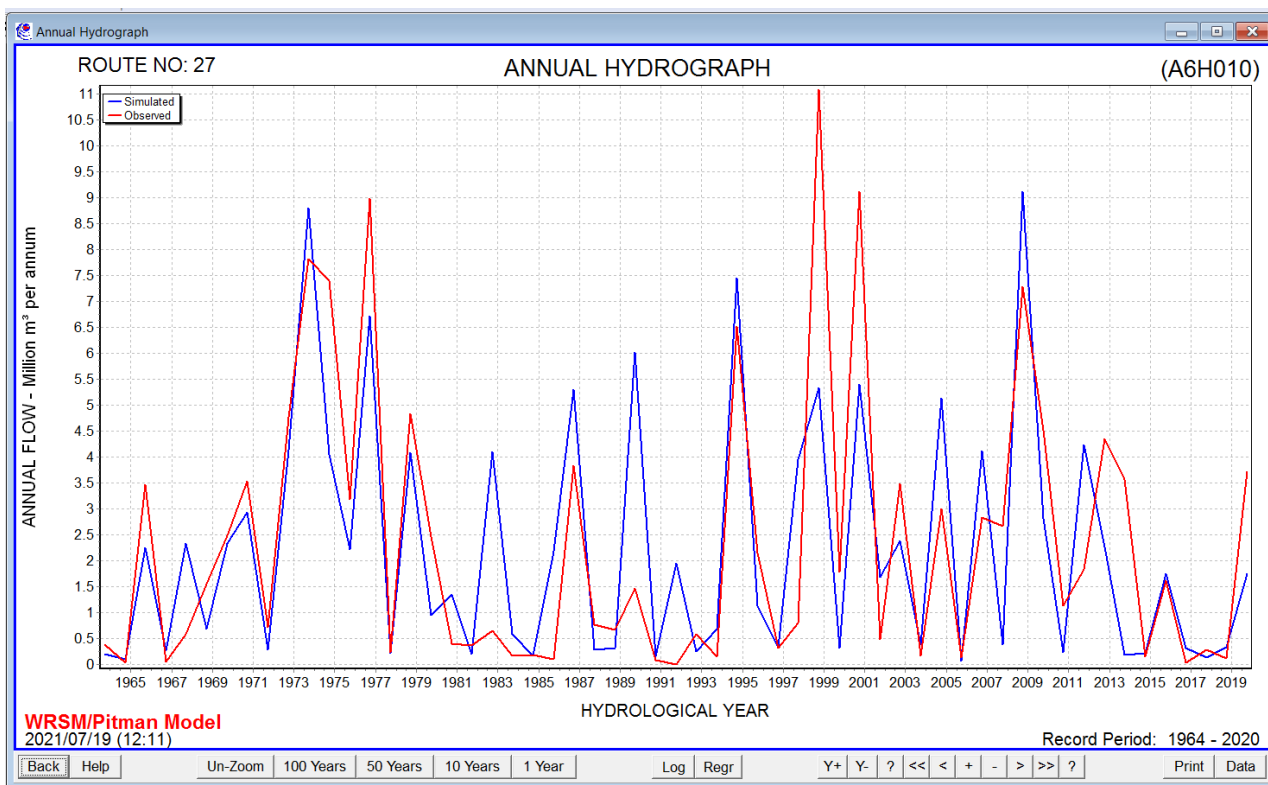


Figure 9 : Annual hydrograph for A6H010

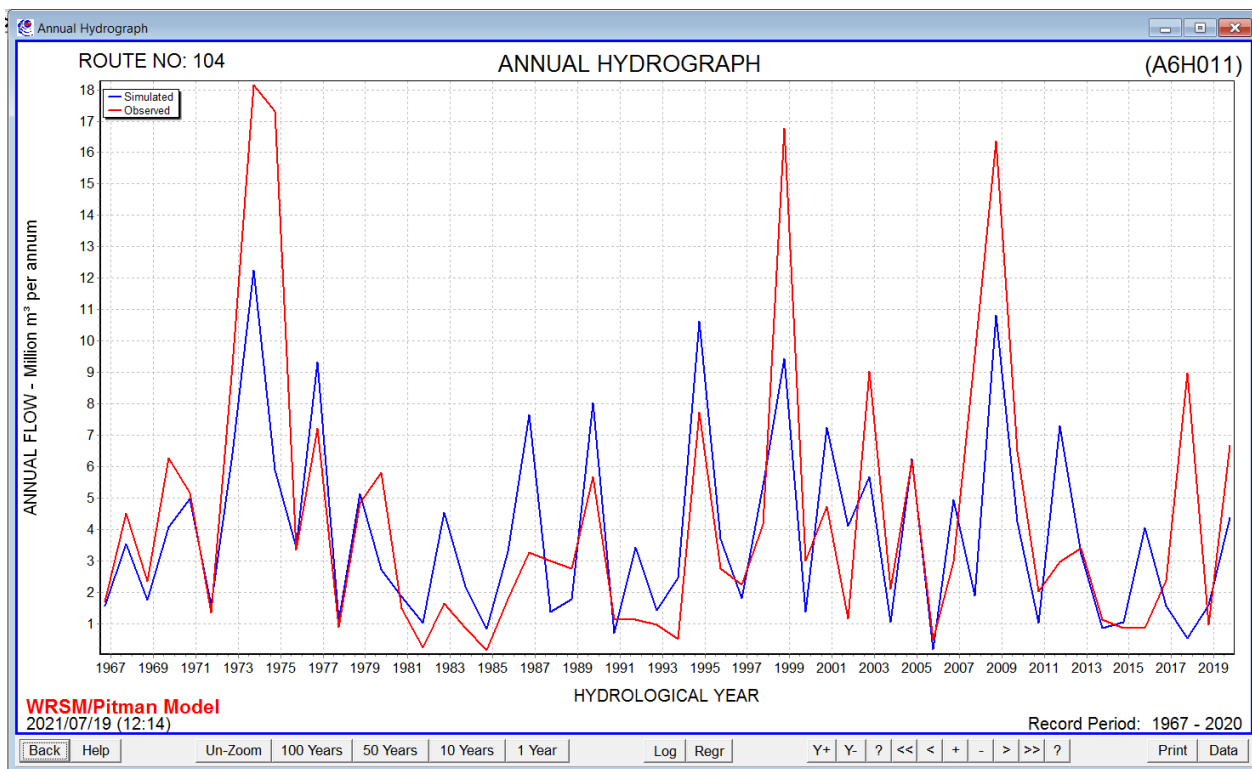


