THE HYDROGEOLOGY OF GROUNDWATER REGION 39

Centre for Water Sciences and Management

WATER RESEARCH COMMISSION

TT 881/22

Obtainable from

Water Research Commission
Private Bag X03
Gezina
PRETORIA, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a WRC project entitled *Hydrogeology of Groundwater Region 39* (WRC Project No. K5/2456).

Printed in the Republic of South Africa

ISBN 978-0-6392-0426-0

Executive Summary

Vegter Region 39 is located in the central Karoo. Groundwater resources within the study area is an important source of water for many towns, farmers and domestic users. However, this resource plays a key role in sustaining many of the ecosystems (e.g. those found at springs and wetlands) within the area. In order to obtain a better understanding the groundwater resources within Region 39, current available groundwater information was statistically analysed according to Vegter's methodology. The geostatistical analyses for the study as a whole are discussed and also the individual analysis of the different geological units as identified in the 1:1 000 000 simplified geological map of the area. Vegter's methodology is followed as closely as possible.

The proposed delineation method, based on the work of Vegter (2001) provides a methodology in which aquifers can be delineated. This allows the groundwater specialists to conduct studies/research on aquifer boundaries which deviates from the current approach of using surface water boundaries to delineate study areas. This approach can for example be applied in Groundwater Resource Directed studies.

This method is not subjective and repeatable. It is however dependent on data availability. The method can also be applied at different scales, thereby becoming a planning tool for potential sites where field work can take place, for example borehole siting.

This study can also be applied in conjunction to the work conducted by Cobbing et al. (2014), which documents the diverse factors influencing long-term success of groundwater schemes for domestic water supplies.

Additional aims of the project were to: (i) analyse and present the related groundwater data in a concise manner, (ii) estimate how much water is available for use and how much is currently being used, (iii) identify possible pollution sources and associated impacts, and (iv) to provide guidelines for the future development and management of groundwater resources. The Reserve was determined together with the groundwater stress index.

Acknowledgements

The research described in this report emanated from a project funded by the Water Research Commission entitled: THE HYDROGEOLOGY OF GROUNDWATER REGION 39.

Contributions throughout the duration of the project by members of the Reference Group are gratefully acknowledged. The Reference Group responsible for this project included the following people:

- Dr S Adams (Water Research Commission)
- Prof. M Dippenaar (University of Pretoria)
- Dr M Holland (Delta H)
- Mr E Bertram (Department of Water and Sanitation)
- Mr F Fourie (Department of Water and Sanitation)
- Mr U Nzotte (Council for Geoscience)
- Ms D Hohne (Department of Water and Sanitation)
- Dr J Nel (University of the Western Cape)

Table of Contents

1 Introduction

1.1 Preamble

South Africa is a relatively dry and drought-prone country. The country has limited water resources and is ranked globally amongst the twenty most water-scarce countries (Woodford et al., date unknown). According to Donnenfeld et al. (2018) South Africa is currently overexploiting its surface water resources. In addition it is expected that overexploitation will increase. Failing infrastructure and low dam levels exacerbates the situation. South Africa, therefore, will have to make more use of its groundwater resources. This is especially true in the semi-arid and arid central and western regions of the country.

The Karoo Supergroup underlies approximately 50% of South Africa. This supergroup mainly consists of sandstones, mudstones, shales and siltstones. Secondary aquifers occur within the Karoo formations which if managed correctly can be reliable sources of water.

Groundwater Region No 39 is underlain by the Karoo Supergroup and its associated aquifers. This area is also earmarked for hydraulic fracturing (also known as fracking). Fracking is borehole-stimulation technique in which a high-pressure fluid (usually water mixed with sand and chemicals) is injected into a borehole in order to create small fractures in the deep-rock formations. When the hydraulic pressure is removed from the borehole, natural gas can be released from the shale formations.

According to the WRC (2012), the proposed fracking in the Karoo has been met with concern relating to potential impacts on water resources. These impacts include (O'Day and Reece, 2012):

- Contamination of groundwater as a result of spills, faulty borehole construction, or other means, including disposal in boreholes.
- Stress on existing water supply. Surface and groundwater withdrawals used in the due to fracking can place strain on the water resources.
- Management of Wastewater. The wastewater associated with shale gas extraction can contain high levels of total dissolved solids, fracturing fluid additives, metals, and

naturally occurring radioactive materials which can potentially contamination of water resources.

In order to obtain a better understanding the groundwater resources within Region 39, current available groundwater information has to be statistically analysed according to Vegter's methodology. This approach will be useful to collate in a single reference the current knowledge and understanding of these hydrogeological systems which in turn can be used to manage and protect the aquifers within the study area.

1.2 Aims of the Project

Groundwater resources within the study area is an important source of water for many towns, farmers and domestic users. However, this resource plays a key role in sustaining many of the ecosystems (e.g. those found at springs and wetlands) within the area.

As there are concerns relating to development within the area, it is necessary for local authorities to be equipped with the necessary information, data and tool sets to successfully manage their resources. It is envisioned that this will be addressed during the project.

The Reserve requirements will be addressed within the scope of the project and will therefore assist the Department of Water and Sanitation in processing many of the license applications that might arise.

The aims of the project are therefore to:

- Analyse and present the related groundwater data in a concise manner
- Estimate how much water is available for use and how much is currently being used
- Identify possible pollution sources and associated impacts
- Provide guidelines for the future development and management of groundwater resources
- Provide a document (standard format for the Groundwater regions as set out by Vegter), and suggestions to assist in the management of groundwater resources within the study area.

The outcomes of the project are therefore:

- A detailed physiographic and geological description of the study area

- A description of anthropogenic activities and the associated impacts of these activities.
- A detailed investigation of the relationship between groundwater and surface water systems.
- A statistical analysis to analyse groundwater systems and the associated water quality for management purposes.
- Data shortages will be highlighted which will allow authorities to plan correctly.

2 Background

2.1 Introduction and Location

A characteristic of the Karoo Supergroup, is their low transmissivity, with the majority of boreholes having very low yields (<1 l/s). However, large volumes of groundwater are pumped from wellfields supplying towns, mines and the basements of buildings on a daily basis in areas underlain by the Karoo formations, which is not what one would expect from aquifers with a limited yield (Woodford and Chevallier, 2002). Generally the altitude ranges between 800 and 3650 mamsl. Altitudes are highest in the east, decreasing gradually as the surface slopes down to the west. The generally flat-relief is broken by the plateau edges and the escarpment. A well-known characteristic of the landscape are flat-topped hills which are often capped by the more dolerite sills or sandstone (Woodford and Chevallier, 2002).

The location of the Vegter Region to be investigated is shown in Figure 1. It is located to the south of the Karoo Basin. The main towns in Region 39 are Victoria West, Hanover, Colesberg, Noupoort, Philippolis, Richmond, Bethulie and Springfontein (Figure 2).

2.2 Climate

A summary of the climate for the major towns are included in Sections 3.2.1 to 3.2.8. More detail concerning climate is documented in Appendix A.

2.2.1 Victoria West

Victoria West has a desert climate. Most of the rainfall occurs in autumn. The rainfall here averages 261 mm per year. The driest month is August, with 6 mm of rainfall. Victoria West, the average annual temperature is 14.9°C. The warmest month of the year is January, with an average temperature of 22.3°C. The lowest average temperatures in the year occur in July, when it is around 6.5°C.

2.2.2 Colesberg

In Colesberg, there is little rainfall throughout the year. About 392 mm of precipitation falls annually. The temperature here averages 13.9°C. The temperatures are highest on average in January, at around 21.6°C. July has the lowest average temperature of the year at 2.3°C.

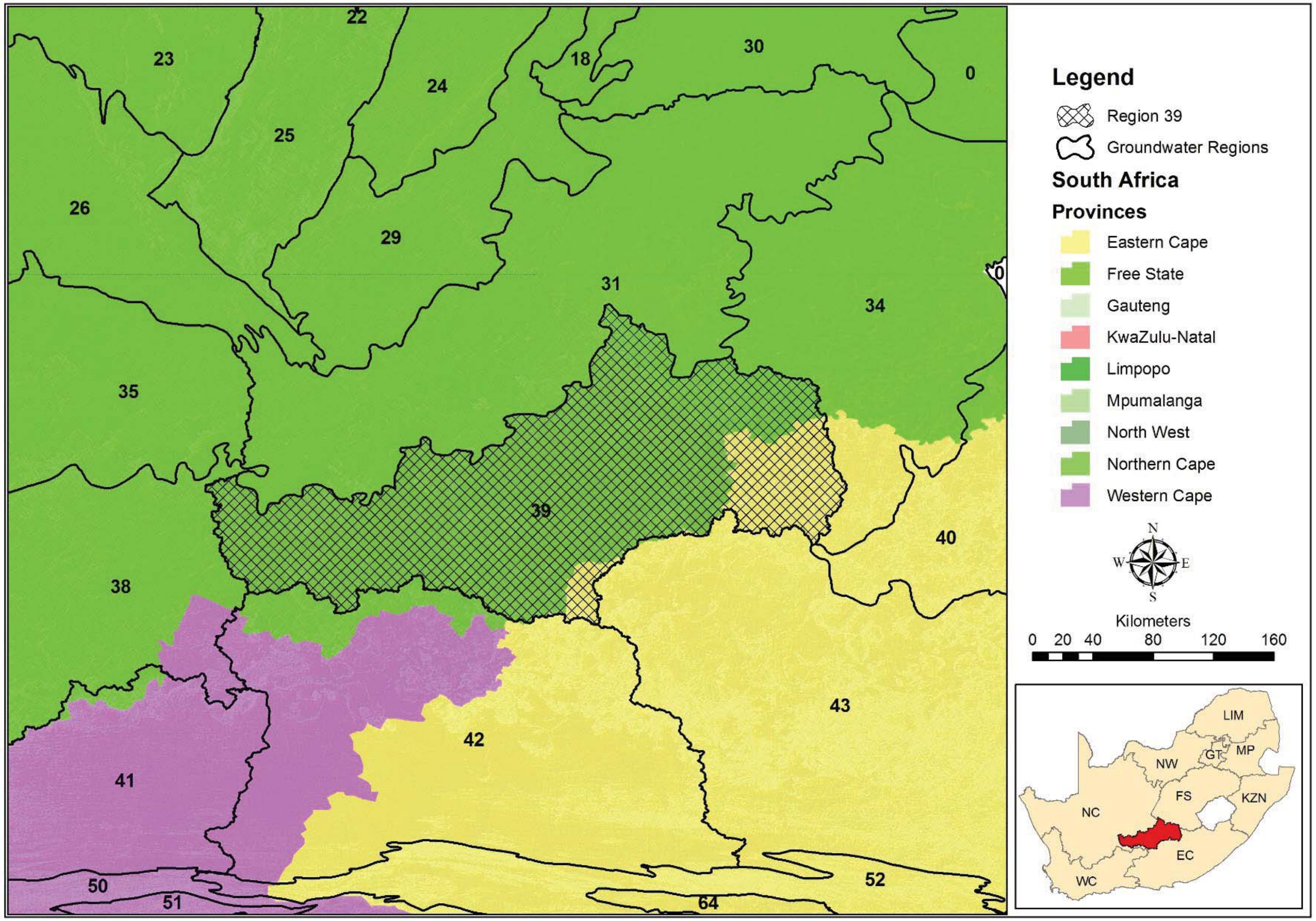


Figure 1: Location of Vegter Region 39

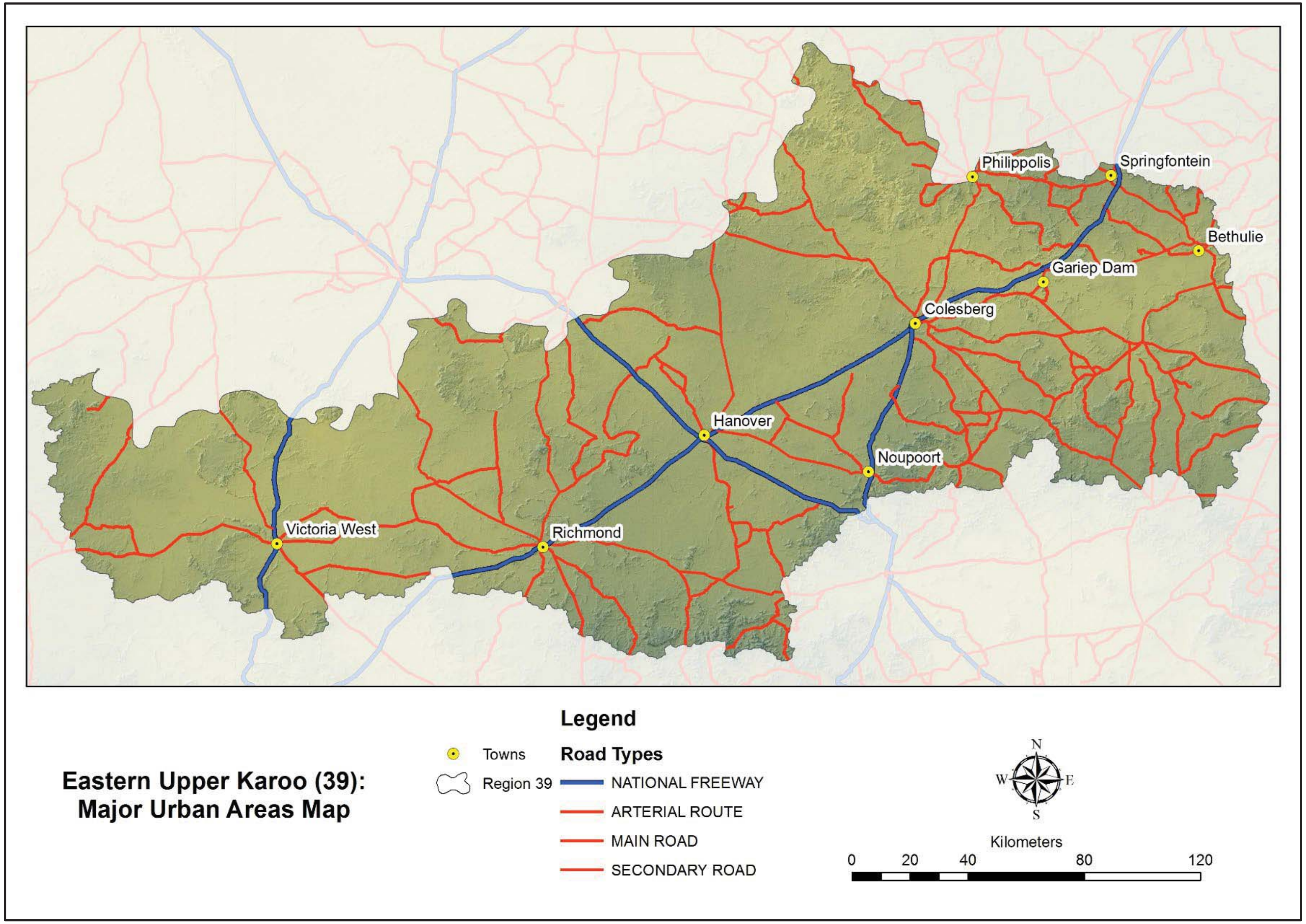


Figure 2: Towns within study area

2.2.3 Hanover

The average annual rainfall is 331 mm. The driest month is July, with 9 mm of rain. March has the highest precipitation average of 63 mm. The average annual temperature is 14.5°C. January is the warmest month of the year. The temperature in January averages 21.8°C. At 6.4°C on average, July is the coldest month of the year.

2.2.4 Noupoort

The average annual precipitation is 417 mm. The driest month is July, with 11 mm of rain. Most of the precipitation here falls in March, averaging 72 mm. January is the warmest month of the year. The temperature in January averages 20.6°C. July is the coldest month, with temperatures averaging 5.2°C.

2.2.5 Philippolis

Philippolis has an average rainfall of 391 mm per year. Precipitation is the lowest in June, with an average of 9 mm. With an average of 64 mm, the most precipitation falls in February. At an average temperature of 23°C, January is the hottest month of the year. July has the lowest average temperature of the year at 6.4°C.

2.2.6 Richmond

Richmond's average annual rainfall is 447 mm. The lowest rainfall occurs in June/July, with an average of 1.5 mm. The highest monthly rainfall occurs in January/February, with an average of 86 mm. The temperatures are highest on average in January, at around 28°C. The lowest average temperatures in the year occur in July, when it is around 8°C.

2.2.7 Bethulie

The average monthly rainfall is 481 mm. The driest month is June, with 13 mm of rain. February has the highest rainfall with an average of 80 mm/a. January is the warmest month of the year with an average temperature of 22.7°C. July has the lowest average temperature of 8.3°C.

2.2.8 Springfontein

Springfontein's average rainfall is approximately 448 mm per year. The driest month is June with 10 mm of rain. The month that receives the most precipitation is March with an average of 74 mm. January is the hottest of the year with an average temperature of 21.8°C. July is the coldest month, with an average temperature of 6.2°C.

2.3 Geology (taken from Woodford and Chevallier, 2002)

The major lithostratigraphic units of the Karoo Supergroup are shown in Figure 3. Each Group corresponds to a changing depositional environment.

2.3.1 Dwyka Group

The Dwyka sediments consist mainly of diamictite (tillite), which is generally massive with little jointing. It can also be stratified. Subordinate rock types are conglomerate, sandstone, rhythmite and mudrock. The Dwyka Group forms low-yielding fractured aquifers, with groundwater being confined to narrow discontinuities like jointing and fractures. They therefore tend to form aquitards rather than aquifers. There are however a few sandstone bodies of limited extent which can be seen as aquifers. However since the Dwyka sediments were deposited mainly under marine conditions, the water in these aquifers tends to be saline.

2.3.2 Ecca Group

The Permian-aged Ecca Group comprises a total of 16 formations, reflecting the lateral facies changes that characterise this succession:

- The Prince Albert Formation is characterised by the predominance of greyish to olive green, micaceous shale and grey, silty shale, as well as a pronounced transition from the underlying glacial deposits. The southern facies is characterised by dark grey, pyrite-bearing, splintery shale, siltstone and dark coloured chert.
- The Whitehill Formation consists of white, weathered mudrocks. The facies is predominately black, carbonaceous, pyrite-bearing shale.
- Outcrops of the Collingham consists of a rhythmic alternation of thin, continuous beds of hard, dark grey, siliceous mudrock and very thin beds of softer yellowish tuff.
- The predominantly argillaceous Vischkuil Formation consists essentially of dark shale, alternating with subordinate fine-grained sandstone, siltstone and minor yellowish tuff layers.
- The Laingsburg Formation usually comprises four sandstone-rich units separated by shale units. It wedges out towards the west and north.
- The Ripon Formation consists of lithofeldspathic sandstone, alternating with dark grey, clastic rhythmite and mudrock.

- The Fort Brown Formation consists of rhythmite and mudrock with minor sandstone inter-calations.
- The arenaceous Waterford Formation consists of lithofeldspathic sandstone and mudrock or clastic rhythmite units. The Britskraal Shale Member consists essentially of dark grey mudrock and rhythmite. Thin mud-flake conglomerate layers are occasionally present.
- The Tierberg Formation comprises mainly of well laminated, dark grey to black shale.
- The Skoorsteenberg Formation is a lenticular, arenaceous unit It comprises five sandstone-rich units with shale units separating them.
- The Kookfontein Formation overlies the Skoorsteenberg Formation. The lower part of the formation comprises horizontally laminated dark grey shales alternating with clastic rhythmites.
- The major rock types in the Waterford Formation are fine- to medium-grained sandstone, siltstone, shale and rhythmite.
- The Pietermaritzburg Formation comprises dark, upward coarsening, silty mudrock.
- The Vryheid Formation comprises mudrock, rhythmite, siltstone and fine- to coarse-grained sandstone (pebbly in places). The Formation contains up to five (mineable) coal seams.
- The Volksrust Formation is a predominantly argillaceous unit, which consists of grey to black, silty shale with siltstone or sandstone lenses and bed.

The Ecca Group consists mainly of shales and poorly sorted sandstones with low porosities and therefore does not constitute a good aquifer.

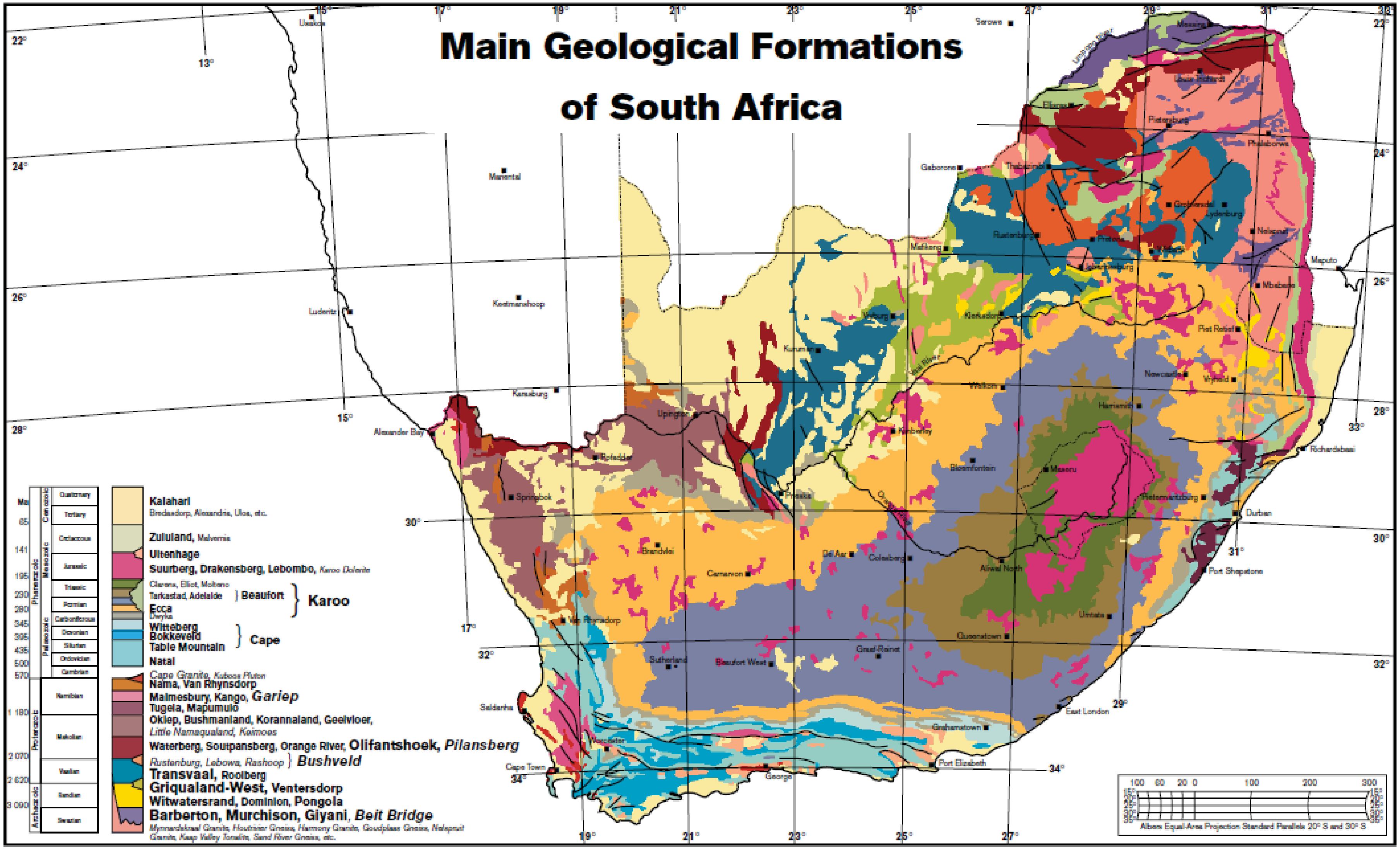


Figure 3: Geological map of South Africa with the main Karoo Basin (Taken from Woodford and Chevallier, 2002)

2.3.3 Beaufort Group

The Beaufort Group consists of the following sun-groups:

- In the southern and central parts of the Basin, the Adelaide Subgroup consists of alternating bluish-grey, greenish-grey or greyish-red mudrock and grey, very fine- to medium-grained, lithofeldspathic sandstone. In the northern part of the Basin, coarse to very coarse sandstone are common.
- The Triassic Tarkastad Subgroup is characterised by both sandstone and red mudstone. In the south, the Tarkastad Subgroup comprises of a sandstone-rich Katberg Formation and an upper, mudstone-rich Burgersdorp Formation.

The sedimentary units in the Group therefore usually have very low primary permeabilities. The geometry of these aquifers is complicated by the lateral migration of meandering streams over a floodplain. Aquifers in the Beaufort Group will thus not only be multi-layered, but also multi-porous, with variable thicknesses. The contact plane between two different sedimentary layers will cause a discontinuity in the hydraulic properties of the composite aquifer. In addition the life-span of a high-yielding borehole in the Beaufort Group may therefore limited if the aquifer is not recharged frequently.

2.3.4 Molteno, Elliot and Clarens Formations

The Molteno, Elliot and Clarens Formations are discussed in the following section:

- The late Triassic Molteno Formation comprises alternating medium- to coarse-grained, sandstones and grey mudrocks, with sporadic coal seams.
- The late Triassic to early Jurassic Elliot Formation comprises an alternating sequence of mudrock and subordinate fine- to medium-grained sandstone.
- The early to middle Jurassic Clarens Formation consists mainly of wind-blown, fine-grained sandstone and siltstone. Channel-filled wadi sandstones and horizontally-laminated sheet-flood sandstones are also present.

The pebble conglomerates, coarse-grained sandstones and other sedimentary rocks of the Molteno Formation can form aquifers. The red mudstones are aquicludes.

The Clarens Formation consists almost entirely of well-sorted, medium- to fine-grained sandstones, deposited as thick consistent layers. In addition its porosity is quite high and uniform porosity (average 8.5%). However due to the fact that it is poorly fractured and has a very low permeability, the Formation may be able to store large volumes of water, but is unable to release it quickly.

The weathering and erosion of the Karoo Supergroup caused the underlying rocks uplift isostatically resulting in the formation of fractures, which in turn improved porosity and permeability formations.

The Karoo sedimentation was ended by widespread volcanism at the beginning of the Jurassic Age related to the movement of Gondwanaland. This magmatic activity is linked with the intrusion of the ring-shaped dyke structures and sills, which are common in large parts of the Karoo landscape.

The geology of Region 39 is shown in Figure 4. The aerial magnetic map for the study areas are shown in Figure 5.

2.4 Topography and Drainage

The topography for the area is shown in Figure 6. The high lying areas in both study areas edges the central Southern African plateau, is a major geological formation in Africa. The eastern portion of the Great Escarpment within the borders of South Africa is referred to as the Drakensberg. The Lesotho Drakensberg have hard erosion resistant upper surfaces and therefore have a very high and rugged appearance, combining steep-sided blocks and pinnacles. The KwaZulu-Natal-Free State Drakensberg escarpment is composed of softer rocks and therefore has a more rounded, softer appearance from below. The top of the Escarpment is generally almost table-top flat and smooth.

There are numerous rivers within the regions (Figure 7). The major rivers in Region 39 include the Orange, Seekoei and Ongers Rivers. The Van der Kloof and Gariep Dams are located in Region 39.

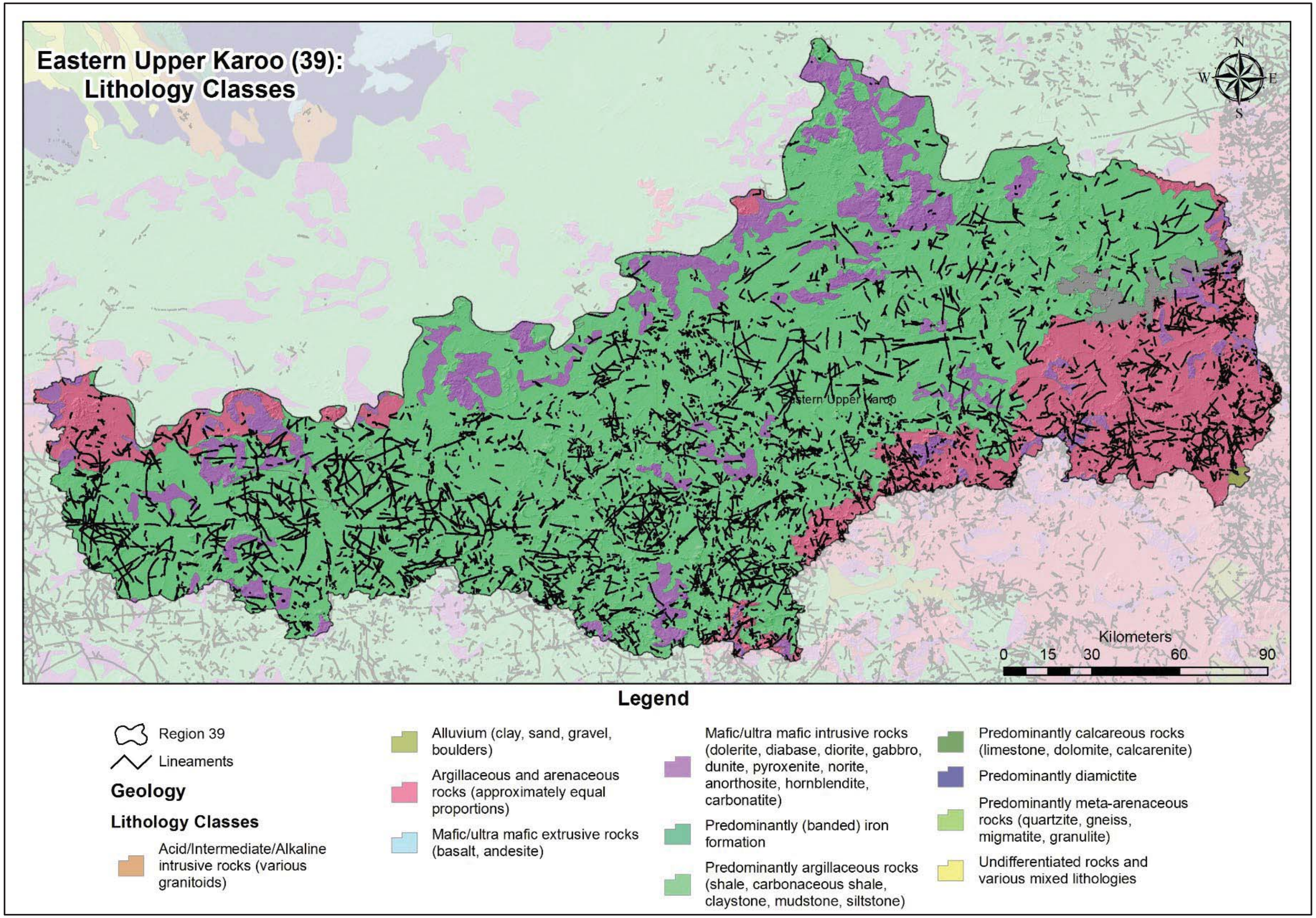


Figure 4: Geology of Region 39

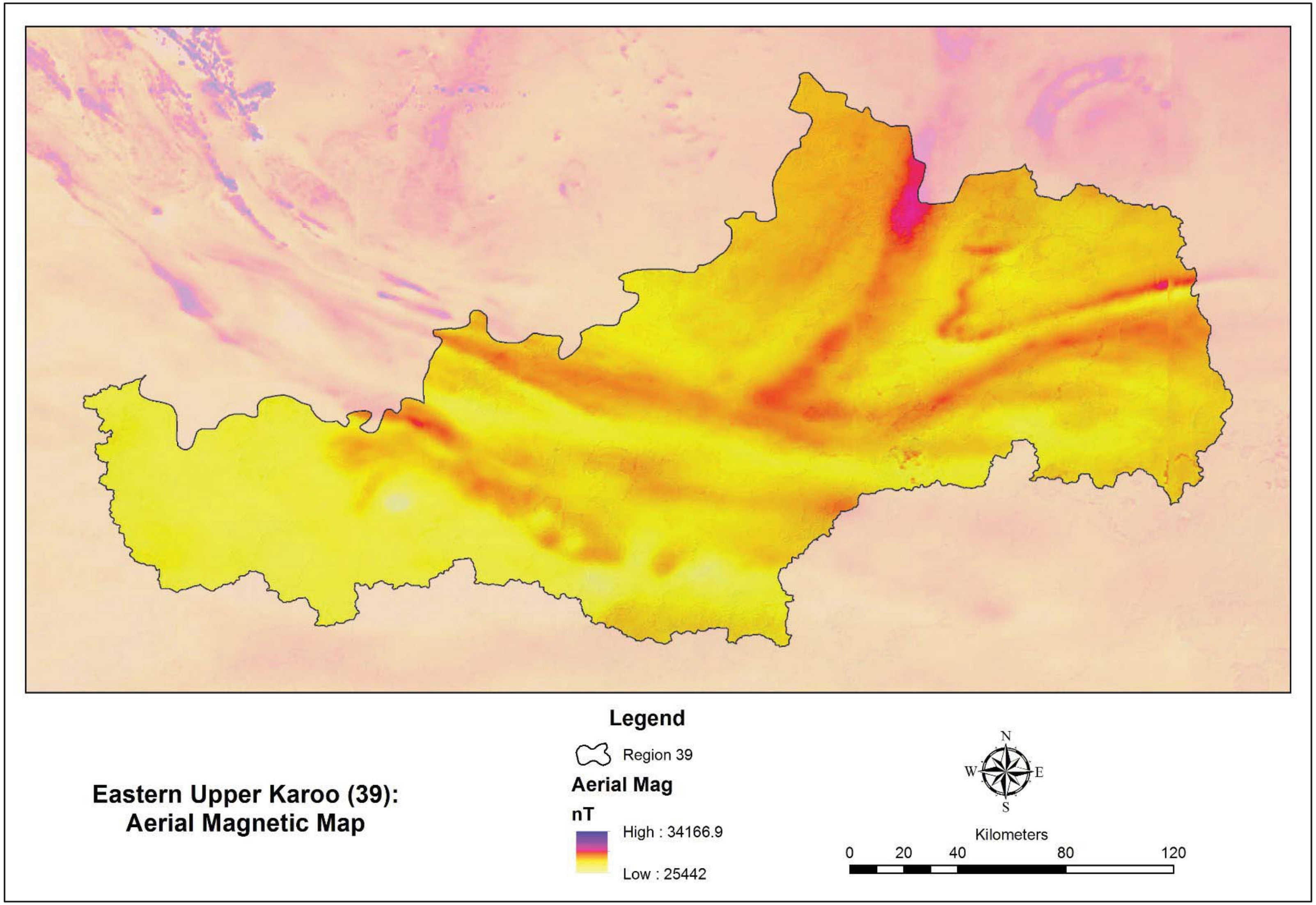


Figure 5: Aerial Magnetic Map of Region 39

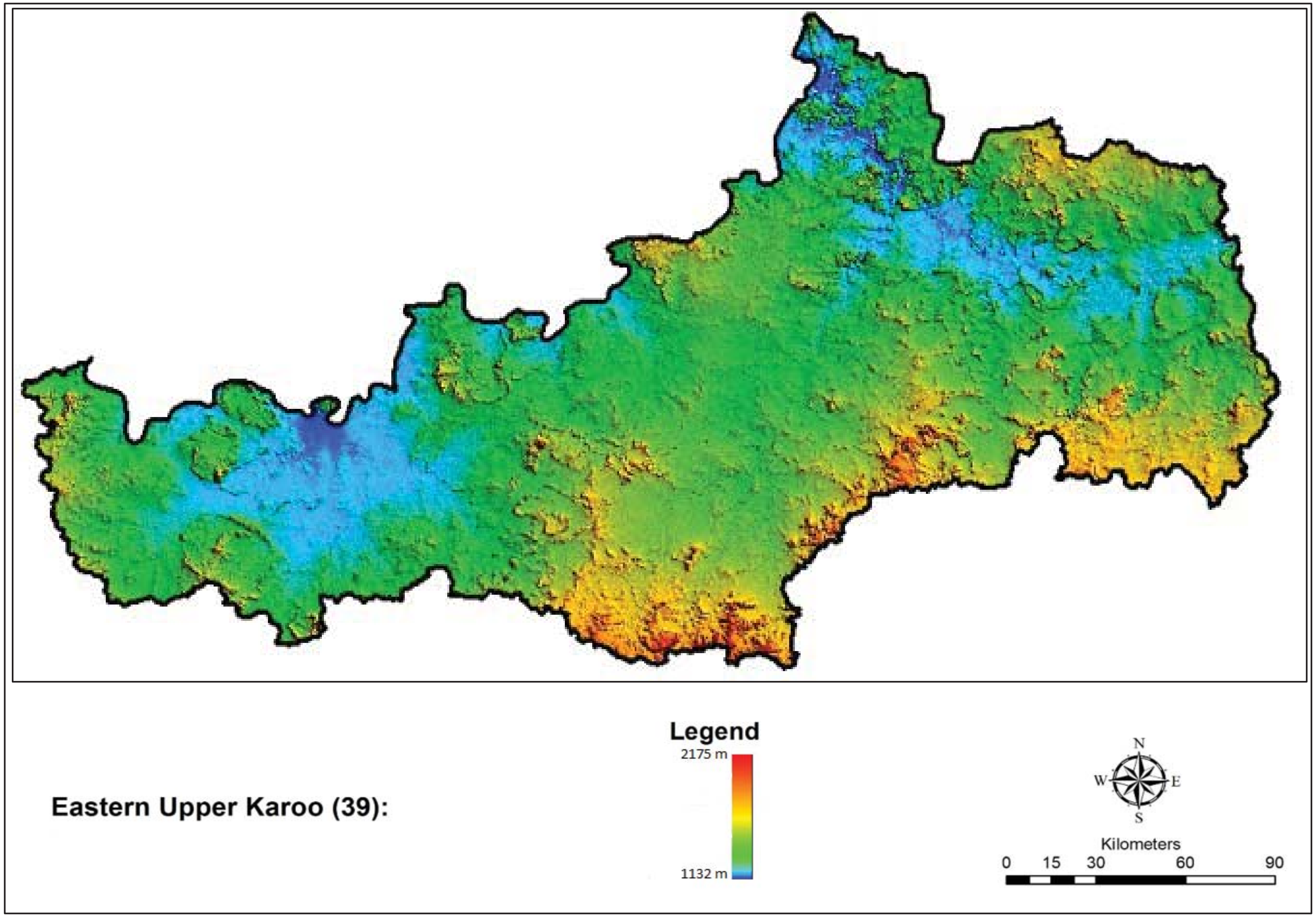


Figure 6: Topography Region 39

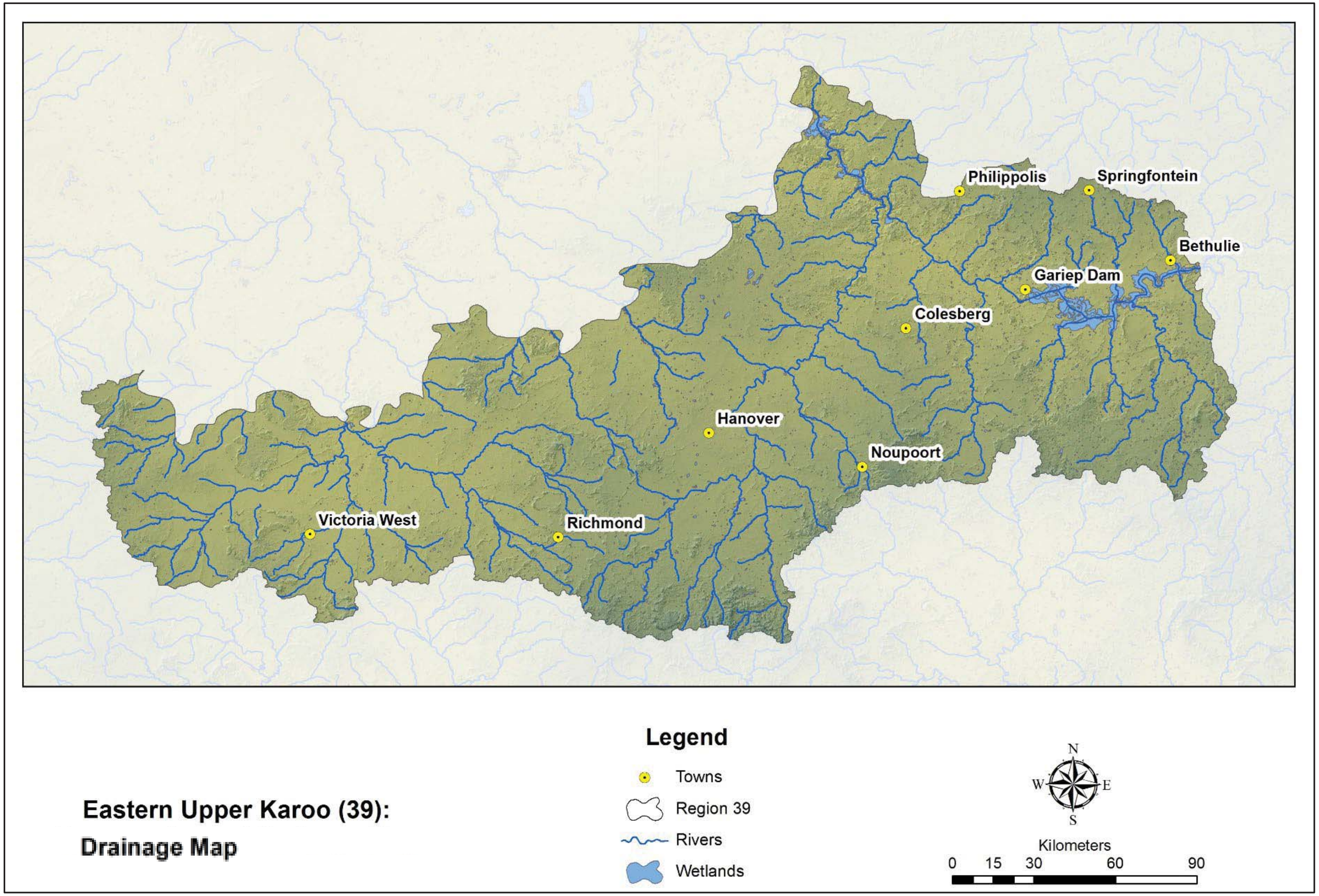


Figure 7: Rivers Region 39

2.5 Groundwater

Borehole information was obtained from the National Groundwater Archive (NGA). The locations of the boreholes are plotted in Figure 8. There are 2 aquifer types found in the regions, namely fractured and, intergranular and fractured. For most of the region the borehole yields vary between 0.5 and 5 l/s. Groundwater use was obtained from the WARMS database as shown in Figure 10. As can be seen from these figures the registered groundwater use is not high. Recharge for the study area was also assessed. The recharge over the region is shown in Figure 11. The recharge varies from 5 mm /a in the west to 25 mm/a in the east.

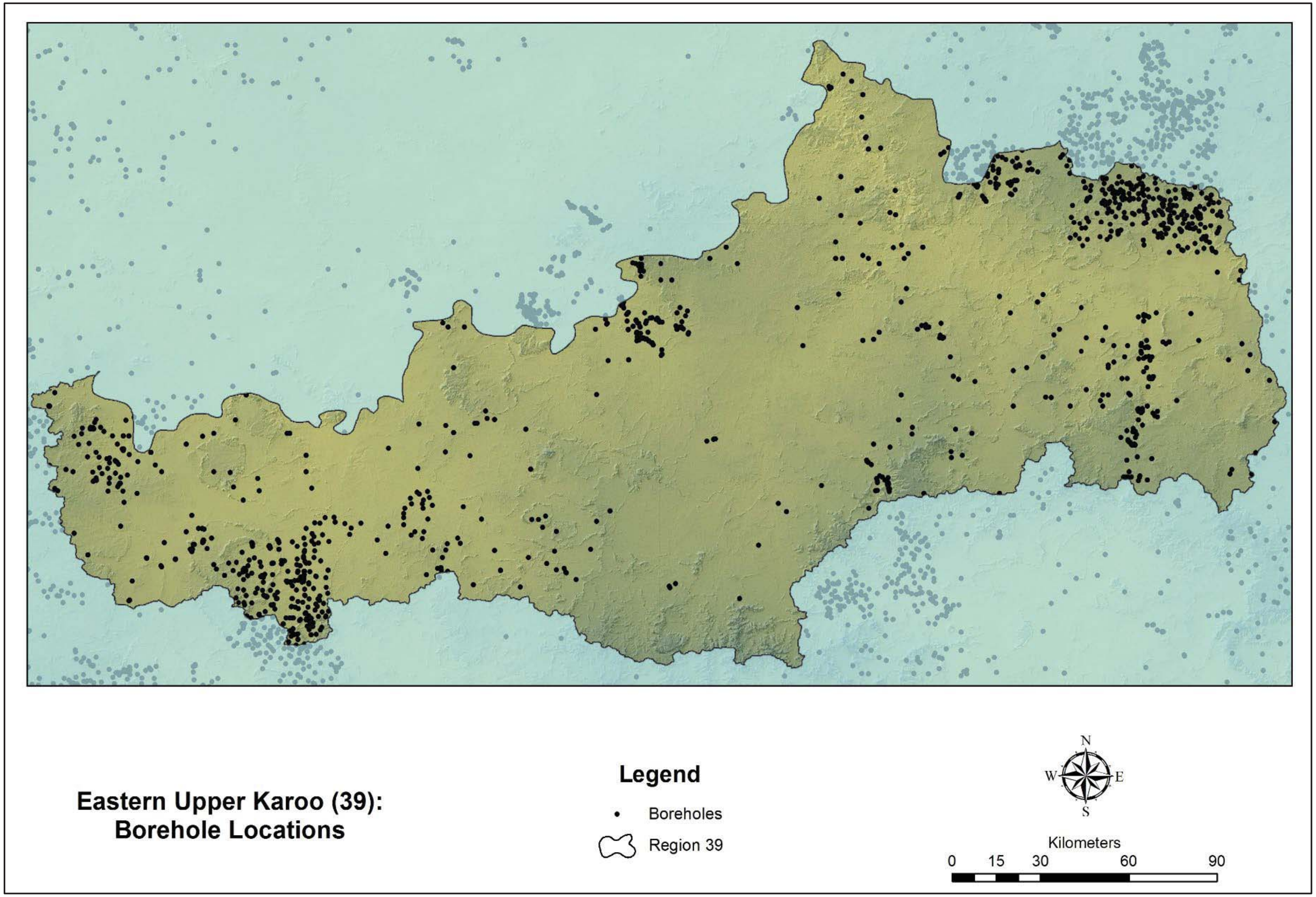


Figure 8: Boreholes for Region 39

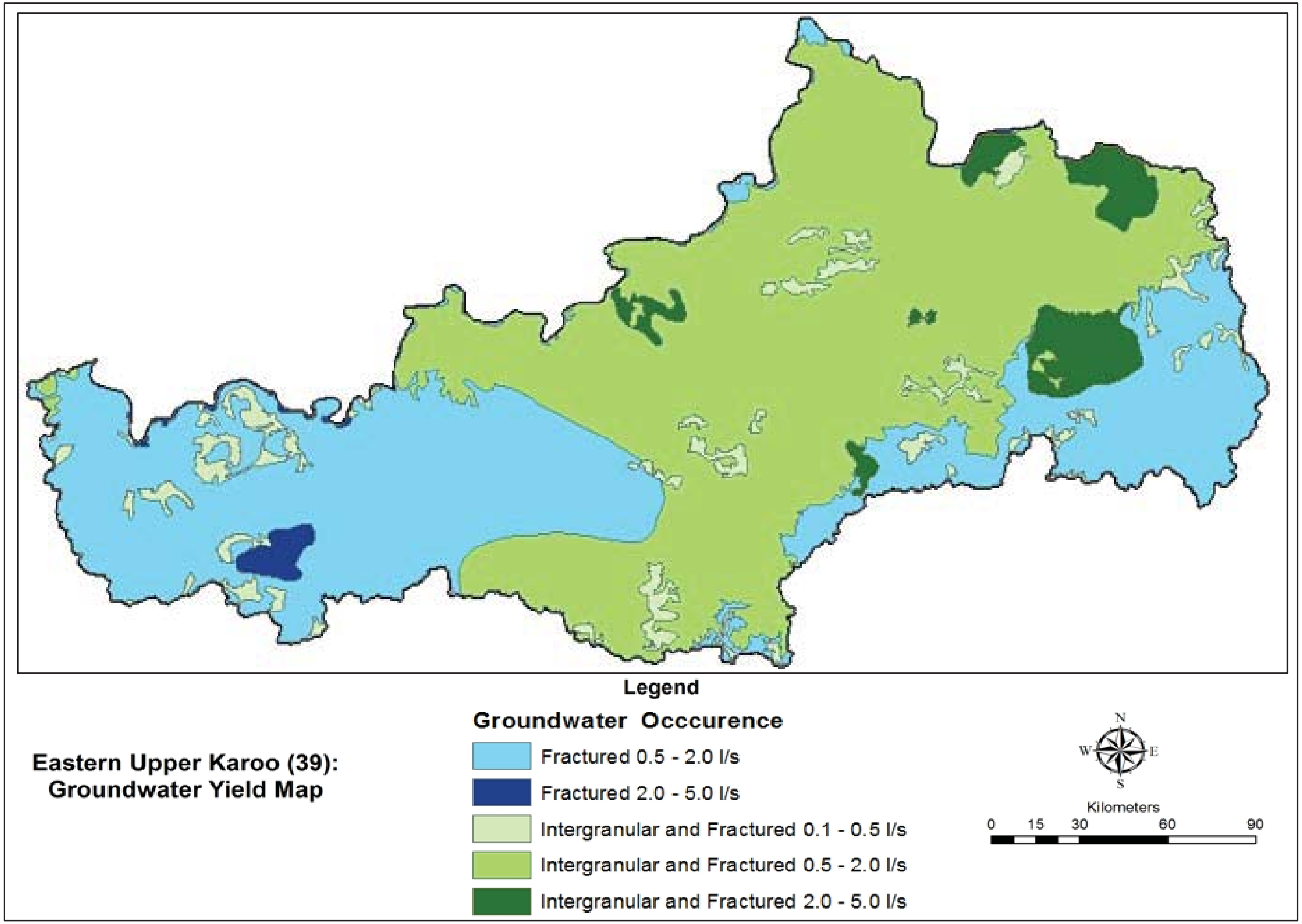


Figure 9 Groundwater yield map for Region 39

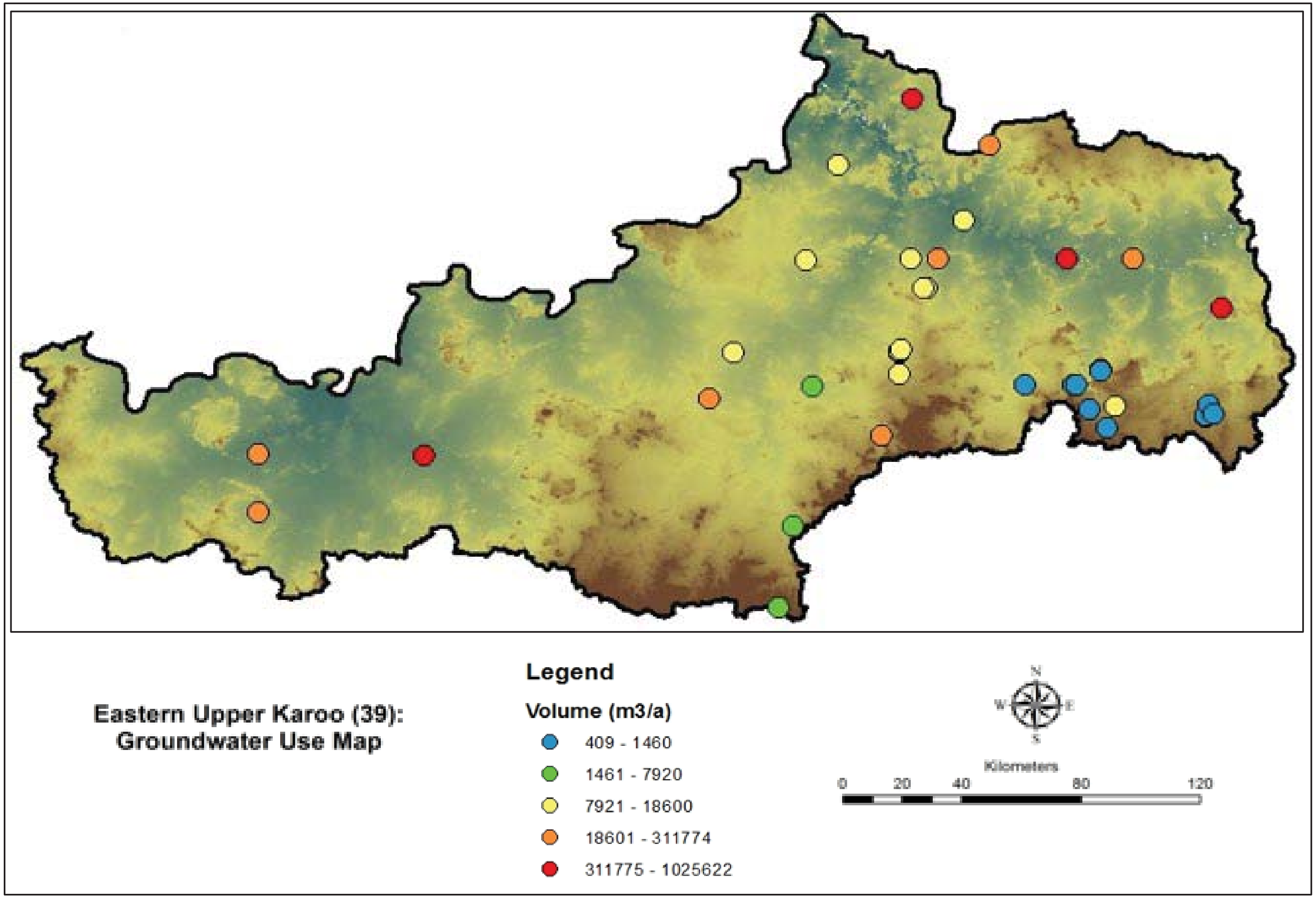


Figure 10: Groundwater use for Region 39

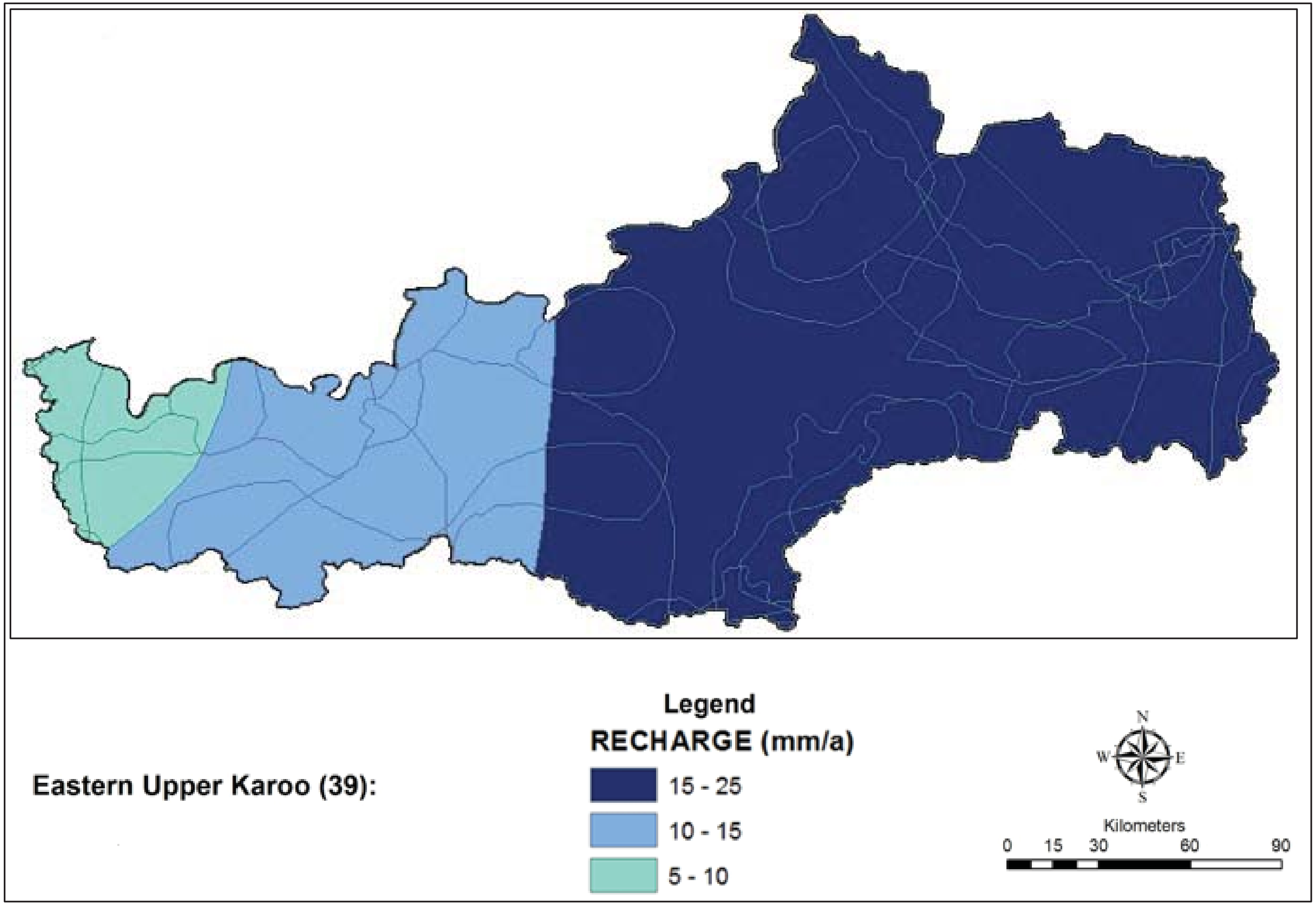


Figure 11: Recharge for Region 39

3 Geostatistical Analysis of Borehole Data

3.1 Preamble

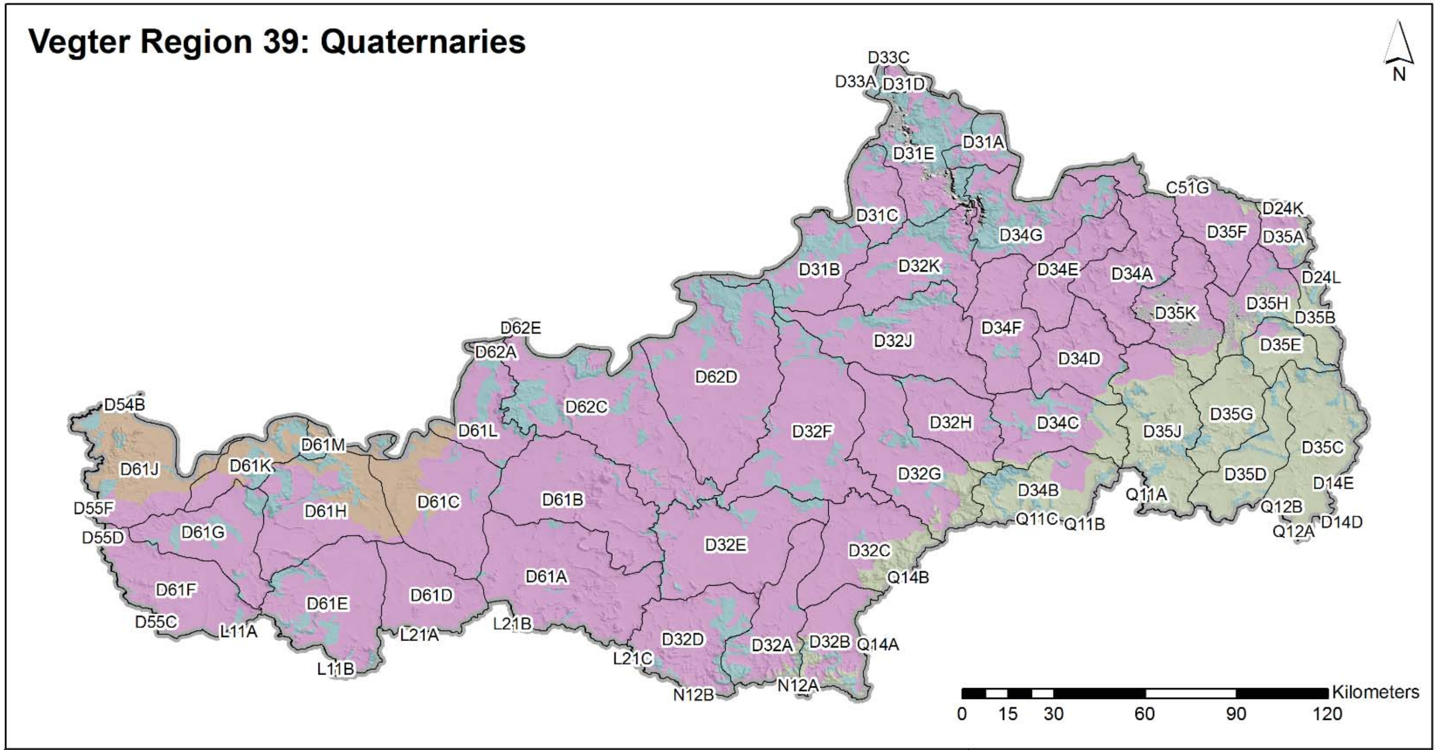
The geostatistical analyses for the study as a whole are discussed and also the individual analysis of the different geological units as identified in the 1:1 000 000 simplified geological map of the area. The data used in the analysis comprise borehole information from the NGA (National Groundwater Archive) and data obtained from various consultants that have done work within the study area – mostly water supply. Vegter's methodology as discussed in the previous section is followed as closely as possible, but due to the absence of certain datasets not all Vegter analyses could be repeated. Production costs and associated drilling control procedures are not addressed in this report.

3.2 Simplified Geology

The 1:1 000 000 Simplified Geological Map available from the Council for Geoscience was used in the analysis. This was done to reduce the complexity of the data available in the 1:50 000 geological maps in relation to the available borehole data. The quaternary catchments within the area are shown Figure 12 and Figure 13. The lithostratigraphic definitions in the map are listed in Table 1.

Table 1: Geological map label definitions

Geology	Stratigraphy	Lithology 1	Lithology 2	Lithostrategraphic Unit	Group / Formation / Complex
Jd	Karoo Dolerite	Dolerite		Dolerite Dyke	KAROO SUPERGROUP
Pa	Karoo	Mudstone	Arentite	Adelaide	KAROO SUPERGROUP - BEAUFORT
Pc	Koedoesberg	Arentite	Shale	Koedoesberg	KAROO SUPERGROUP
Pvo	Volksrust	Shale		Volksrust	KAROO SUPERGROUP - ECCA
TRt	Tarkastad	Musdtone	Arentite	Tarkastad	KAROO SUPERGROUP - BEAUFORT



Legend

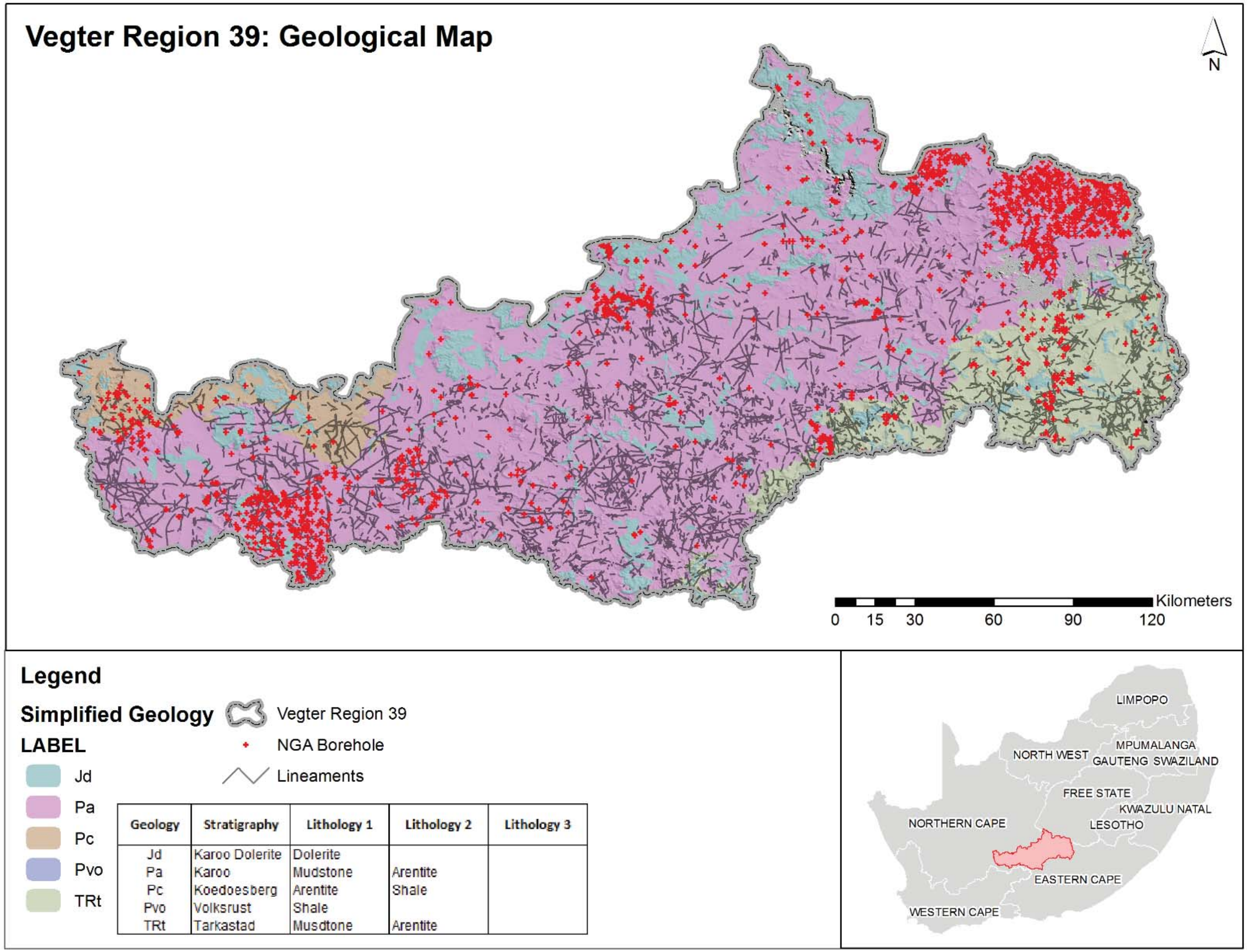
Simplified Geology Vegter Region 39

LABEL Quaternary

- Jd
- Pa
- Pc
- Pvo
- TRt

Geology	Stratigraphy	Lithology 1	Lithology 2	Lithology 3
Jd	Karoo Dolerite	Dolerite		
Pa	Karoo	Mudstone	Arentite	
Pc	Koedoesberg	Arentite	Shale	
Pvo	Volksrust	Shale		
TRt	Tarkastad	Musdtone	Arentite	

Figure 12: quaternary catchments



Geology	Stratigraphy	Lithology 1	Lithology 2	Lithology 3
Jd	Karoo Dolerite	Dolerite		
Pa	Karoo	Mudstone	Arentite	
Pc	Koedoesberg	Arentite	Shale	
Pvo	Volksrust	Shale		
TRt	Tarkastad	Musdtone	Arentite	

Figure 13: Simplified geological map

The lithology associated with each of the geological units as well as an aquifer rating are given in Table 2. From the aquifer ratings it is clear the Shales are the poorest aquifers.

Table 2: Lithologies and aquifer rating

Geology	Stratigraphy	Lithology 1	Lithology 2	Aquifer Index
Jd	Karoo Dolerite	Dolerite		4
Pa	Karoo	Mudstone	Arentite	2
Pc	Koedoesberg	Arentite	Shale	2
Pvo	Volksrust	Shale		1
TRt	Tarkastad	Musdtone	Arentite	2

It is expected that boreholes in similar geologies should behave in a similar fashion therefore all analyses done were done in the context of the different lithostrategraphic units. The behaviour of each lithostrategraphic unit will become clear in subsequent analyses.

3.3 Borehole Distribution

Borehole data was obtained from the following sources:

- NGA
- GRIP
- Private Consultants

A total of 3184 boreholes were obtained for the study. It should be noted however that not all boreholes had the same dataset. The borehole statistics in later sections will highlight this fact.

A summary of the borehole densities per quaternary and surface geology is given in Table 3 and Table 4 respectively assuming a uniform distribution of boreholes over the area.

Table 3: Borehole summary per quaternary

Quaternary	Boreholes	Clipped Area (km2)	Density (BH/km2)
D14D	0	0.3	0.00
D31A	37	379.4	0.10
D31B	18	652.1	0.03
D31C	2	399.4	0.01
D31D	2	89.7	0.02
D31E	34	860.1	0.04
D32A	0	710.8	0.00
D32B	1	569.1	0.00
D32C	12	843.2	0.01
D32D	4	844.1	0.00
D32E	8	1155.4	0.01
D32F	16	1441.3	0.01
D32G	92	1041.3	0.09
D32H	19	571.8	0.03
D32J	37	1112.5	0.03
D32K	52	823.4	0.06
D34A	104	792.2	0.13
D34B	20	696.8	0.03
D34C	18	760.0	0.02
D34D	19	598.9	0.03
D34E	0	518.8	0.00
D34F	75	691.3	0.11
D34G	136	856.7	0.16
D35A	141	245.5	0.57
D35B	14	247.1	0.06
D35C	22	920.8	0.02
D35D	18	583.4	0.03
D35E	5	311.8	0.02
D35F	301	552.8	0.54
D35G	181	551.8	0.33
D35H	59	498.2	0.12
D35J	67	999.0	0.07
D35K	155	674.1	0.23
D61A	53	1456.2	0.04
D61B	28	1196.8	0.02
D61C	40	1117.2	0.04
D61D	20	640.7	0.03
D61E	460	1079.6	0.43
D61F	77	863.2	0.09
D61G	67	744.1	0.09
D61H	28	1086.1	0.03
D61J	162	950.4	0.17
D61K	38	439.6	0.09
D61L	11	558.1	0.02
D61M	0	140.1	0.00
D62A	4	56.9	0.07
D62C	8	1670.8	0.00
D62D	516	1810.3	0.29
Total	3181	35803	

Table 4: Borehole summary per geology

Geology	Boreholes	Clipped Area (km2)	Density (BH/km2)
Jd	320	4456	0.07
Pa	2301	25058	0.09
Pc	144	1565	0.09
Pvo	16	163	0.10
TRt	402	4561	0.09
Total	3183	35803	

3.4 Geophysical Maps

Little geophysical information is available for the area. The aerial magnetic map with together with the boreholes intersecting dykes are shown in Figure 14. It is clear that there exists a strong correlation between the boreholes intersecting dykes and the proximity to magnetic features.

3.5 Water Level Analysis

Water levels versus topography has been analysed for each of the surface geologies where boreholes are present. The methodology followed was to rank the boreholes based on water level depth and different systems were identified from the ranking plots. Water level correlation with surface topography was analysed for each of the identified systems.

3.5.1 Jd Water Levels

The Jd comprise a total number of 168 boreholes and two different systems are identified as shown in Figure 15, each exibiting a high correlation between water level and surface topography as shown in Figure 16.

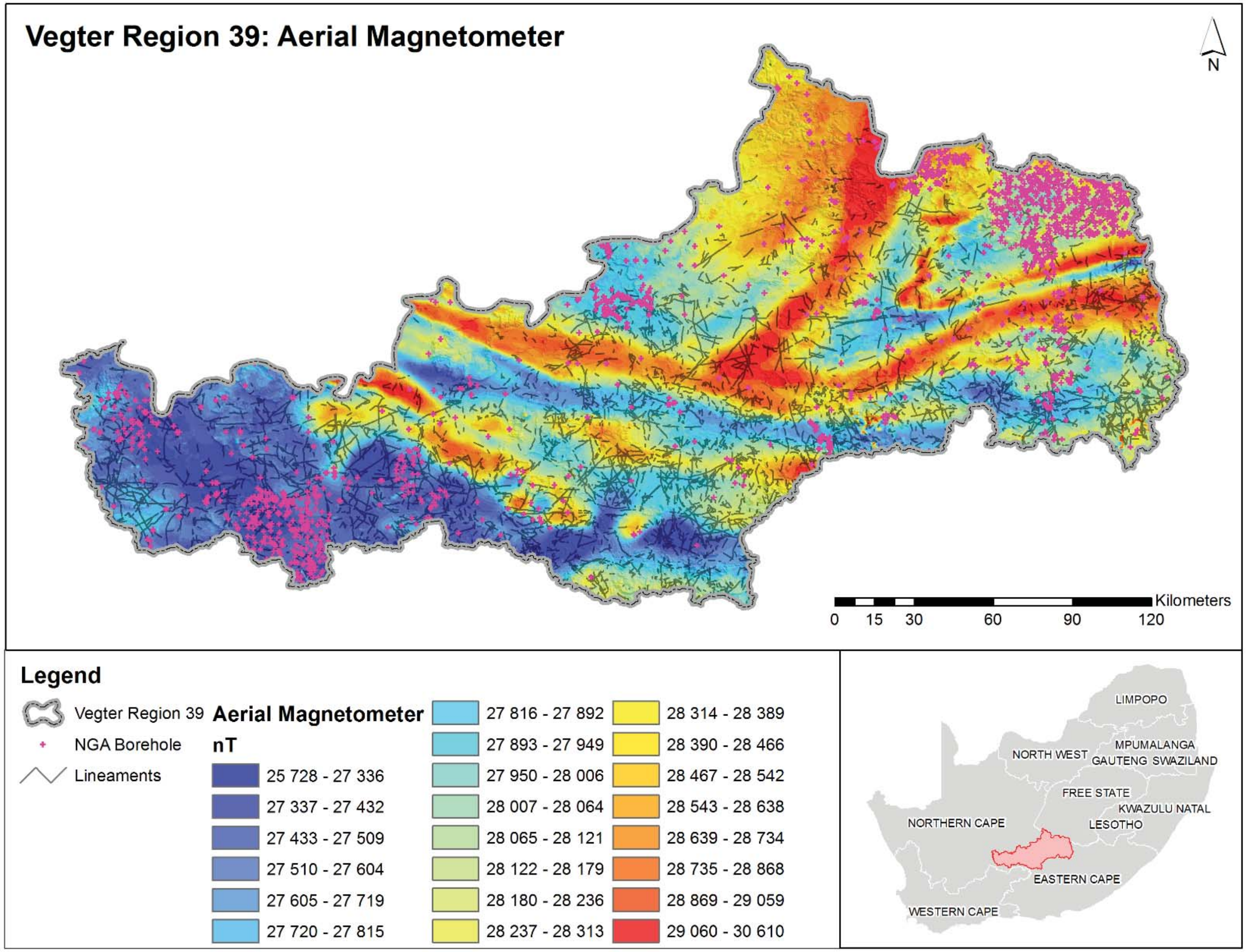


Figure 14: Aerial magnetic map and boreholes intersecting dykes

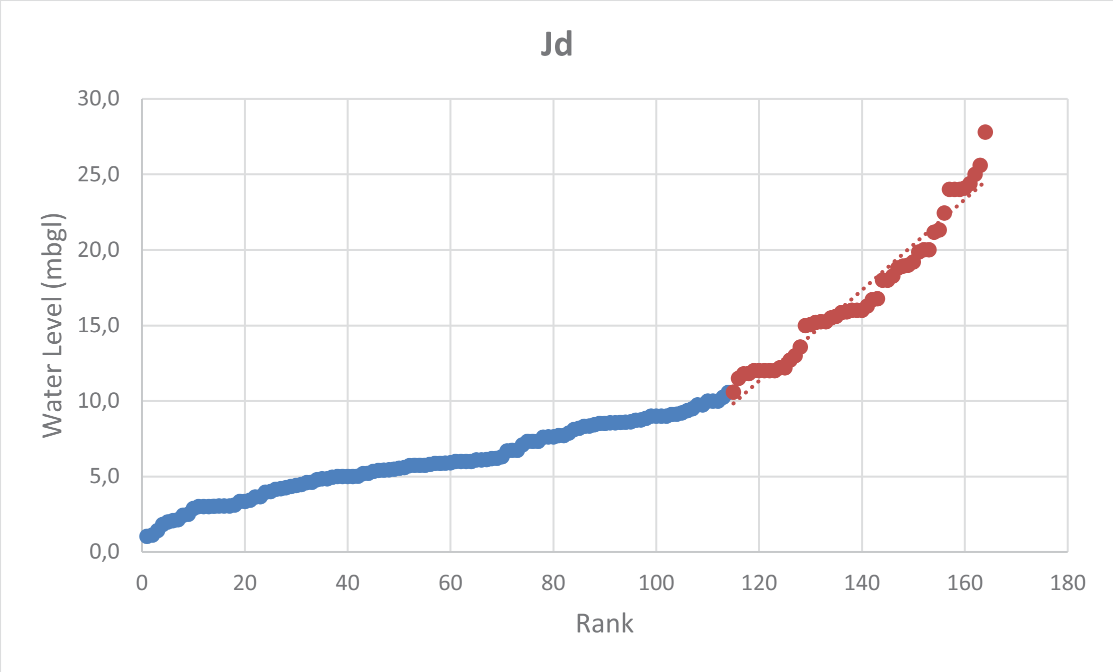


Figure 15: Jd water level vs rank

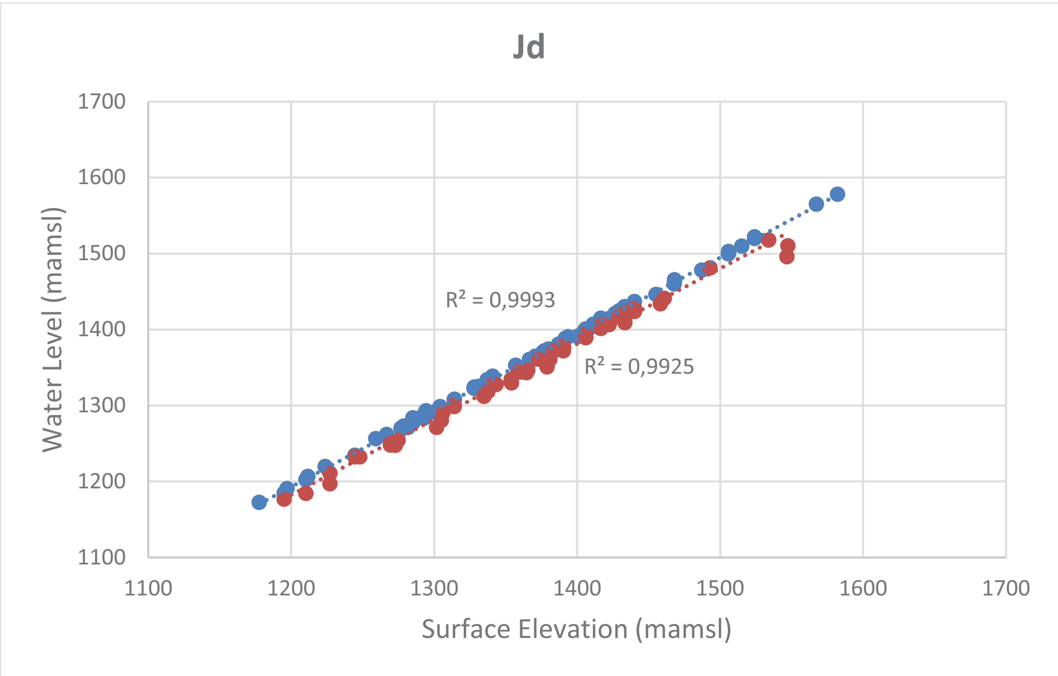


Figure 16: JD groundwater level vs surface elevation

The distribution of groundwater levels per depth and the number of boreholes passing through the depth range is shown in Figure 17.

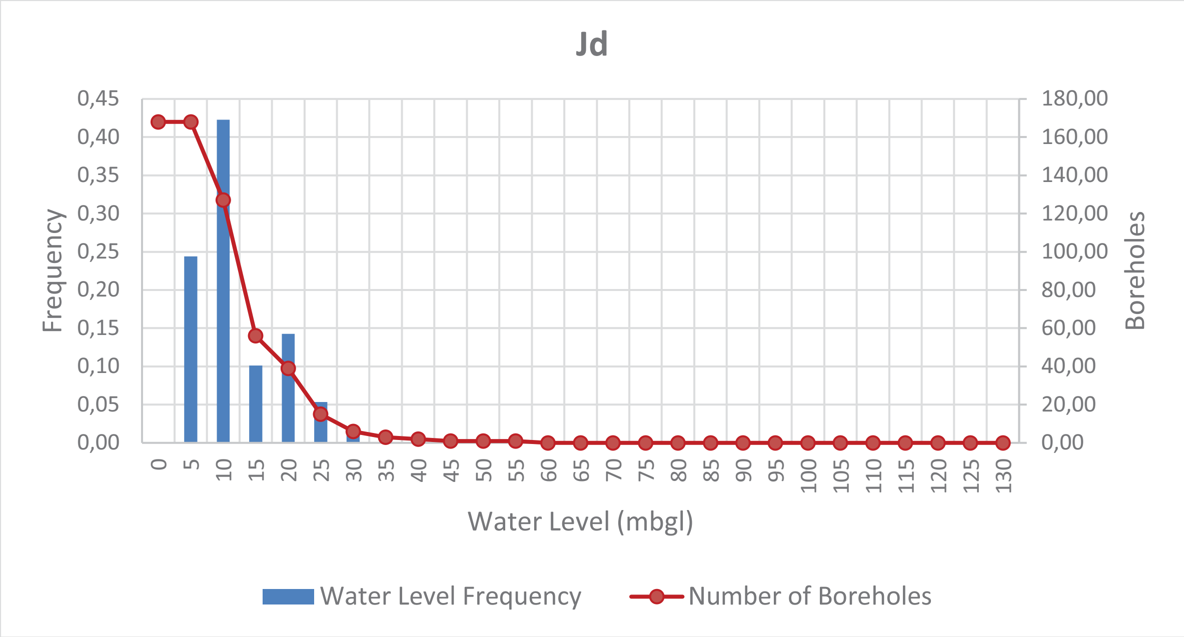


Figure 17: JD distribution of groundwater levels

3.5.2 Pa Water Levels

The Pa comprise a total number of 1153 boreholes and four different systems are identified as shown in Figure 18. All systems show a high correlation between groundwater levels and surface elevation as shown in Figure 19.

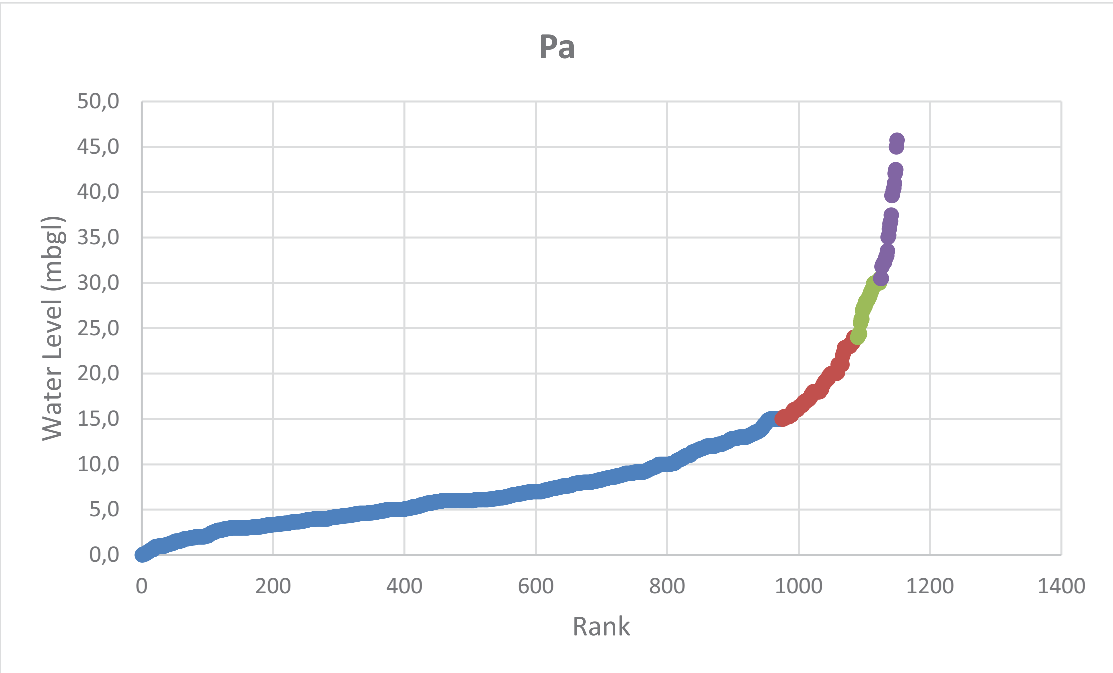


Figure 18: PA water levels vs rank

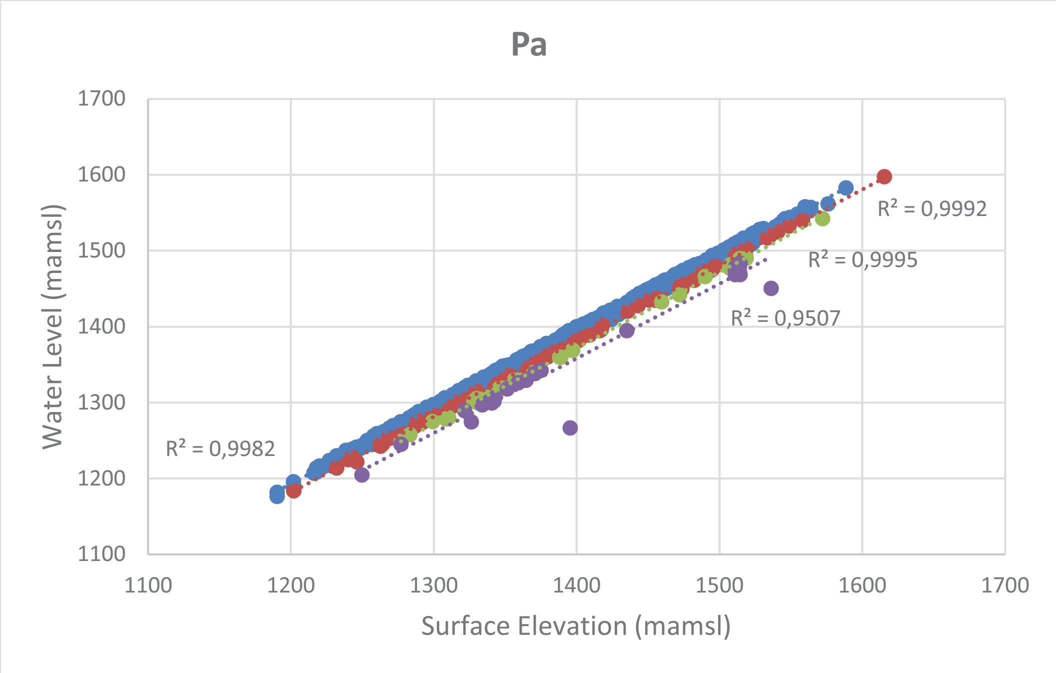


Figure 19: PA groundwater level vs surface elevation

The distribution of groundwater levels per depth and the number of boreholes passing through the depth range is shown in Figure 20.

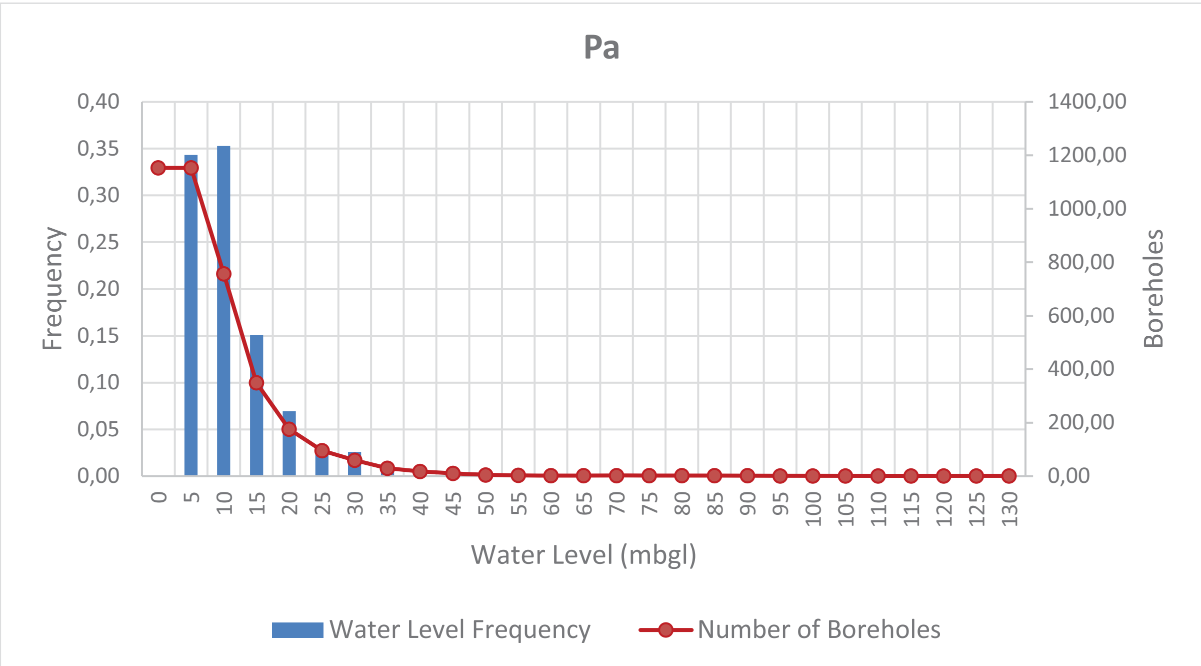


Figure 20: PA distribution of groundwater levels

3.5.3 Pc Water Levels

The Pc comprise a total number of 81 boreholes and 3 systems are identified as shown in Figure 21, exibiting a very high correlation between water level and surface topography as shown in Figure 22.

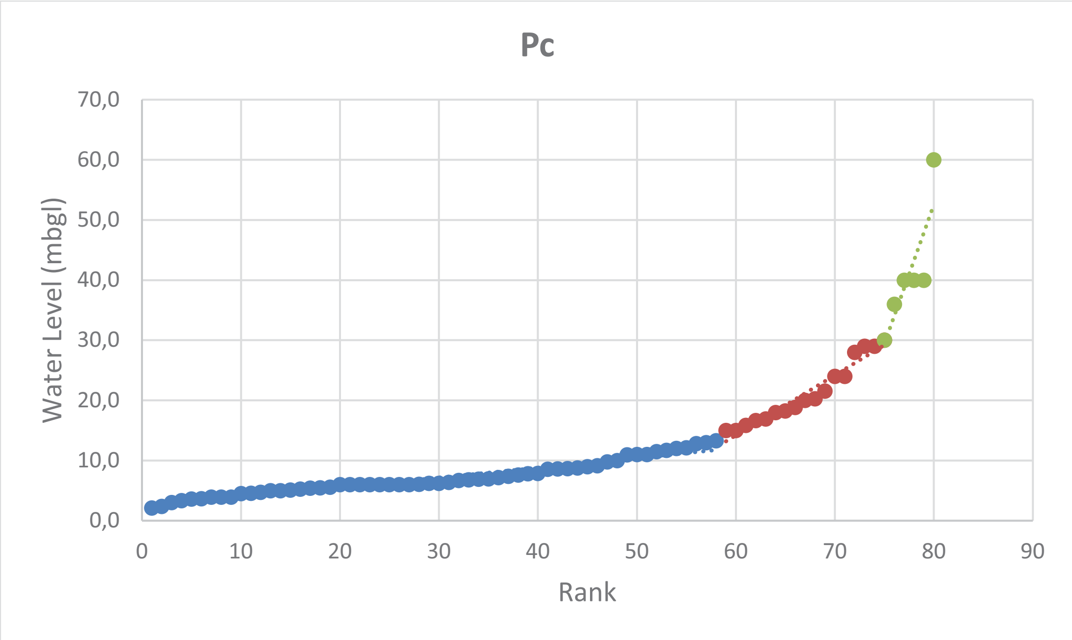


Figure 21: Pc water levels vs rank

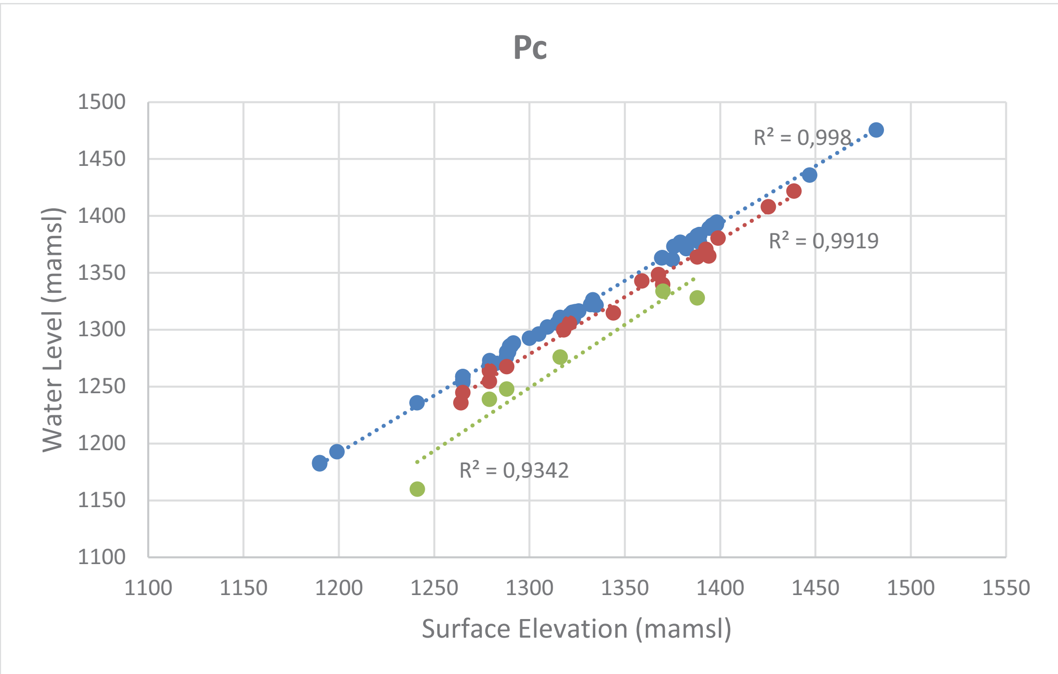


Figure 22: Pc Groundwater levels vs surface elevation

The distribution of groundwater levels per depth and the number of boreholes passing through the depth range is shown in Figure 23.

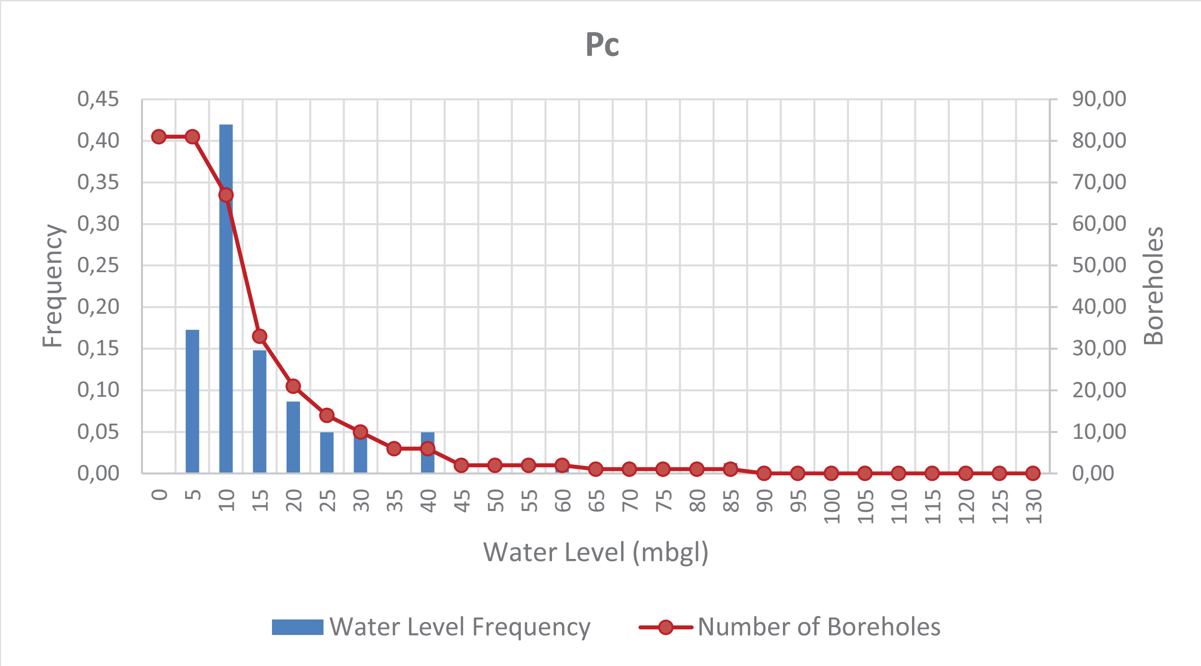


Figure 23: Pc distribution of groundwater levels

3.5.4 Pvo Water Levels

The Pvo boreholes comprise a total number of 10 boreholes and one system is identified as shown in Figure 24, with a high correlation between water level and surface topography as shown in Figure 25.

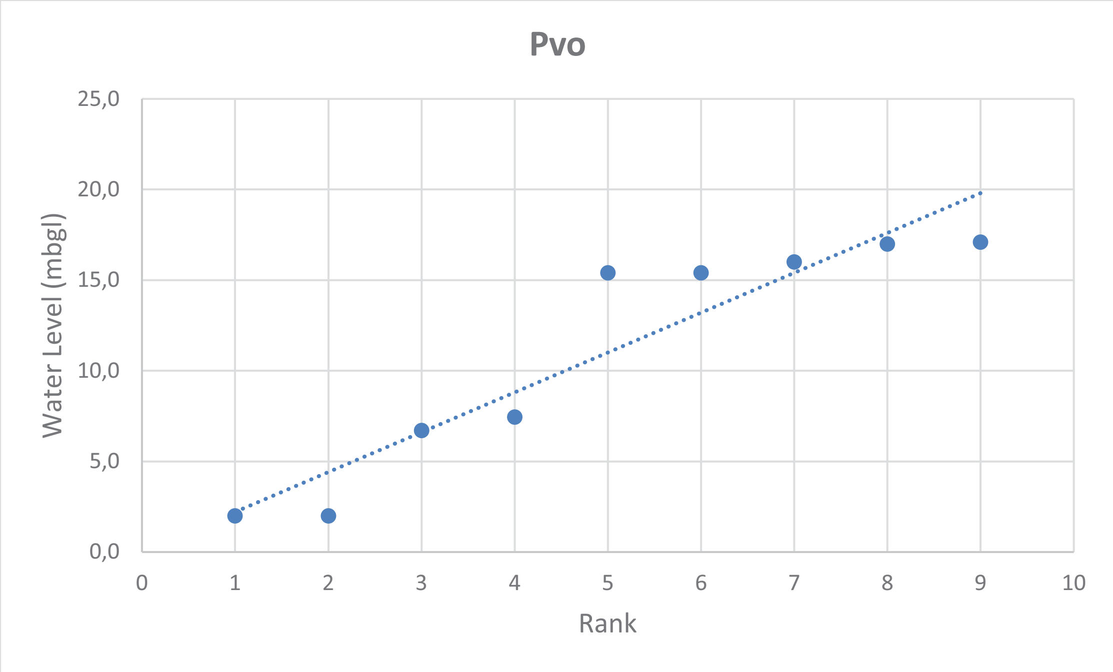


Figure 24: PVo water levels vs rank

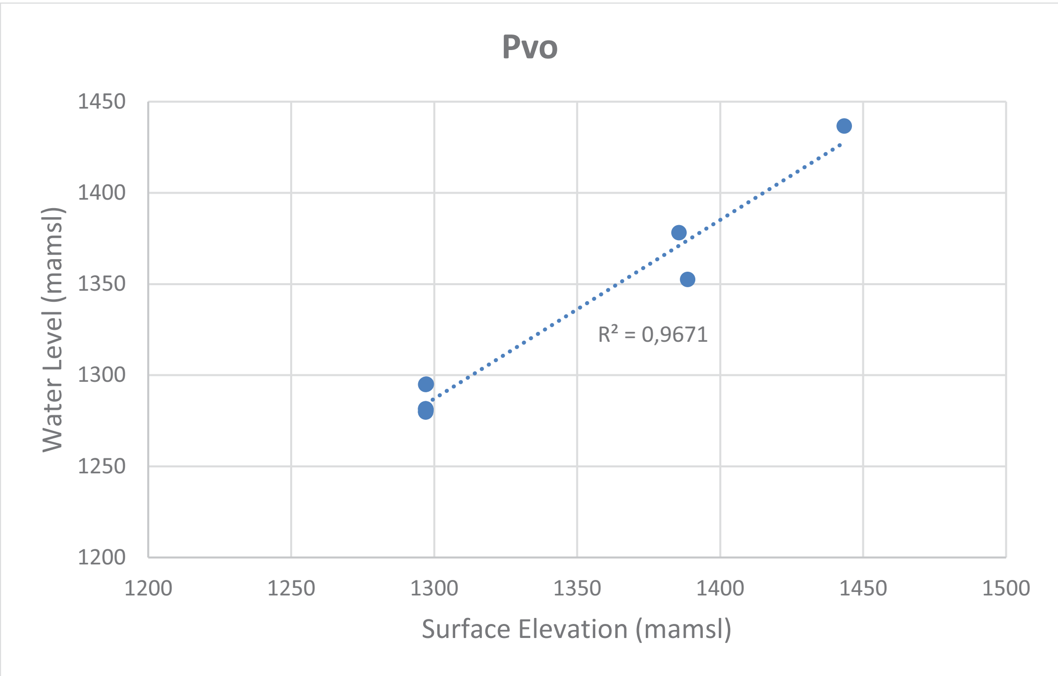


Figure 25: PVO groundwater levels vs surface elevation

The distribution of groundwater levels per depth and the number of boreholes passing through the depth range is shown in Figure 26.

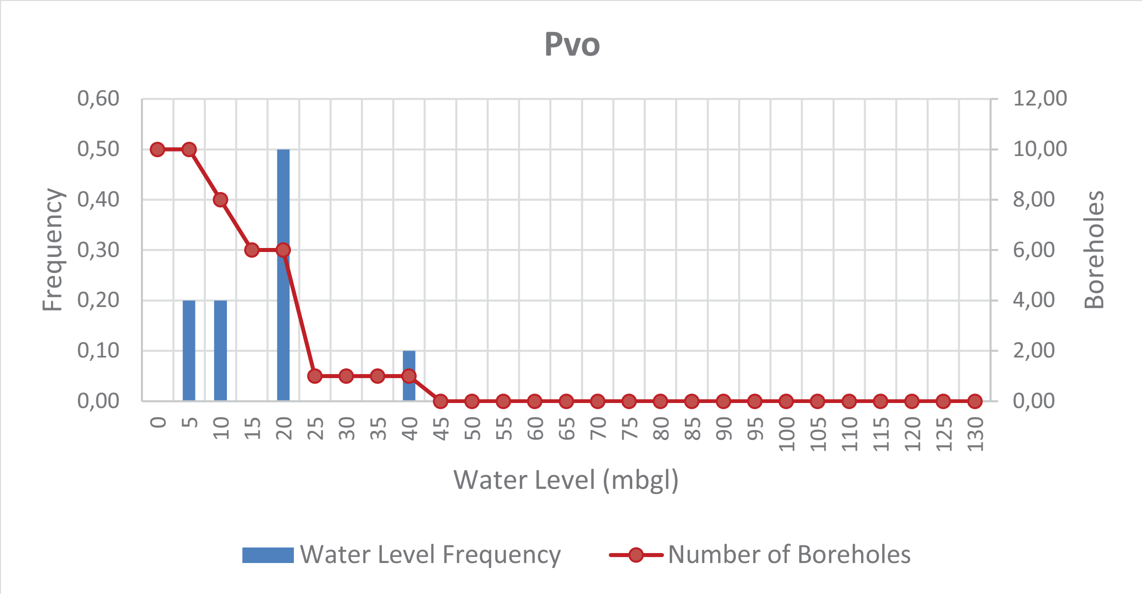


Figure 26: PVO distribution of groundwater levels

3.5.5 TRt Water Levels

The TRt comprise a total number of 231 boreholes and five different systems are identified as shown in Figure 27, each exibiting a high correlation between water level and surface topography as shown in Figure 28.