Figure 10: Annual hydrograph for A6H011

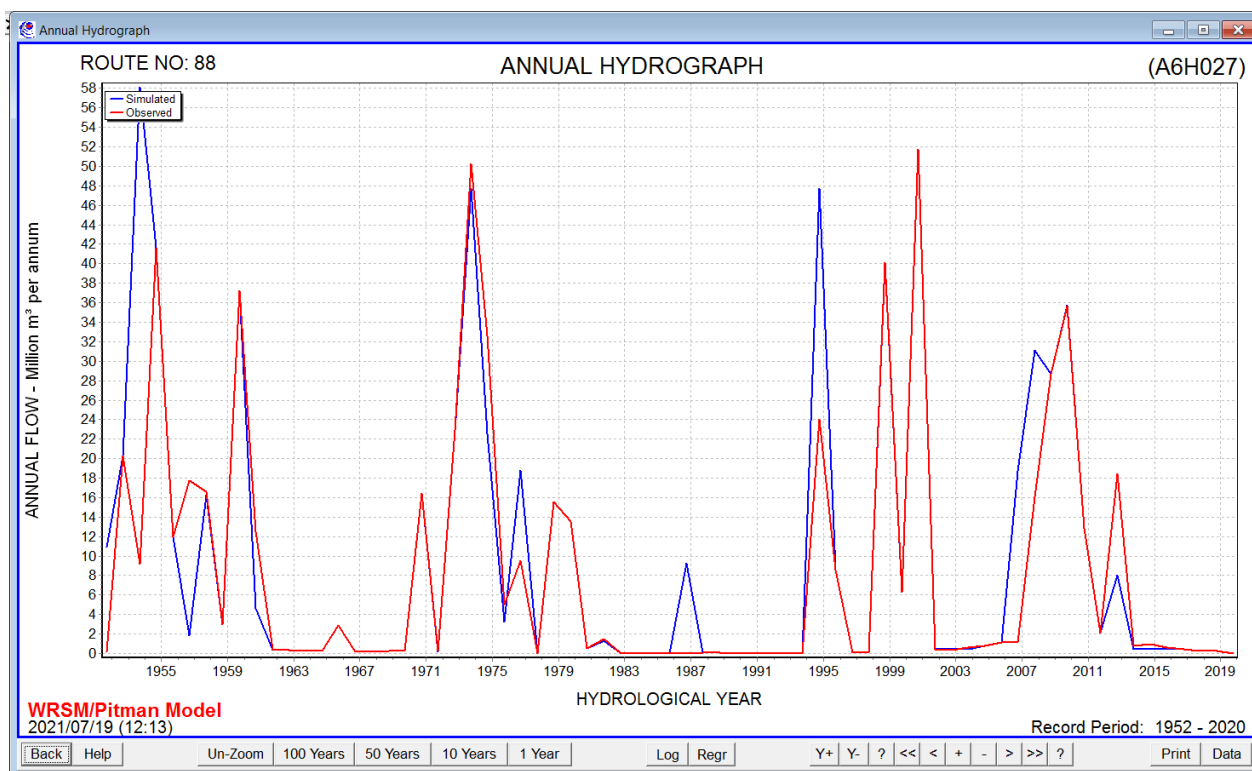


Figure 11: Annual