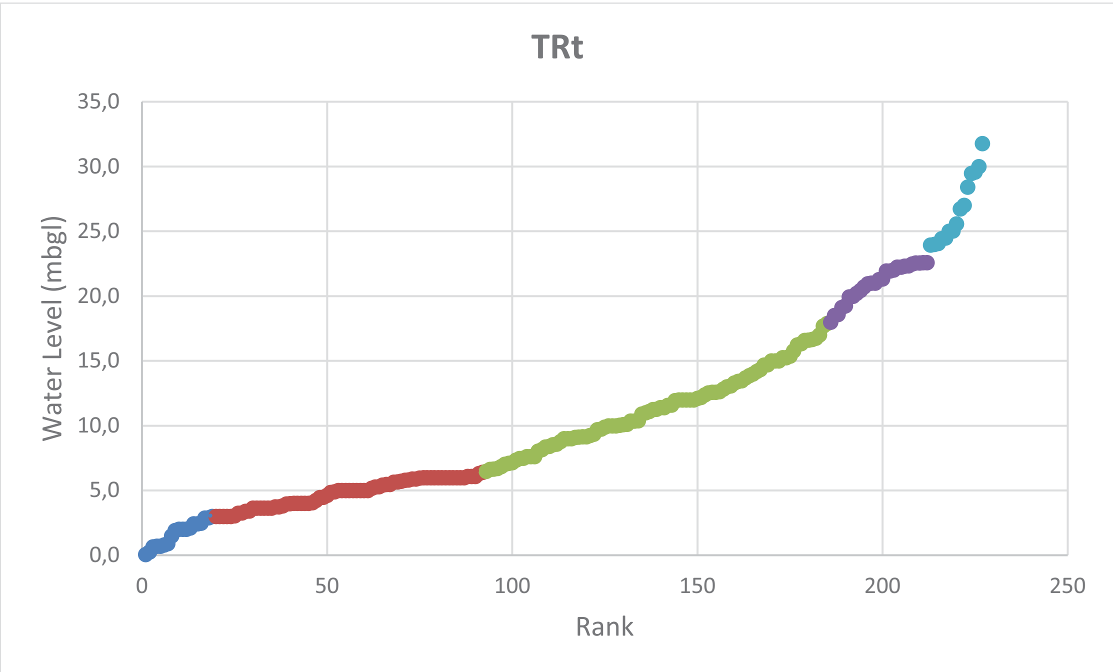


Figure 27: Trt water level vs rank

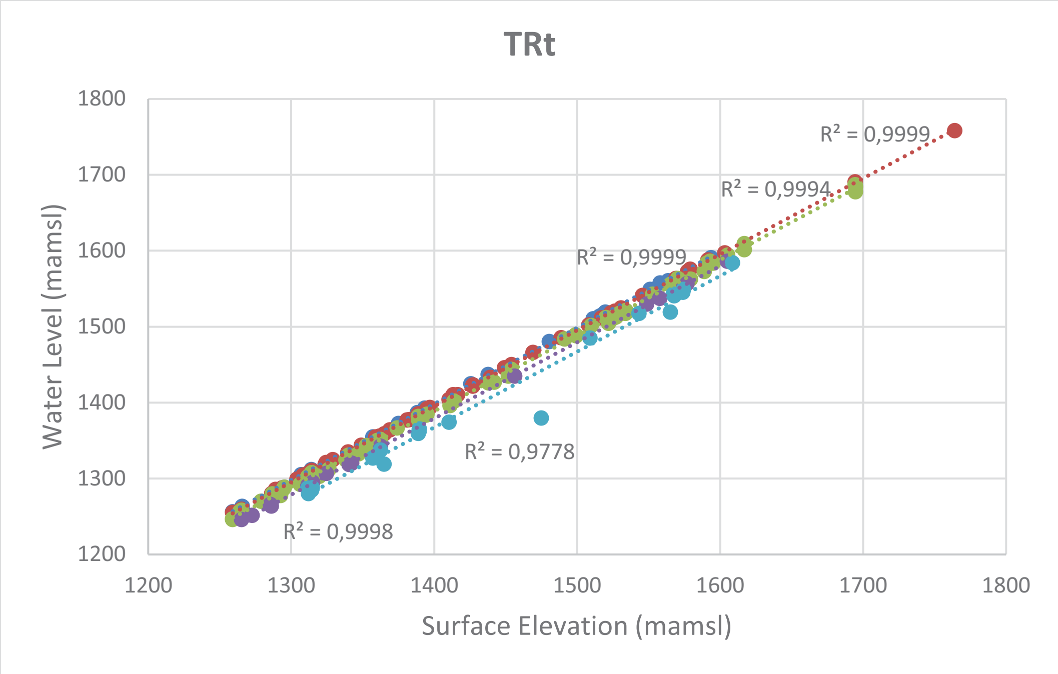


Figure 28: Trt groundwater level vs surface water elevation

The distribution of groundwater levels per depth and the number of boreholes passing through the depth range is shown in Figure 29.

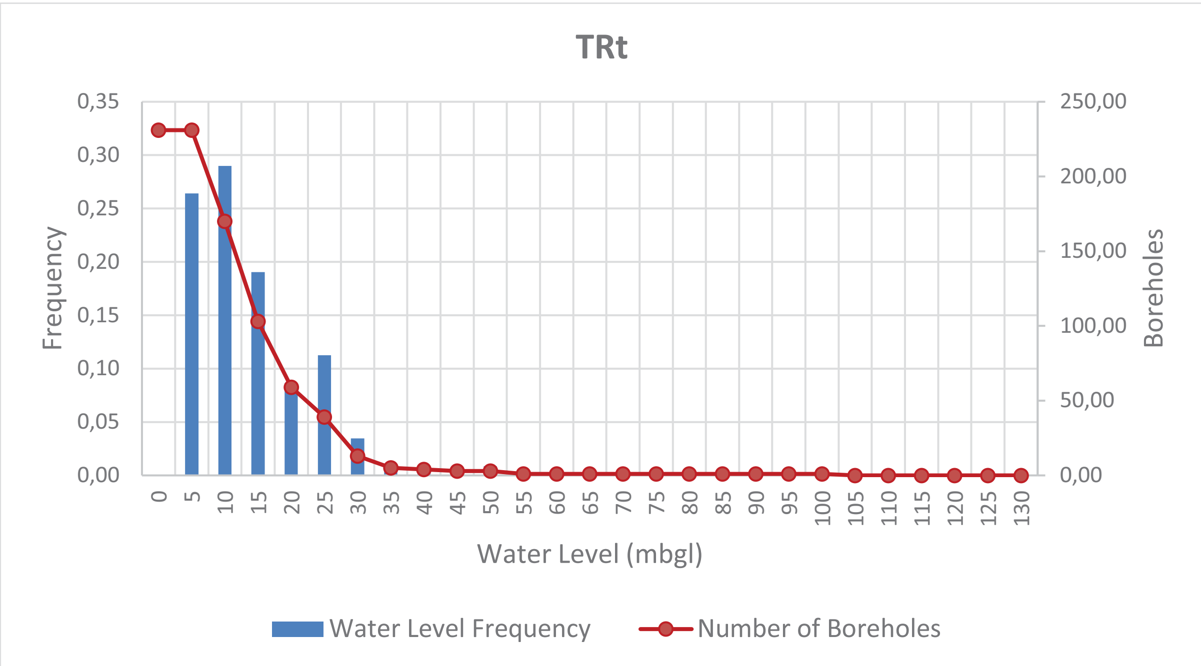


Figure 29: Trt distribution of groundwater levels

3.6 Borehole Yields

Very few borehole yields were available and therefore a geostatistical analysis was not possible.

3.7 Borehole Depths

A summary of average borehole depths and water levels is shown in Table 5.

Table 5: Summary of average borehole depths and water levels

Geology	% Area	Borehole Depth (mbgl)			Borehole Water Level (mbgl)		
		Average	Std. Dev	Count	Average	Std. Dev	Count
Jd	12.4	46	47	312	10	7	168
Pa	70.0	37	39	2035	9	9	1153
Pc	4.4	44	26	140	13	13	81
Pvo	0.5	51	19	15	14	10	10
TRt	12.7	46	28	382	11	10	231

The borehole depth values in descending order is presented in Figure 30.

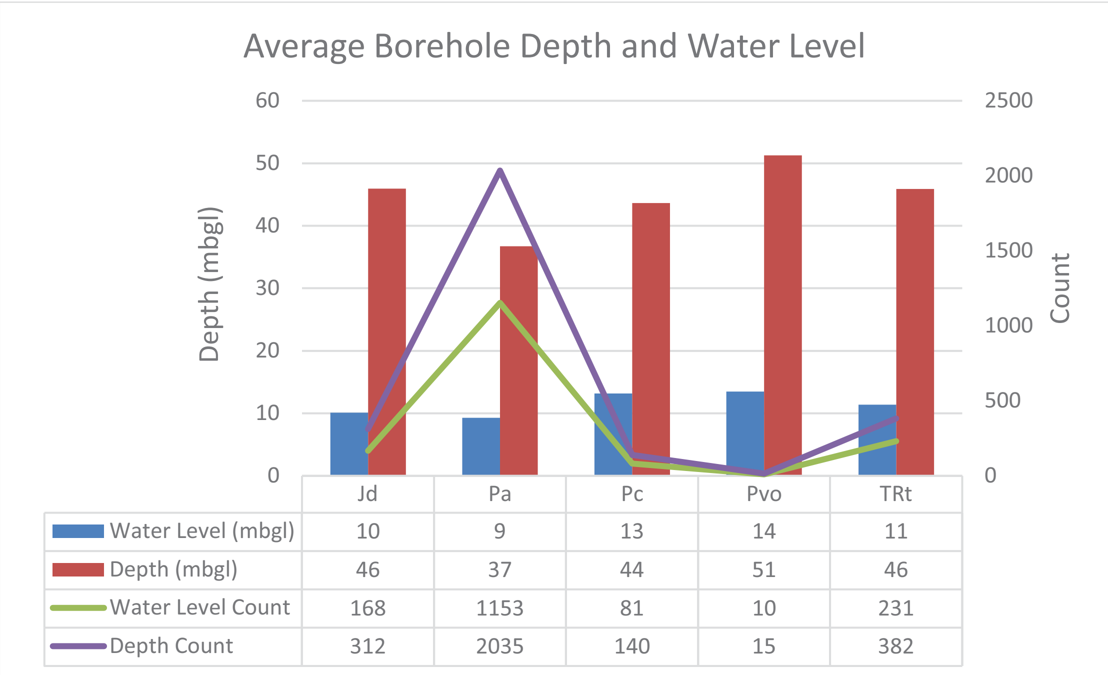


Figure 30: Average borehole depth and water level

The borehole frequency per depth range for each of the lithostratigraphic units in the study area are presented in the following sections.

3.7.1 Jd Depth Frequency

The depth frequency for the Jd lithostratigraphic units is shown in Figure 31. A total of 312 of which 37 boreholes has a depth deeper than 90 m.

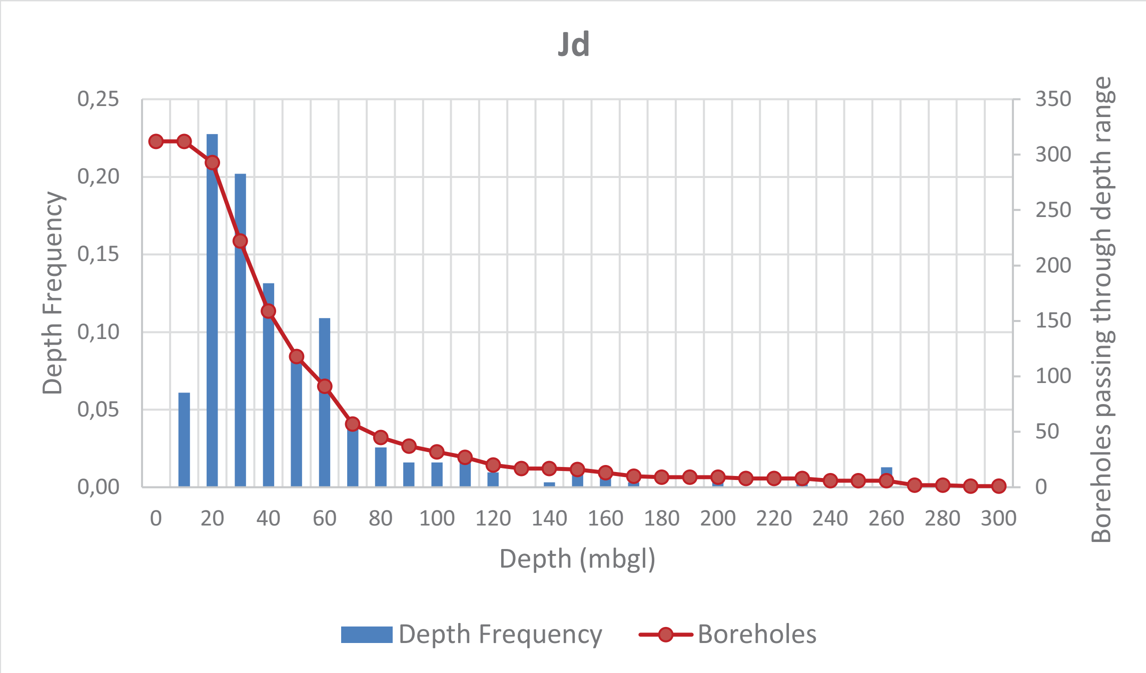


Figure 31: Jd depth frequency plot

3.7.2 Pa Depth Frequency

The depth frequency for the Pa lithostratigraphic units is shown in Figure 32. A total of 2035 boreholes exist with varying depths between 1 m and 190 m.

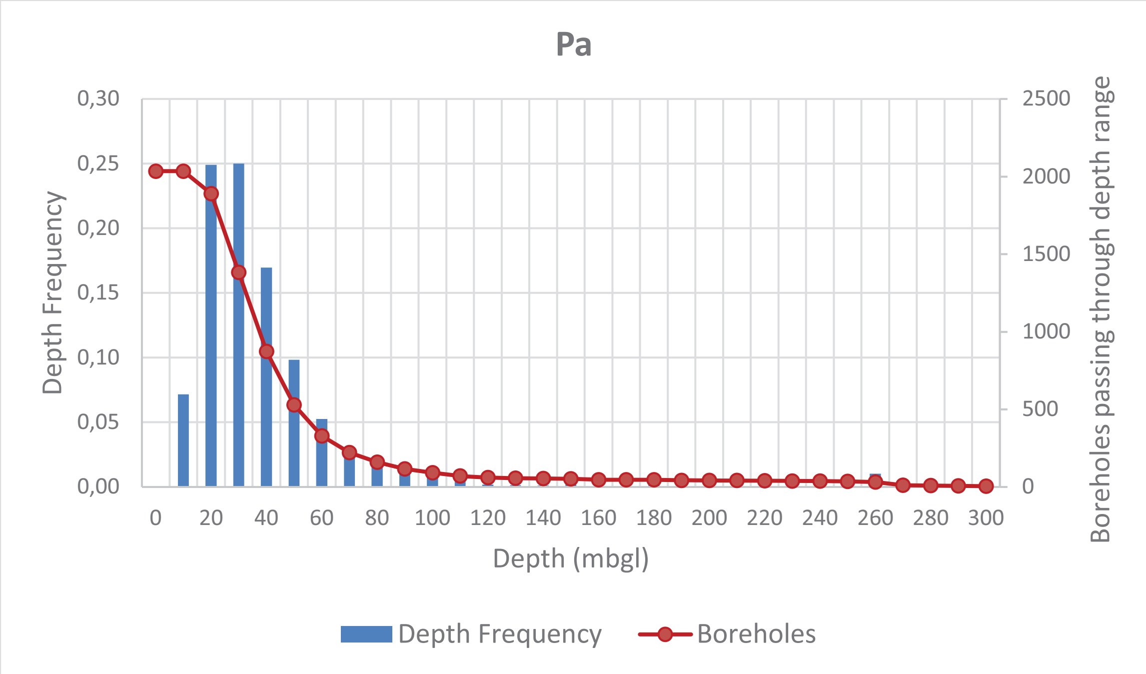


Figure 32: Pa depth frequency plot

3.7.3 Pc Depth Frequency

The depth frequency for the Pc lithostratigraphic units is shown in Figure 33. A total of 140 boreholes exist with 11 being deeper than 90 m.

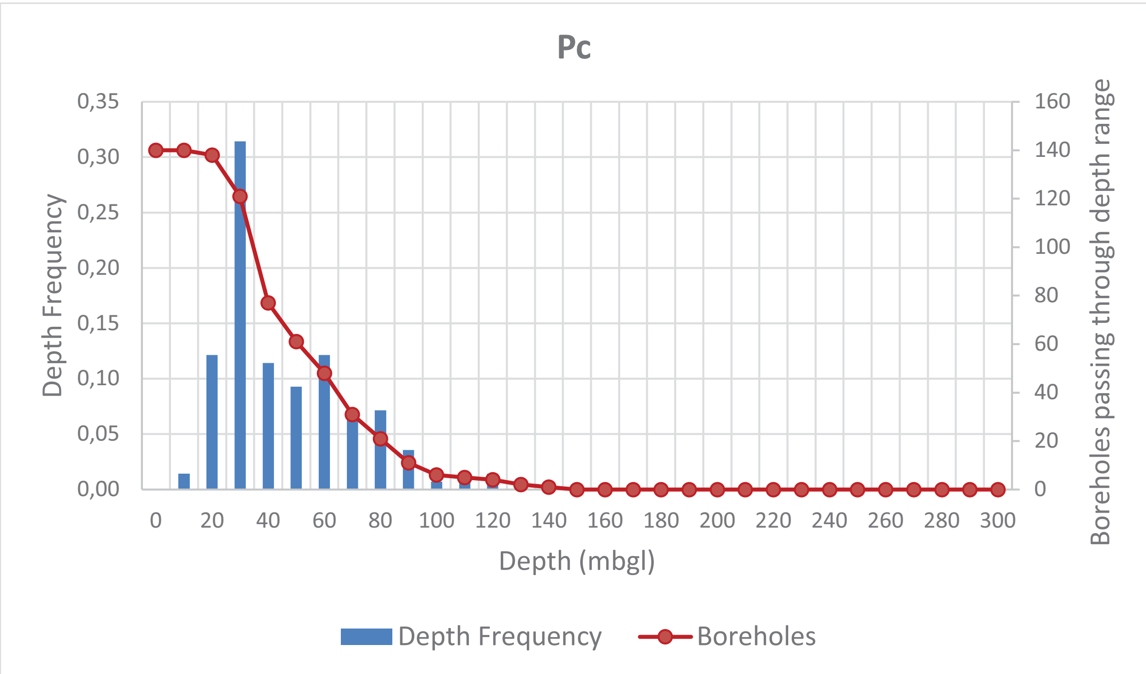


Figure 33: Pc depth frequency plot

3.7.4 Pvo Depth Frequency

The depth frequency for the Pvo lithostratigraphic units is shown in Figure 34. A total of 15 boreholes exist of which only one has a depth deeper than 90 m.

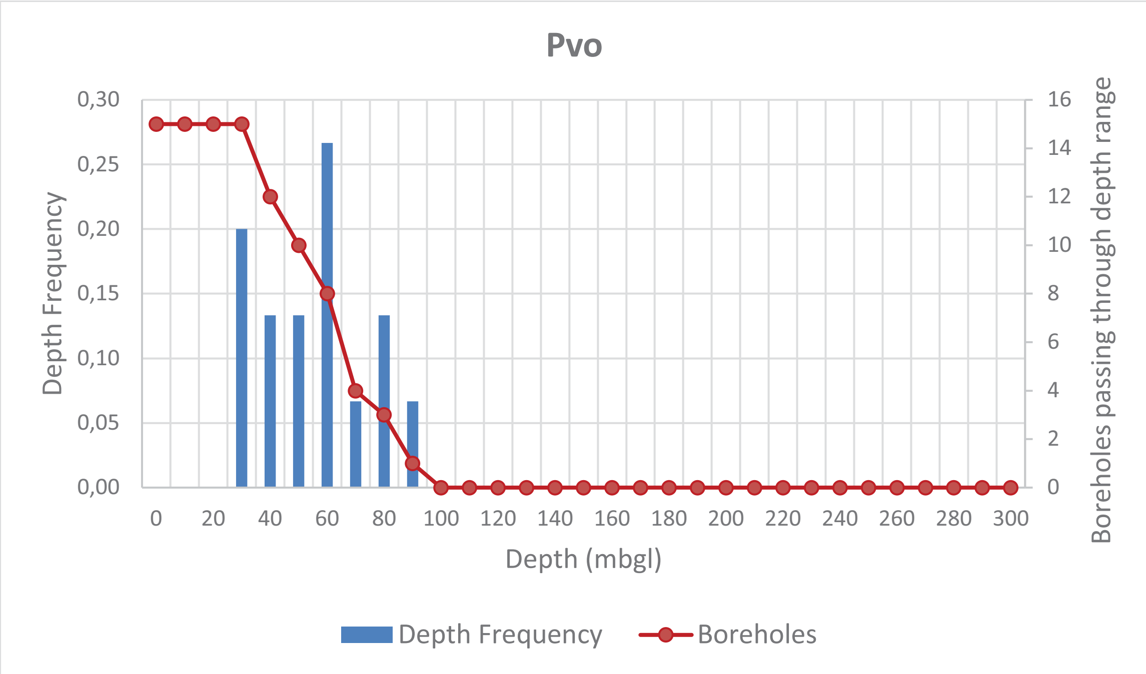


Figure 34: Pvo depth frequency plot

3.7.5 TRt Depth Frequency

The depth frequency for the TRt lithostratigraphic units is shown in Figure 35. A total of 382 boreholes exist with a 51 of them being deeper than 90 m.

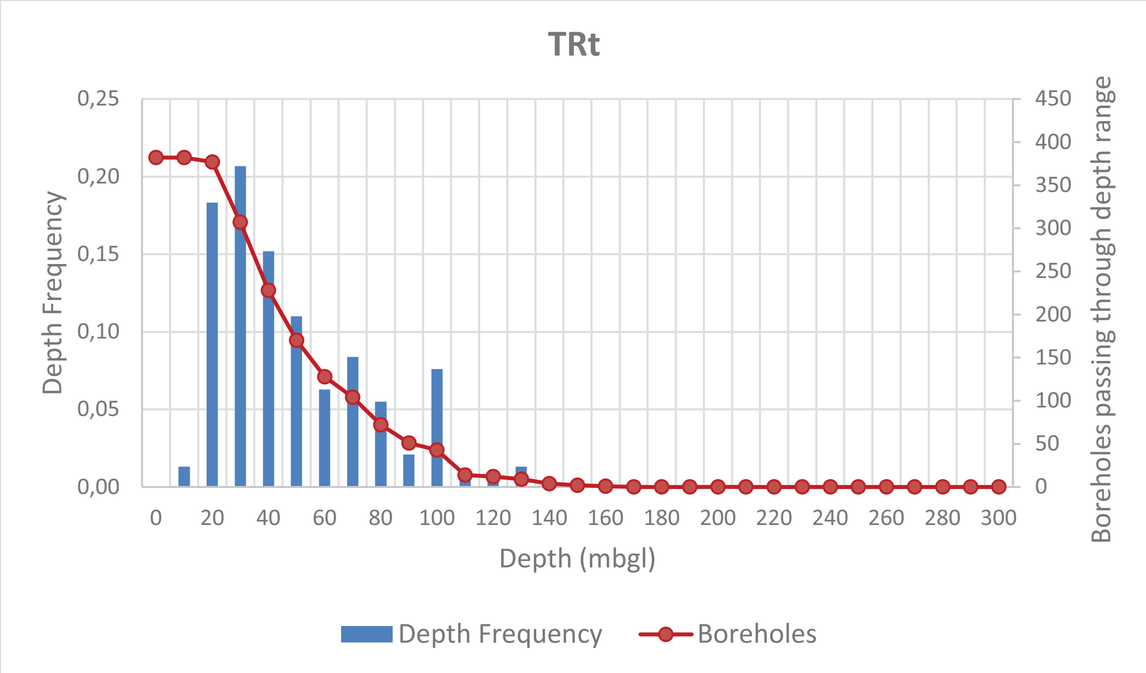


Figure 35: Trt depth frequency plot

3.8 Water Strikes

The strike frequency used in the sections that follow is formulated as follows:

$$Strike\ Frequency = \frac{Number\ of\ strikes\ per\ depth\ range\ below\ surface}{Number\ of\ boreholes\ passing\ through\ depth\ range}$$

The cumulative strike frequency is defined as the sum of the all the preceding strike frequencies per depth range.

3.8.1 Jd Strike Frequency

The strike frequency and the cumulative strike frequency for the Jd unit is shown in Figure 36 and Figure 37 respectively. Note only 232 boreholes with strike information were used.

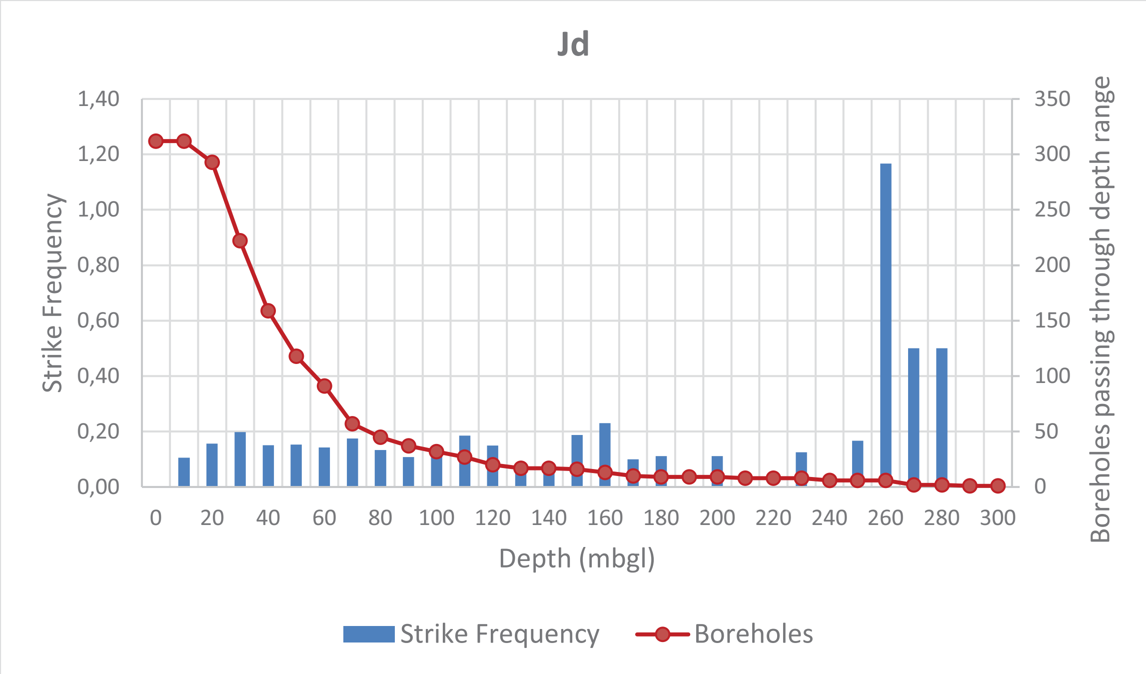


Figure 36: Jd strike frequency graph

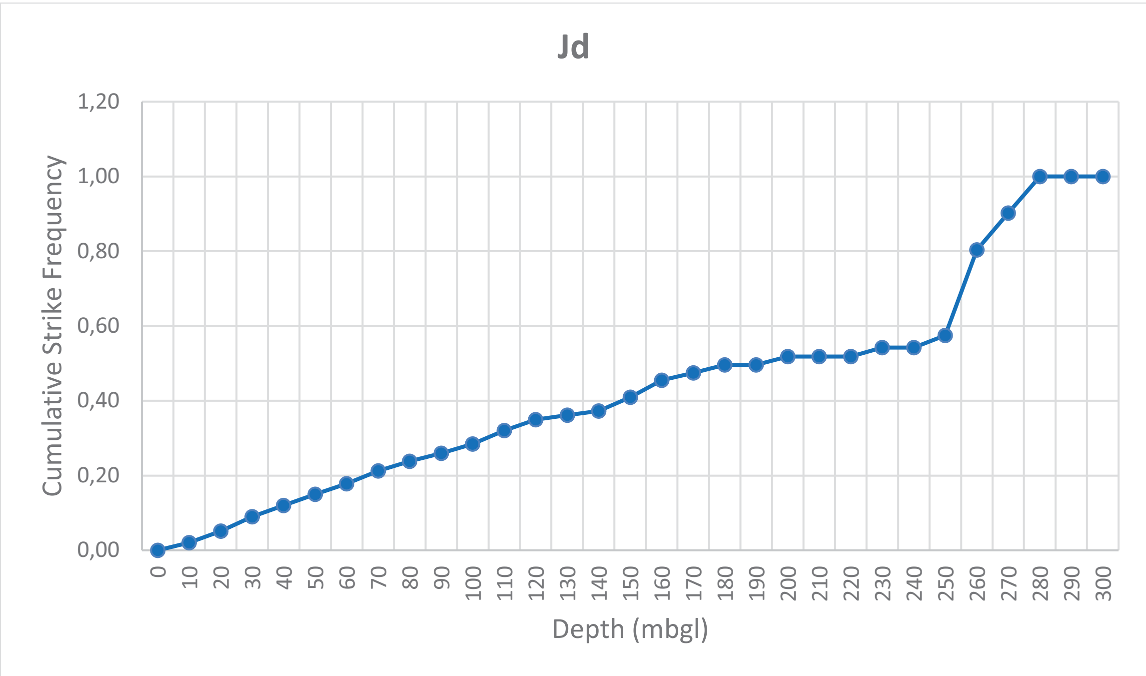


Figure 37: JD cumulative strike frequency graph

3.8.2 Pa Strike Frequency

The strike frequency and the cumulative strike frequency for the Pa unit is shown in Figure 38 and Figure 39 respectively. From the available data the predominant strike frequencies are within the first 120 m below surface.

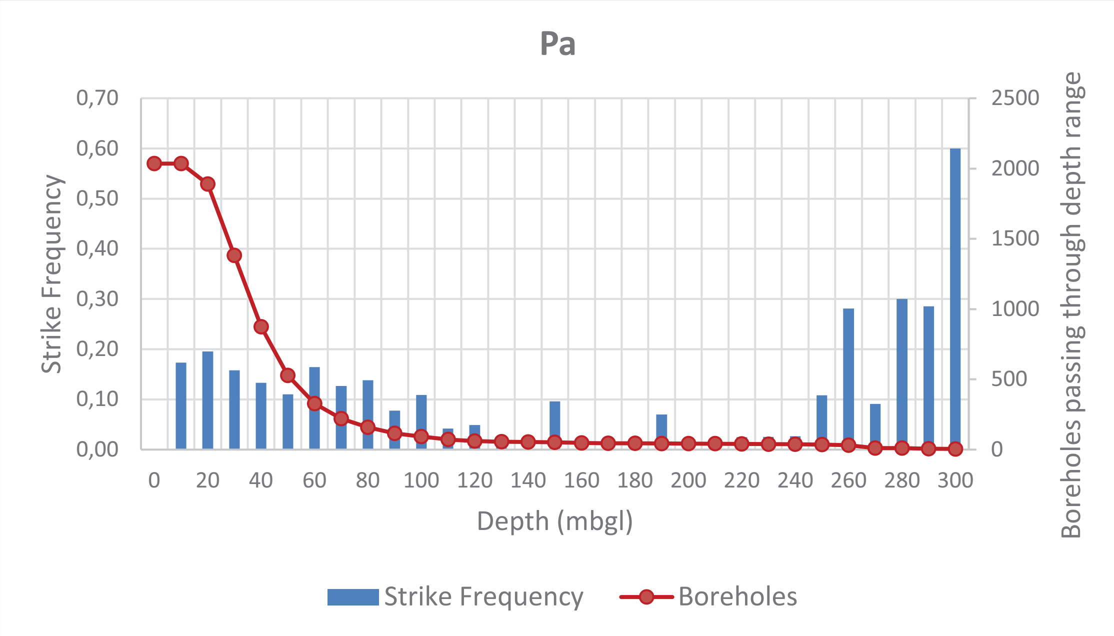


Figure 38: Pa strike frequency graph

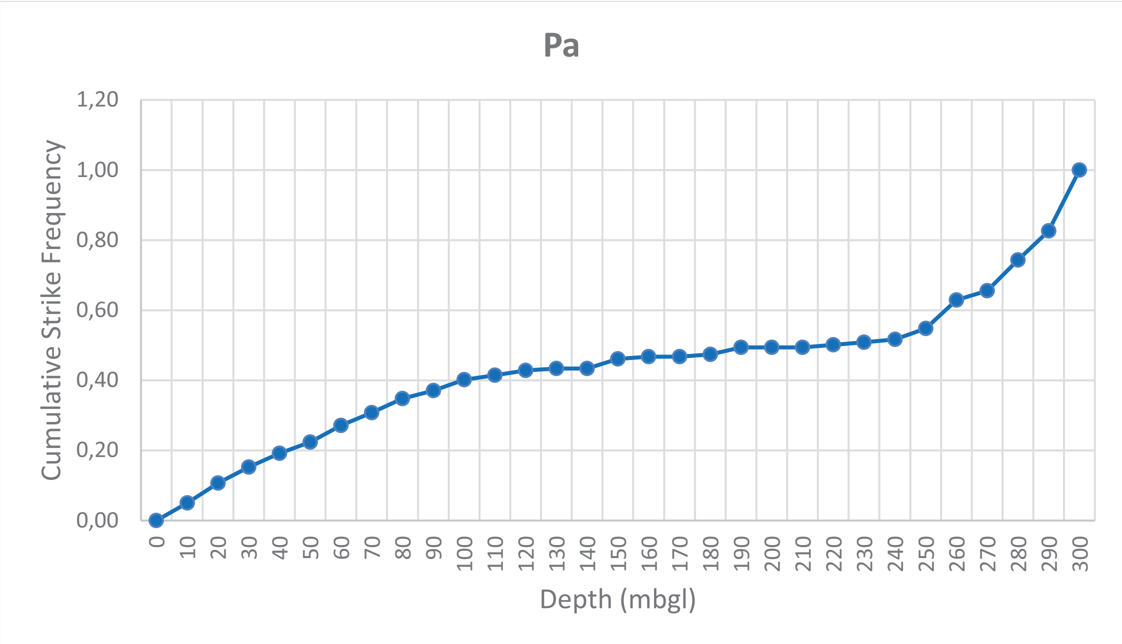


Figure 39: Pa cumulative strike frequency graph

3.8.3 Pc Strike Frequency

The strike frequency and the cumulative strike frequency for the Pc unit is shown in Figure 40 and Figure 41 respectively. Note 55 boreholes with strike information was used to generate the graph. From the available data the predominant strike frequency are within the first 100 m below surface.

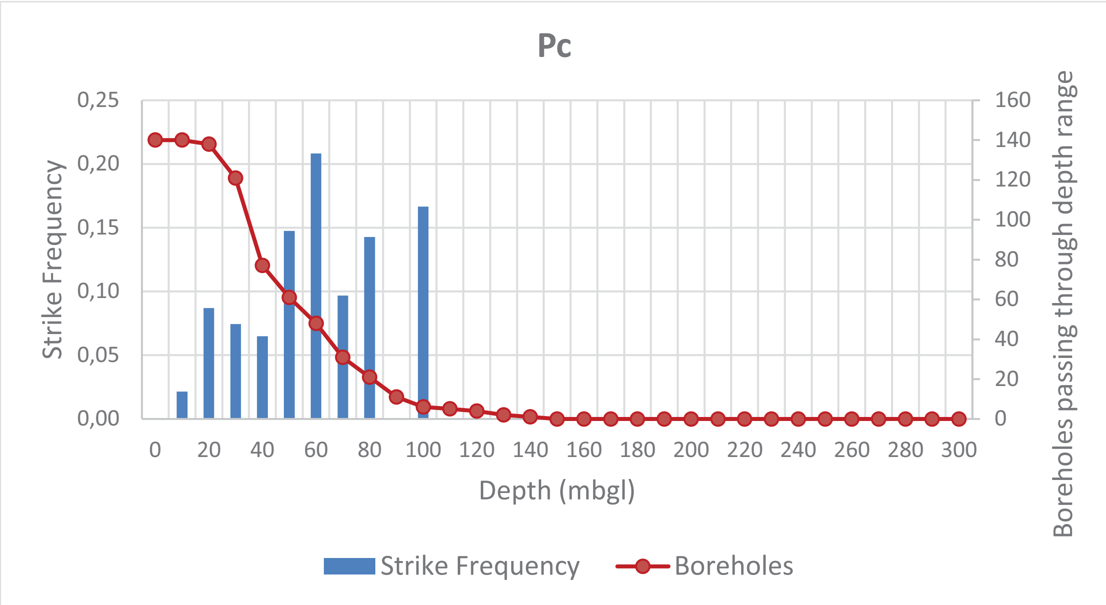


Figure 40: PC strike frequency graph

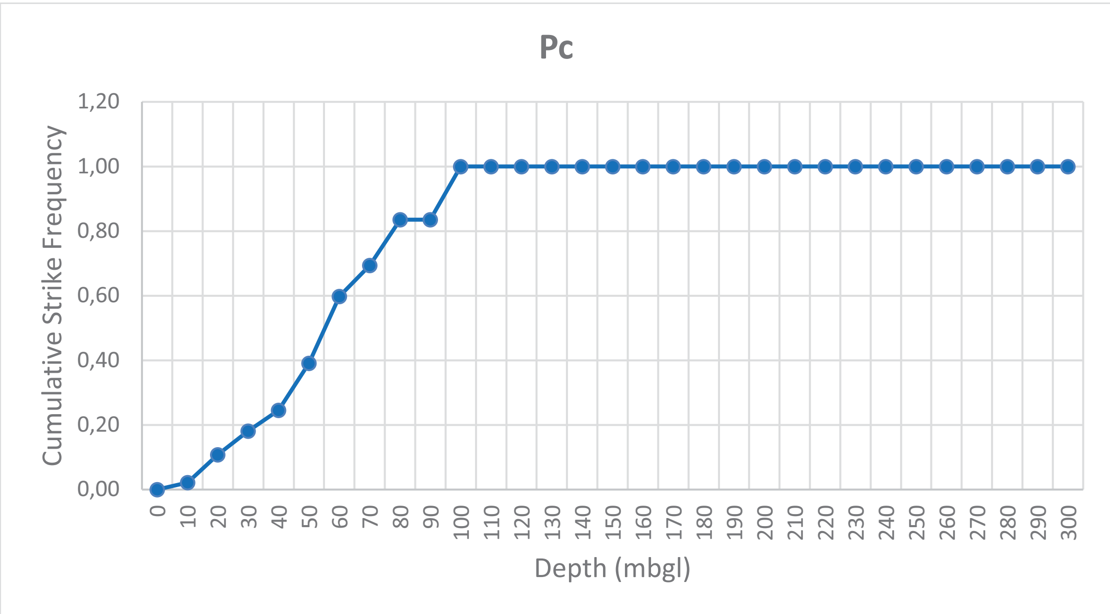


Figure 41: PC cumulative strike frequency

3.8.4 Pvo Strike Frequency

The strike frequency and the cumulative strike frequency for the Pvo unit is shown in Figure 36 and Figure 37 respectively. Note only 80 boreholes with strike information was used hence the stepwise nature of the cumulative graph.

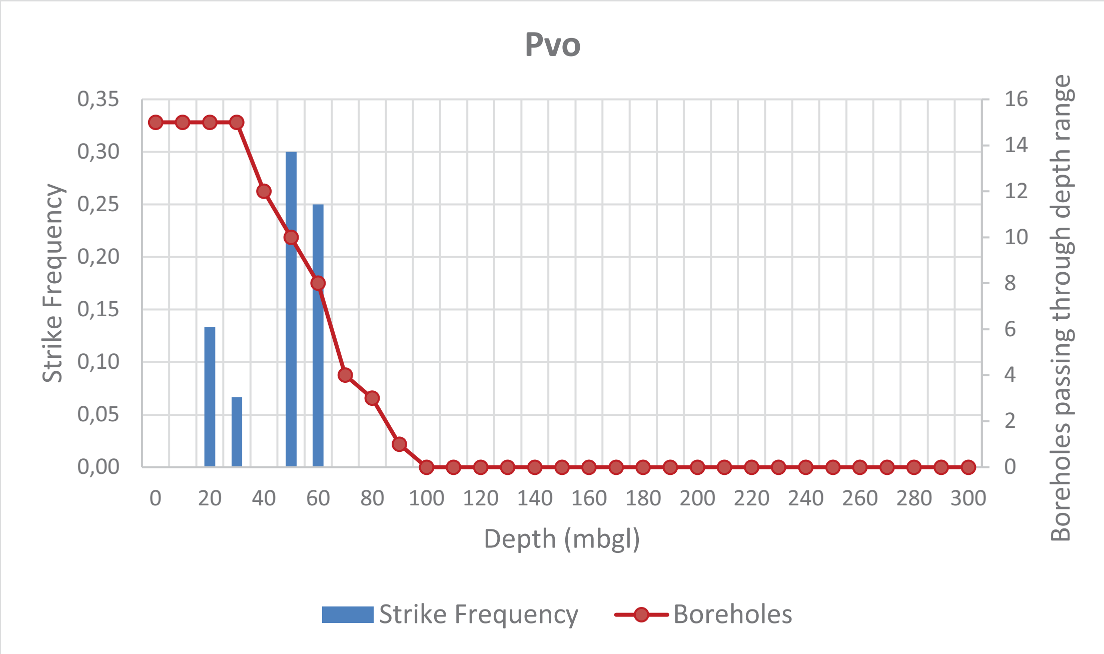


Figure 42: Pvo strike frequency graph

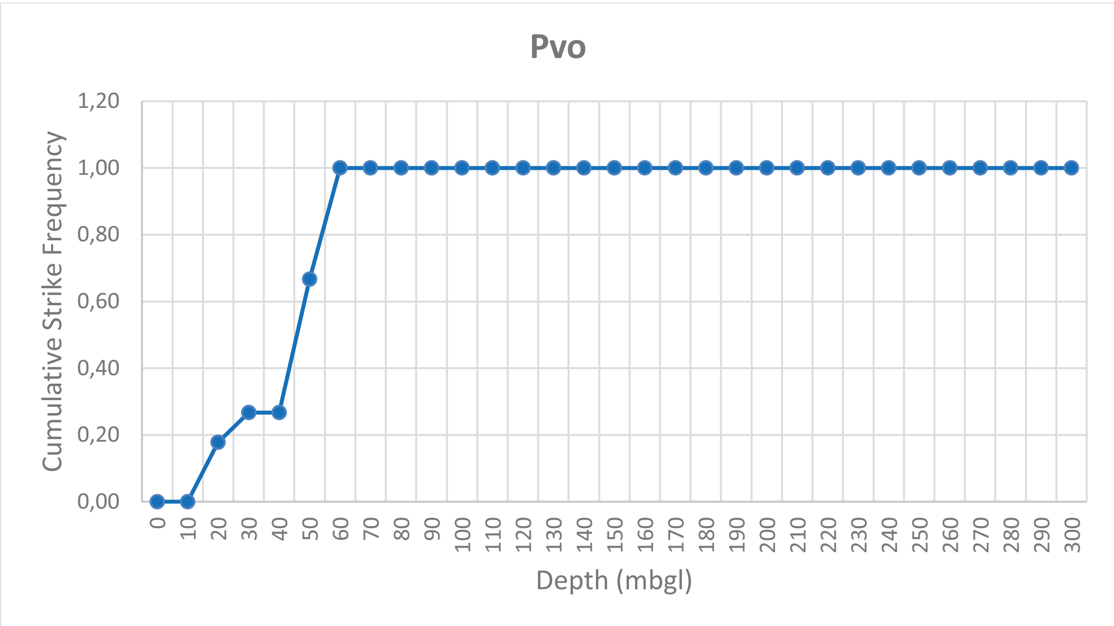


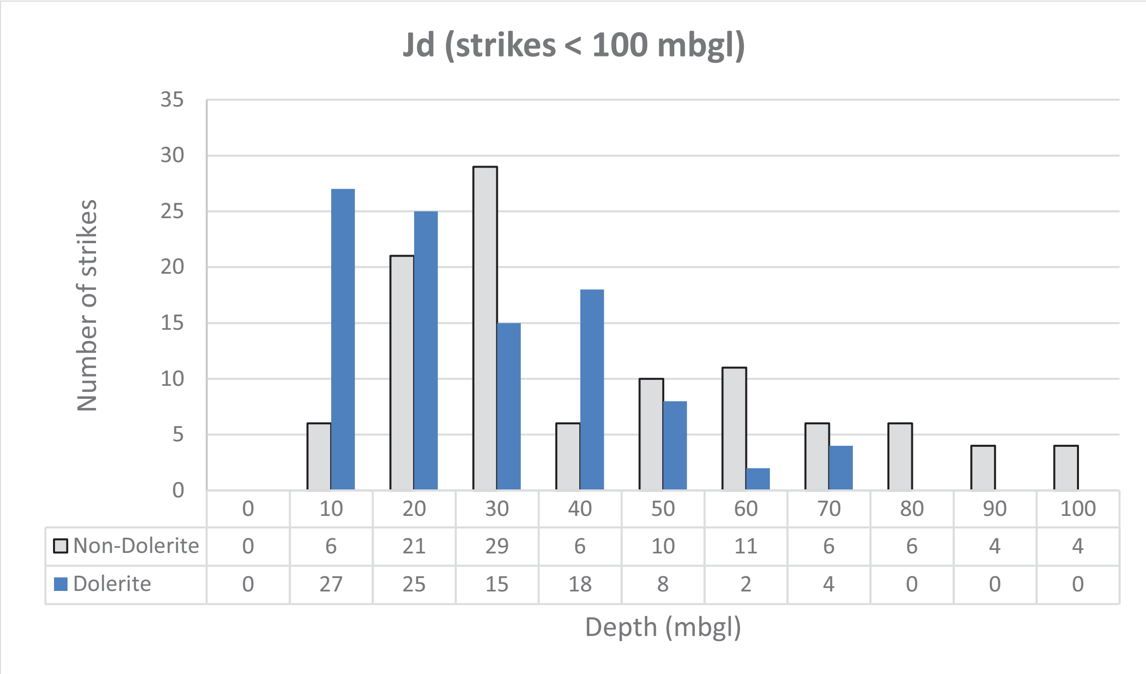
Figure 43: Pvo cumulative strike frequency graph

3.9 Water Strikes and Dyke Structures

In this section the no water strikes in dykes compared to the surrounding geologies.

3.9.1 Jd Water Strikes

The number of water strikes with depth are shown in Figure 44. There are more water strikes in the dolerites at a depth of 40 m below surface.



	0	10	20	30	40	50	60	70	80	90	100
Non-Dolerite	0	6	21	29	6	10	11	6	6	4	4
Dolerite	0	27	25	15	18	8	2	4	0	0	0

Figure 44: Jd Water strike graph

3.9.2 Pa Water Strikes

The number of water strikes with depth are shown in Figure 45. At all depths there are less strikes in the dolerites.

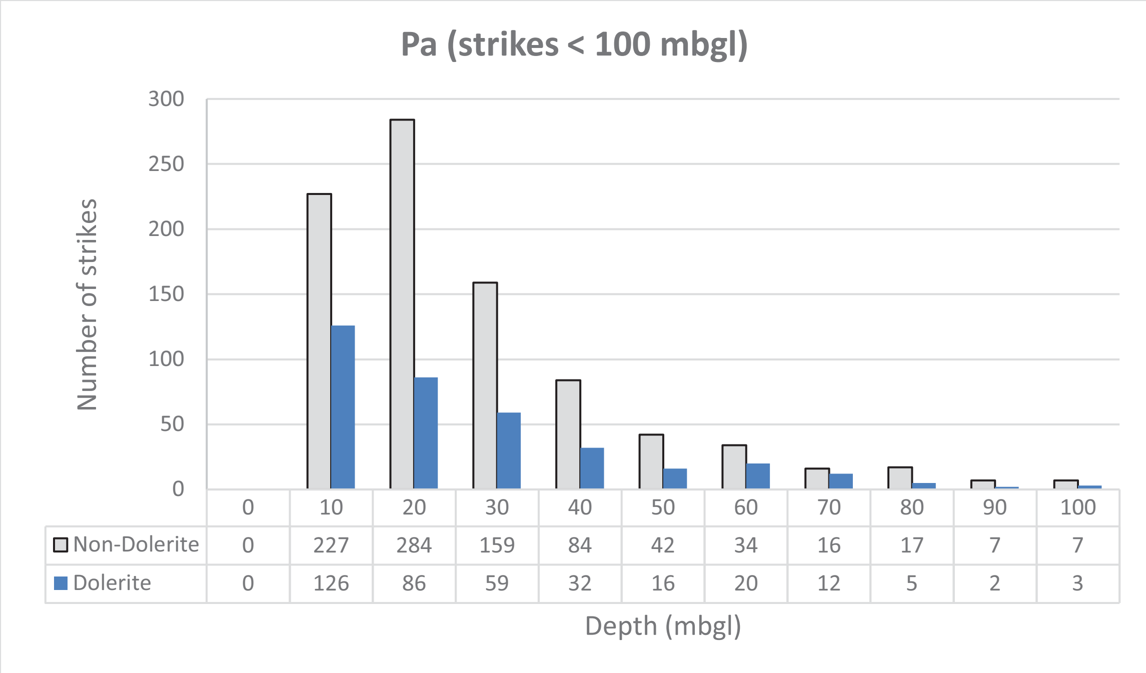


Figure 45: Pa Water strike graph

3.9.3 Pc Water Strikes

The number of water strikes with depth are shown in Figure 46. At 20 m below surface there are more water strikes in the dolerites.

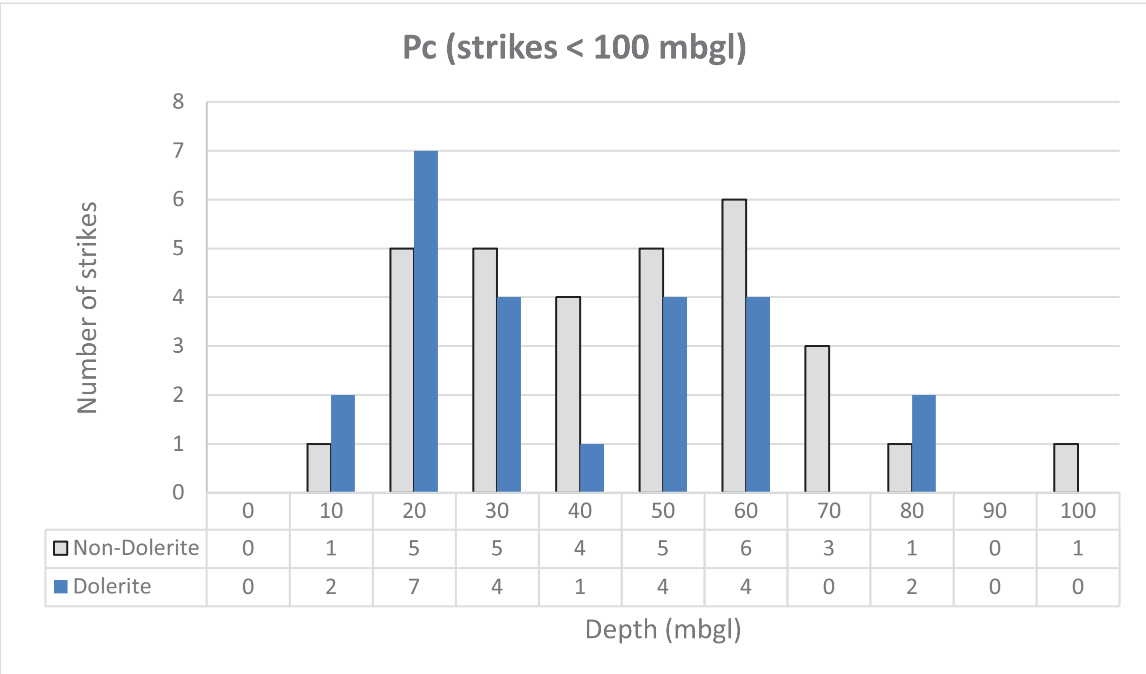


Figure 46: Pc Water strike graph

3.9.4 Pvo Water Strikes

The number of water strikes with depth are shown in Figure 47. At 50 m below surface there are more water strikes in the dolerites.

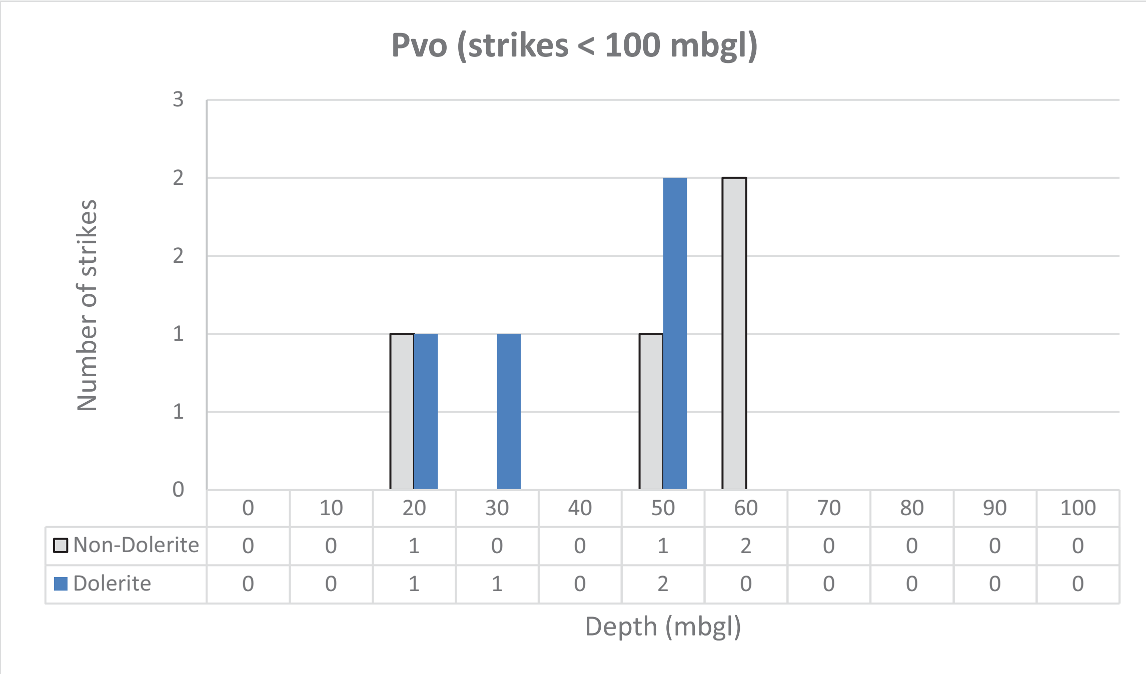
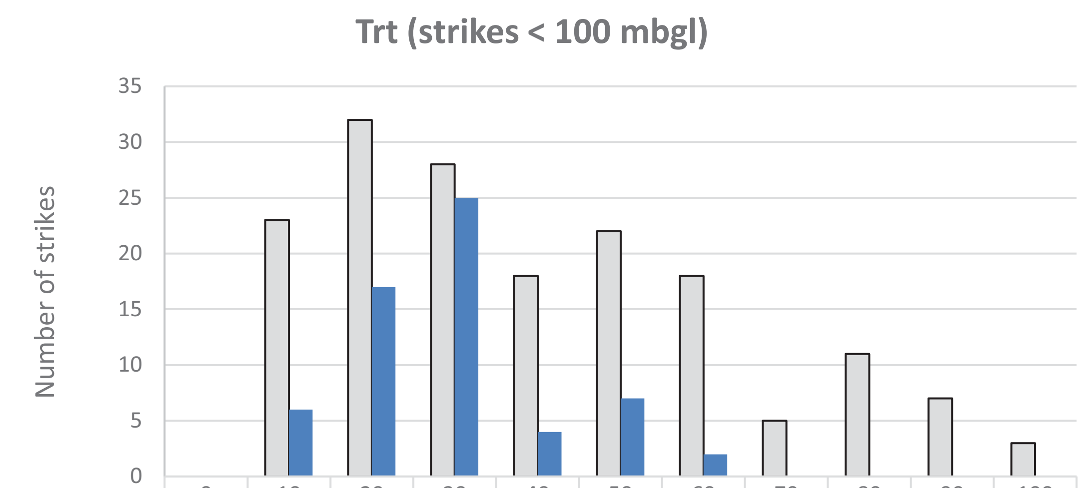


Figure 47: Pvo Water strike graph

3.9.5 Trt Water Strikes

The number of water strikes with depth are shown in Figure 48. At all depths there are less strikes in the dolerites.



	0	10	20	30	40	50	60	70	80	90	100
Non-Dolerite	0	23	32	28	18	22	18	5	11	7	3
Dolerite	0	6	17	25	4	7	2	0	0	0	0

Figure 48: Trt Water strike graph

3.10 Geophysical Methods

3.10.1 Magnetic Method

The magnetic method may be used to locate and trace dykes that are not exposed on the surface. These dykes are then targeted as water bearing structures. The aerial magnetic map shown in Figure 14 show little magnetic structures over the area and no information is available on the 1:50 000 geological maps of the area. It has also been shown in the previous section that the boreholes intersecting the dykes are not characterised as high yielding boreholes, making the magnetic method less attractive for borehole development.

3.10.2 Electrical Resistivity

Groundwater is found where weathering and fracturing extend to below the water level. The resistivity method of depth probing is eminently suited not only for determining the thickness of the weathered and fractured zone but also for obtaining an indication of the degree of weathering. By correlating statistically resistivity of the weathered zone with borehole success rate and yield, an optimal bandwidth of resistivity for siting boreholes may be determined statistically. Depth-determinations from resistivity probes rest on the assumption of a horizontally stratified earth which means that resistivity varies only in the vertical direction not laterally. As lateral resistivity changes affect depth probes in much the same manner as the vertical variations, it is essential to conduct resistivity surveys in such a manner that lateral variations are recognised and accounted for in depth interpretations. Due to the lack of weathering and fracture data in the study area the statistical analysis mentioned above may prove difficult.

3.10.3 Electromagnetic

In the absence of basins or troughs of weathering/fracturing one has to fall back on narrow zones of vertical and off-vertical fracturing for siting boreholes. In as far as these are not visible on the surface, electromagnetic methods have to be employed, as the resistivity method is not well suited for locating and tracing narrow two-dimensional conductive features.

4 Groundwater-Surface water interaction

4.1 Preamble (http://pubs.usgs.gov)

Groundwater is a major contributor to flow in many streams and rivers and has a strong influence on the health and diversity of aquatic and riparian ecosystems. Groundwater and surface water are interconnected and interdependent in almost all ecosystems.

The areal extent of groundwater-flow systems varies from a few square kilometres or less to tens of thousands of square kilometres. The length of groundwater-flow paths ranges from a few metres to tens, and sometimes hundreds of kilometres. A deep groundwater-flow system with long flow paths between areas of recharge and discharge may be overlain by and in hydraulic connection with, several shallow, more local, flow systems as seen in Figure 49.

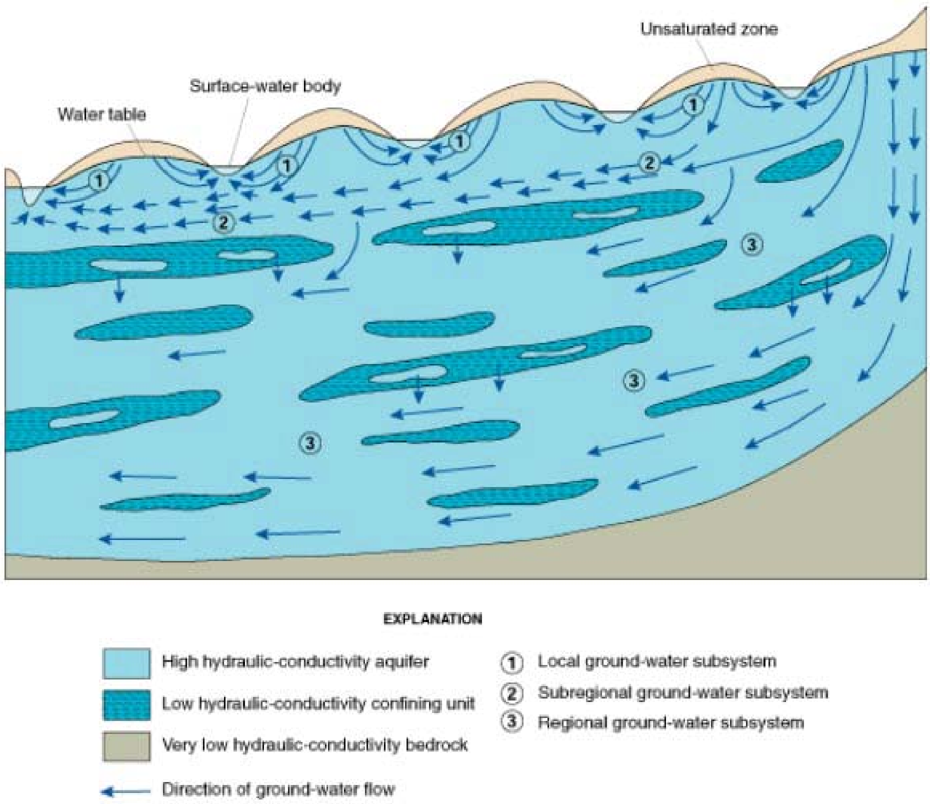


Figure 49: Groundwater flow systems (Source: http://pubs.usgs.gov)

Figure 49 shows a regional groundwater-flow system include (1) local groundwater subsystems in the upper water table aquifer that discharge to the nearest surface water bodies (lakes or streams) and are separated by groundwater divides beneath topographically high areas; (2) a sub-regional groundwater subsystem in the water table aquifer in which flow paths originating at the water table do not discharge into the nearest surface-water body but into a more distant one; and (3) a deep, regional groundwater-flow subsystem.

4.2 Groundwater-surface water interaction in quaternary catchments D61

4.2.1 Background

The quaternary catchments included in this area are D61A, D61B, D61C, D61D, D61E, D61F, D61H and D61L (see Figure 50). There are only a few towns including: Victoria West, Richmond, Deelfontein, Merriman, Hutchinson and Meltomwald. Basic information regarding the quaternary catchments are summarised in Table 6.

Figure 50: Location of D61 Catchments

Table 6: Basic information regarding quaternary catchments

Catchment	Area (km^2)	Rainfall (mm/a)	% no flow in rivers
D61A	1463.9	275	55
D61B	1196.4	272	57
D61C	1168.5	274	64
D61D	650.1	242	67
D61E	1089.6	231	67
D61F	872.9	204	72
D61G	743.3	216	70
D61H	1085.2	231	67
D61L	1014.5	270	60

4.2.2 Surface water

The 3 main river systems within the study area are the Klein Brak and Visgat Rivers which are tributaries of the Brak River and in the east is the Ongers River. The location of these rivers is shown in Figure 51.

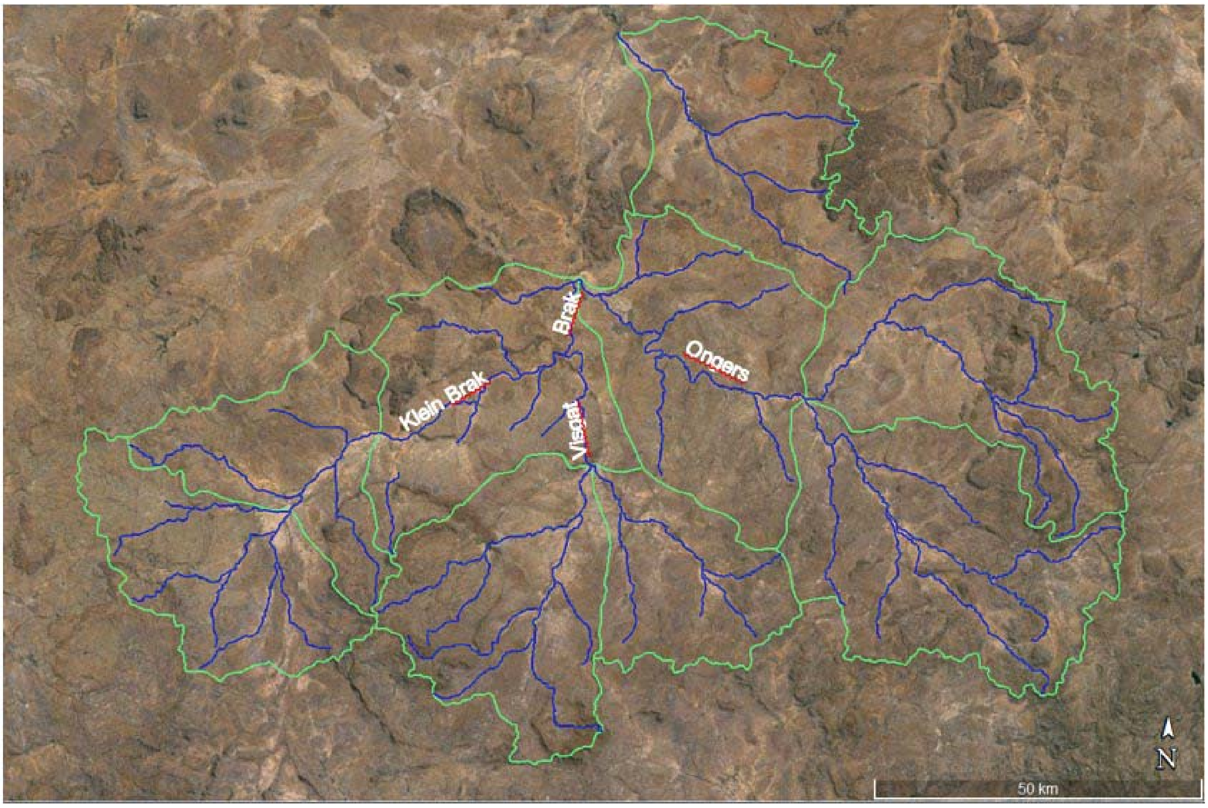


Figure 51: Location of rivers

4.2.3 Groundwater contribution to baseflow of rivers

The groundwater contribution to baseflow of rivers is calculated using the Herold method (Herold, 1980). The fitting curves are documented in Appendix B. The results are documented in Table 7.

Table 7: baseflow per catchment

Catchment	Calculated Baseflow (Mm^3/a)	Hughes Baseflow (Mm^3/a)	Pitman Baseflow (Mm^3/a)	Schultz Baseflow (Mm^3/a)
D61A	0.15	0	0	0
D61B	0.19	0	0	0
D61C	0.75	0	0	0
D61D	0.44	0	0	0
D61E	0.09	0	0	0
D61F	0.05	0	0	0
D61G	0.05	0	0	0
D61H	0.09	0	0	0
D61L	0.02	0	0	0

4.3 Groundwater-surface water interaction in quaternary catchments D62

4.3.1 Background

The quaternary catchments included in this area are D62C and D62D (see Figure 52). There are no towns within the area. Basic information regarding the quaternary catchments are summarised in Table 8.

Figure 52: location of D62 Catchments

Table 8: Basic information regarding quaternary catchments

Catchment	Area (km^2)	Rainfall (mm/a)	% no flow in rivers
D62C	2126	278	54
D62D	2396.8	299	51

4.3.2 Surface water

The 2 main river systems within the study area are the Brak and Elandsfontein Rivers. The location of these rivers is shown in Figure 53.

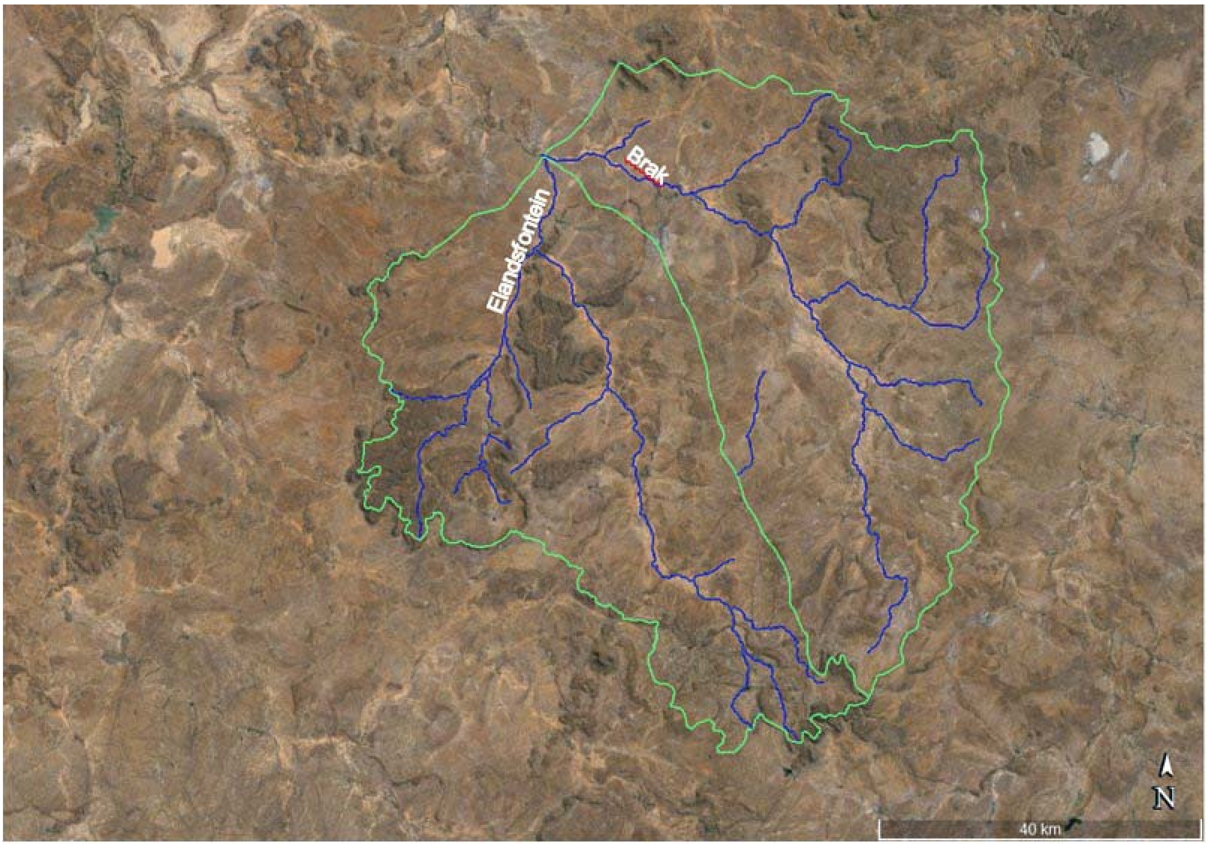


Figure 53: Location of rivers

4.3.3 Groundwater contribution to baseflow of rivers

The groundwater contribution to baseflow of rivers is calculated using the Herold method (Herold, 1980). The fitting curves are documented in Appendix B. The results are documented in Table 9.

Table 9: baseflow per catchment

Catchment	Calculated Baseflow (Mm^3/a)	Hughes Baseflow (Mm^3/a)	Pitman Baseflow (Mm^3/a)	Schultz Baseflow (Mm^3/a)
D62C	0.21	0	0	0
D62D	0.36	0	0	0

4.4 Groundwater-surface water interaction in quaternary catchments D32

4.4.1 Background

The quaternary catchments included in this area are D32A, D32B, D32C, D32D, D32E, D32F, D32H, D32J and D32K (see Figure 54). There are only a few towns including Hanover and Noupoort. Basic information regarding the quaternary catchments are summarised in Table 10.

Figure 54: Location of D32 Catchments

Table 10: Basic information regarding quaternary catchments

Catchment	Area (km^2)	Rainfall (mm/a)	% no flow in rivers
D32A	714.7	314	54
D32B	580.9	341	52
D32C	849	316	53
D32D	849.6	312	54
D32E	1155.2	274	58
D32F	1441.2	305	51
D32G	1043.9	330	49
D32H	571.8	328	53
D32J	1112.5	315	51
D32K	823.4	324	52

4.4.2 Surface water

The 3 main river systems within the study area are the Seekoei, Elandskloof and Klein Seekoei Rivers. The location of these rivers is shown in Figure 55.

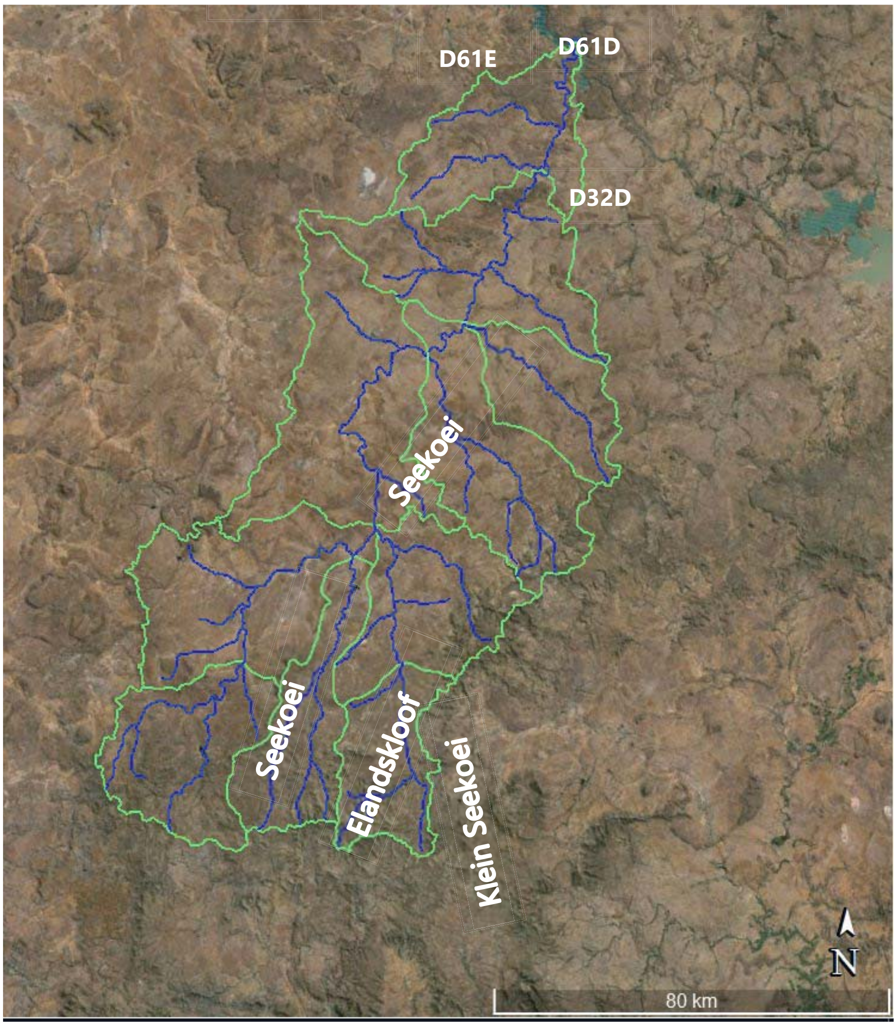


Figure 55: Location of rivers

4.4.3 Groundwater contribution to baseflow of rivers

The groundwater contribution to baseflow of rivers is calculated using the Herold method (Herold, 1980). The fitting curves are documented in Appendix B. The results are documented in Table 11.

Table 11: baseflow per catchment

Catchment	Calculated Baseflow (Mm^3/a)	Hughes Baseflow (Mm^3/a)	Pitman Baseflow (Mm^3/a)	Schultz Baseflow (Mm^3/a)
D32A	0.13	0	0	0
D32B	0.16	0	0	0
D32C	0.17	0	0	0
D32D	0.16	0	0	0
D32E	0.12	0	0	0
D32F	0.22	0	0	0
D32G	0.23	0	0	0
D32H	0.12	0	0	0
D32J	0.19	0	0	0
D32K	0.15	0	0	0

4.5 Groundwater-surface water interaction in quaternary catchments D31

4.5.1 Background

The quaternary catchments included in this area are D31B, D31E and D31C (see Figure 56). The towns of Van der Kloof and Philipstown lies on the boundary of the study area. The Van der Kloof Dam is also located in the area. Basic information regarding the quaternary catchments are summarised in Table 12.

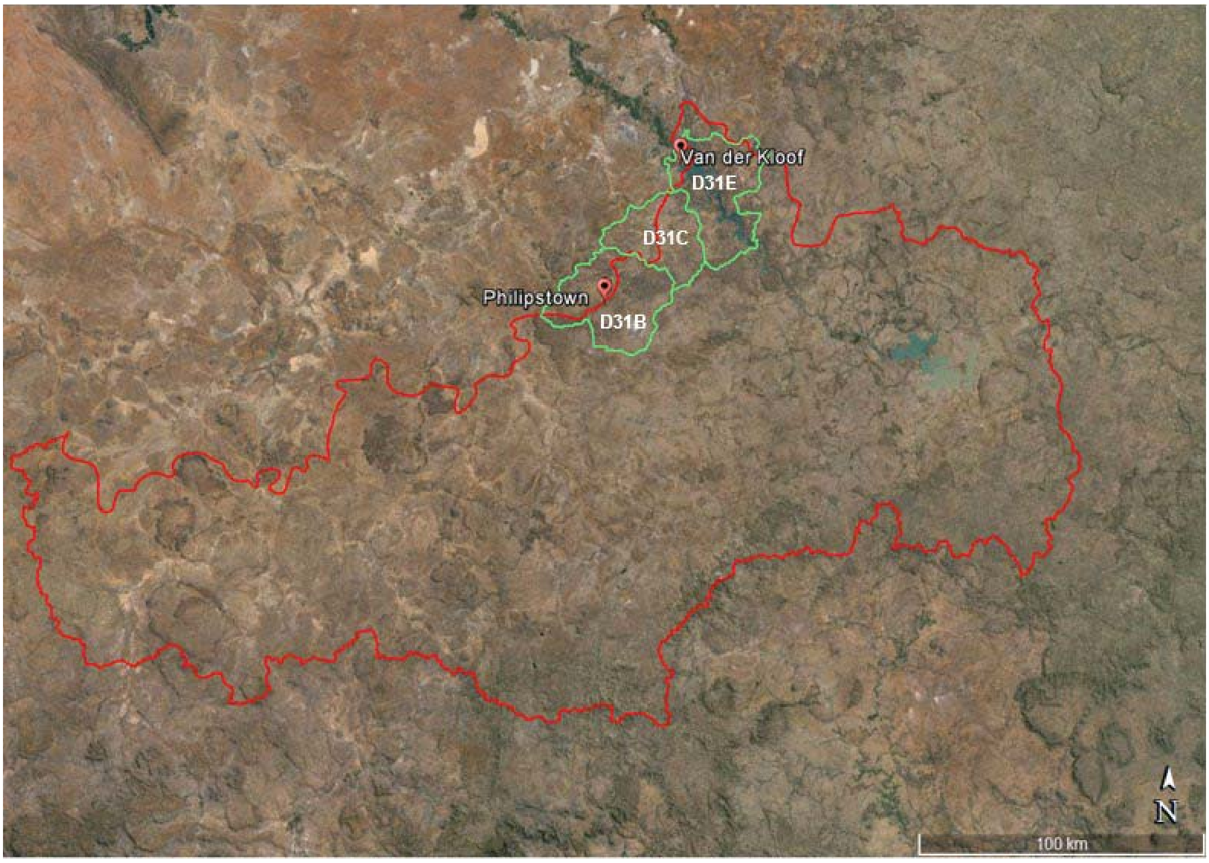


Figure 56: Location of D31 Catchments

Table 12: Basic information regarding quaternary catchments

Catchment	Area (km^2)	Rainfall (mm/a)	% no flow in rivers
D31B	994.9	314	52
D31C	676.2	328	53
D31D	968.4	353	48

4.5.2 Surface water

The 2 main river systems within the study area are the Orange and Hondeblaf Rivers. The location of these rivers is shown in Figure 57.

Figure 57: Location of rivers

4.5.3 Groundwater contribution to baseflow of rivers

The groundwater contribution to baseflow of rivers is calculated using the Herold method (Herold, 1980). The fitting curves are documented in Appendix B. The results are documented in Table 13.

Table 13: baseflow per catchment

Catchment	Calculated Baseflow (Mm^3/a)	Hughes Baseflow (Mm^3/a)	Pitman Baseflow (Mm^3/a)	Schultz Baseflow (Mm^3/a)
D31B	0.15	0	0	0
D31C	0.16	0	0	0
D31E	0.33	0	0	0

4.6 Groundwater-surface water interaction in quaternary catchments D34

4.6.1 Background

The quaternary catchments included in this area are D34A, D34B, D34C, D34D, D34E, D34F, and D34G (see Figure 58). There are only a few towns including: Philippolis, Waterkloof and Colesberg. The Gariep Dam is located on the eastern boundary. Basic information regarding the quaternary catchments are summarised in Table 14.

Figure 58: Location of D34 Catchments

Table 14: Basic information regarding quaternary catchments

Catchment	Area (km²)	Rainfall (mm/a)	% no flow in rivers
D34A	793.3	385	45
D34B	705.4	361	48
D34C	760	343	50
D34D	598.9	349	50
D34E	518.8	364	50
D34F	691.3	338	51
D34G	793.3	385	45

4.6.2 Surface water

The main river systems within the study area are the Oorlogspoort and Orange Rivers. The location of these rivers is shown in Figure 59.

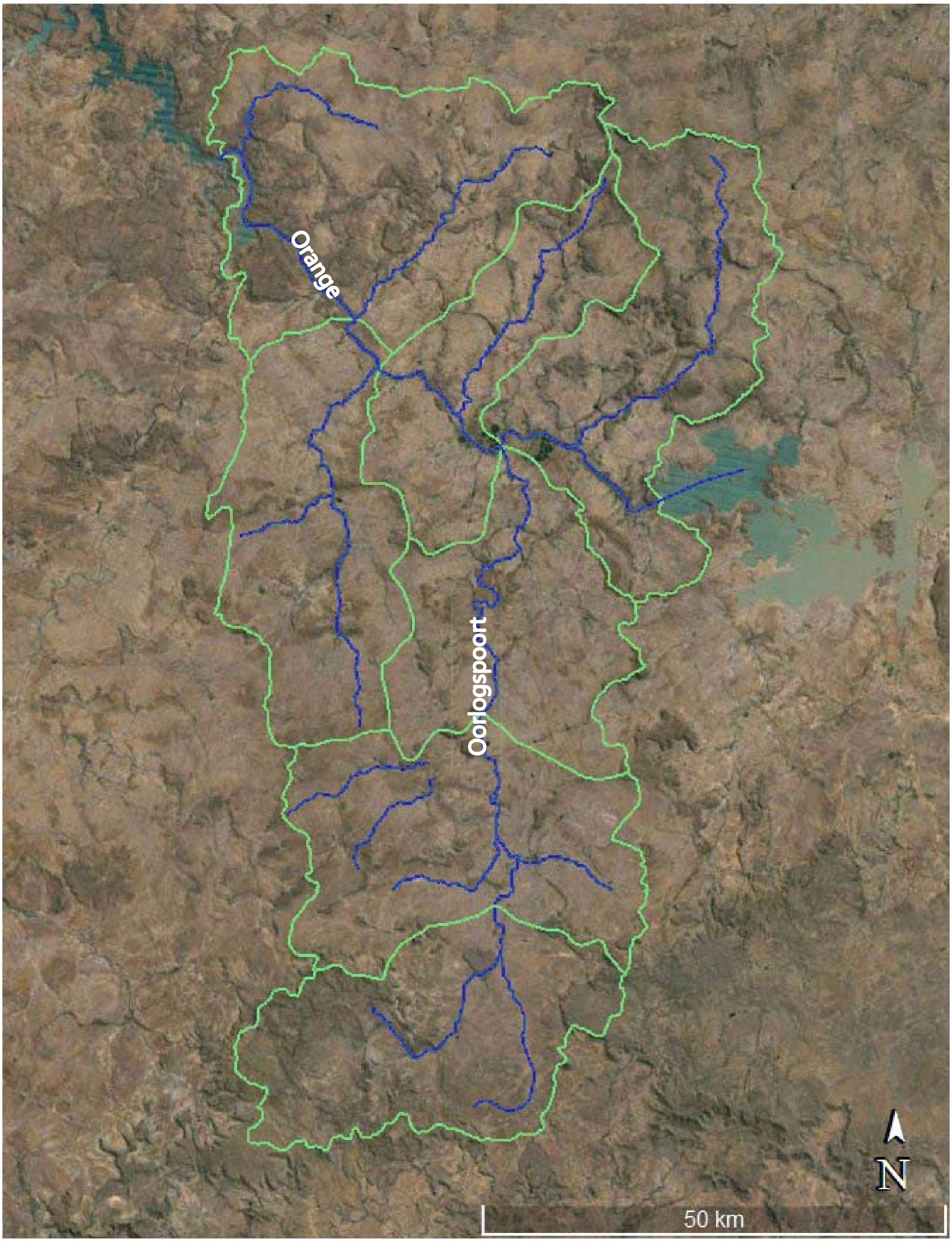


Figure 59: Location of rivers

4.6.3 Groundwater contribution to baseflow of rivers

The groundwater contribution to baseflow of rivers is calculated using the Herold method (Herold, 1980). The fitting curves are documented in Appendix B. The results are documented in Table 15.

Table 15: baseflow per catchment

Catchment	Calculated Baseflow (Mm^3/a)	Hughes Baseflow (Mm^3/a)	Pitman Baseflow (Mm^3/a)	Schultz Baseflow (Mm^3/a)
D34A	0.38	0.02	0	0
D34B	0.25	0	0	0
D34C	0.22	0	0	0
D34D	0.19	0	0	0
D34E	0.19	0	0	0
D34F	0.19	0	0	0
D34G	0.38	0.01	0	0

4.7 Groundwater-surface water interaction in quaternary catchments D35

4.7.1 Background

The quaternary catchments included in this area are D35A, D35B, D35C, D35D, D35E, D35F, D35G, D61H, D35J and D35K (see Figure 60). There are only a few towns including Springfontein, Bethulie and Venterstad. A large portion of the Gariep Dam falls within the area. Basic information regarding the quaternary catchments are summarised in Table 16.

Figure 60: Location of D35 Catchments

Table 16: Basic information regarding quaternary catchments

Catchment	Area (km^2)	Rainfall (mm/a)	% no flow in rivers
D35A	254.4	436	46
D35B	260.1	423	47
D35C	943	408	40
D35D	586.2	390	45
D35E	312	403	48
D35F	557.2	425	43
D35G	551.7	387	45
D35H	498.1	401	45
D35J	1001.1	371	43
D35K	674	385	45

4.7.2 Surface water

The 3 main river systems within the study area are the Orange, Broekspruit and Brakspruit Rivers. The location of these rivers is shown in Figure 61.

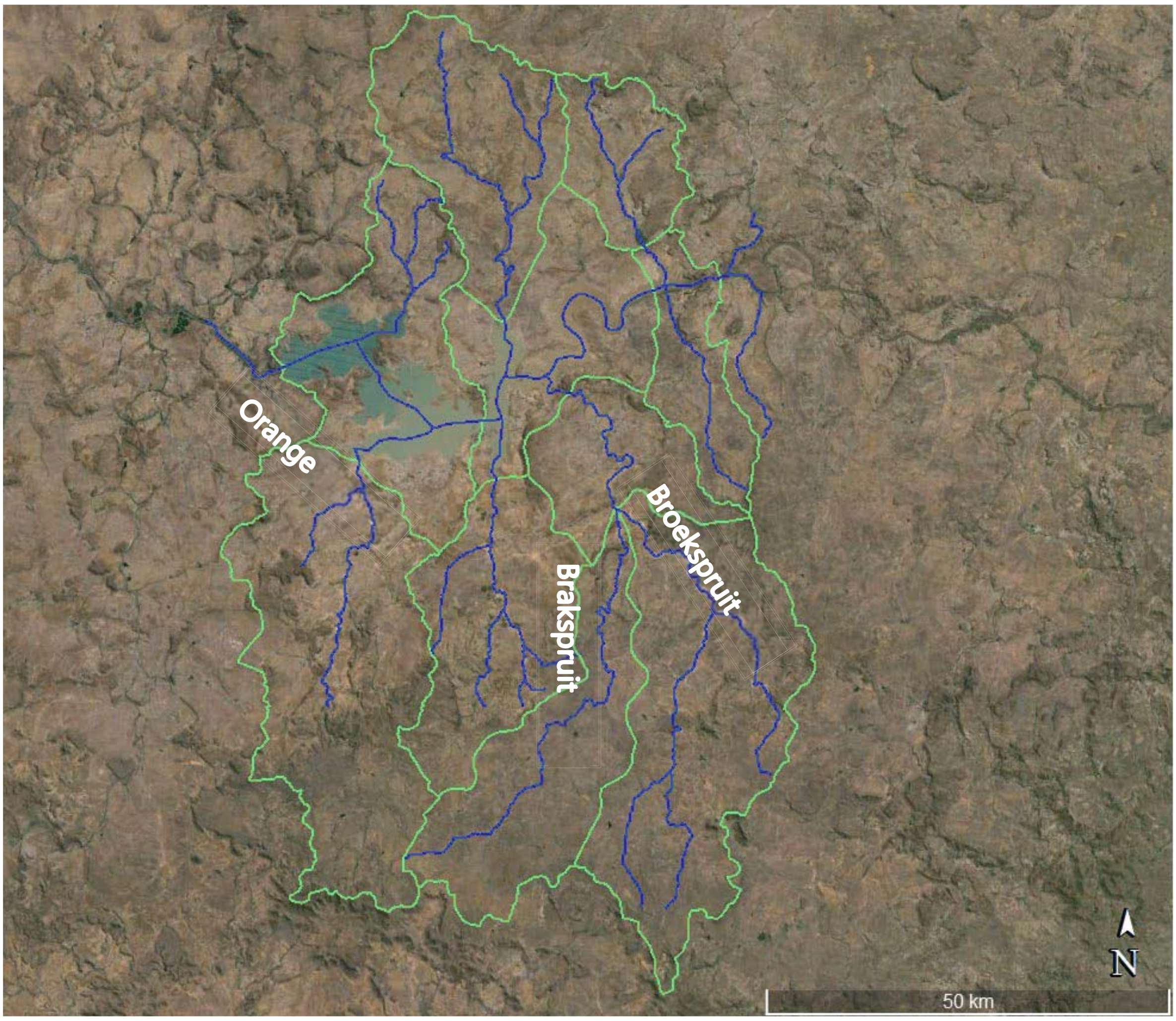


Figure 61: Location of rivers

4.7.3 Groundwater contribution to baseflow of rivers

The groundwater contribution to baseflow of rivers is calculated using the Herold method (Herold, 1980). The fitting curves are documented in Appendix B. The results are documented in Table 17.

Table 17: baseflow per catchment

Catchment	Calculated Baseflow (Mm^3/a)	Hughes Baseflow (Mm^3/a)	Pitman Baseflow (Mm^3/a)	Schultz Baseflow (Mm^3/a)
D35A	0.18	0	0	0
D35B	0.17	0	0	0
D35C	0.52	0.32	0	0
D35D	0.26	0.03	0	0
D35E	0.16	0	0	0
D35F	0.36	0.21	0	0
D35G	0.24	0.02	0	0
D35H	0.26	0	0	0
D35J	0.36	0.08	0	0
D35K	0.30	0	0	0

5 Quantification of water use, Water balance, Reserve and Aquifer stress

5.1 Preamble

Water use according to Chapter 4 of the National Water Act (1998) is defined as:

Water use is defined broadly, and includes taking and storing water, activities which reduce stream flow, waste discharges and disposals, controlled activities (activities which impact detrimentally on a water resource), altering a watercourse, removing water found underground for certain purposes, and recreation. In general, a water use must be licensed unless it is listed in Schedule I, is an existing lawful use, is permissible under a general authorisation, or if a responsible authority waives the need for a licence. The Minister may limit the amount of water which a responsible authority may allocate. In making regulations the Minister may differentiate between different water resources, classes of water resources and geographical areas.

For the purposes of this Act, water use includes:

- *(a) taking water from a water resource;*
- *(b) storing water;*
- *(c) impeding or diverting the flow of water in a watercourse;*
- *(d) engaging in a stream flow reduction activity contemplated in section 36;*
- *(e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);*
- *(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;*
- *(g) disposing of waste in a manner which may detrimentally impact on a water resource;*
- *(h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;*
- *(i) altering the bed, banks, course or characteristics of a watercourse;*
- *(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and*
- *(k) using water for recreational purposes.*

The Karoo is an arid region, highly dependent upon precarious groundwater supplies for drinking water, agriculture and other economic activities. Any contamination of this water resource will have a direct impact on people's lives, and thus great certainty is required before allow any process to interfere with groundwater supplies.

The groundwater use will also be quantified according to the Reserve calculations in the study area. According to the National Water Act (1998), Reserve is defined as:

Reserve means the quantity and quality of water required –

a) *to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No 108 of 1997), for people who are now or who will, in the reasonably near future, be –*

   relying upon;

   taking water from; or

   being supplied from,

   the relevant water resource; and

b) *to protect aquatic ecosystems in order to secure ecologically sustainable development and use the relevant water resource.*

The concept of stressed water resources is addressed by the NWA, but is not defined. Water quantity stress is where demands for water are approaching or exceed the available supply.

The groundwater stress index reflects water availability versus water used. Groundwater use should include water utilised by current water users, water required to sustain the Reserve as well as for basic human needs.

The Stress Index for an assessment area is defined as follows:

$$Stress = \frac{Groundwater\ use}{Recharge} x\ 100$$

The following section will address the current groundwater use, water balance, Reserve and aquifer stress per quaternary catchment.

5.2 Quaternary catchments D61

5.2.1 Water Use

The basic information for the study area is summarised Table 18.

Table 18: Basic Information concerning D61[1]

Catchment	Groundwater use (Mm^3/a)	Population	Evaporation (mm/a)	Current ecological class
D61A	0.24	4941	2100	B
D61B	0.07	0	2100	B
D61C	0.08	0	2100	B
D61D	4.13	0	2100	B
D61E	0.42	10485	2250	B
D61F	0.6	0	2250	B
D61G	0.05	-	2250	B
D61H	0.08	-	2250	B
D61L	0.07	-	2100	B

According to the Groundwater Reserve Directed Measures methodology every person is entitled to 25 l/d, making the total groundwater use for basic human needs 0.14 Mm^3/a. It is assumed that this value will remain constant throughout the year. Evapotranspiration varies monthly. The average monthly evapotranspiration figures calculated by Murray et al. (2011) are shown in Figure 62. One abstraction point for the area was recorded on the WARMS database (see Table 19).

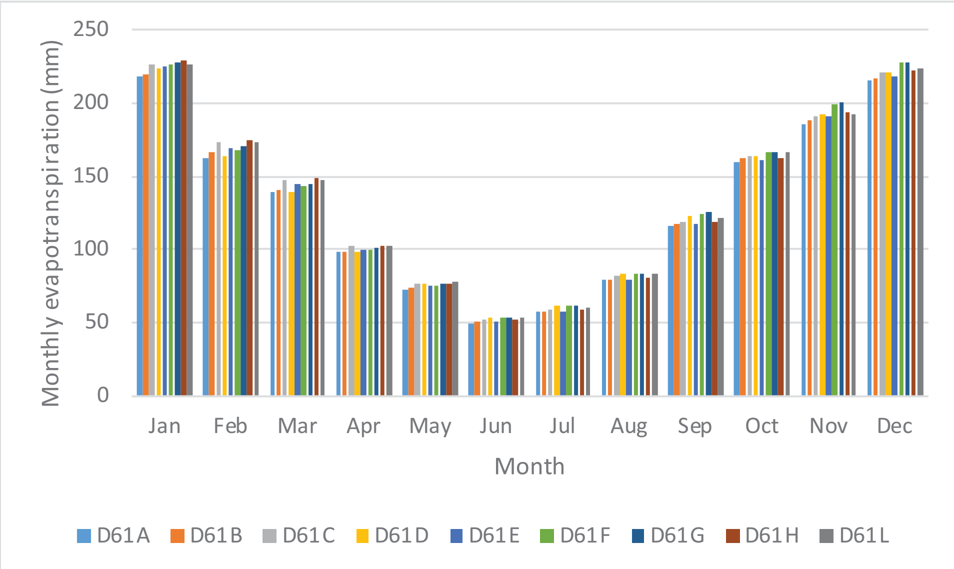


Figure 62: Average monthly evapotranspiration

[1] Obtained from Aquiworx database

Table 19: Additional groundwater use data

Catchment	Latitude	Longitude	Volume abstracted (m^3/a)
D61E	-31.24070	23.07078	311774

5.2.2 Water Balance and Groundwater Availability

The average monthly groundwater available for D61A is documented in Figure 63.

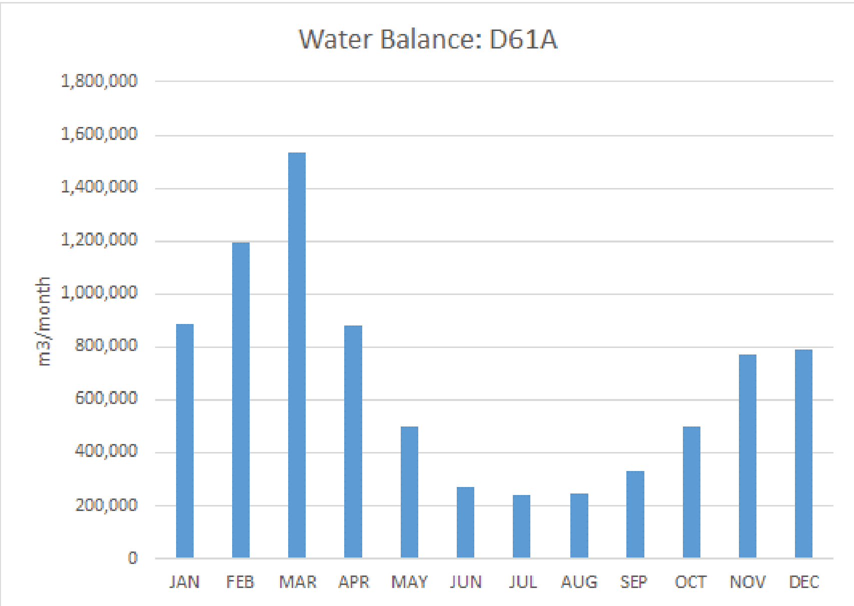


Figure 63: Average monthly groundwater available

The average monthly groundwater available for D61B is documented in Figure 64.

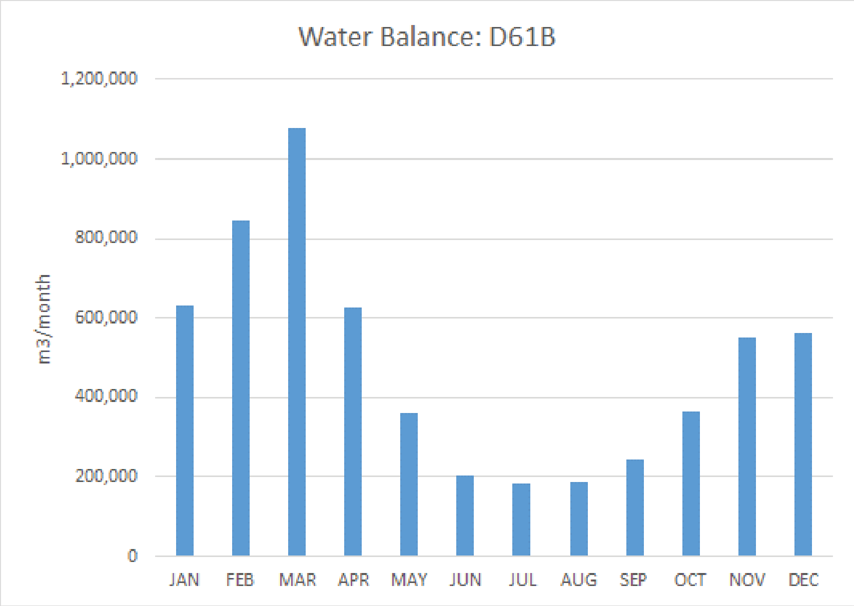


Figure 64: Average monthly groundwater available

The average monthly groundwater available for D61C is documented in Figure 65.

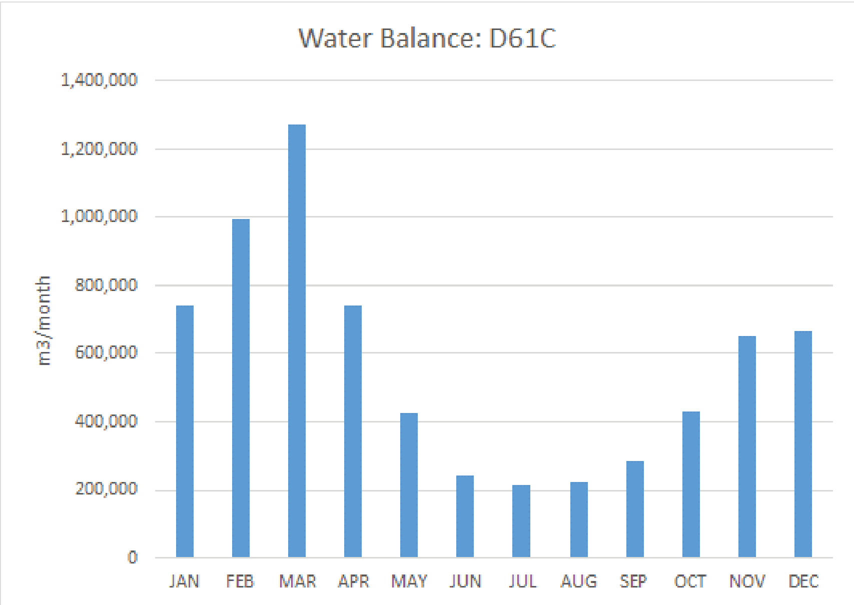


Figure 65: Average monthly groundwater available

The average monthly groundwater available for D61D is documented in Figure 66.

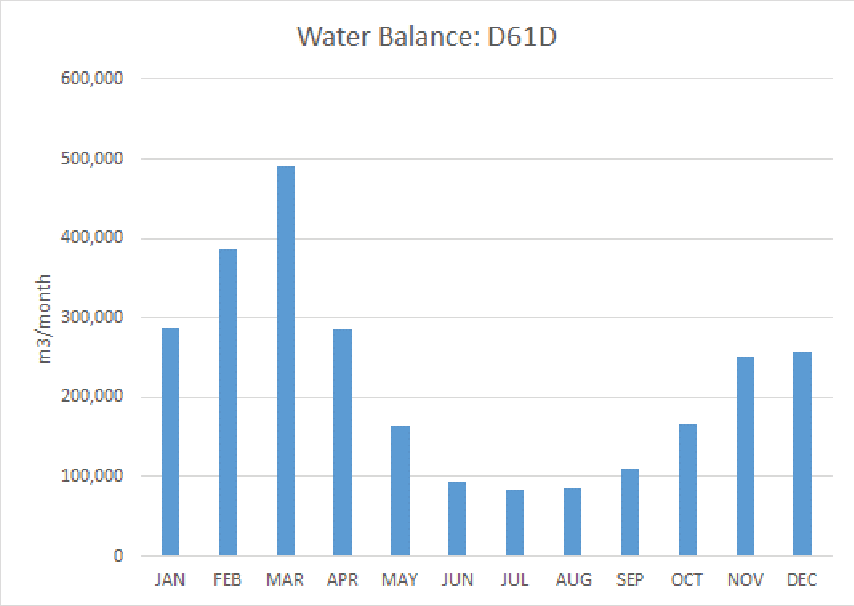


Figure 66: Average monthly groundwater available

The average monthly groundwater available for D61E is documented in Figure 67.

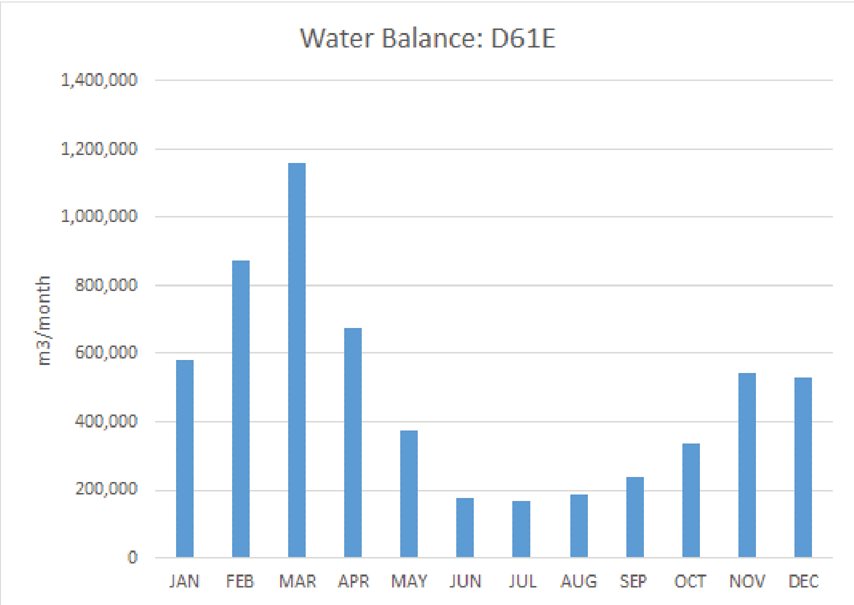


Figure 67: Average monthly groundwater available

The average monthly groundwater available for D61F is documented in Figure 68.

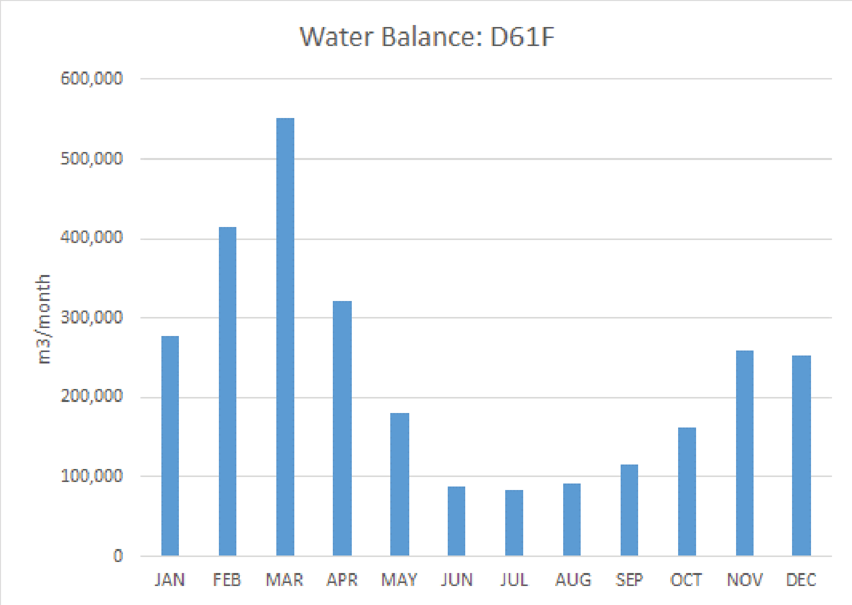


Figure 68: Average monthly groundwater available

The average monthly groundwater available for D61G is documented in Figure 69.