hydrograph for A6H027

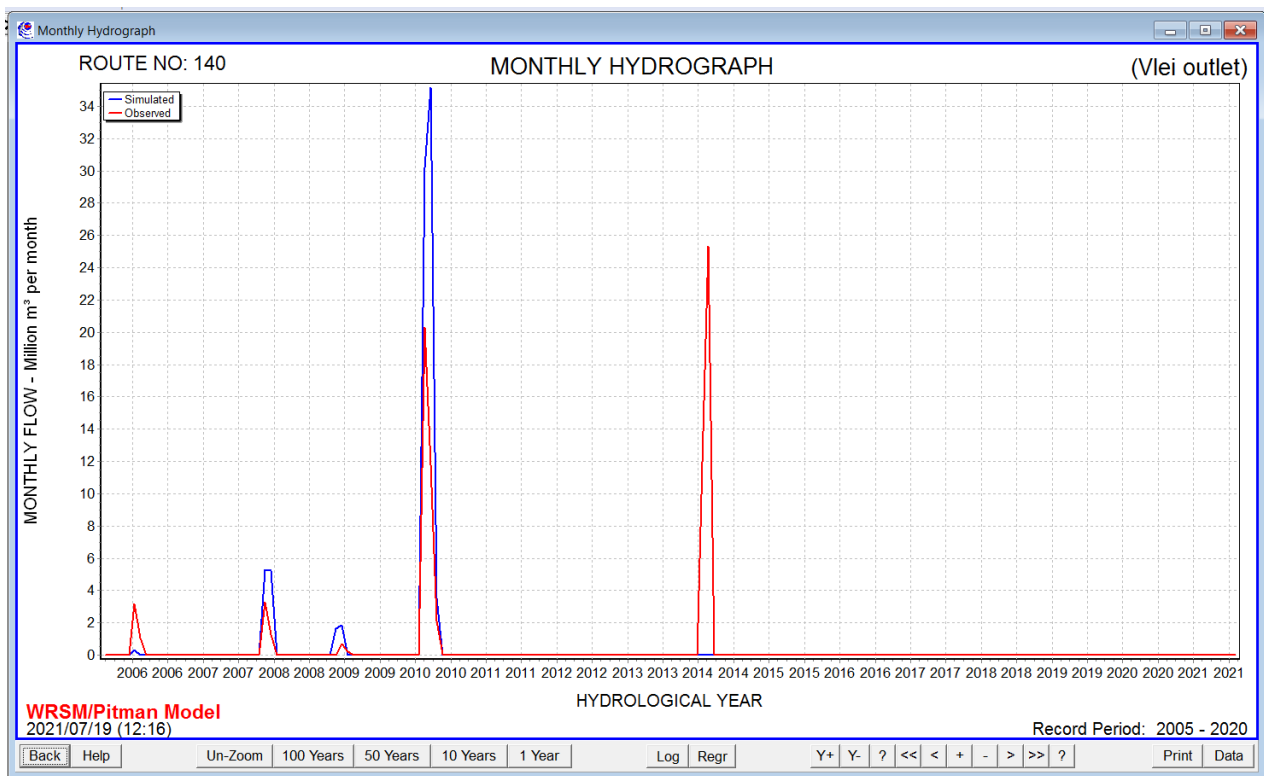


Figure 12: Monthly hydrograph for A6H033 (Vlei outlet)