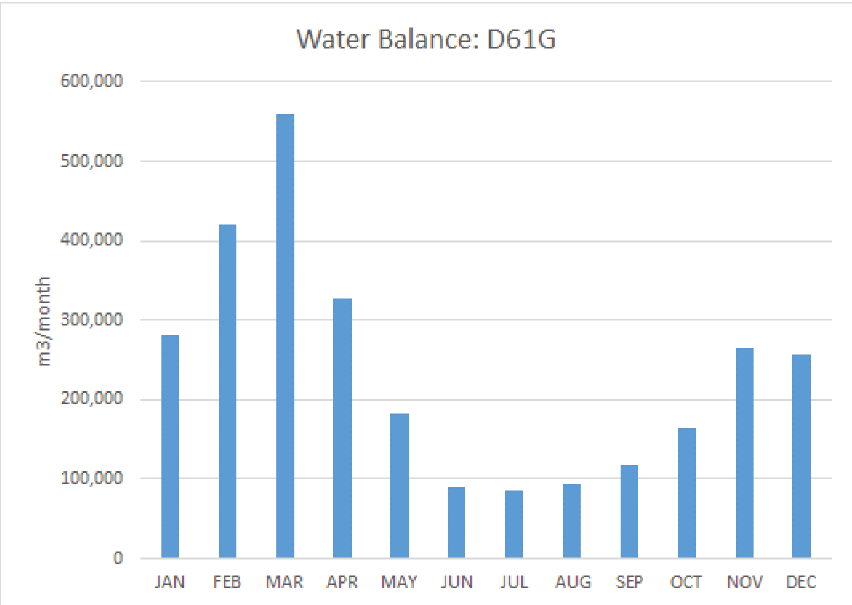


Figure 69: Average monthly groundwater available

The average monthly groundwater available for D61H is documented in Figure 70.

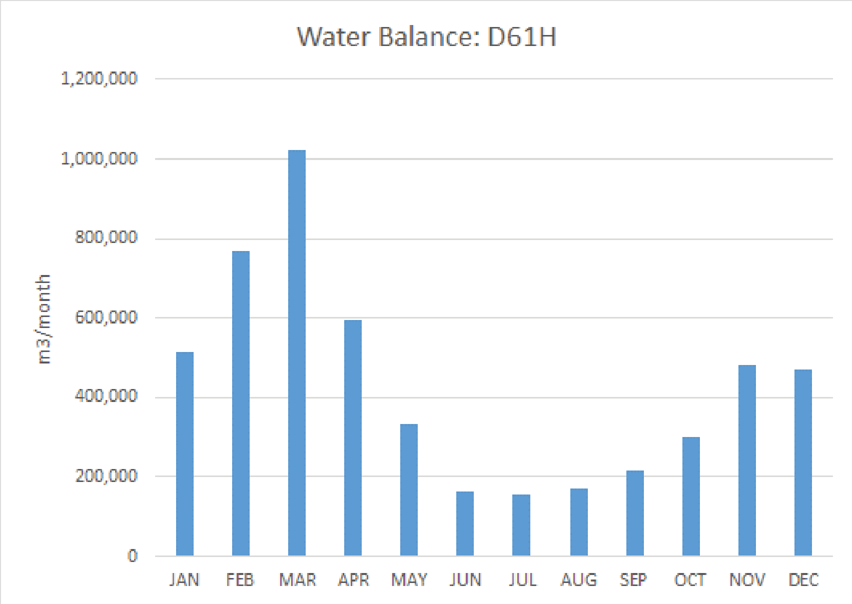


Figure 70: Average monthly groundwater available

The average monthly groundwater available for D61H is documented in Figure 71.

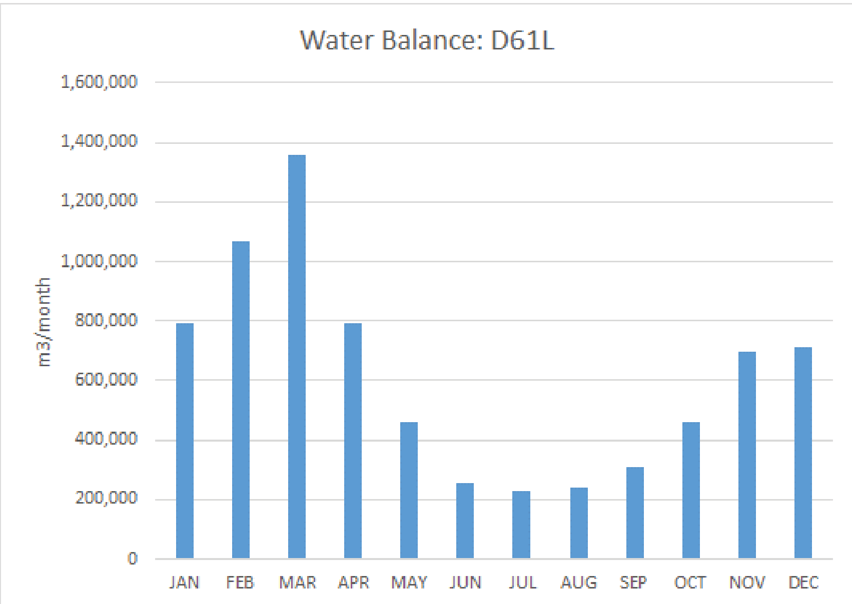


Figure 71: Average monthly groundwater available

5.2.3 Reserve

The average groundwater Reserve as expressed as a percentage of recharge for D61A s documented in Figure 72.

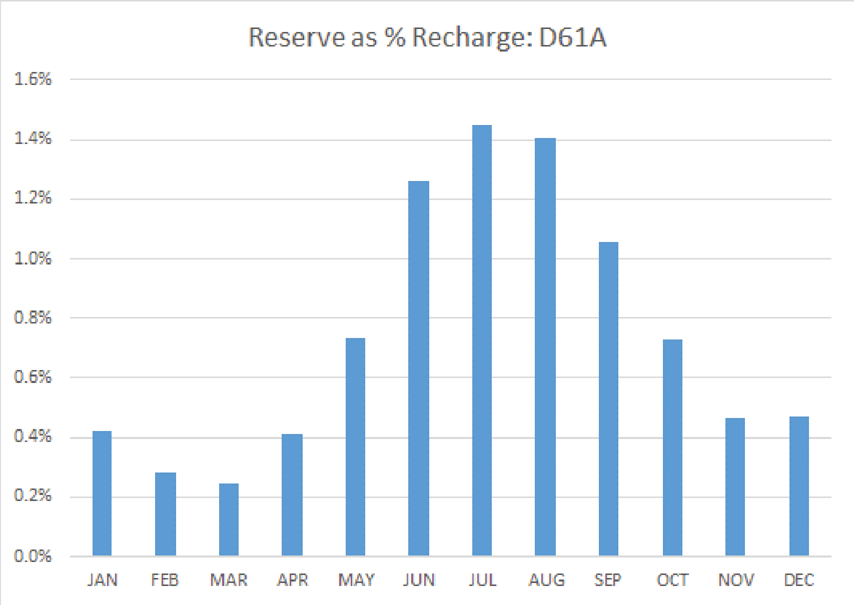


Figure 72: Reserve expressed as a percentage recharge

With current data the Reserve expressed as a percentage recharge for D61B is zero.

With current data the Reserve expressed as a percentage recharge for D61C is zero.

With current data the Reserve expressed as a percentage recharge for D61D is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D61E is documented in Figure 73.

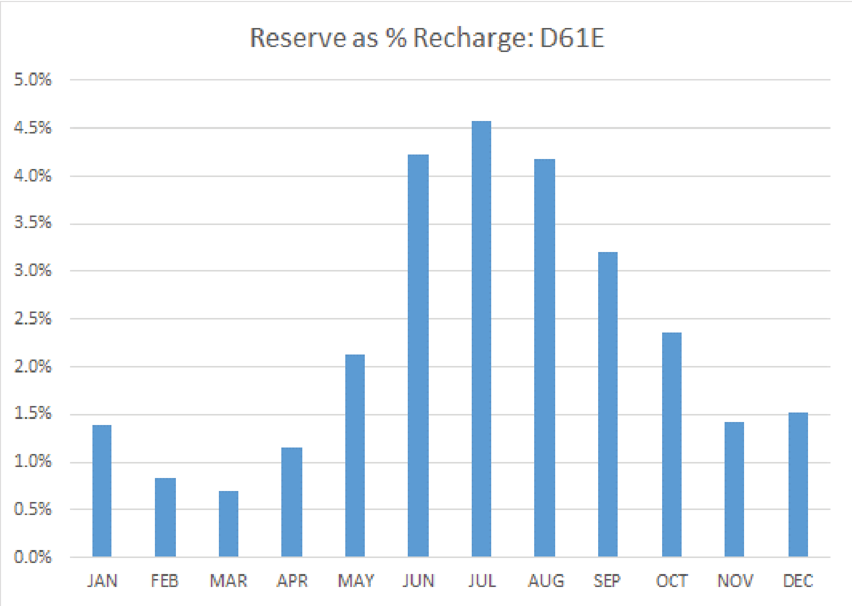


Figure 73: Reserve expressed as a percentage recharge

With current data the Reserve expressed as a percentage recharge for D61F is zero.

With current data the Reserve expressed as a percentage recharge for D61G is zero.

With current data the Reserve expressed as a percentage recharge for D61H is zero.

With current data the Reserve expressed as a percentage recharge for D61L is zero.

5.2.4 Groundwater Stress

The monthly stress index as defined by (WRC, 2013) for D61A is documented in Figure 74.

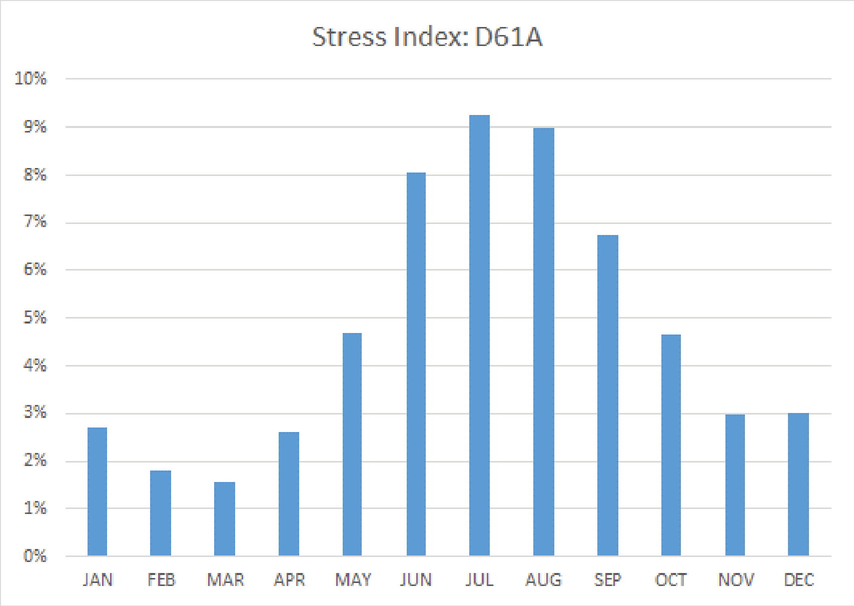


Figure 74: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61B is documented in Figure 75.

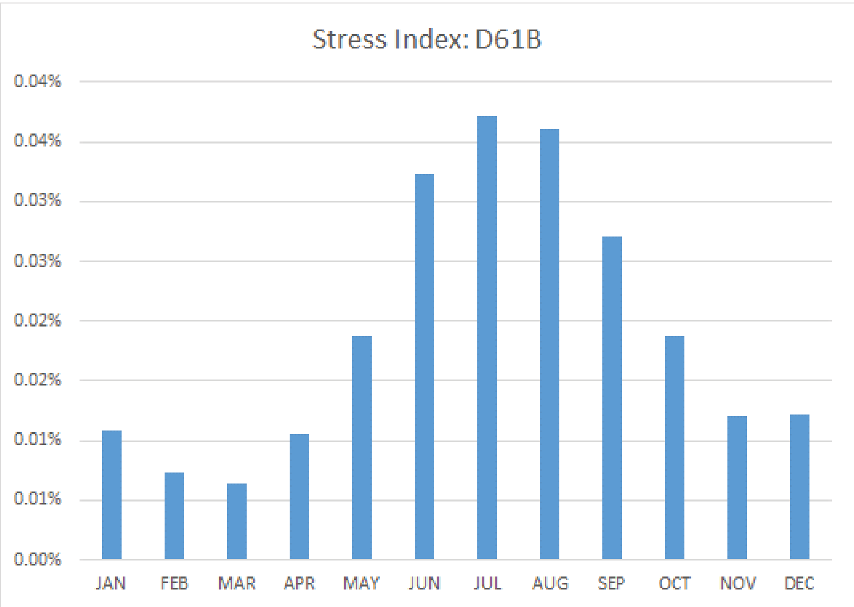


Figure 75: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61C is documented in Figure 76.

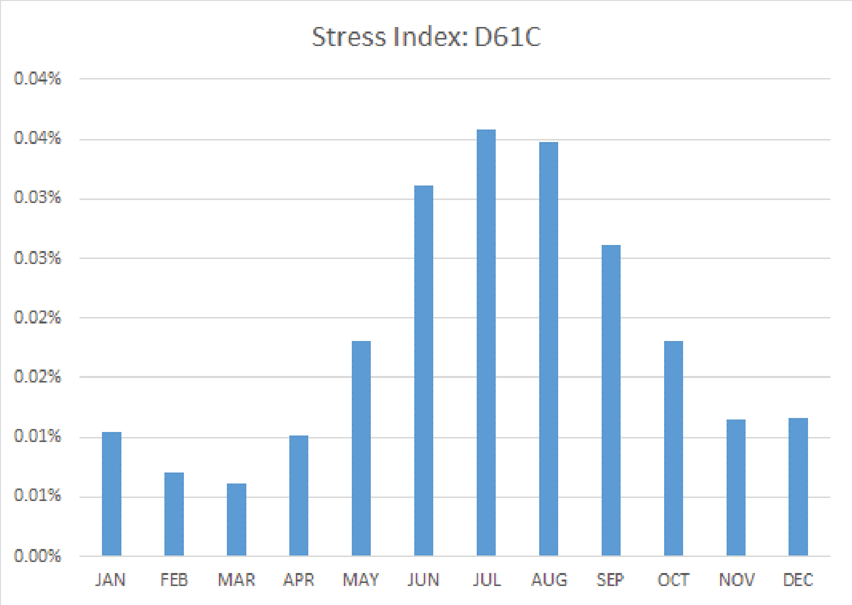


Figure 76: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61D is documented in Figure 77.

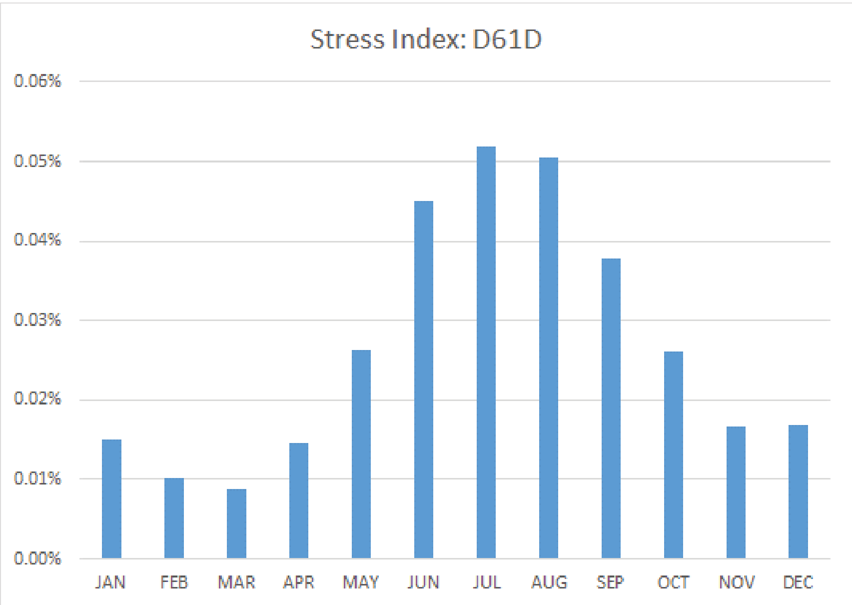


Figure 77: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61E is documented in Figure 78.

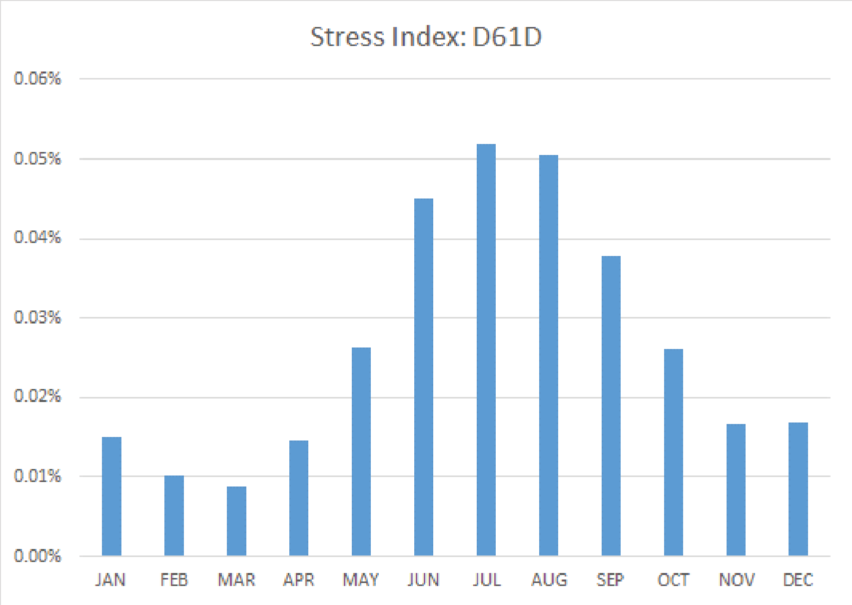


Figure 78: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61F is documented in Figure 79.

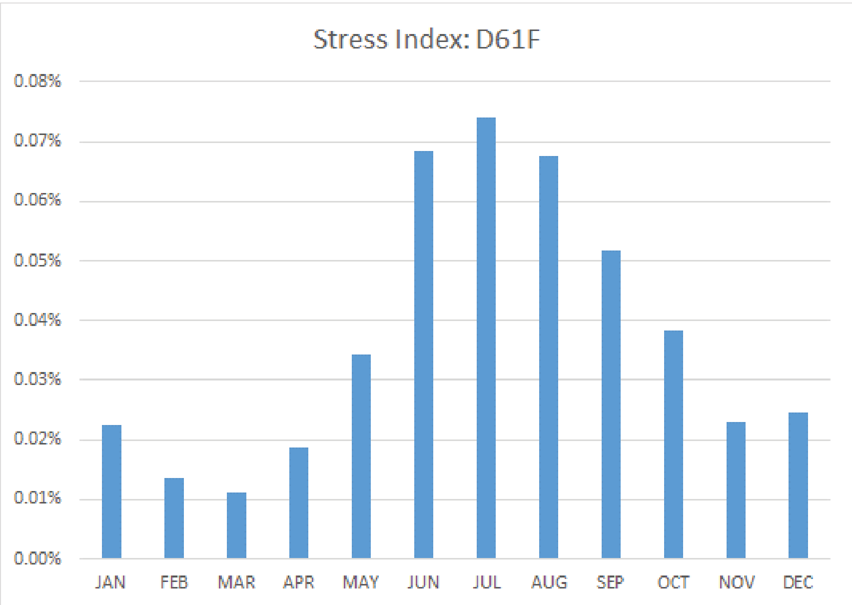


Figure 79: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61G is documented in Figure 80.

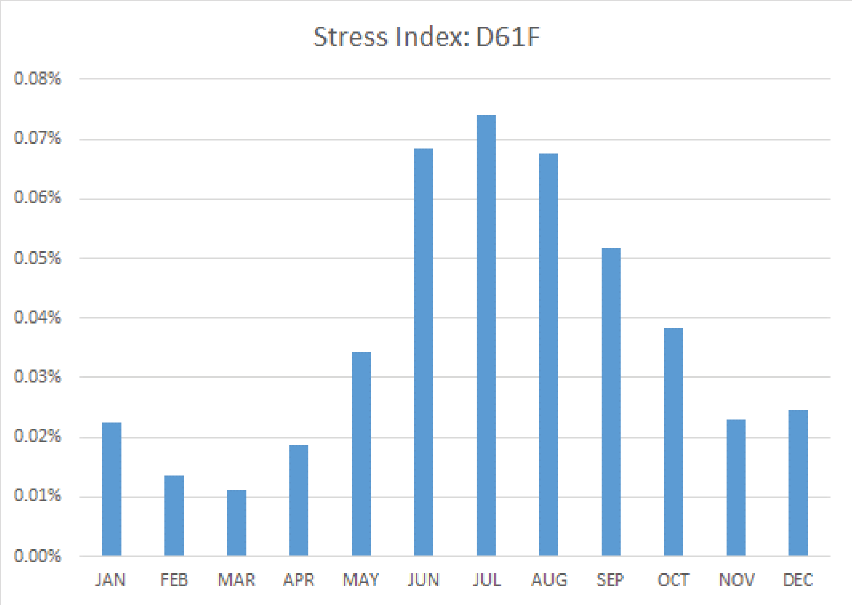


Figure 80: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61H is documented in Figure 81.

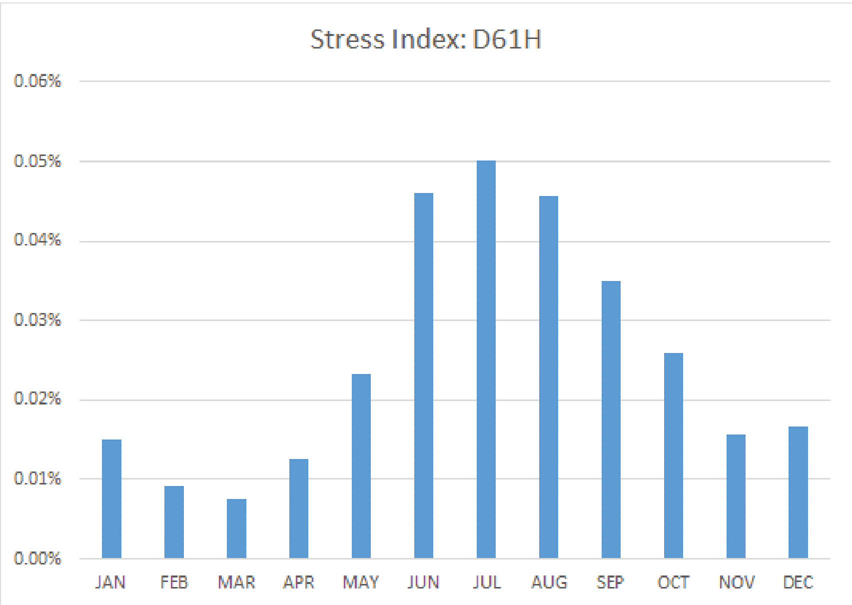


Figure 81: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D61L is documented in Figure 82.

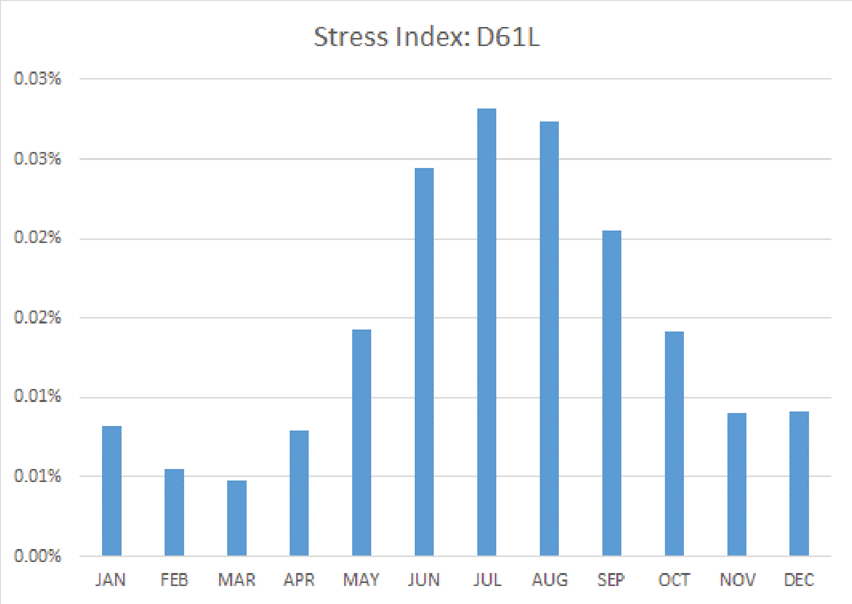


Figure 82: Monthly stress index

5.3 Quaternary catchments D62

5.3.1 Water Use

The basic information for the study area is summarised in Table 20.

Table 20: Basic Information concerning D62[2]

Catchment	Groundwater use (Mm^3/a)	Population	Evaporation (mm/a)	Current ecological class
D62C	7.46	0	2150.0	B
D62D	11.92	28981	2150.0	B

According to the Groundwater Reserve Directed Measures methodology every person is entitled to 25 l/d, making the total groundwater use for basic human needs 0.26 Mm^3/a. It is assumed that this value will remain constant throughout the year. Evapotranspiration varies monthly. The average monthly evapotranspiration figures calculated by Murray et al. (2011)

[2] Obtained from Aquiworx database

are shown in Figure 83. Two abstraction points for the area was recorded on the WARMS database (see Table 21).

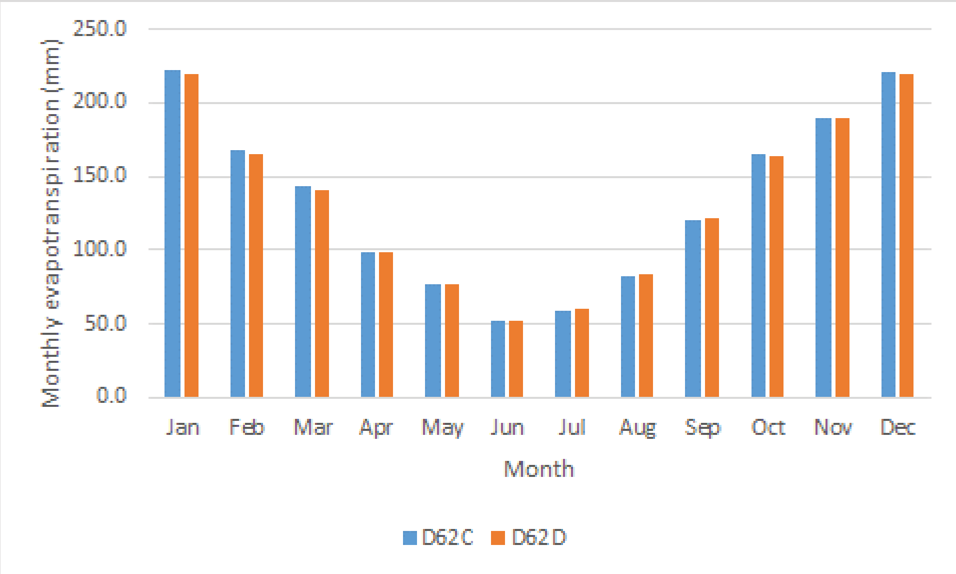


Figure 83: Average monthly evapotranspiration

Table 21: Additional groundwater use data

Catchment	Latitude	Longitude	Volume abstracted (m^3/a)
D62D	-30.64490	24.01143	2567248
D62D	-30.64660	24.01182	3000

5.3.2 Water Balance and Groundwater Availability

The average monthly groundwater available for D62C is documented in Figure 84.

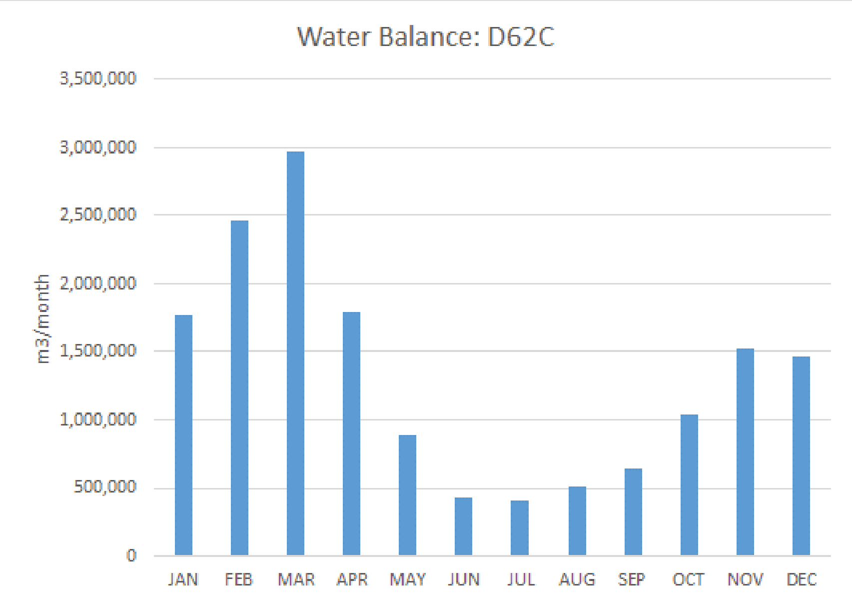


Figure 84: Average monthly groundwater available

The average monthly groundwater available for D62D is documented in Figure 85.

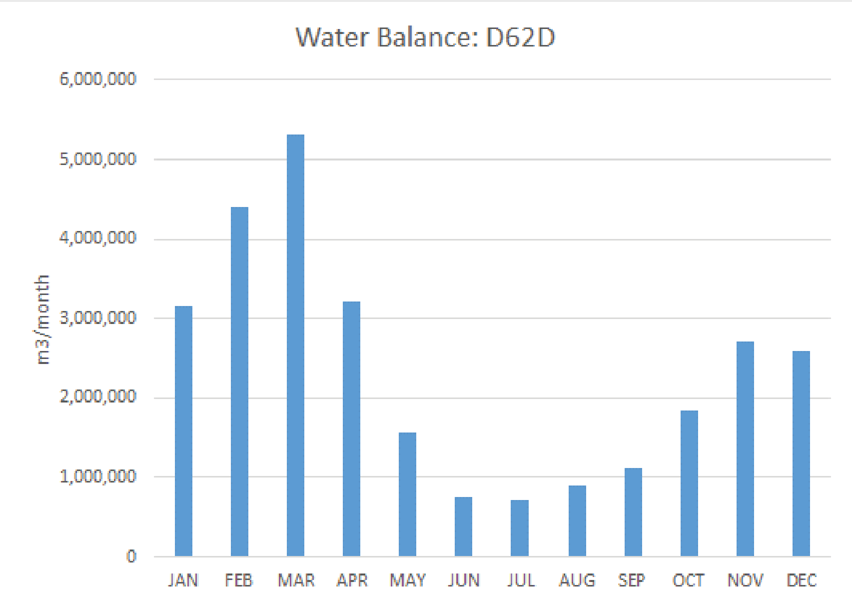


Figure 85: Average monthly groundwater available

5.3.3 Reserve

With current data the Reserve expressed as a percentage recharge for D62C is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D62D is documented in Figure 86.

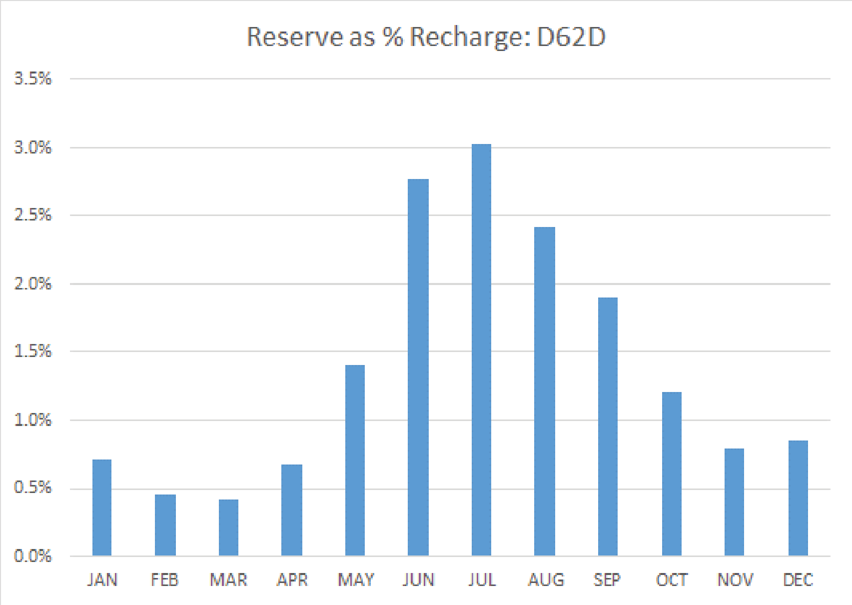


Figure 86: Reserve expressed as a percentage recharge

5.3.4 Groundwater Stress

The monthly stress index as defined by (WRC, 2013) for D62C is documented in Figure 87.

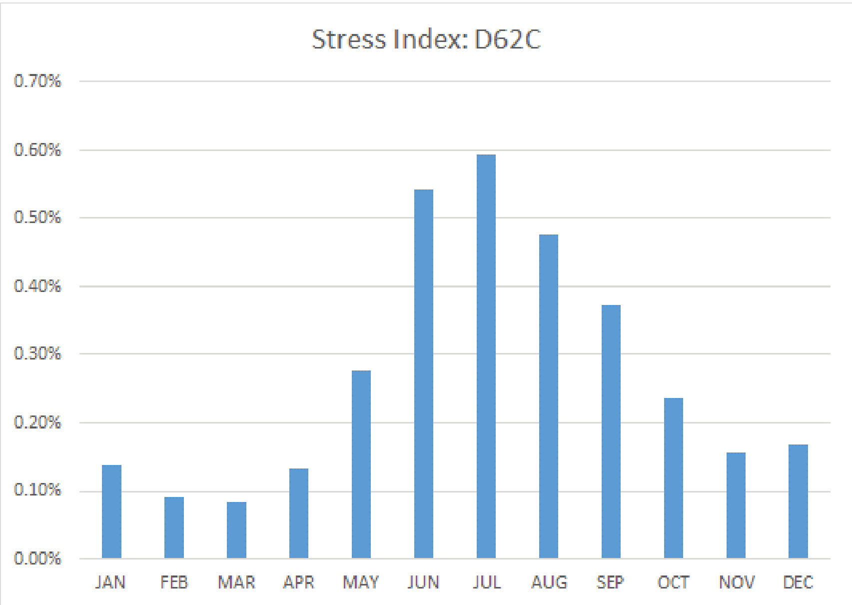


Figure 87: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D62D is documented in Figure 88.

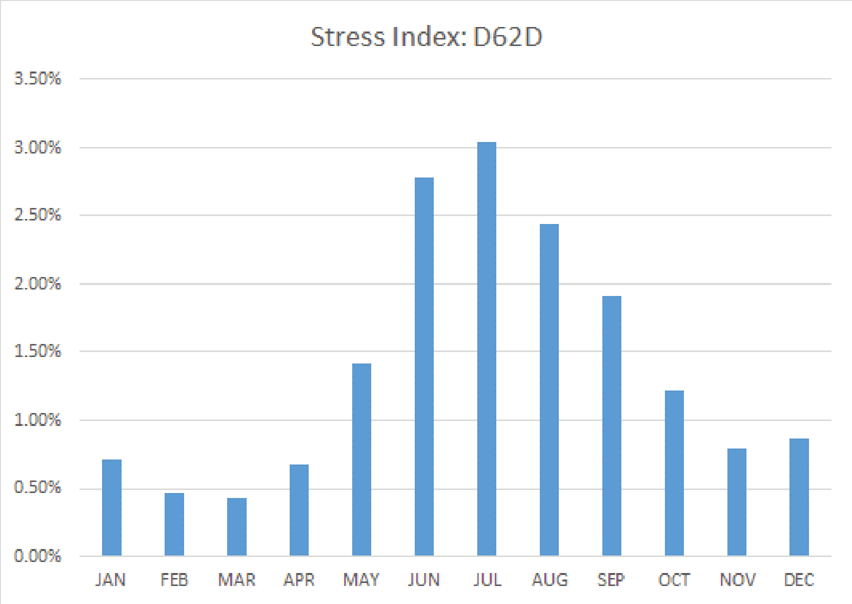


Figure 88: Monthly stress index

5.4 Quaternary catchments D32

5.4.1 Water Use

The basic information for the study area is summarised in Table 22.

Table 22: Basic Information concerning D32[3]

Catchment	Groundwater use (Mm^3/a)	Population	Evaporation (mm/a)	Current ecological class
D32A	0.05	0	1925	B
D32B	0.01	0	1925	B
D32C	0.41	0	1925	B
D32D	0.05	0	1925	B
D32E	0.1	0	1925	B
D32F	0.61	3846	1900	B
D32G	1.1	7934	1900	B
D32H	1.15	0	1900	B
D32J	3	0	1900	B
D32K	2.08	0	1900	E or F

[3] Obtained from Aquiworx database

According to the Groundwater Reserve Directed Measures methodology every person is entitled to 25 l/d, making the total groundwater use for basic human needs 0.11 Mm^3/a. It is assumed that this value will remain constant throughout the year. Evapotranspiration varies monthly. The average monthly evapotranspiration figures calculated by Murray et al. (2011) are shown in Figure 89. Six abstraction points for the area was recorded on the WARMS database (see Table 23).

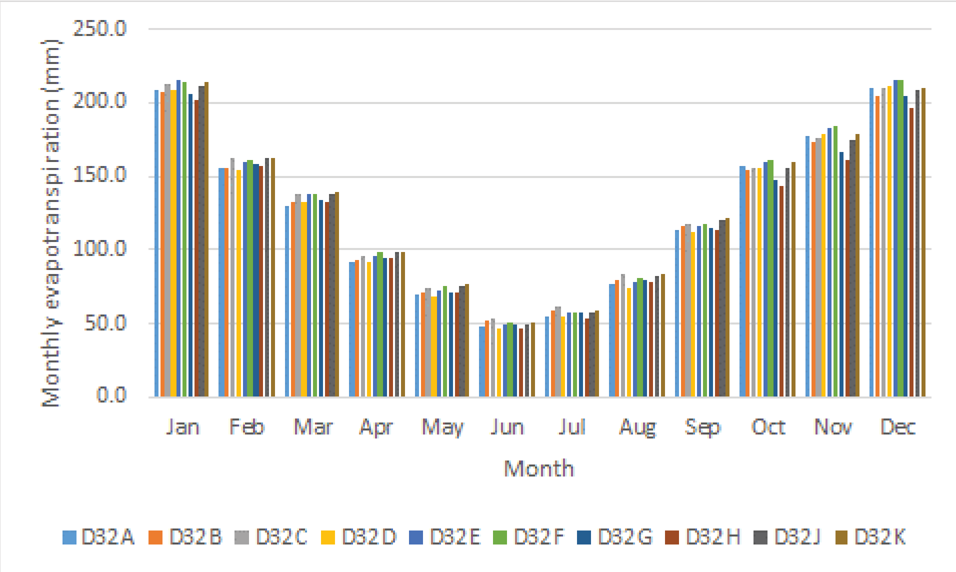


Figure 89: Average monthly evapotranspiration

Table 23: Additional groundwater use data

Catchment	Latitude	Longitude	Volume abstracted (m^3/a)
D32B	-31.46960	24.68259	6600[4]
D32F	-30.92100	24.50481	10920
D32F	-31.06680	24.43258	162344
D32G	-31.18680	24.95149	220000
D32G	-31.18680	24.95149	220000
D32G	-31.03020	24.73926	5200

[4] Spring

5.4.2 Water Balance and Groundwater Availability

The average monthly groundwater available for the catchment is documented in Figure 90.

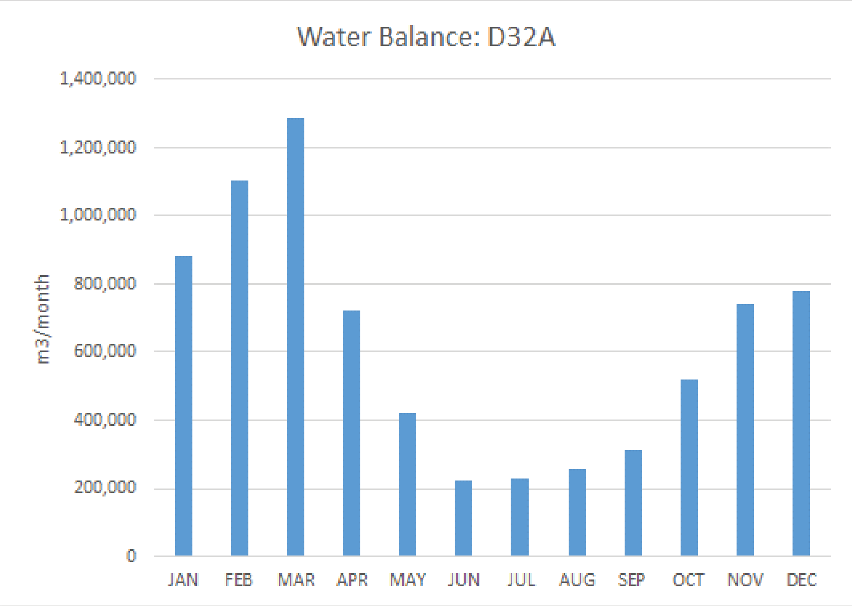


Figure 90: Average monthly groundwater available

The average monthly groundwater available for D32B is documented in Figure 91.

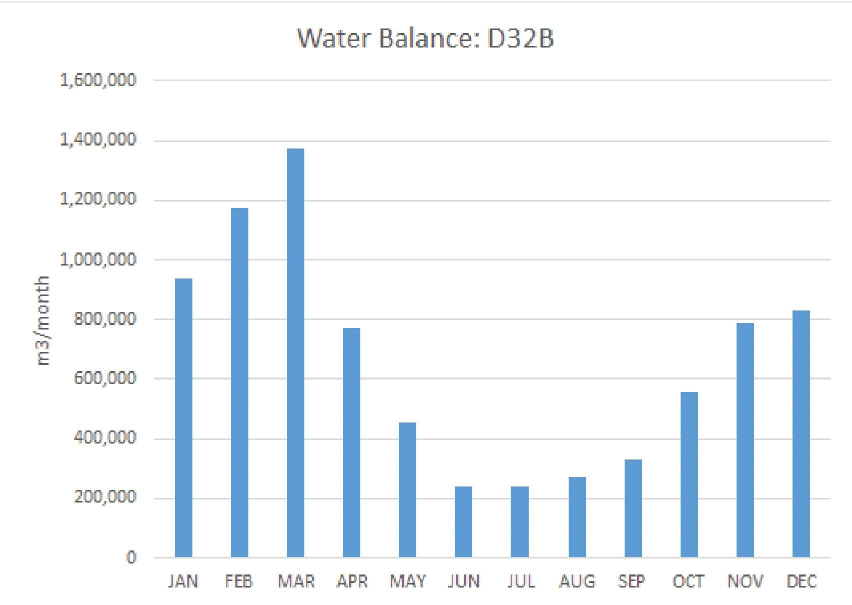


Figure 91: Average monthly groundwater available

The average monthly groundwater available for D32C is documented in Figure 92.

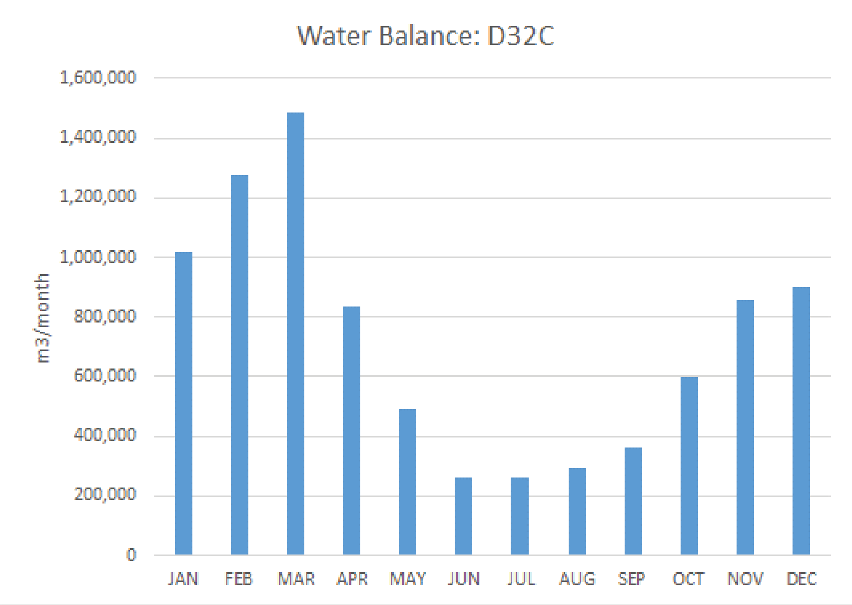


Figure 92: Average monthly groundwater available

The average monthly groundwater available for D32D is documented in Figure 93.

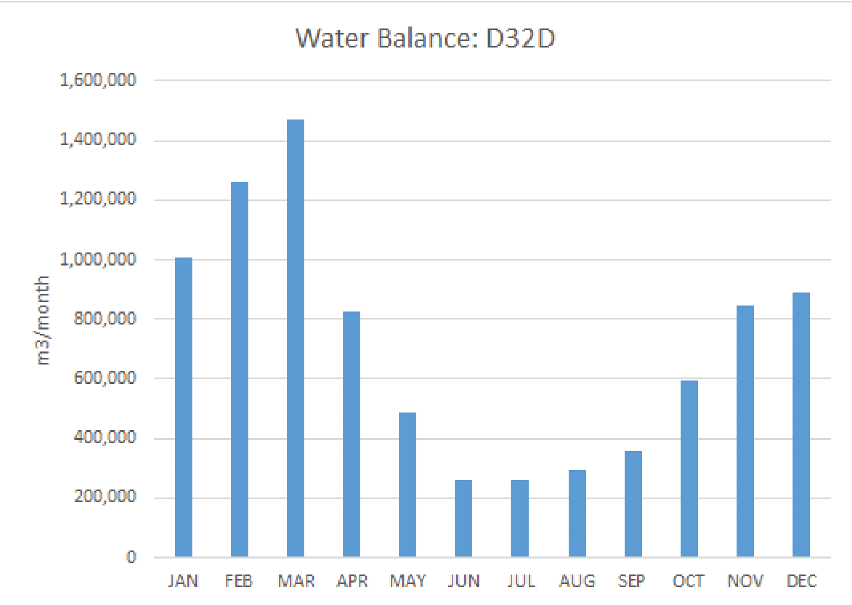


Figure 93: Average monthly groundwater available

The average monthly groundwater available for D32E is documented in Figure 94.

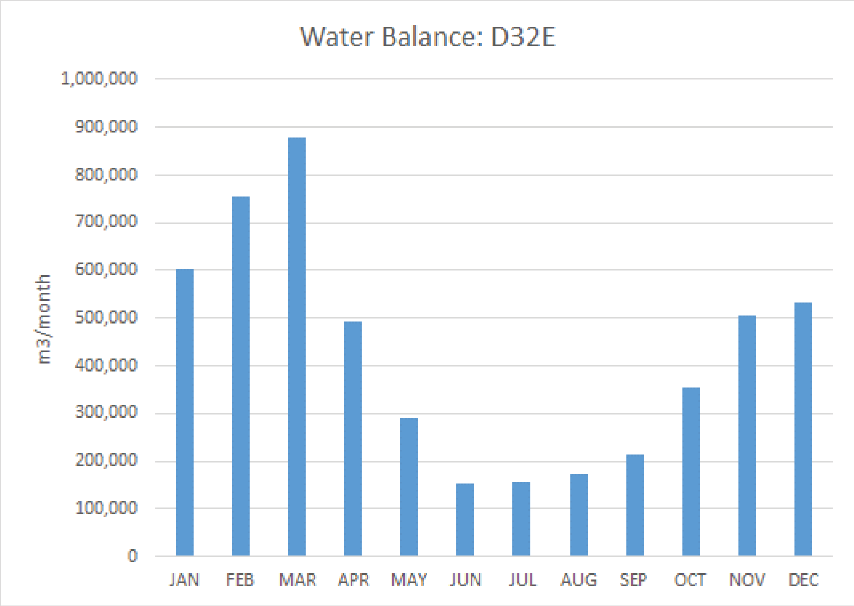


Figure 94: Average monthly groundwater available

The average monthly groundwater available for D32F is documented in Figure 95.

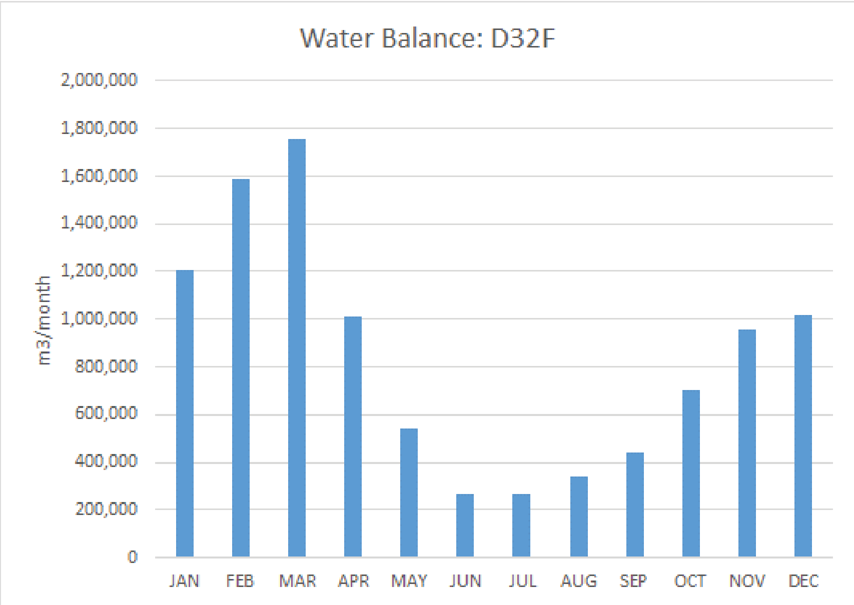


Figure 95: Average monthly groundwater available

The average monthly groundwater available for D32G is documented in Figure 96.

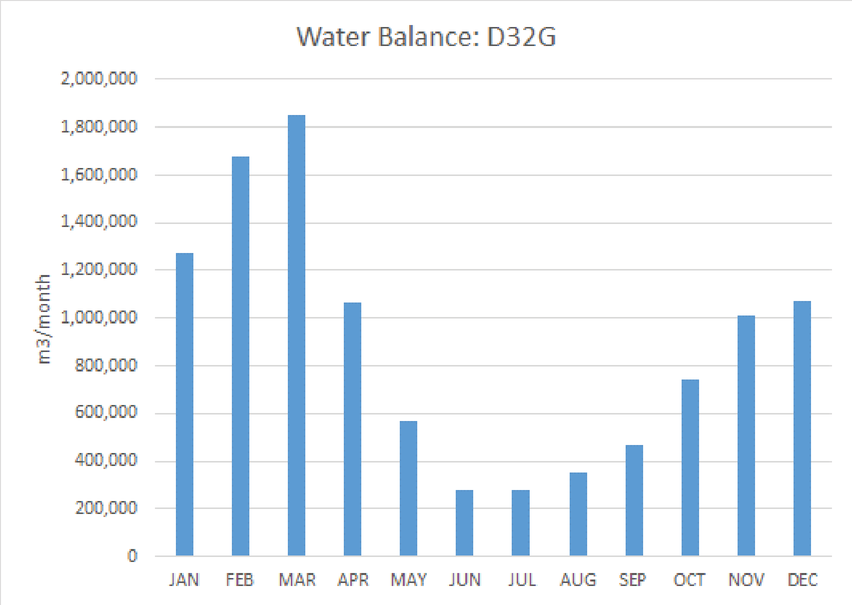


Figure 96: Average monthly groundwater available

The average monthly groundwater available D32H is documented in Figure 97.

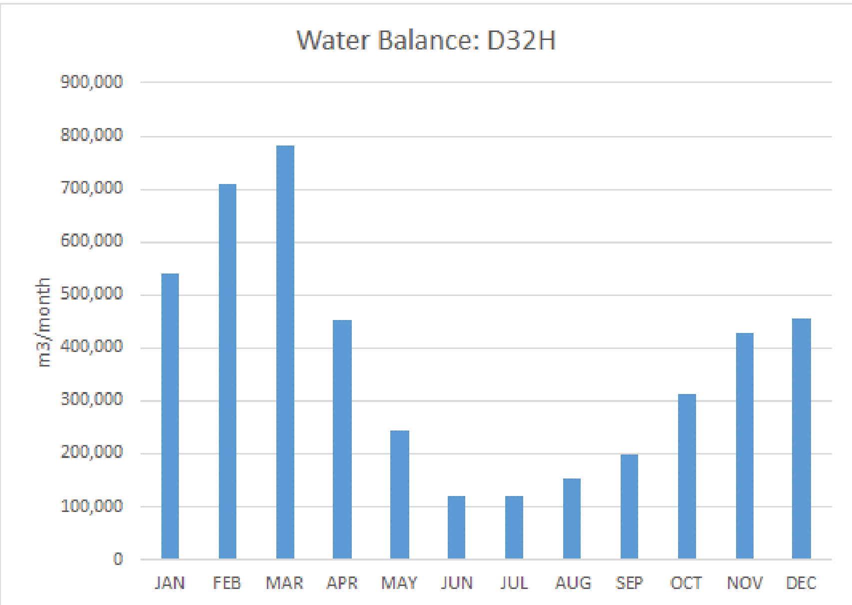


Figure 97: Average monthly groundwater available

The average monthly groundwater available for D32J is documented in Figure 98.

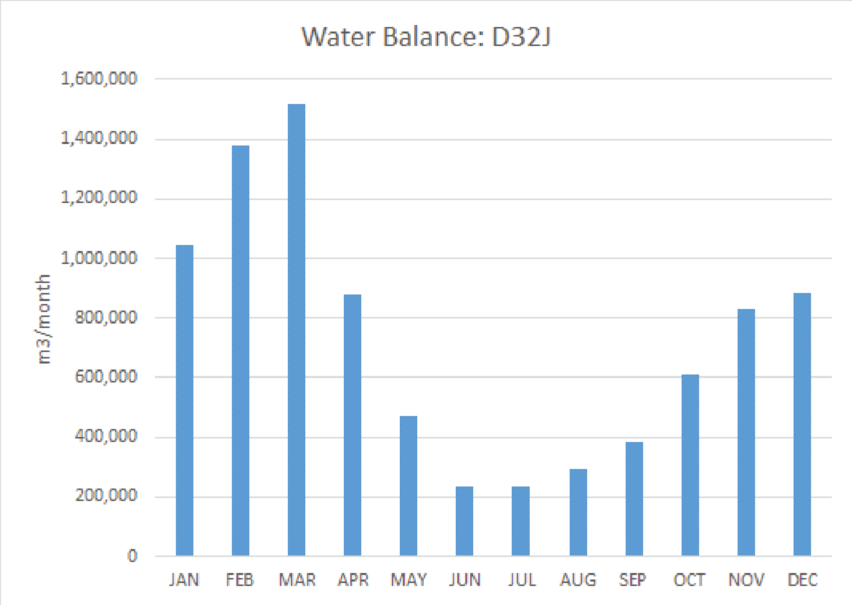


Figure 98: Average monthly groundwater available

The average monthly groundwater available for D32K is documented in Figure 99.

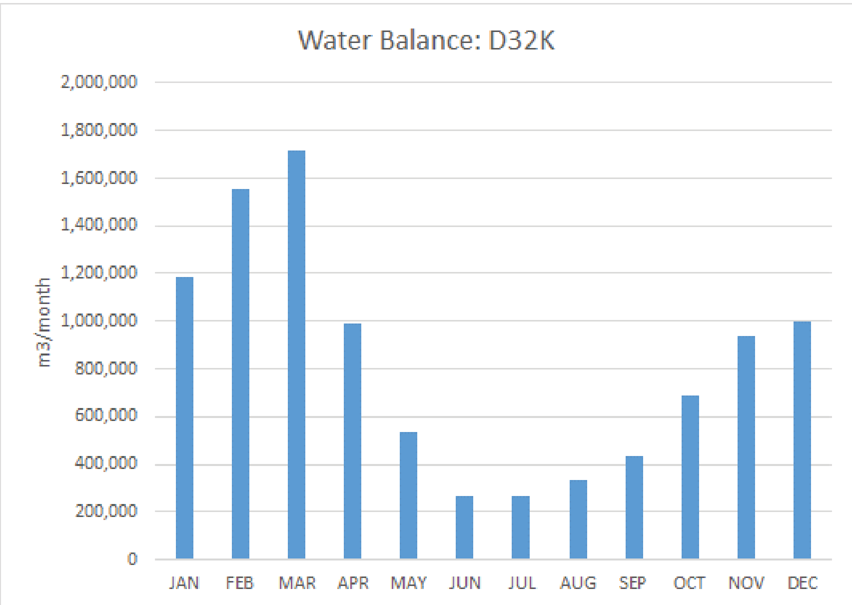


Figure 99: Average monthly groundwater available

5.4.3 Reserve

With current data the Reserve expressed as a percentage recharge for D32A is zero.

With current data the Reserve expressed as a percentage recharge for D32B is zero.

With current data the Reserve expressed as a percentage recharge for D32C is zero.

With current data the Reserve expressed as a percentage recharge for D32D is zero.

With current data the Reserve expressed as a percentage recharge for D32E is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D32F is documented in Figure 100.

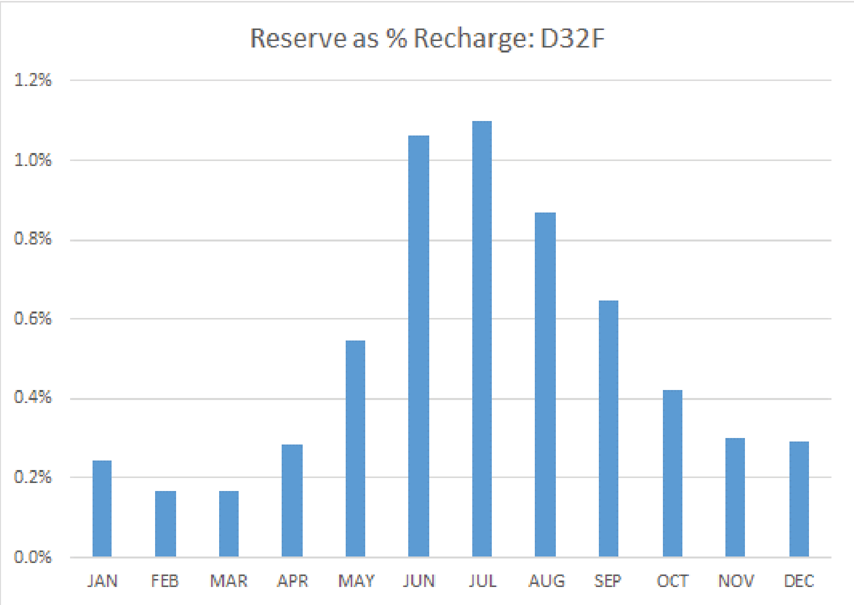


Figure 100: Reserve expressed as a percentage recharge

The average groundwater Reserve as expressed as a percentage of recharge for D32G is documented in Figure 101.

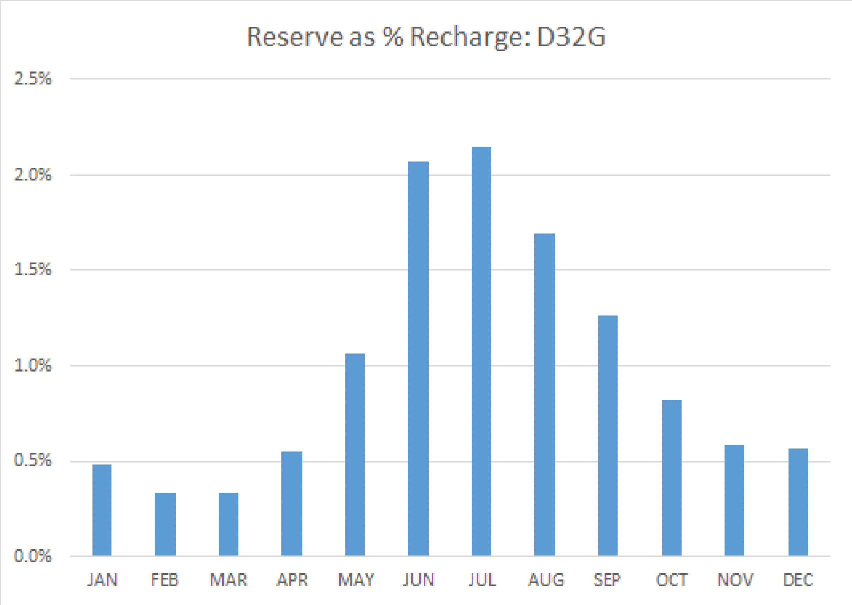


Figure 101: Reserve expressed as a percentage recharge

With current data the Reserve expressed as a percentage recharge for D32H is zero.

With current data the Reserve expressed as a percentage recharge for D32J is zero.

With current data the Reserve expressed as a percentage recharge for D32K is zero.

5.4.4 Groundwater Stress

The monthly stress index as defined by (WRC, 2013) for D32A is documented in Figure 102.

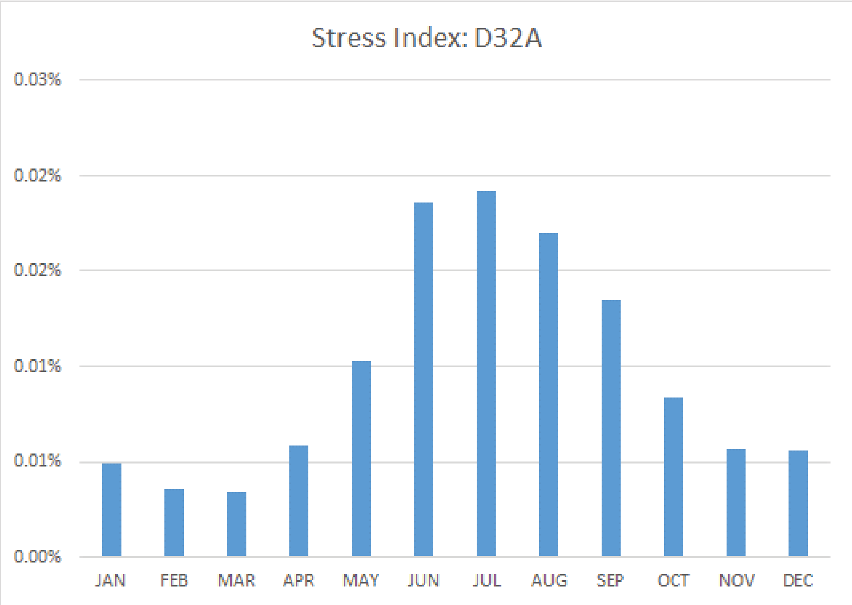


Figure 102: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32B is documented in Figure 103.

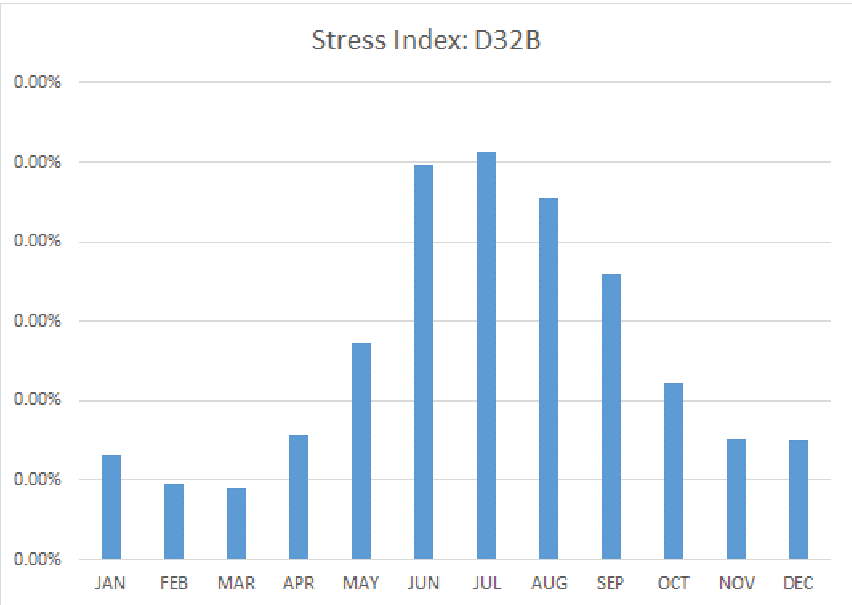


Figure 103: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32C is documented in Figure 104.

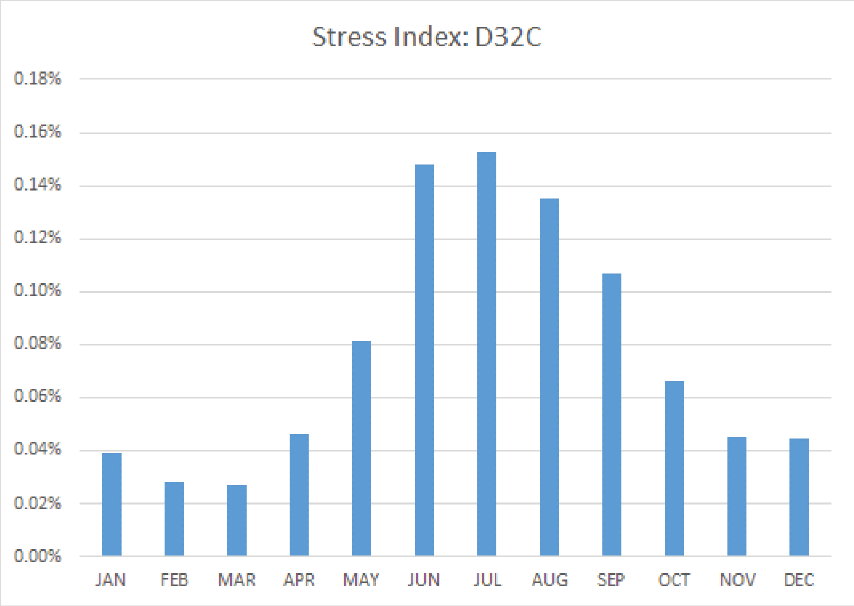


Figure 104: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32D is documented in Figure 105.

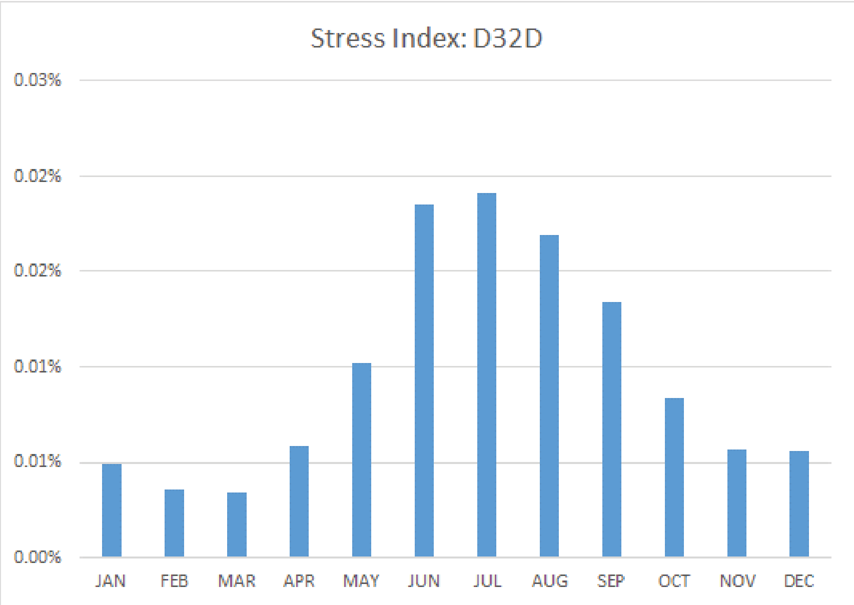


Figure 105: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32E is documented in Figure 106.

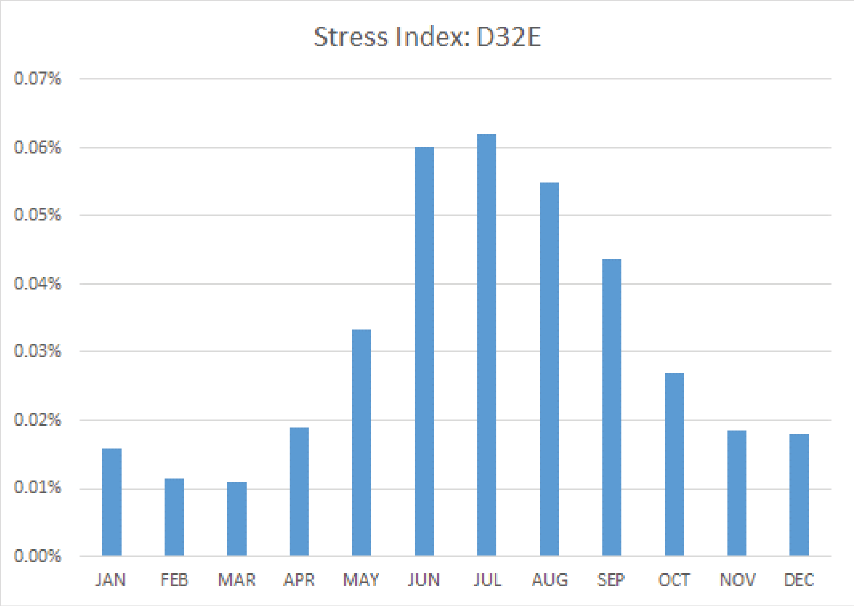


Figure 106: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32F is documented in Figure 107.

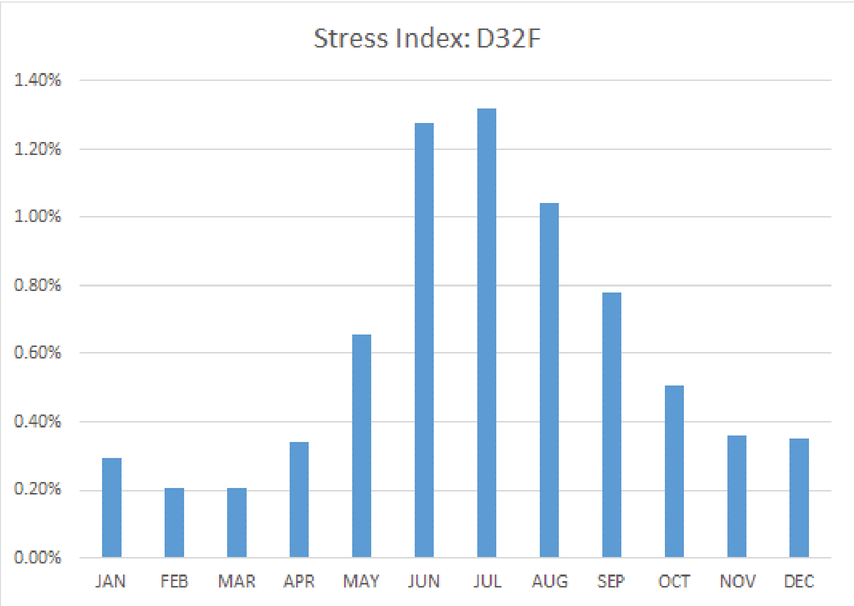


Figure 107: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32G is documented in Figure 108.

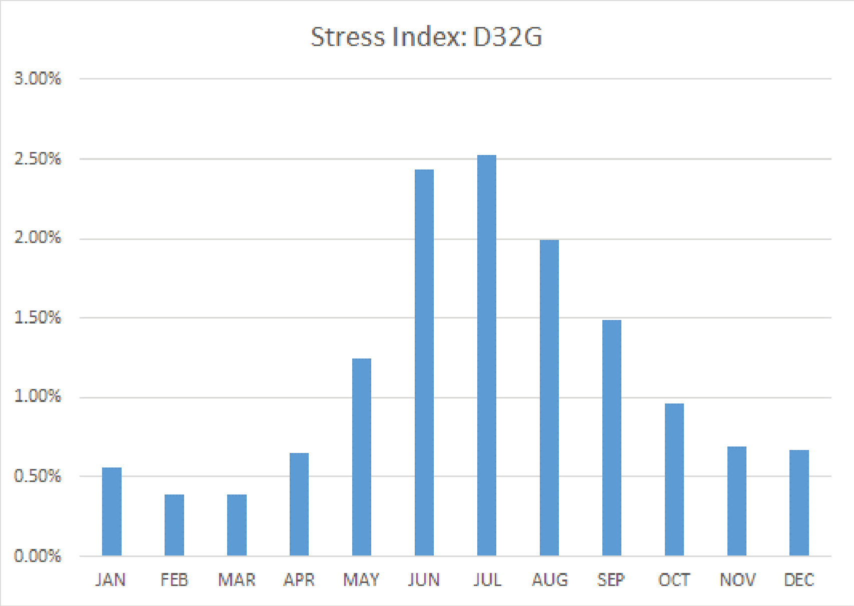


Figure 108: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32H is documented in Figure 109.

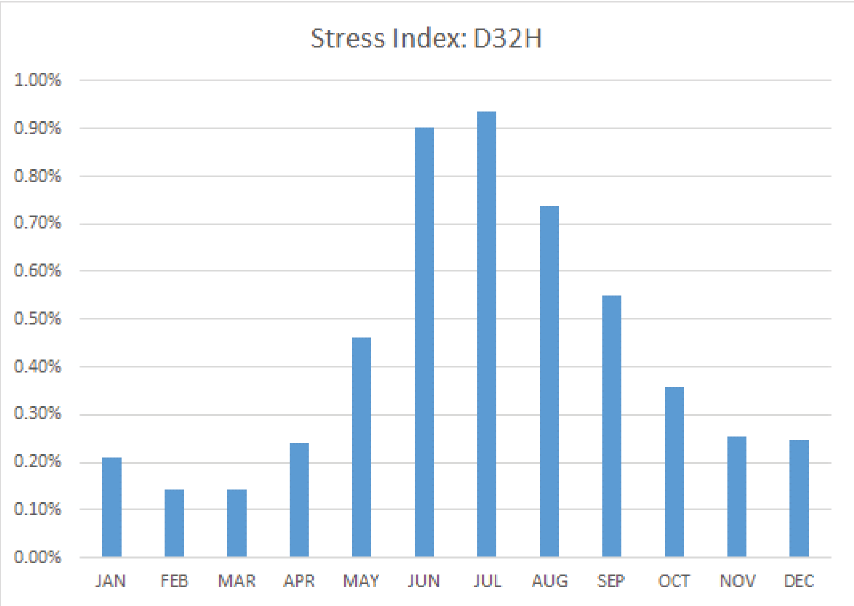


Figure 109: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32J is documented in Figure 110.

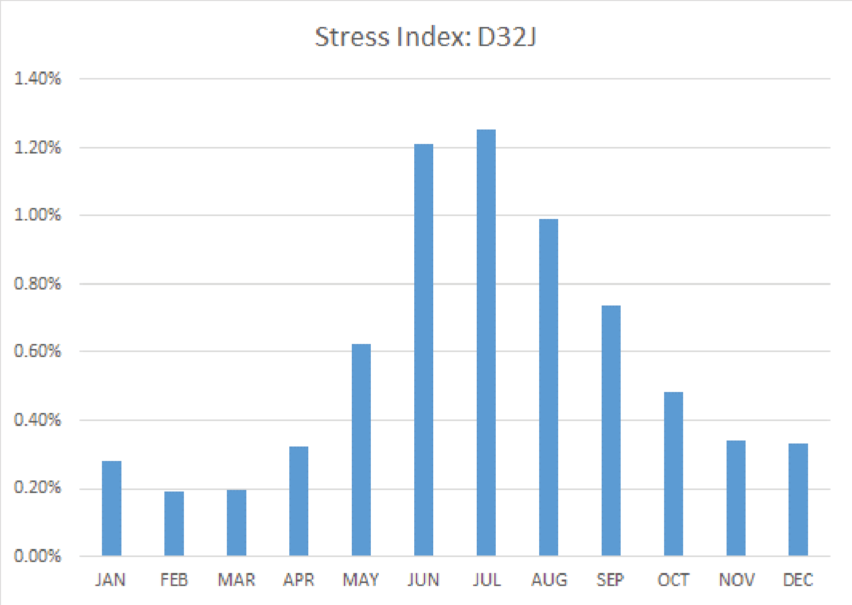


Figure 110: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D32K is documented in Figure 111.

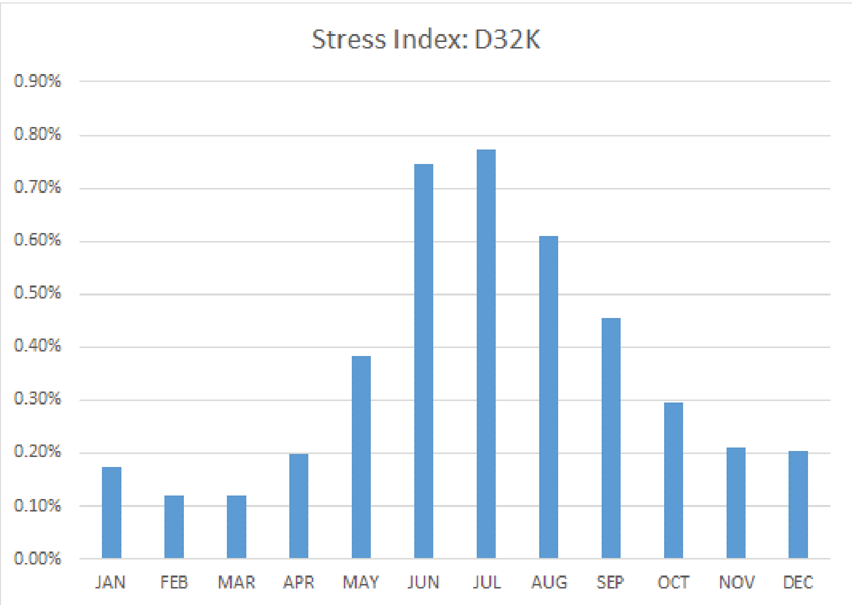


Figure 111: Monthly stress index

5.5 Quaternary catchments D31

5.5.1 Water Use

The basic information for the study area is summarised in Table 24.

Table 24: Basic Information concerning D31[5]

Catchment	Groundwater use (Mm^3/a)	Population	Evaporation (mm/a)	Current ecological class
D31B	1.49	3682	1900	B
D31C	0.1	0	1900	B
D31D	18.65	0	1900	B

According to the Groundwater Reserve Directed Measures methodology every person is entitled to 25 l/d, making the total groundwater use for basic human needs 0.03 Mm^3/a. It is assumed that this value will remain constant throughout the year. Evapotranspiration varies monthly. The average monthly evapotranspiration figures calculated by Murray et al. (2011) are shown in Figure 112. Two abstraction points for the area was recorded on the WARMS database (see Table 25).

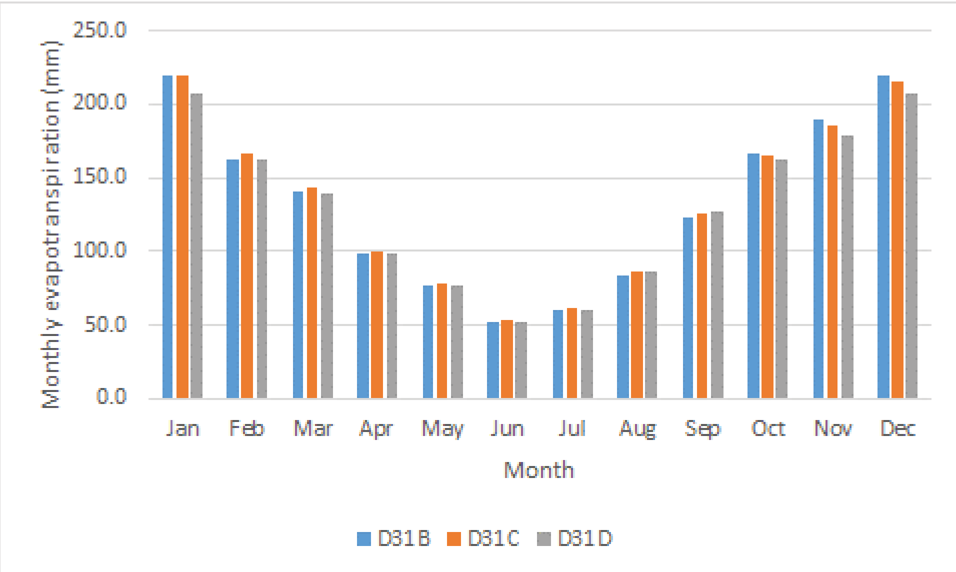


Figure 112: Average monthly evapotranspiration

[5] Obtained from Aquiworx database

Table 25: Additional groundwater use data

Catchment	Latitude	Longitude	Volume abstracted (m^3/a)
D31B	-30.43910	24.48397	3240
D31C	-30.32940	24.81871	12000

5.5.2 Water Balance and Groundwater Availability

The average monthly groundwater available for D31B is documented in Figure 113.

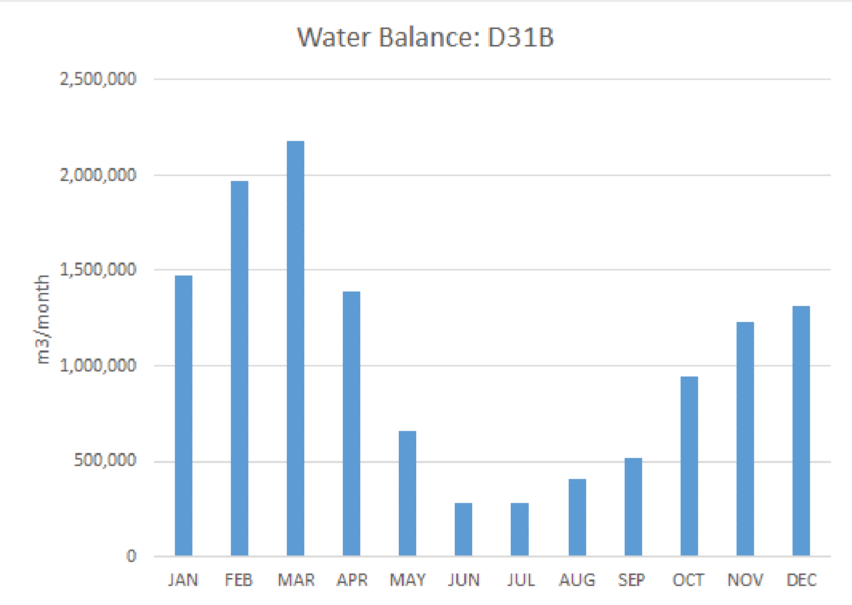


Figure 113: Average monthly groundwater available

The average monthly groundwater available for D31C is documented in Figure 114.

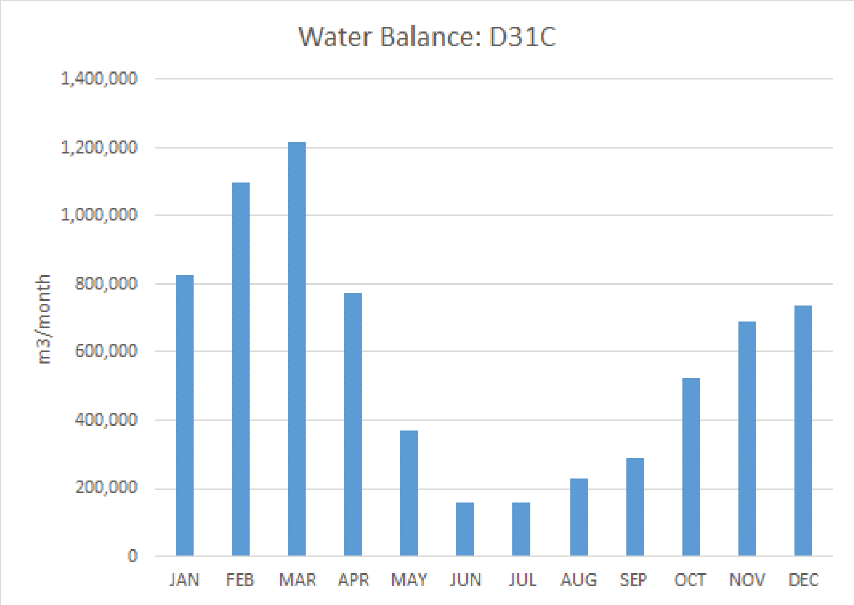


Figure 114: Average monthly groundwater available

The average monthly groundwater available for D31E is documented in Figure 115.

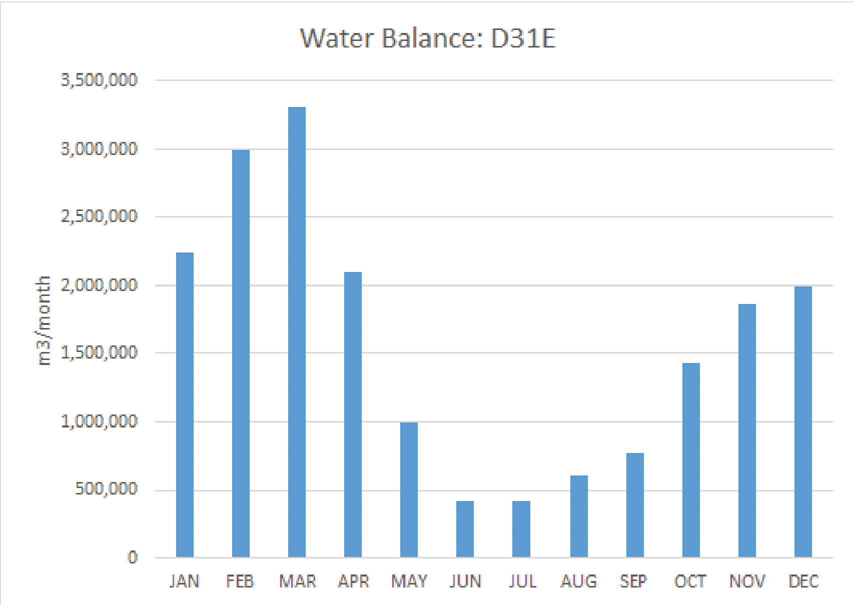


Figure 115: Average monthly groundwater available

5.5.3 Reserve

The average groundwater Reserve as expressed as a percentage of recharge for D31B is documented in Figure 116.

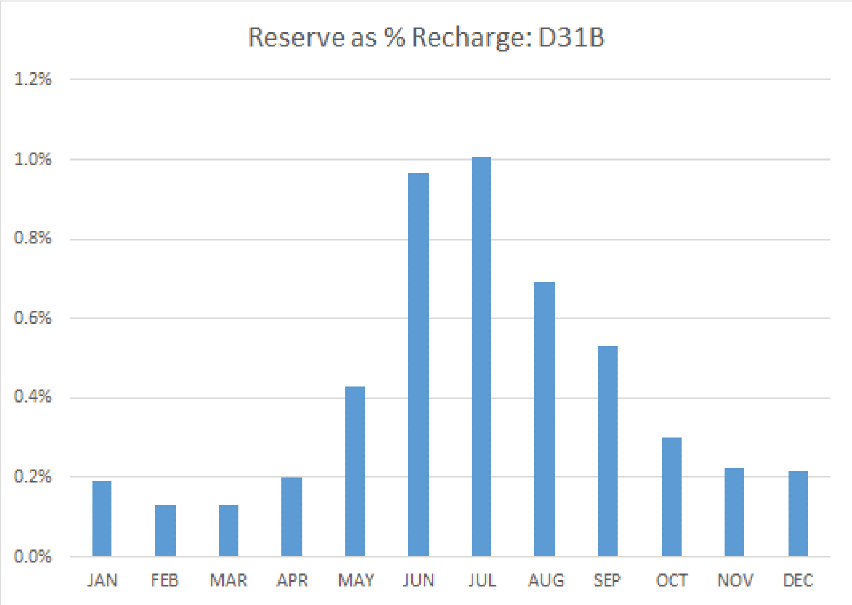


Figure 116: Reserve expressed as a percentage recharge

With current data the Reserve expressed as a percentage recharge for D31C is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D31E is documented in Figure 117.

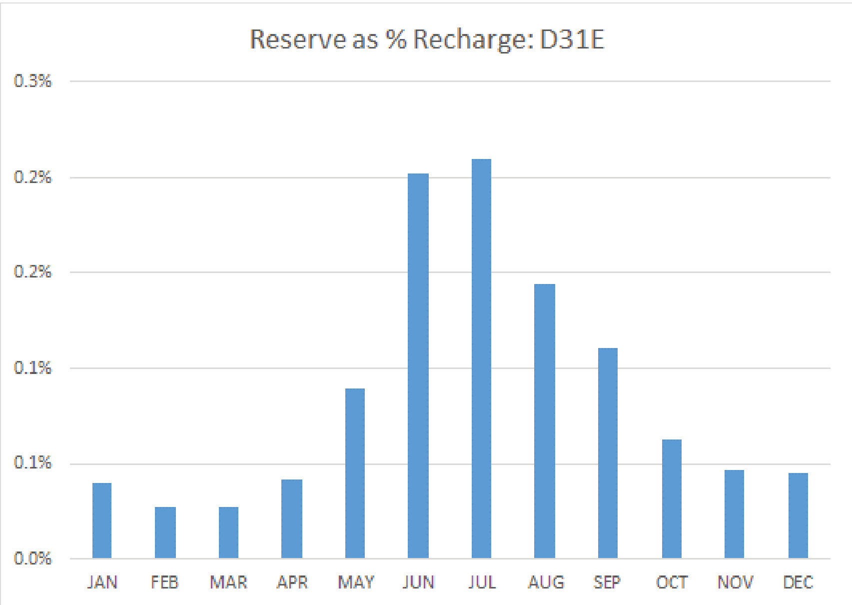


Figure 117: Reserve expressed as a percentage recharge

5.5.4 Groundwater Stress

The monthly stress index as defined by (WRC, 2013) for D31B is documented in Figure 118.

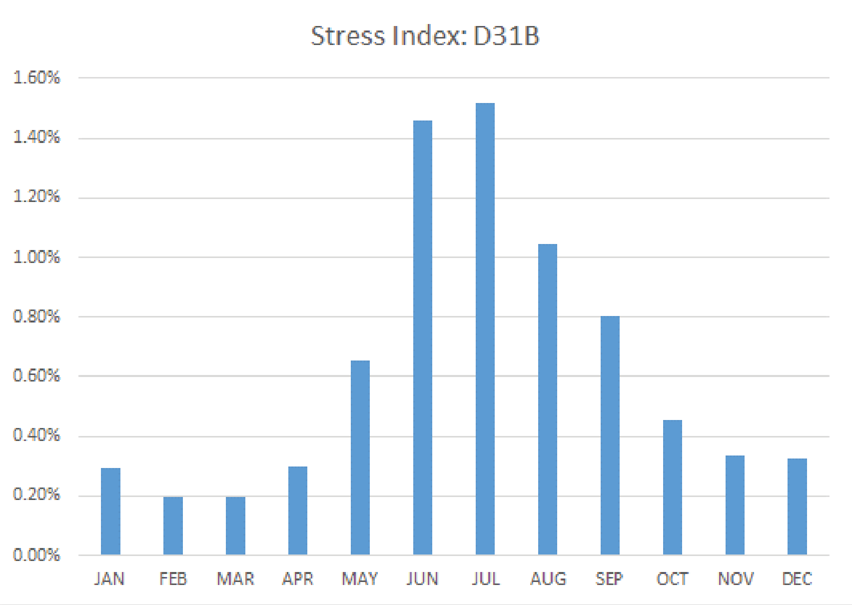


Figure 118: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D31C is documented in Figure 119.

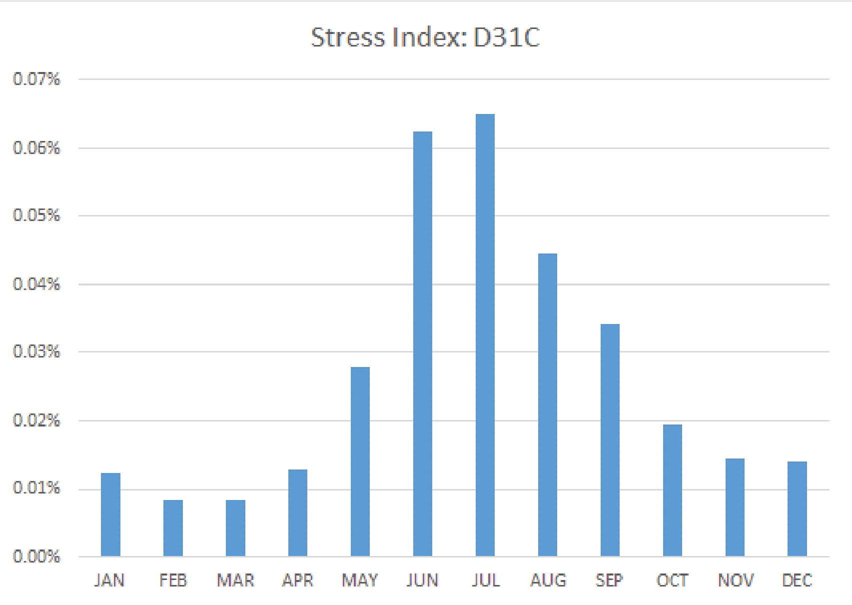


Figure 119: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D31E is documented in Figure 120.

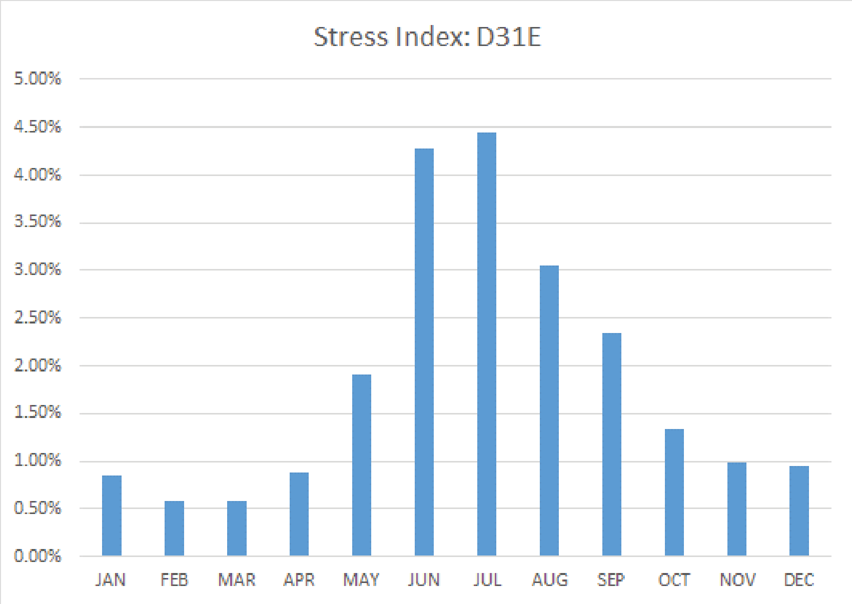


Figure 120: Monthly stress index

5.6 Quaternary catchments D34

5.6.1 Water Use

The basic information for the study area is summarised in Table 27.

Table 26: Basic Information concerning D34[6]

Catchment	Groundwater use (Mm^3/a)	Population	Evaporation (mm/a)	Current ecological class
D34A	1.33	1698	1750	C
D34B	0.67	0	1800	B
D34C	1.72	0	1800	C
D34D	1.38	0	1800	C
D34E	1.37	0	1800	C
D34F	2.08	14870	1800	C
D34G	1.33	4559	1800	C

According to the Groundwater Reserve Directed Measures methodology every person is entitled to 25 l/d, making the total groundwater use for basic human needs 0.19 Mm^3/a. It is assumed that this value will remain constant throughout the year. Evapotranspiration varies

[6] Obtained from Aquiworx database

monthly. The average monthly evapotranspiration figures calculated by Murray et al. (2011) are shown in Figure 121. Two abstraction points for the area was recorded on the WARMS database (see Table 27).

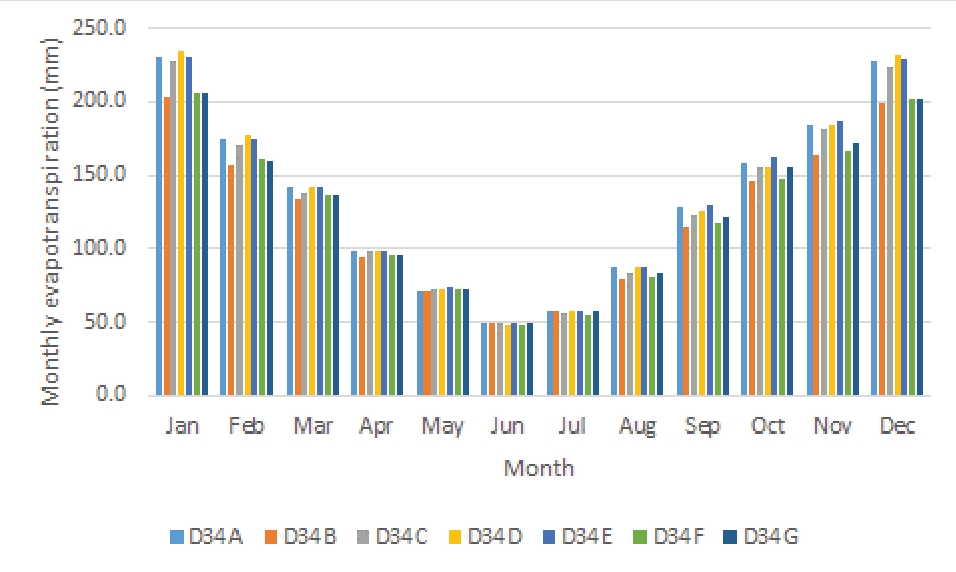


Figure 121: Average monthly evapotranspiration

Table 27: Additional groundwater use data

Catchment	Latitude	Longitude	Volume abstracted (m^3/a)
D34F	-30.62520	25.03930	10800
D34G	-30.26830	25.27725	101917

5.6.2 Water Balance and Groundwater Availability

The average monthly groundwater available for D34A is documented in Figure 122.

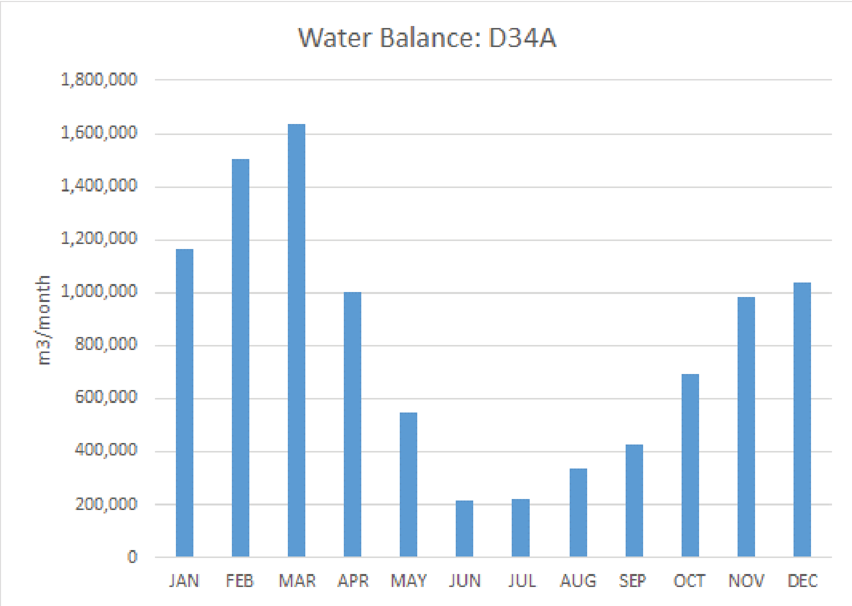


Figure 122: Average monthly groundwater available

The average monthly groundwater available for D34B is documented in Figure 123.

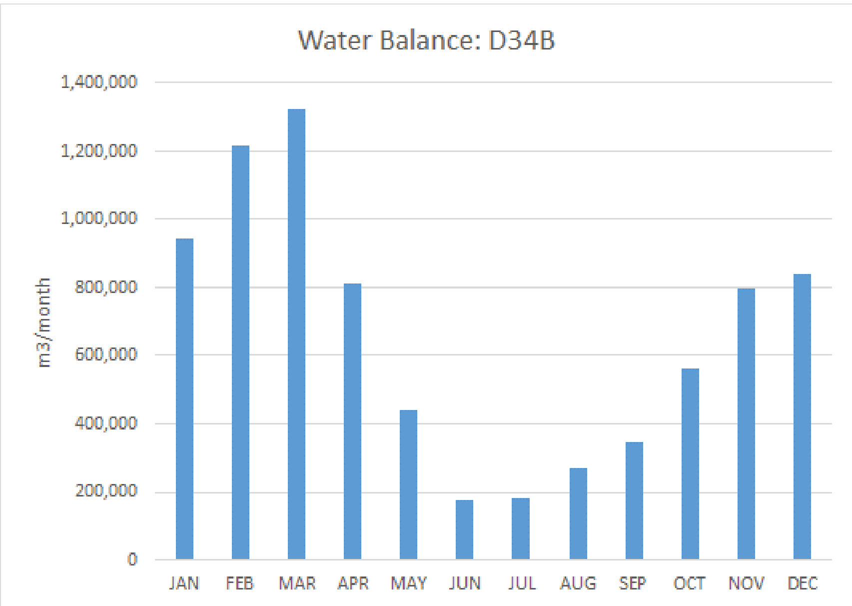


Figure 123: Average monthly groundwater available

The average monthly groundwater available for D34C is documented in Figure 124.

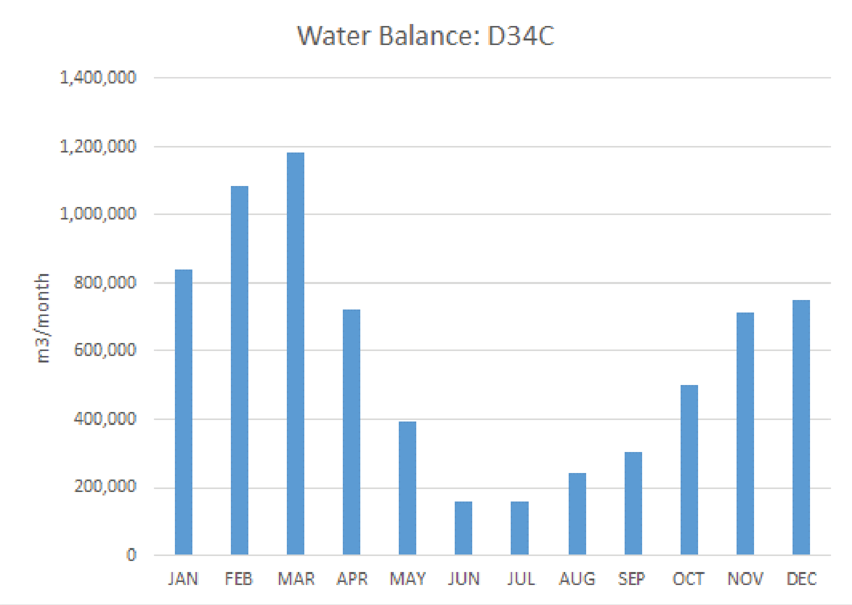


Figure 124: Average monthly groundwater available

The average monthly groundwater available for D34D is documented in Figure 125.

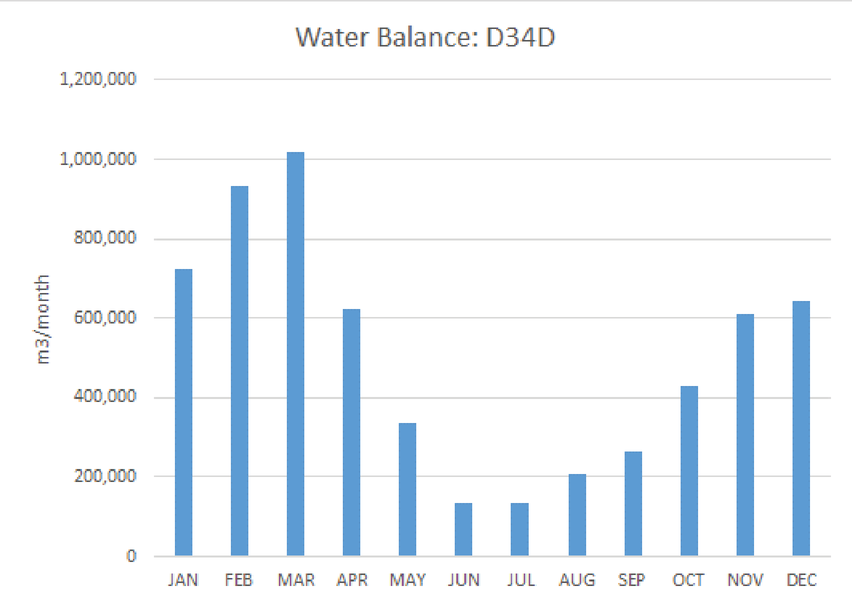


Figure 125: Average monthly groundwater available

The average monthly groundwater available for D34E is documented in Figure 126.

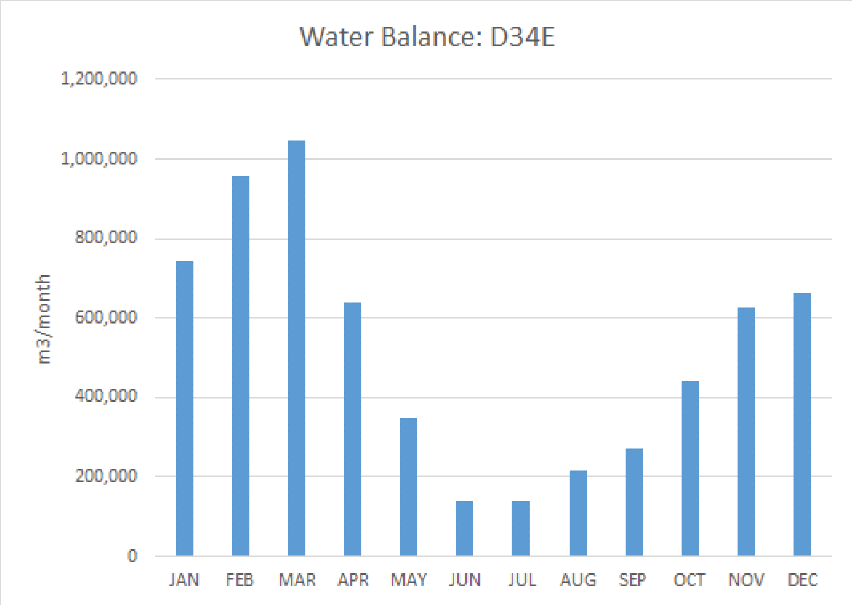


Figure 126: Average monthly groundwater available

The average monthly groundwater available for D34F is documented in Figure 127.