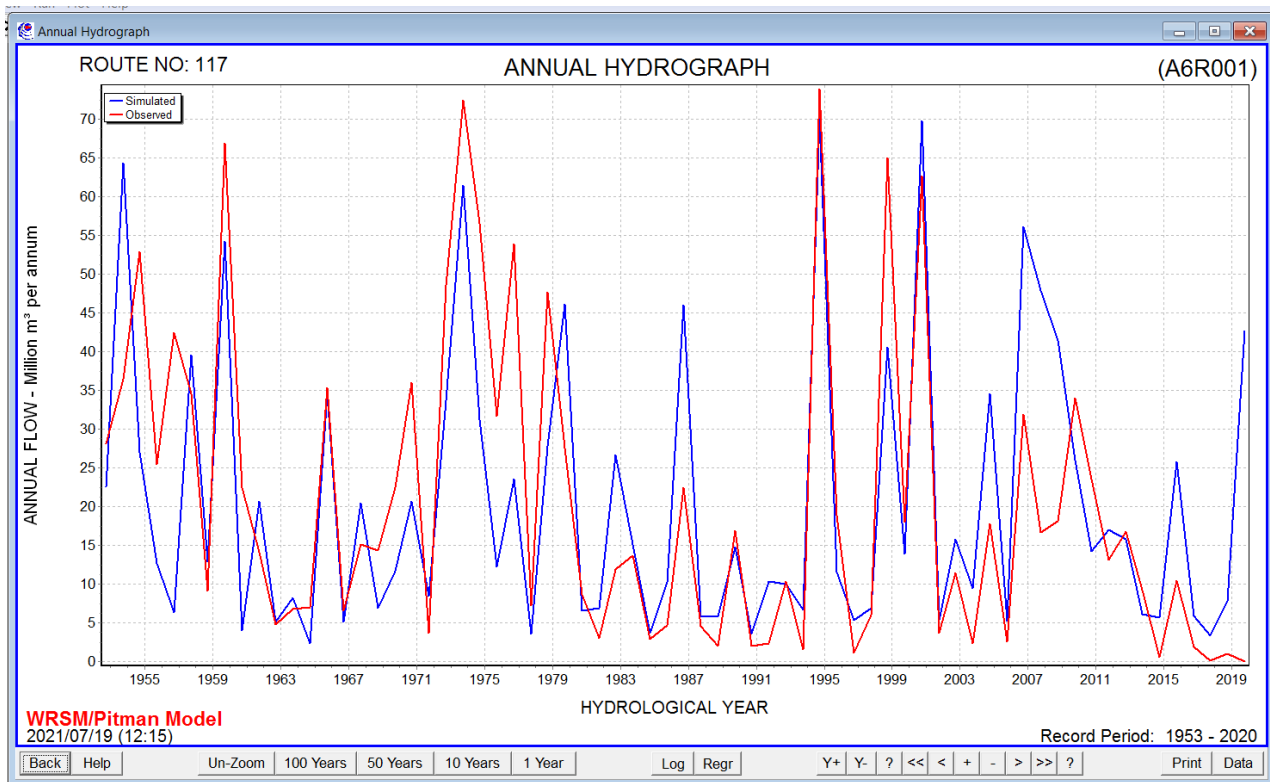


Figure 13: Annual hydrograph for A6R001

10. Conclusions

Using both SAWS and CHIRPS rainfall data was a useful exercise in determining rainfall data up to September 2021.

A successful calibration was achieved at the 6 streamflow gauges and 1 dam as shown in the statistics and graphs.

The high rainfall events towards the end of 2020 did not appear to result in any outflow to the vlei at A6H033 (see Figure 13).

Reservoir Records for the last 2 years are not available from DWS. They have been asked to update but it appears that there are some issues with unaccounted losses which they need to investigate. This is not critical as Doorndraai Dam is at the lowest end of the system but it would be useful to complete the “picture”.

11. Recommendations

Doorndraai Dam data should be updated when it becomes available.

In order to understand the response of the Nylsvlei wetland to changing climatic data and possibly climate change effects, it is recommended that the study data be updated at a suitable data every 5 years or so.

12. References

1. CHIRPS rainfall data: <https://www.chc.ucsb.edu/data/chirps> (accessed March 2021)
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3. Pitman, W.V. and Bailey, A.K. "Can CHIRPS fill the gap left by the decline in the availability of rainfall stations in Southern Africa?", 2021. Water SA 47(2) 162–171 / Apr 2021.
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APPENDIX A

Network Diagram