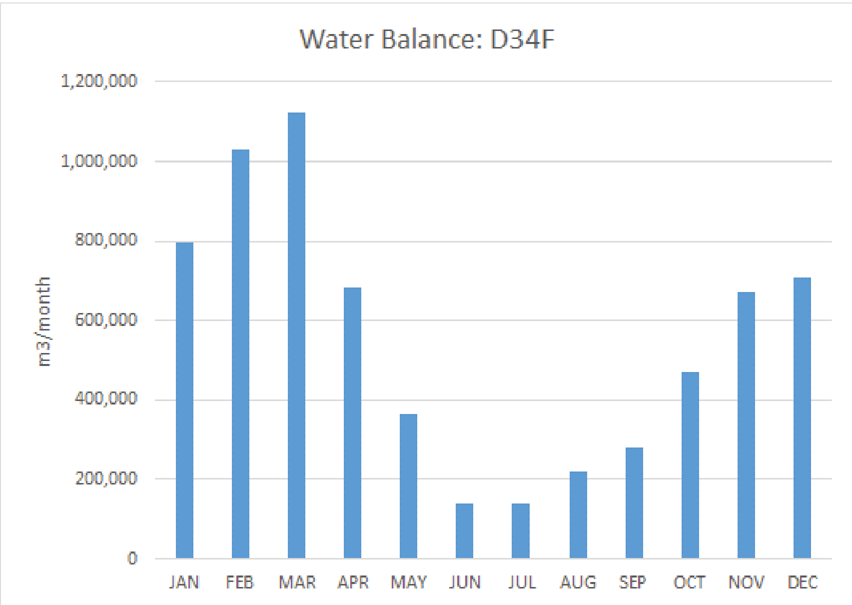


Figure 127: Average monthly groundwater available

The average monthly groundwater available for D34G is documented in Figure 128.

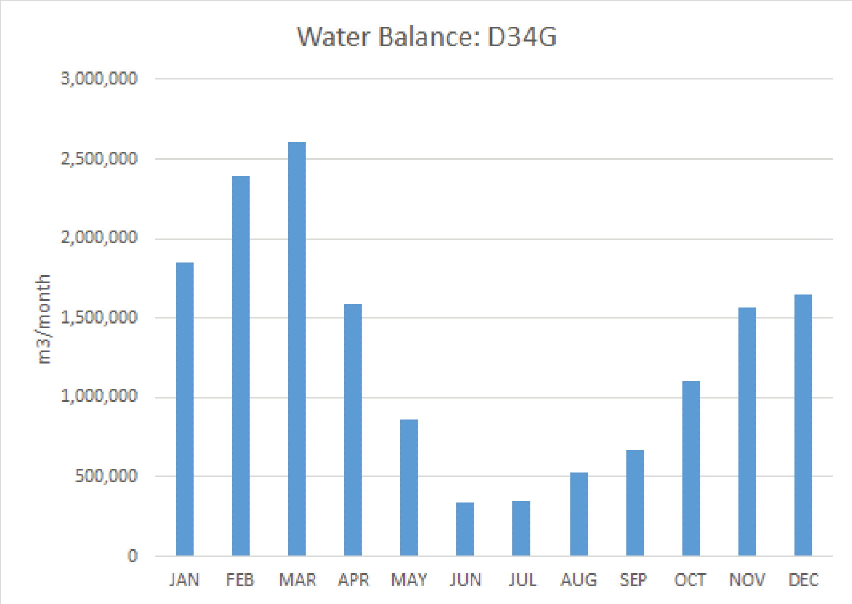


Figure 128: Average monthly groundwater available

5.6.3 Reserve

The average groundwater Reserve as expressed as a percentage of recharge for D34A is documented in Figure 129.

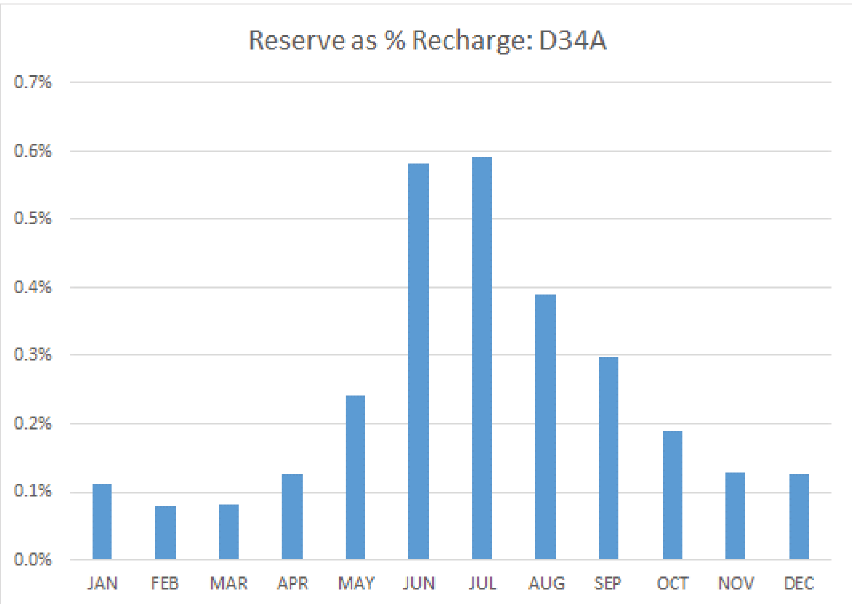


Figure 129: Reserve expressed as a percentage recharge

With current data the Reserve expressed as a percentage recharge for D34B is zero.

With current data the Reserve expressed as a percentage recharge for D34C is zero.

With current data the Reserve expressed as a percentage recharge for D34D is zero.

With current data the Reserve expressed as a percentage recharge for D34E is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D34F is documented in Figure 130.

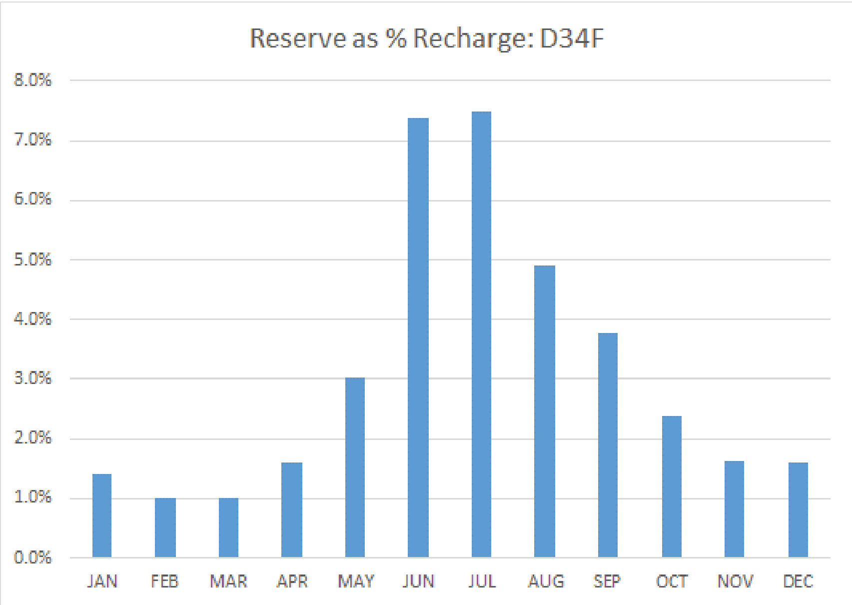


Figure 130: Reserve expressed as a percentage recharge

The average groundwater Reserve as expressed as a percentage of recharge for D34G is documented in Figure 131.

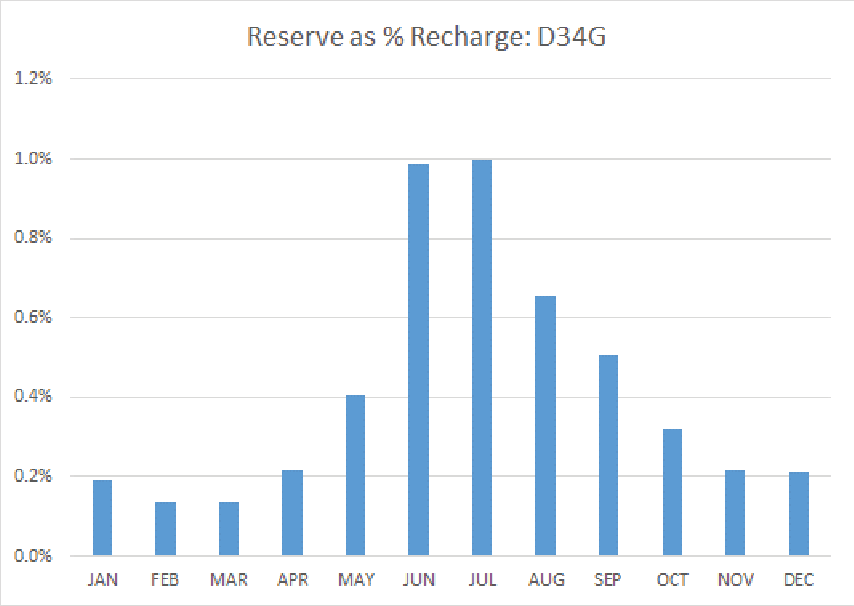


Figure 131: Reserve expressed as a percentage recharge

5.6.4 Groundwater Stress

The monthly stress index as defined by (WRC, 2013) for D34A is documented in Figure 132.

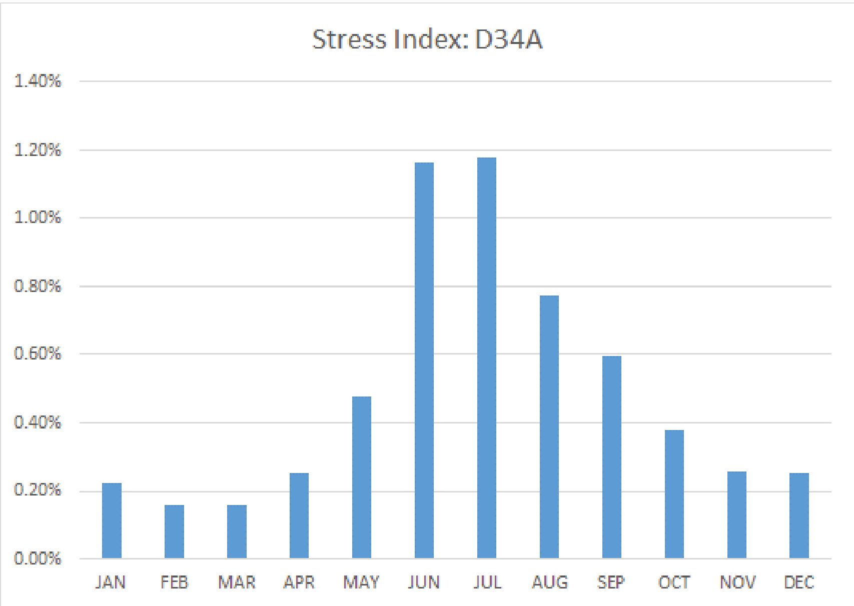


Figure 132: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D34B is documented in Figure 133.

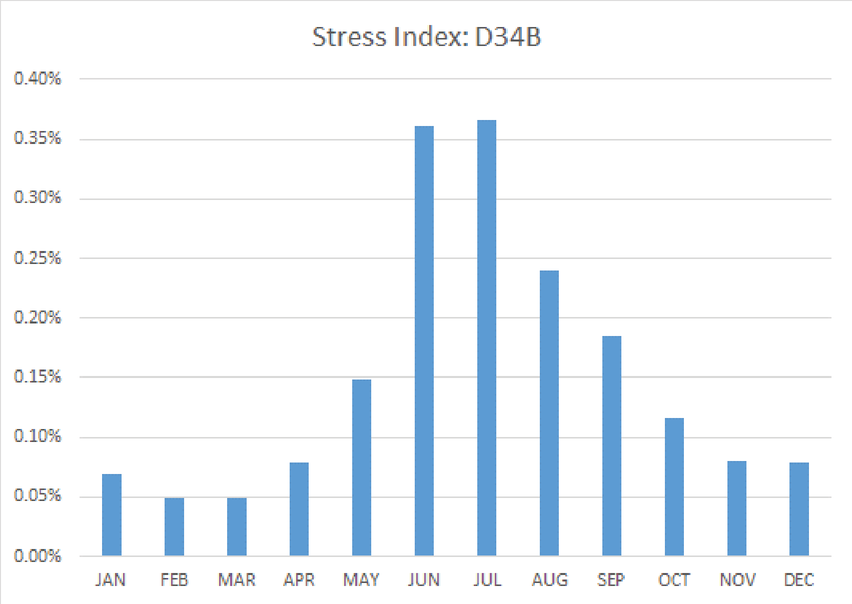


Figure 133: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D34C is documented in Figure 134.

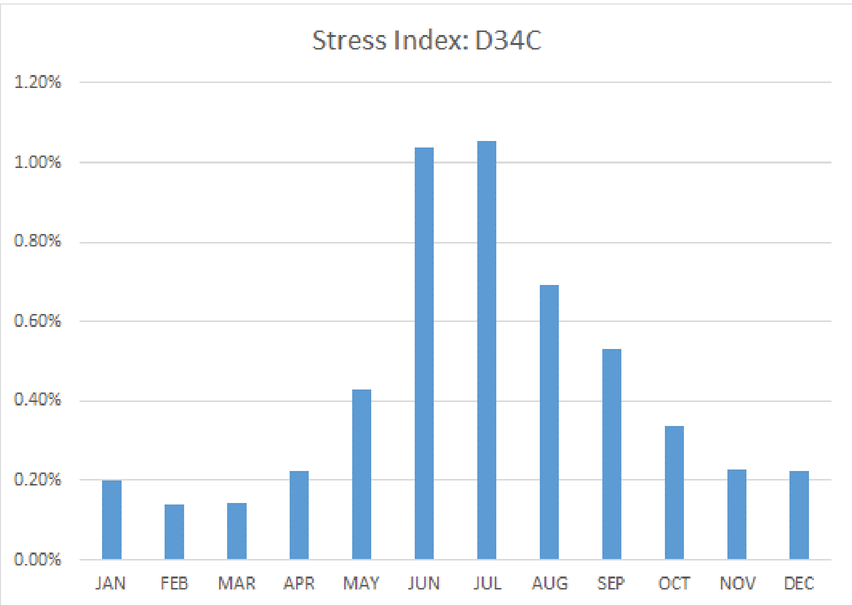


Figure 134: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D34D is documented in Figure 135.

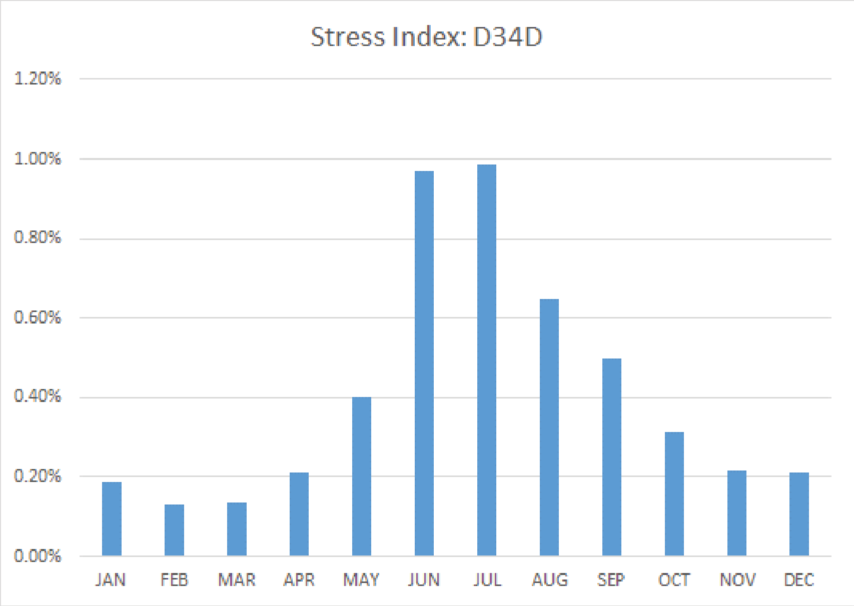


Figure 135: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D34E is documented in Figure 136.

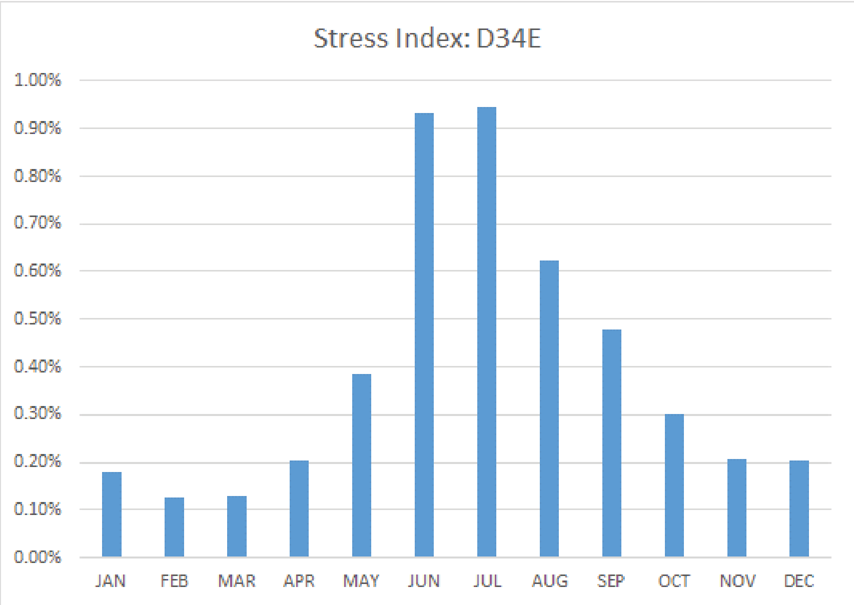


Figure 136: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D34F is documented in Figure 137.

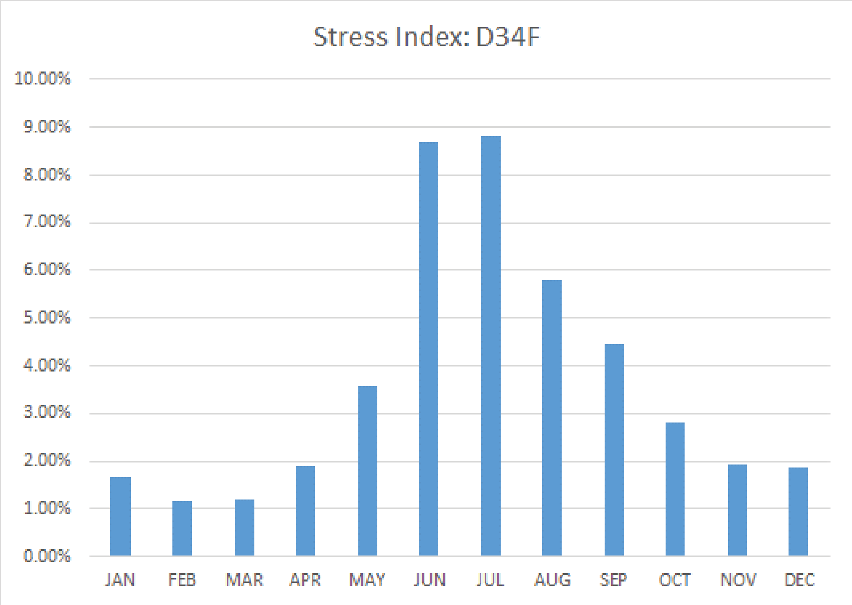


Figure 137: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D34G is documented in Figure 138.

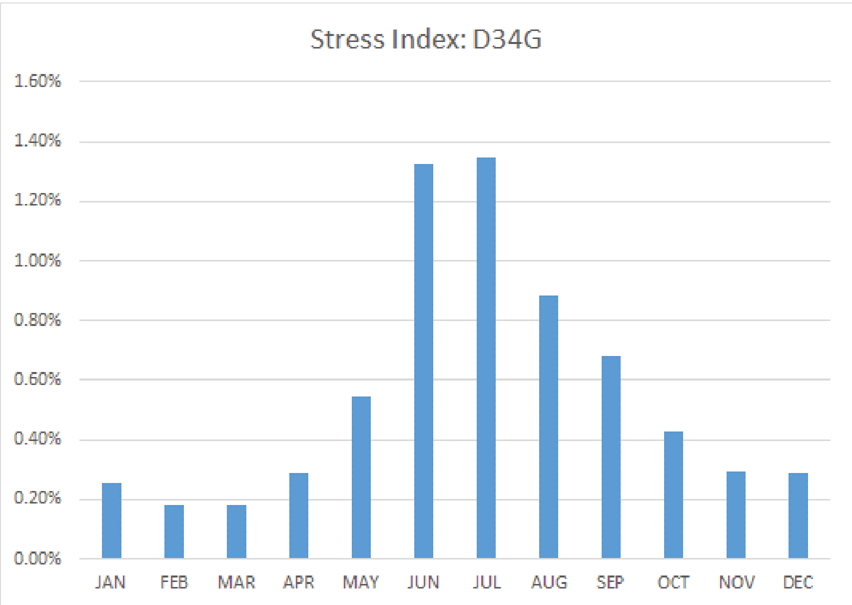


Figure 138: Monthly stress index

5.7 Quaternary catchments D35

5.7.1 Groundwater Use

The basic information for the study area is summarised in Table 28.

Table 28: Basic Information concerning D35[7]

Catchment	Groundwater use (Mm^3/a)	Population	Evaporation (mm/a)	Current ecological class
D35A	0.2	0	1700	C
D35B	0.34	8111	1700	B
D35C	1.31	0	1725	B
D35D	0.1	0	1725	B
D35E	0.1	0	1725	B
D35F	0.5	14358	1725	B
D35G	0.12	9268	1750	B
D35H	0.58	1660	1725	E OR F
D35J	0.25	0	1750	B
D35K	0.38	1405	1725	E OR F

According to the Groundwater Reserve Directed Measures methodology every person is entitled to 25 l/d, making the total groundwater use for basic human needs 0.32 Mm^3/a. It is assumed that this value will remain constant throughout the year. Evapotranspiration varies monthly. The average monthly evapotranspiration figures calculated by Murray et al. (2011) are shown in Figure 139. Eight abstraction points for the area was recorded on the WARMS database (see Table 29).

[7] Obtained from Aquiworx database

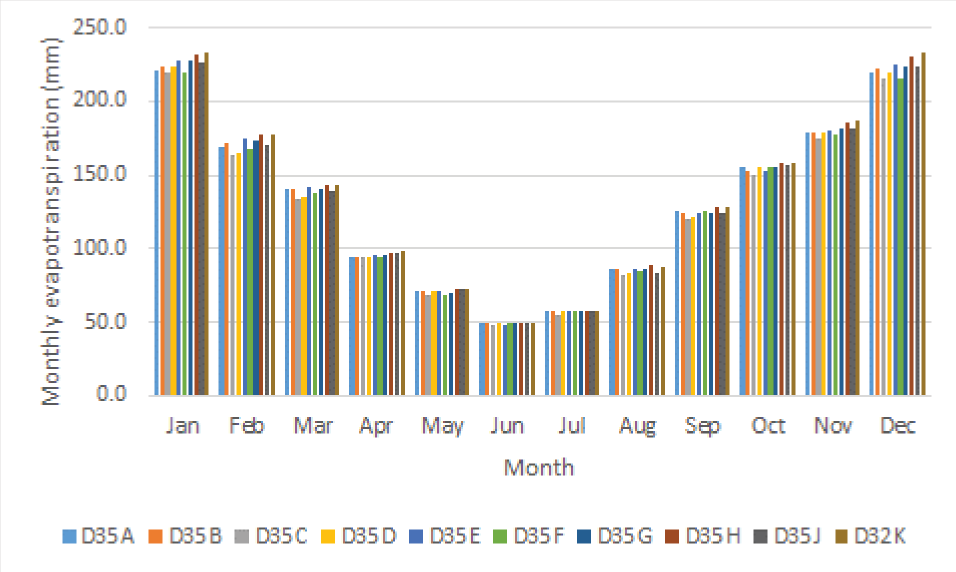


Figure 139: Average monthly evapotranspiration

Table 29: Additional groundwater use data

Catchment	Latitude	Longitude	Volume abstracted (m^3/a)
D35C	-31.08920	25.93869	409
D35C	-31.12300	25.92490	677
D35C	-31.12300	25.92490	677
D35C	-31.12840	25.92490	677
D35C	-31.12300	25.92490	677
D35C	-31.08920	25.93869	409
D35C	-31.08920	25.93869	409
D35C	-31.08920	25.93869	409

5.7.2 Water Balance and Groundwater Availability

The average monthly groundwater available for D35A is documented in Figure 140.

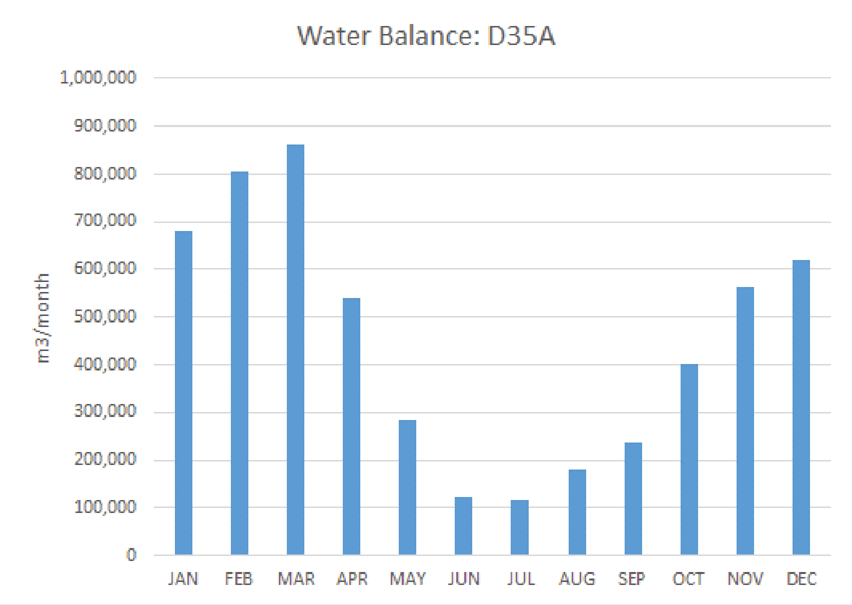


Figure 140: Average monthly groundwater available

The average monthly groundwater available for D35B is documented in Figure 141.

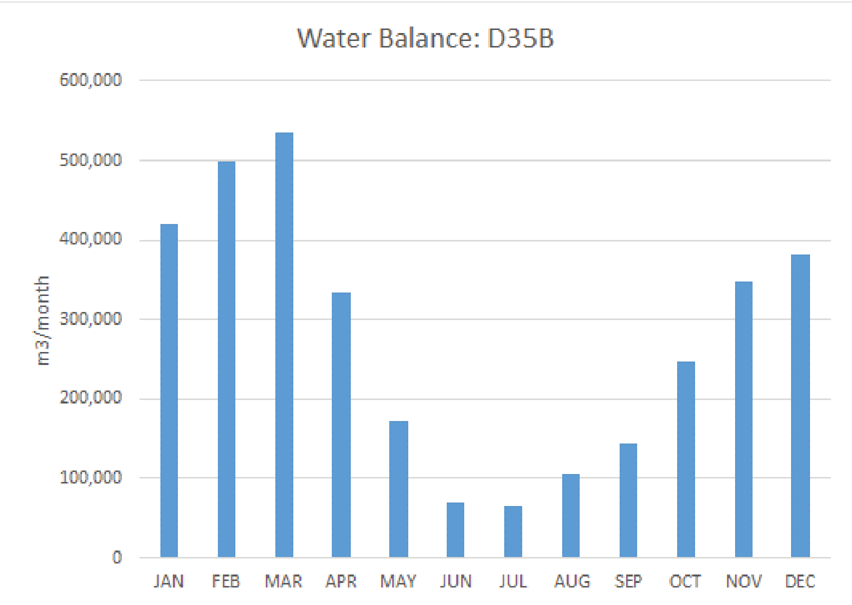


Figure 141: Average monthly groundwater available

The average monthly groundwater available for D35C is documented in Figure 142.

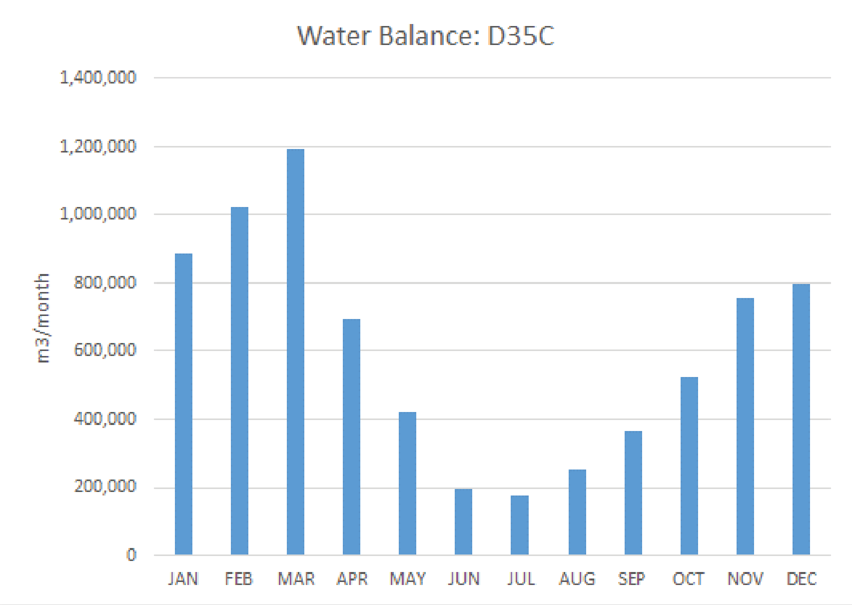


Figure 142: Average monthly groundwater available

The average monthly groundwater available for D35D is documented in Figure 143.

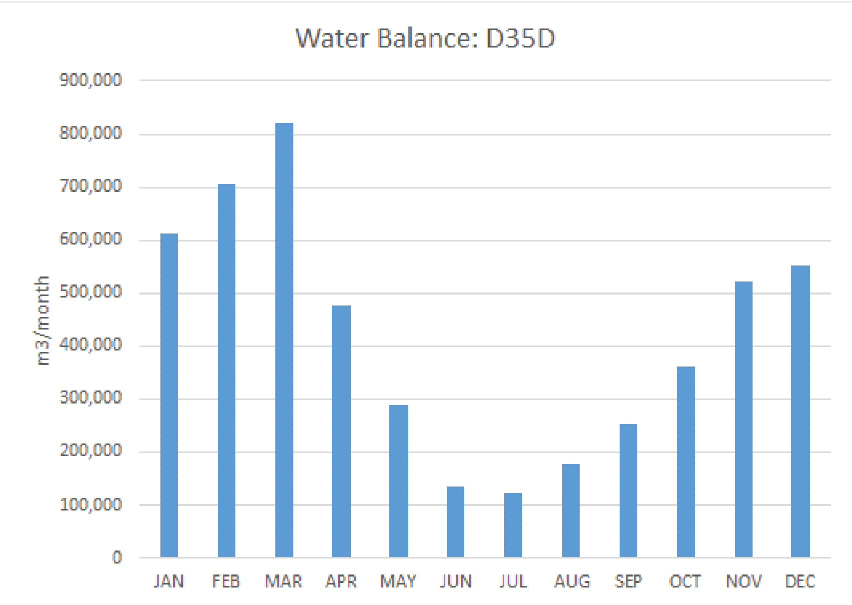


Figure 143: Average monthly groundwater available

The average monthly groundwater available for D35E is documented in Figure 144.

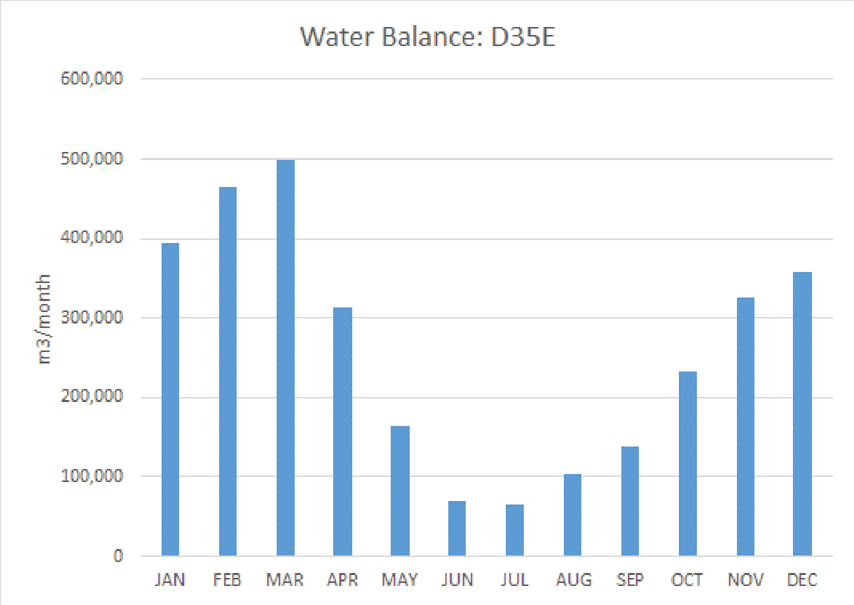


Figure 144: Average monthly groundwater available

The average monthly groundwater available for D35F is documented in Figure 145.

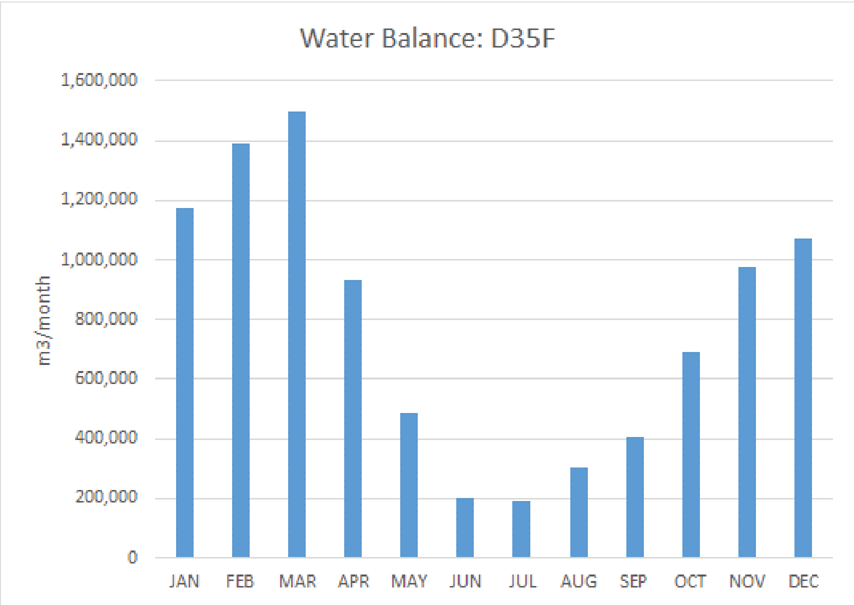


Figure 145: Average monthly groundwater available

The average monthly groundwater available for D35G is documented in Figure 146.

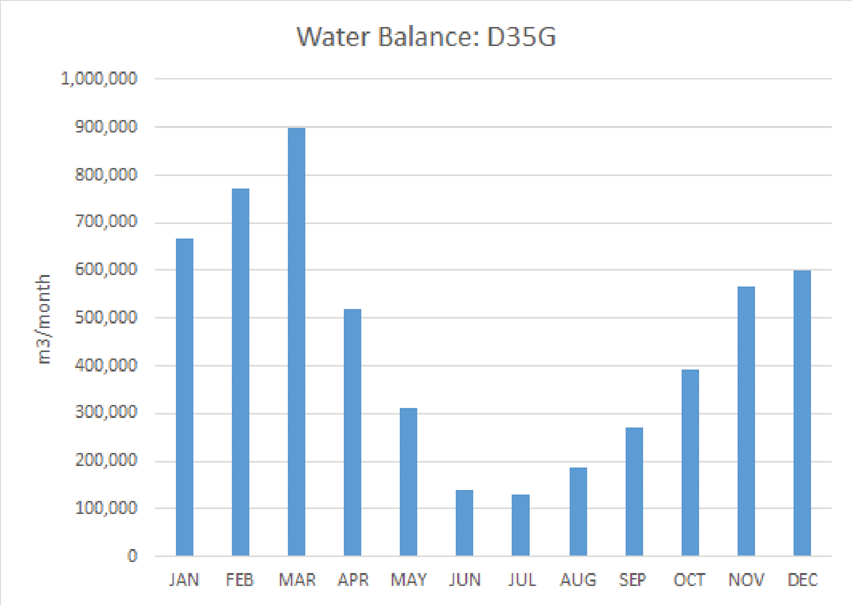


Figure 146: Average monthly groundwater available

The average monthly groundwater available for D35H is documented in Figure 147.

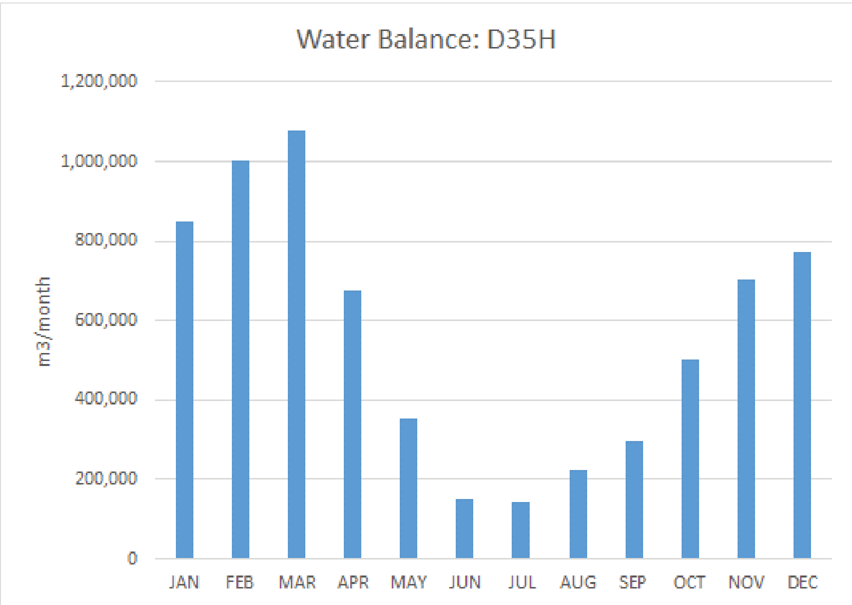


Figure 147: Average monthly groundwater available

The average monthly groundwater available for D35J is documented in Figure 148.

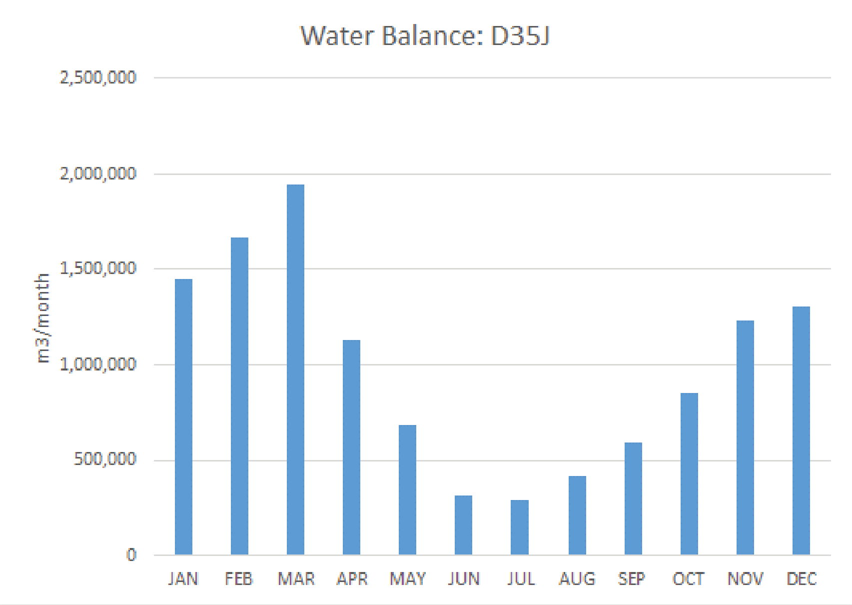


Figure 148: Average monthly groundwater available

The average monthly groundwater available for D35K is documented in Figure 149.

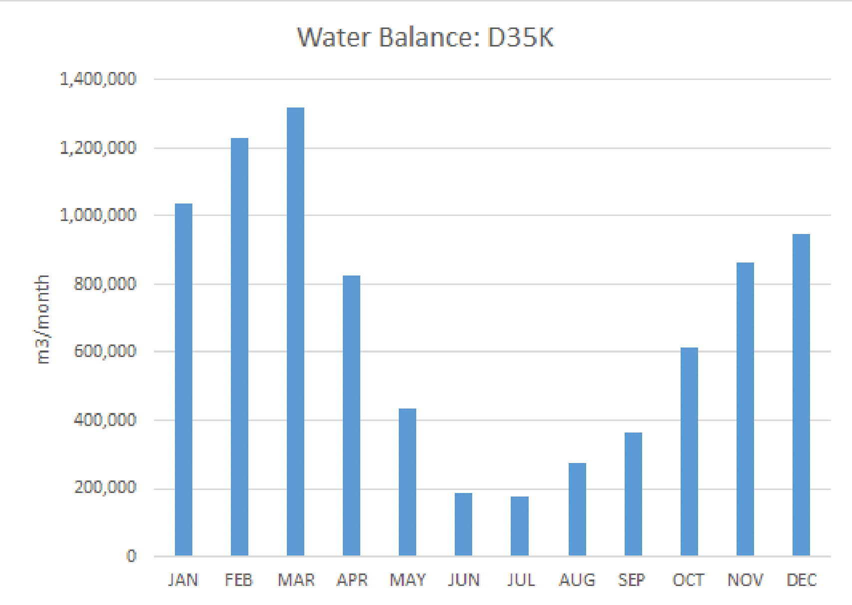


Figure 149: Average monthly groundwater available

5.7.3 Reserve

With current data the Reserve expressed as a percentage recharge for D35A is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D35B is documented in Figure 150.

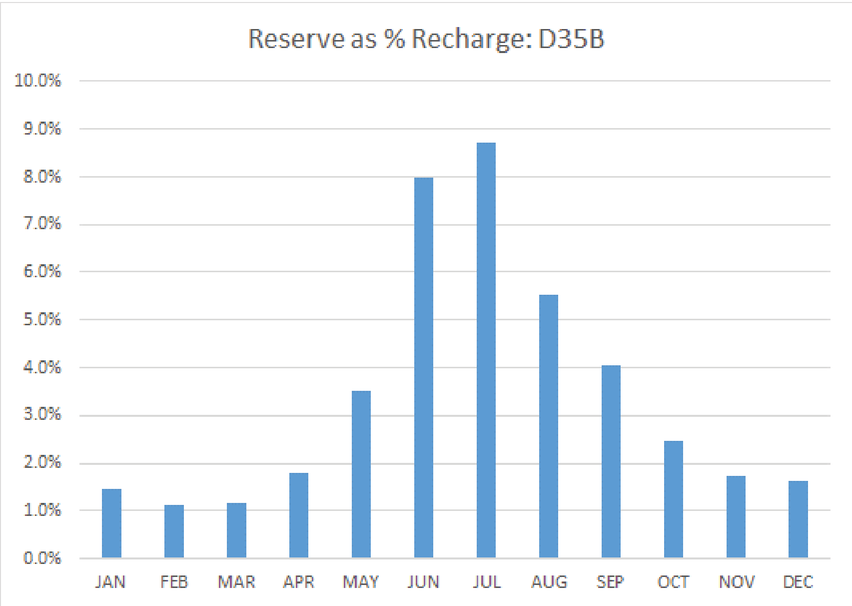


Figure 150: Reserve expressed as a percentage recharge

With current data the Reserve expressed as a percentage recharge for D35C is zero.

With current data the Reserve expressed as a percentage recharge for D35D is zero.

With current data the Reserve expressed as a percentage recharge for D35E is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D35F is documented in Figure 151.

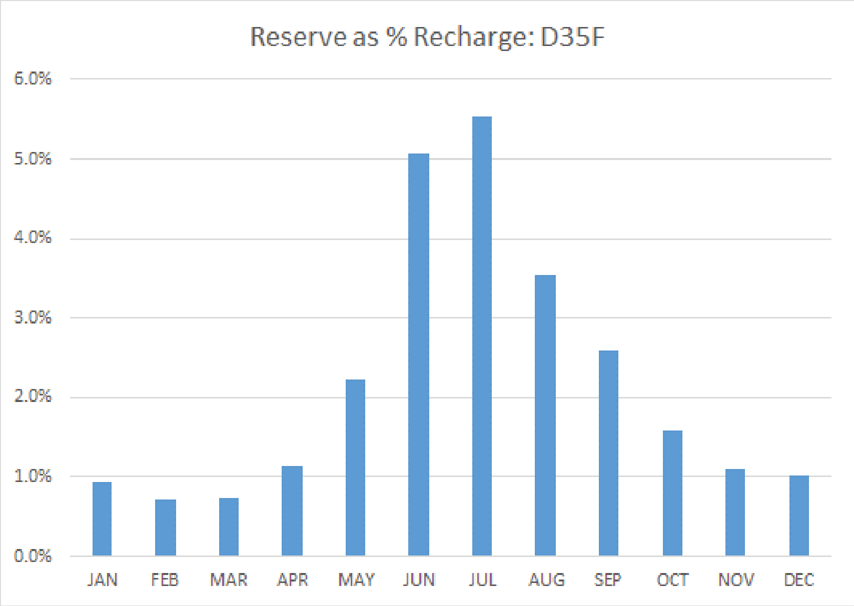


Figure 151: Reserve expressed as a percentage recharge

The average groundwater Reserve as expressed as a percentage of recharge for D35G is documented in Figure 152.

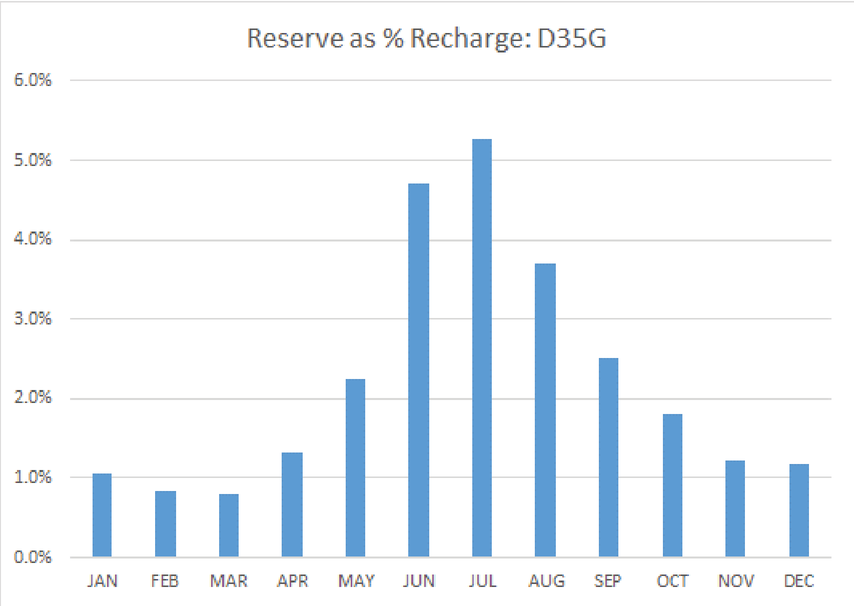


Figure 152: Reserve expressed as a percentage recharge

The average groundwater Reserve as expressed as a percentage of recharge for D35H is documented in Figure 153.

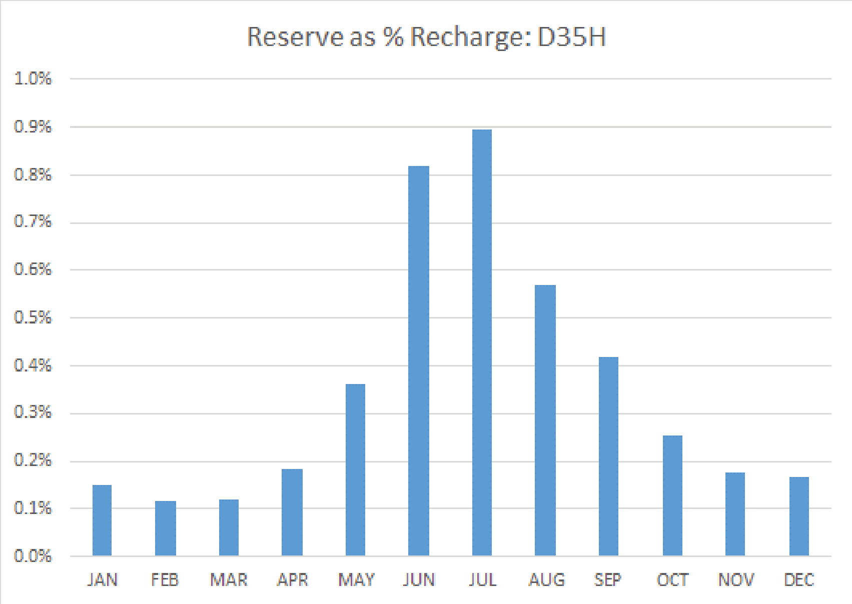


Figure 153: Reserve expressed as a percentage recharge

With current data the Reserve expressed as a percentage recharge for D35J is zero.

The average groundwater Reserve as expressed as a percentage of recharge for D35K is documented in Figure 154.

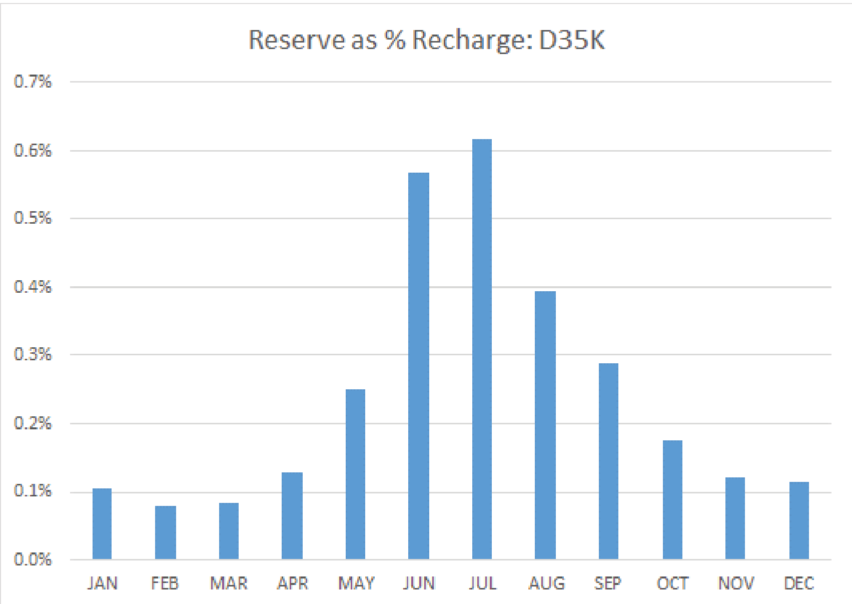


Figure 154: Reserve expressed as a percentage recharge

5.7.4 Groundwater Stress

The monthly stress index as defined by (WRC, 2013) for D35A is documented in Figure 155.

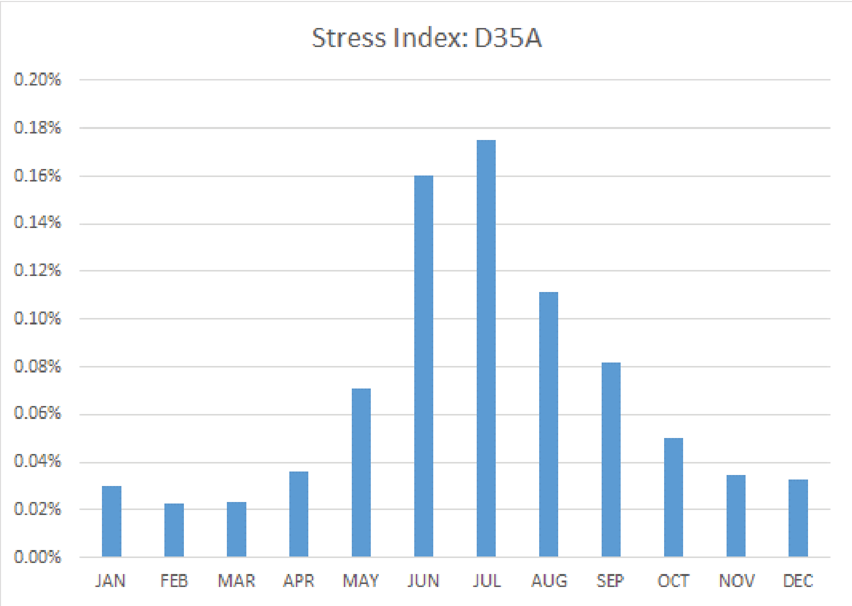


Figure 155: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35B is documented in Figure 156.

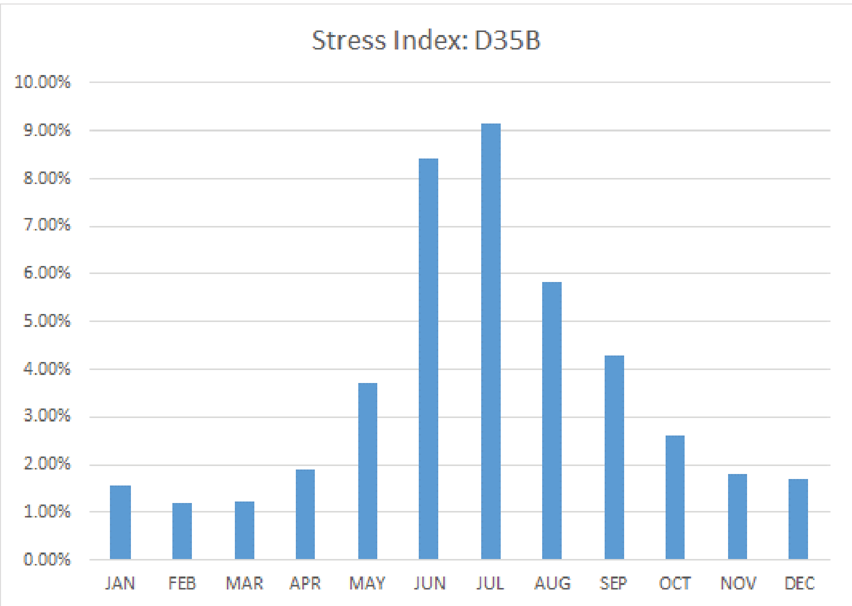


Figure 156: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35C is documented in Figure 157.

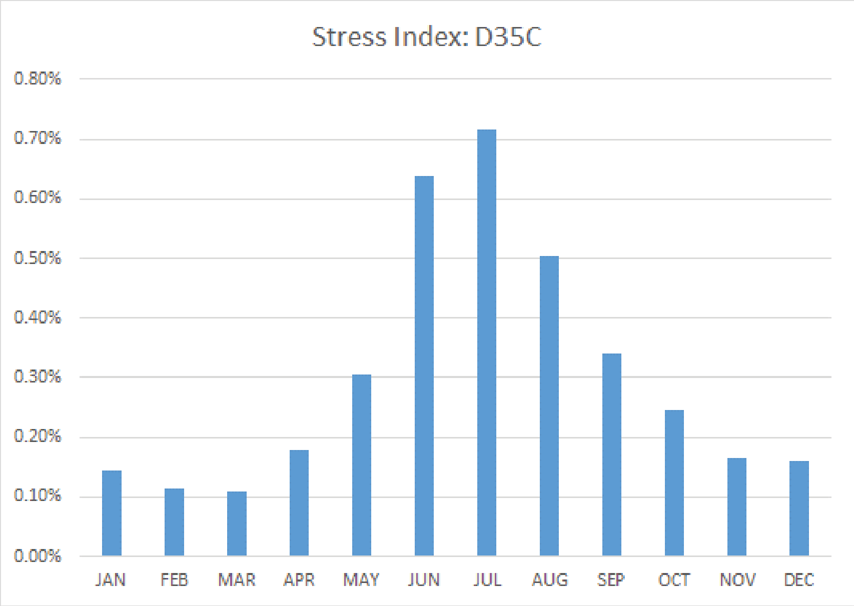


Figure 157: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35D is documented in Figure 158.

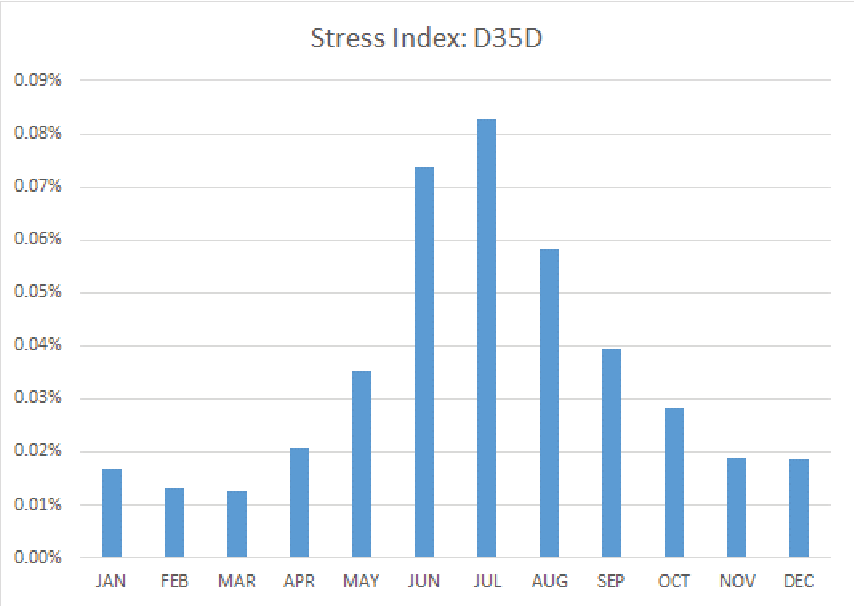


Figure 158: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35E is documented in Figure 159.

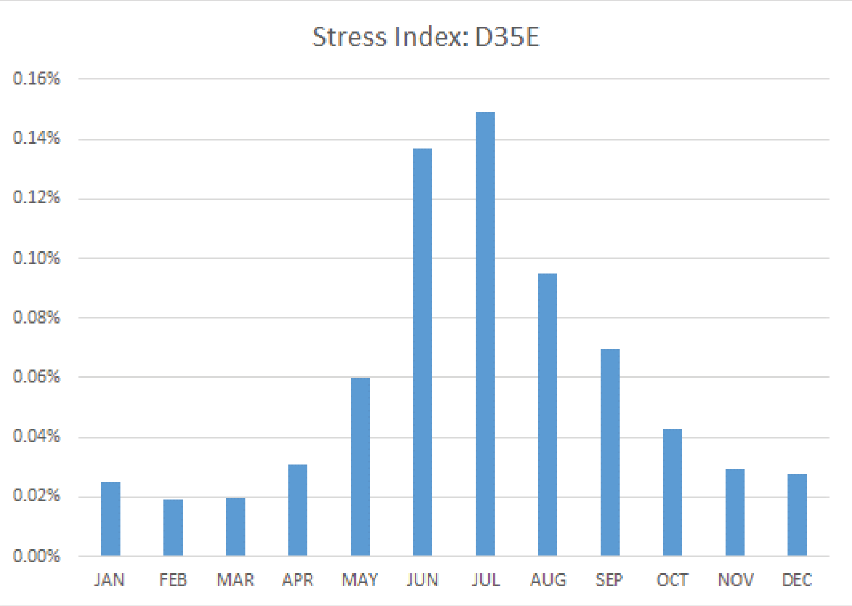


Figure 159: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35F is documented in Figure 160.

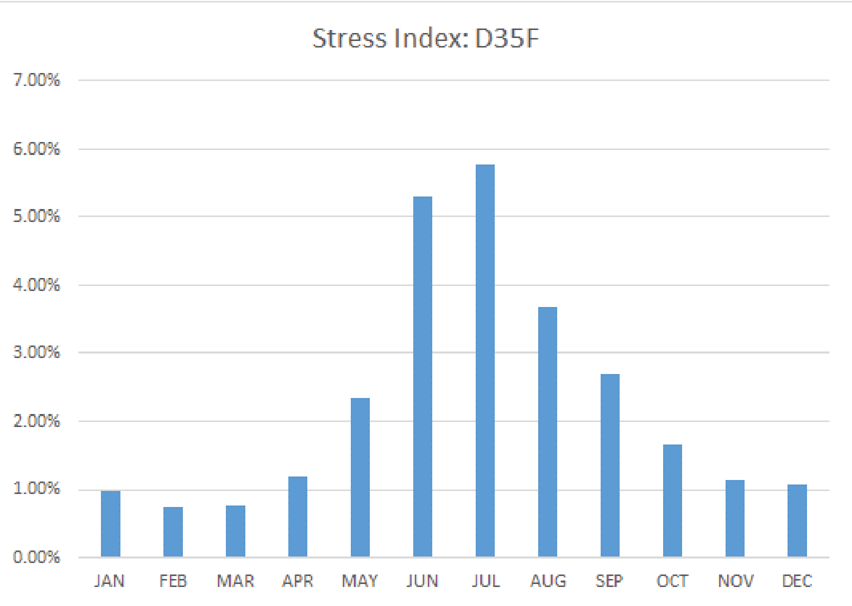


Figure 160: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35G is documented in Figure 161.

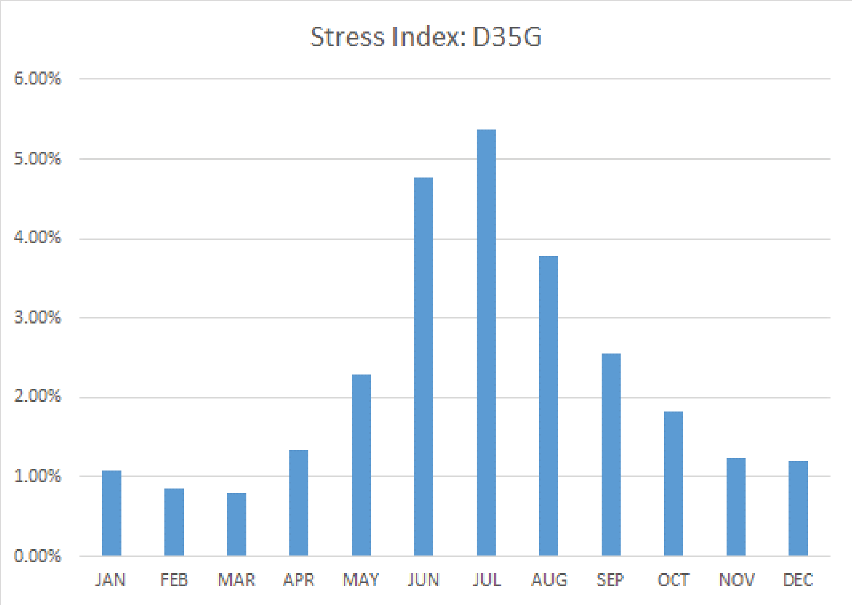


Figure 161: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35H is documented in Figure 162.

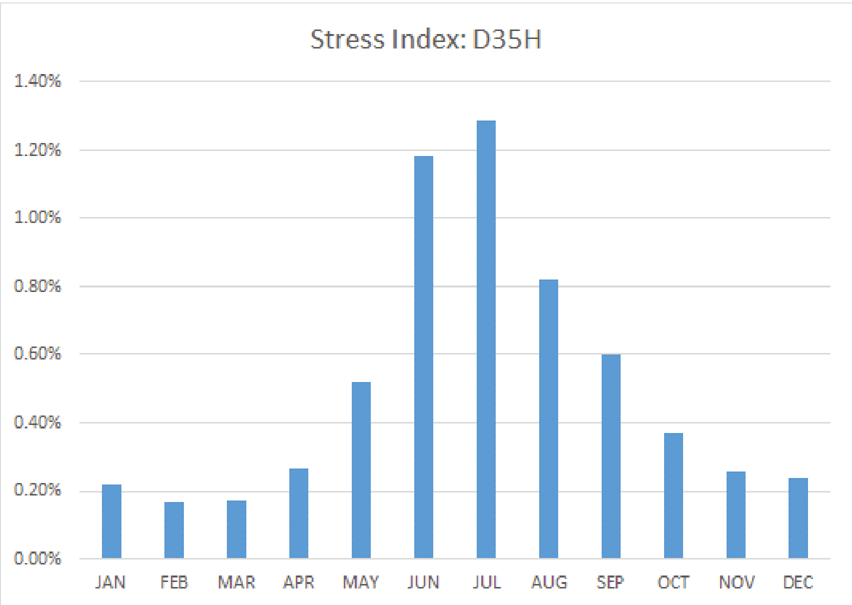


Figure 162: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35J is documented in Figure 163.

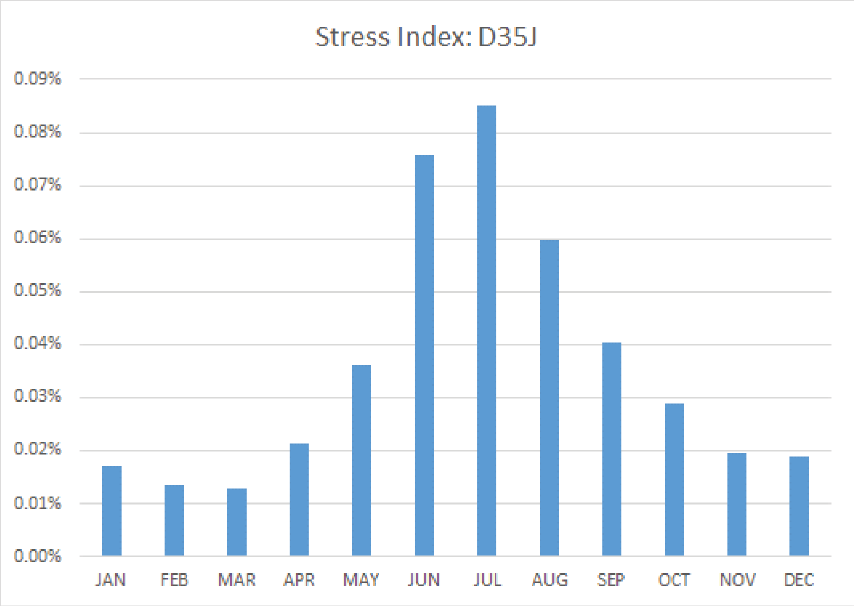


Figure 163: Monthly stress index

The monthly stress index as defined by (WRC, 2013) for D35K is documented in Figure 164.

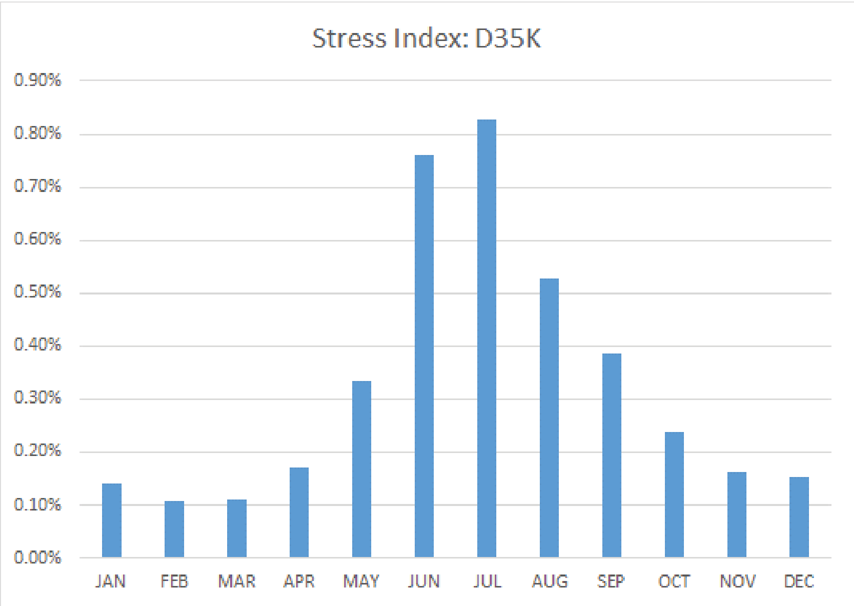


Figure 164: Monthly stress index

6 Identification of pollution sources

6.1 Preamble

According to Chapter 3 of the NWA (1998) the word pollution *means the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it:*

(a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or

(b) harmful or potentially harmful:

(aa) to the welfare, health or safety of human beings;

(bb) to any aquatic or non-aquatic organisms;

(cc) to the resource quality; or

(dd) to property;

This Section discusses the possible pollution sources that can have an effect on the groundwater resources in the study area. As the previous Section, pollution sources will be discussed per quaternary catchment.

6.2 Typical pollutants found in the study area

6.2.1 Possible Pollutants associated with Agriculture

Agricultural activities which may cause groundwater contamination include:

- Application of inorganic fertilizers
- Application of sewage sludge as a soil amendment
- Irrigation with wastewater
- Application of pesticides and herbicides
- Storage and disposal of animal wastes from dairies/feedlots/piggeries
- Disposal of wastewater from abattoirs
- Accidental spills of agrichemicals

The potential groundwater contaminants associated with agricultural activities are predominantly nutrients, microbial pathogens and synthetic organic pesticides (WRC, 2004).

Livestock farming (cattle, sheep, goats) are throughout the study area. The scale of these varies from small scale subsistence farming to large scale commercial farming.

6.2.2 Possible Pollutants in Towns (taken from WRC, 2004)

6.2.2.1 Preamble

South Africa has both formal and informal settlement types, with very different levels of service provision, and potential groundwater impacts. Leaking sewage pipelines, septic tanks in unsuitable locations, unlined maturation ponds and stormwater basins and leaking underground fuel storage tanks are contamination threats from the more formal settlement areas. Uncontrolled sanitation and waste disposal practices also lead to groundwater contamination.

6.2.2.2 On-site Sanitation

Under some hydrogeological conditions, notably where fractured bedrock is close to the surface and/or the water table is extremely shallow, the use of on-site sanitation units of standard design results in a high risk of nearby groundwater sources contamination by nitrates and pathogenic bacteria and viruses.

6.2.2.3 Urban Wastewater

Wastewater is normally collected via a sewer system piped to municipal wastewater treatment works for primary and secondary treatment. Treated wastewater is often retained in shallow oxidation ponds prior to discharge to rivers, to the ground, to marine outfall or for reuse in irrigation. Maturation ponds are often unlined, and leakage can affect the quality of local groundwater. Sewage sludge poses another potential threat to groundwater quality.

6.2.2.4 Underground Storage Tanks

Petrol stations store petroleum products (mostly petrol and diesel) in underground storage tanks (USTs), which pose a threat to the groundwater environment if a release occurs. Based on the number, location and likelihood of leakage, groundwater contamination from USTs is a significant problem in all urban areas in South Africa.

6.2.2.5 Cemeteries

There are a large number of cemeteries in the country, which pose a threat of groundwater contamination and are not subject to the same level of regulatory control as waste disposal sites (Engelbrecht, 1998).

6.2.3 Pollution Sources in the D61 Catchments

This is an arid area with sheep farming being one of the main sources of income. Photos of the area are shown in Table 32.

Table 30: Photos of the Area

There are only a few towns including: Victoria West, Richmond, Deelfontein, Merriman, Hutchinson and Meltomwald. The associated potential sources of pollution are documented in Section 6.2.

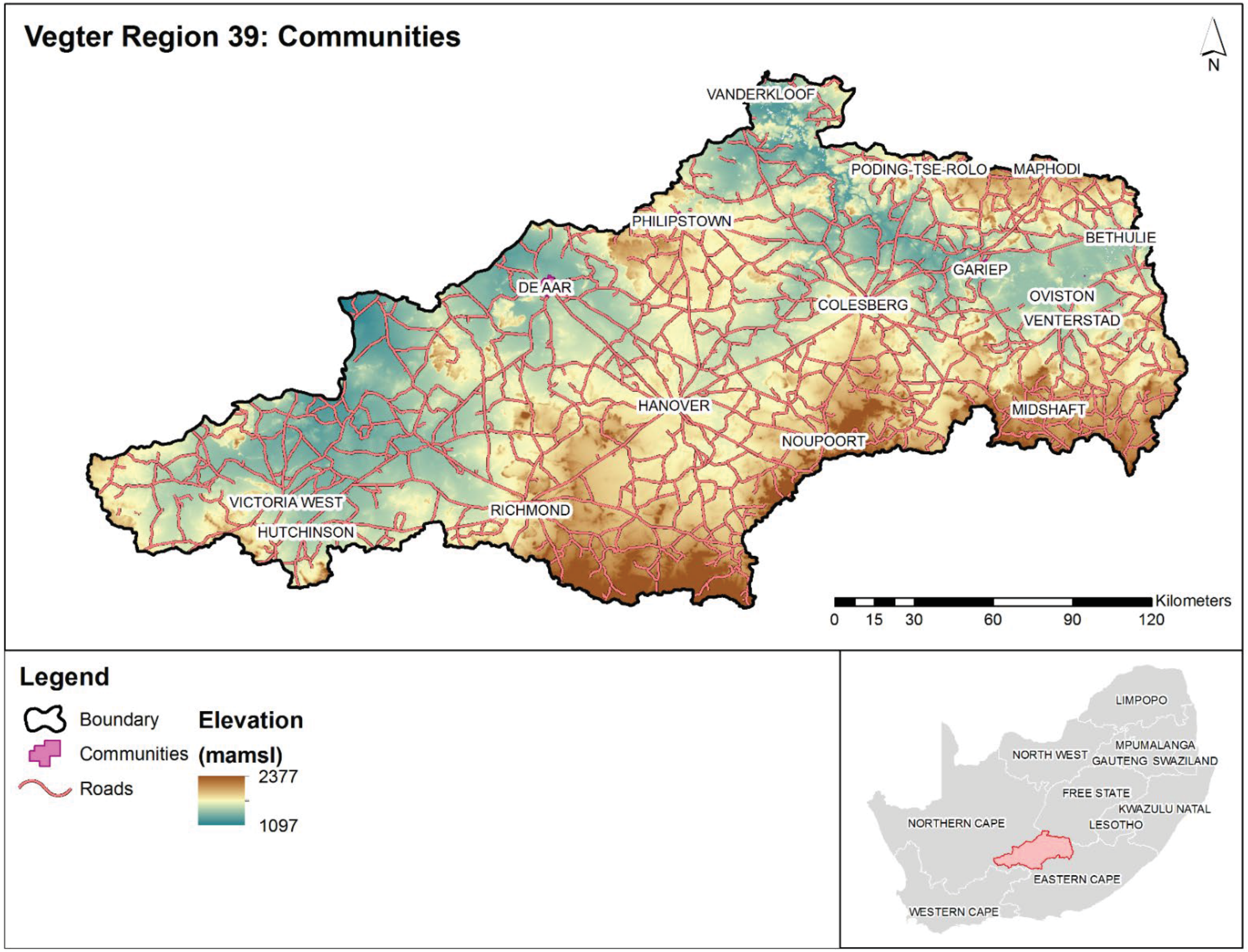


Figure 165: Region 39 – Towns and villages

6.2.4 Pollution Sources in the D62 Catchments

This is an arid area with livestock farming including sheep, ostrich and game being one of the main sources of income. Photos of the area are shown in Table 33. There is also are also solar plants and wind plants at De Aar. A number of hazardous materials are used to clean and purify the semiconductor surface of solar cells. These chemicals, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane, and acetone. Thin-film cells contain a number of more toxic materials than those used in traditional silicon photovoltaic cells, including gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride.

Table 31: Photos of the Area




De Aar is the main town in the study area. The main villages/towns are shown in Figure 165. The associated potential sources of pollution are documented in Section 6.2.

6.2.5 Pollution Sources in the D32 Catchments

This is an arid area with livestock farming including sheep being one of the main sources of income. Photos of the area are shown in Table 34.

Table 32: Photos of the Area

There are only a few towns including Hanover and Noupoort. The main villages/towns are shown in Figure 165. There is a wind plant in Hanover and Noupoort. The associated potential sources of pollution are documented in Section 6.2.

6.2.6 Pollution Sources in the D31 Catchments

This is an arid area with livestock farming including cattle and game. Crop farming (e.g. pecan nuts) also occurs in the area. Photos of the area are shown in Table 35.

Table 33: Photos of the Area

The towns of Van der Kloof and Philipstown lies on the boundary of the study area. The Van der Kloof Dam is also located in the area. An Eskom Hydroelectric Power Station is situated within the dam wall. The main villages/towns are shown in Figure 165. The associated potential sources of pollution are documented in Section 6.2.

6.2.7 Pollution Sources in the D34 Catchments

This is an arid area with livestock farming including sheep and game. Crop farming takes place along the Orange River. Photos of the area are shown in Table 36.

Table 34: Photos of the Area

There are only a few towns including: Philippolis, Waterkloof and Colesberg. The Gariep Dam is located on the eastern boundary. The main villages/towns are shown in Figure 165. The associated potential sources of pollution are documented in Section 6.2.

6.2.8 Pollution Sources in the D35 Catchments

This has livestock farming including game, sheep and horses. Crop farming takes place in the vicinity of the Gariep Dam. Photos of the area are shown in Table 37.

Table 35: Photos of the Area

There are only a few towns including Springfontein, Bethulie and Venterstad. A large portion of the Gariep Dam falls within the area. The main villages/towns are shown in Figure 165. The associated potential sources of pollution are documented in Section 6.2.

7 Delineation of Sub-Regions for Groundwater Management

In the preceding sections the statistical analysis of various borehole parameters per surface geology type was discussed. The aim of this section is to make use of the individual borehole information as basis for delineation of sub-regions.

7.1 Skewness of Data

In probability theory and statistics, skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. The skewness value can be positive or negative, or even undefined. Many models assume normal distribution, i.e. data are symmetric about the mean. The normal distribution has a skewness of zero. But in reality, data points may not be perfectly symmetric.

For the purposes of this document it is important to understand some of the factors influencing the skewness of the data in question. The two major anthropogenic influences are listed as follows:

- Only records of good yielding boreholes are normally kept, e.g. when drilling for water supply takes place, the "dry" boreholes don't get logged as these are not deemed important.
- Borehole density will also affect the proposed delineation as a high concentration of boreholes in certain regions will result in a more detailed delineation as opposed to regions where the borehole distribution is sparse.

7.2 Voronoi Diagram

In mathematics, a Voronoi diagram is a partitioning of a plane into regions based on distance to points in a specific subset of the plane. That set of points (called seeds, sites, or generators) is specified beforehand, and for each seed there is a corresponding region consisting of all points closer to that seed than to any other. These regions are called Voronoi cells.

A Voronoi diagram is a diagram created by taking pairs of points that are close together and drawing a line that is equidistant between them and perpendicular to the line connecting them. All points on the lines in the diagram are equidistant to the nearest two (or more) source points. A graphic representation of the creation of the Voronoi diagram is shown in Figure 166, where the first Voronoi cell is constructed around point A.

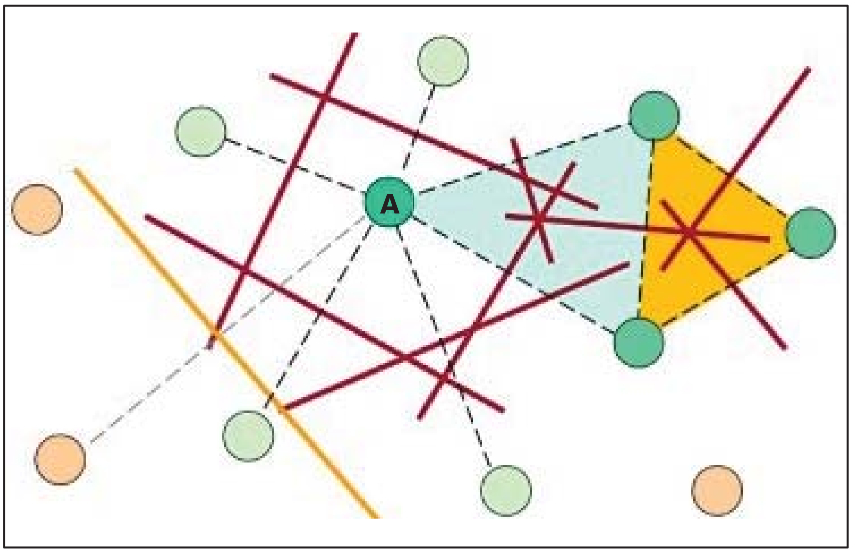


Figure 166: Creation of a Voronoi diagram

7.3 Frequency Analysis of Borehole Parameters

A frequency analysis of all available borehole parameters is conducted on the scale of the study area. The final borehole parameter set considered in the delineation is presented in Table 36.

Table 36: Borehole parameters considered in the delineation process

Parameter	Comment
Water Level	Average borehole water level measured from surface to water level position.
Blow Yield	During the drilling of a borehole, water strikes are encountered and the "blow yield" measured gives an indication of the sustainable yield of the borehole.
Water Strike Depth	During the process of drilling, water strikes are encountered at specific depths. For the purposes of delineation the deepest water strike for each borehole was used.
Water Quality (EC)	The EC (Electrical Conductivity) of a borehole is an indication of the salinity of the water. Very saline water is associated with deep stagnant water, but can also be due to the mineralogy of the host rock.

Data availability was a major factor in identifying the borehole parameters used in the delineation. Borehole discharge was also taken into consideration, but was excluded due to the poor distribution of data. The resultant frequency analysis of the borehole parameters used is presented in Figure 167 to Figure 169. Please note there was insufficient data to produce a realistic histogram for blow yield. Therefore, blow yield was not taken into account in the delineation process.

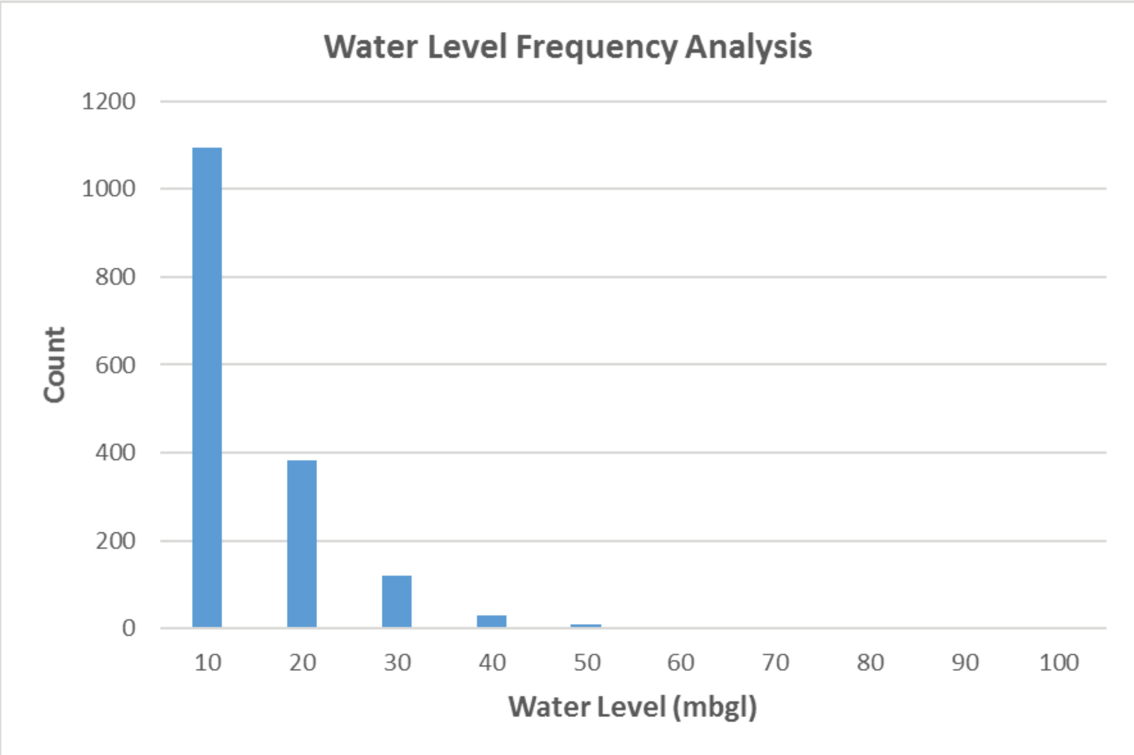


Figure 167: Water level frequency analysis

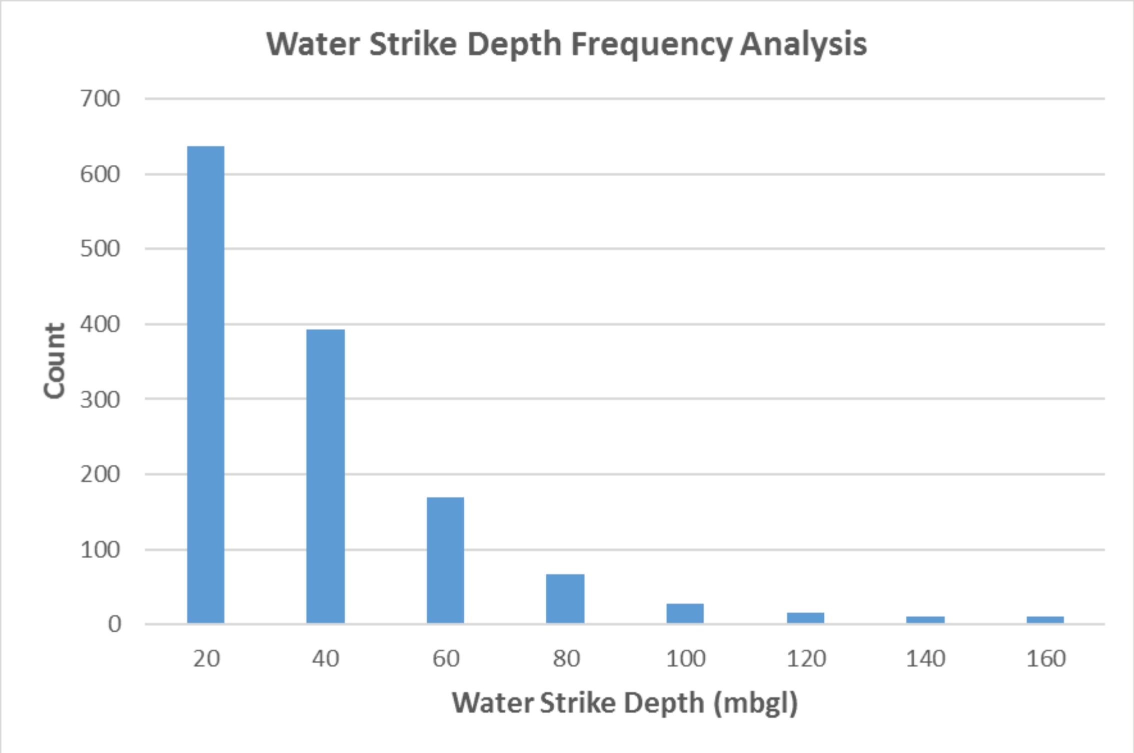


Figure 168: Water strike frequency analysis

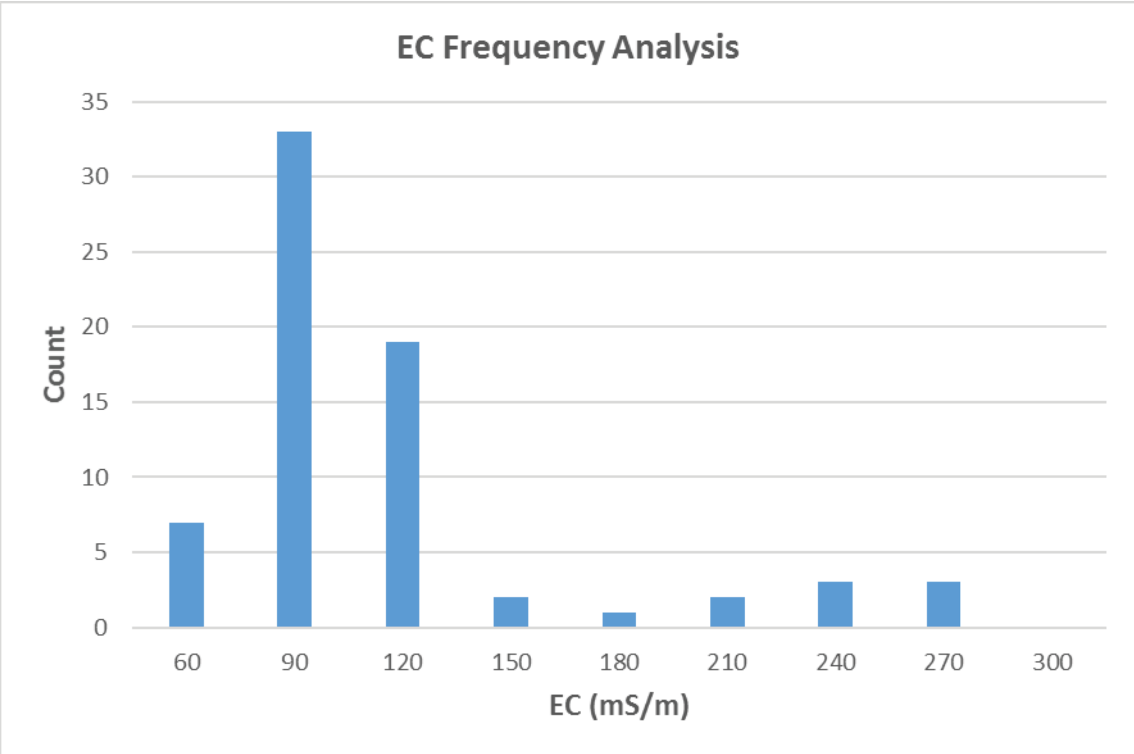


Figure 169: EC frequency analysis

Bin sizes were selected for each of the parameters to yield four bins per parameter that described at least 90% of the total dataset.

A summary of the selected bins per parameter is presented in Table 37.

Table 37: Summary of selected bins per specified borehole parameter

Bin No	**Water Level (mbgl)**		**Water Strike (mbgl)**		**EC (mS/m)**	
	Bin	*Count*	*Bin*	*Count*	*Bin*	*Count*
1	10	1095	20	637	60	7
2	20	383	40	392	90	33
3	30	120	60	170	120	19
4	40	29	80	67	150	2
		1627		1266		61

7.3.1 Delineation Methodology

A Voronoi diagram was constructed for each of the identified borehole parameters, where the borehole position and bin number was used. The bin number enabled a classification of 1 to 4 for each of the parameters in question. Once the Voronoi diagram was created it was simplified through the grouping of Voronoi cells with the same bin number as illustrated in Figure 170.

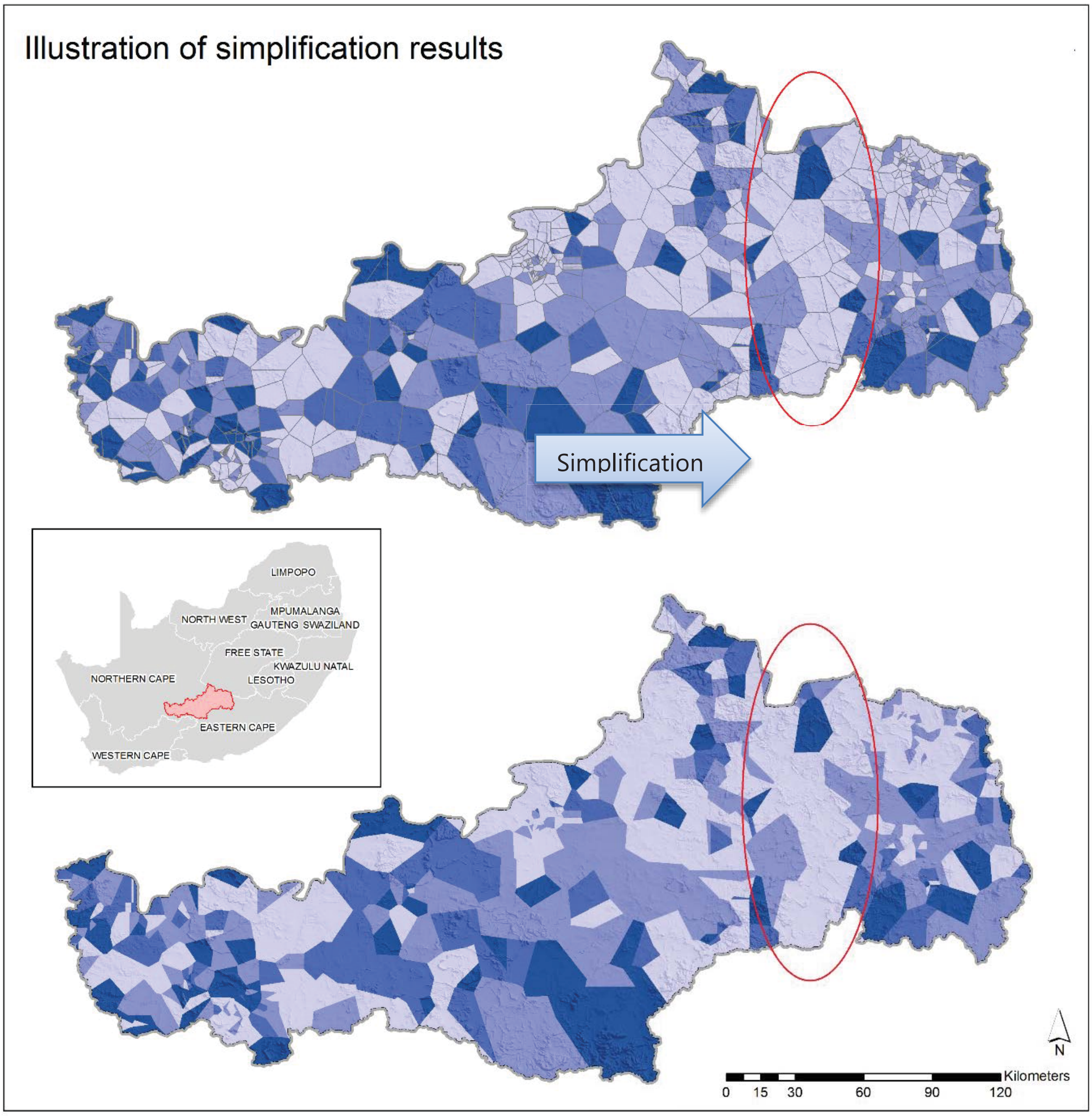


Figure 170: Simplification of Voronoi diagram based on bin numbers

A simplified Voronoi diagram was created for each of the three borehole parameters (Table 37). As very little blow yield data was available, Equation 1 which was used in previous investigations was replaced with Equation 2.

$$Delineation\ Class = \frac{Level + (5 - Yield) + Depth + EC}{4} \quad (1)$$

$$Delineation\ Class = \frac{Level + Depth + EC}{2} \quad (2)$$

The resultant map suffered from a few slivers that were removed by hand. This is a result of combining Voronoi diagrams that do not align with respect to their individual Voronoi cells due to the fact that the borehole positions differ from diagram to diagram.

The final delineation map is shown in Figure 171. The Vegter sub-region delineation with the borehole sets used that represent the four parameters (Equation 1) is shown in Figure 172 to Figure 174.

For the purposes of comparison Vegter sub-regions were overlaid on the simplified surface geology and the result is shown in Figure 175.

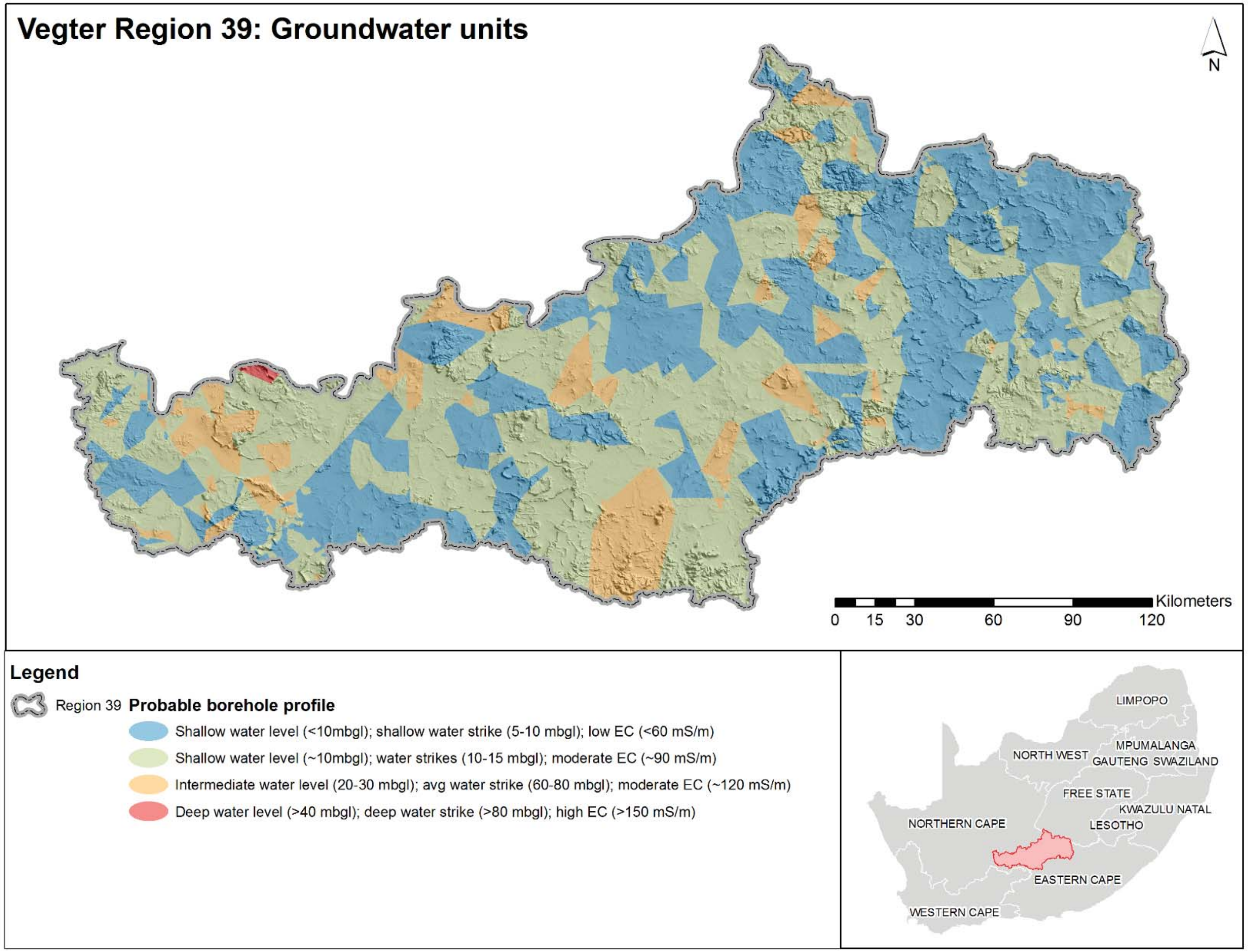


Figure 171: Final sub-region map

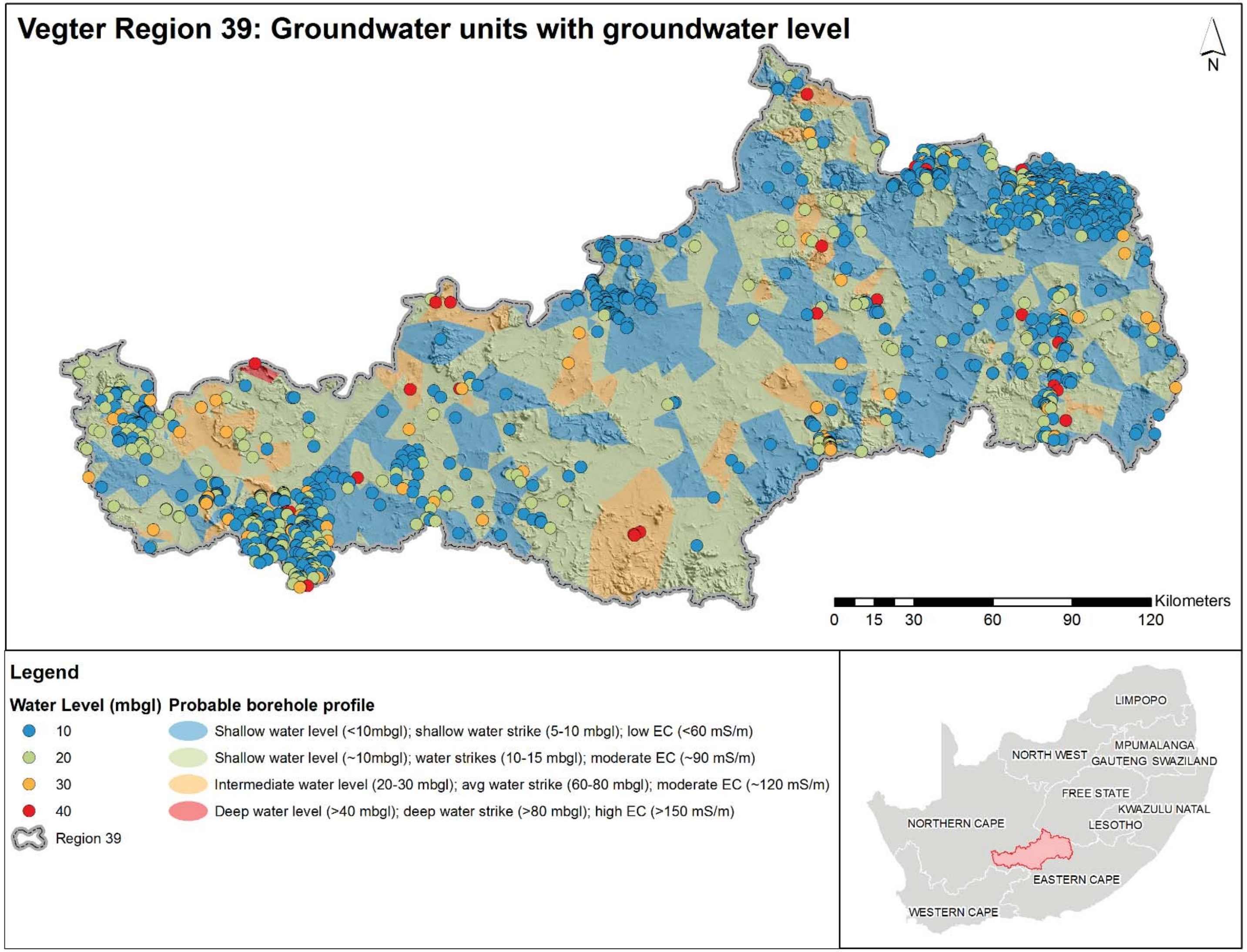


Figure 172: Sub-region map with probable borehole water levels

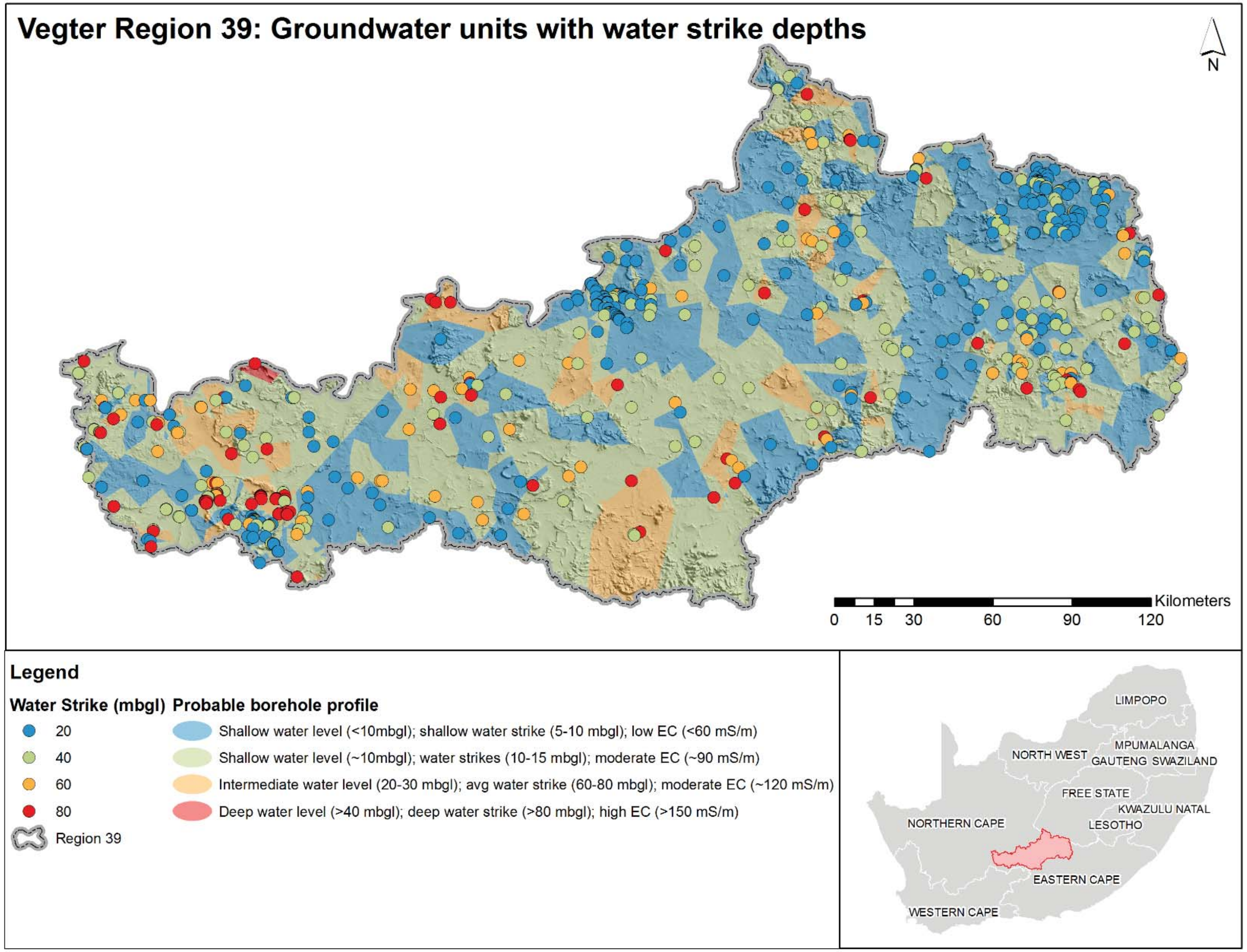


Figure 173: Sub-region map with probable borehole water strike positions

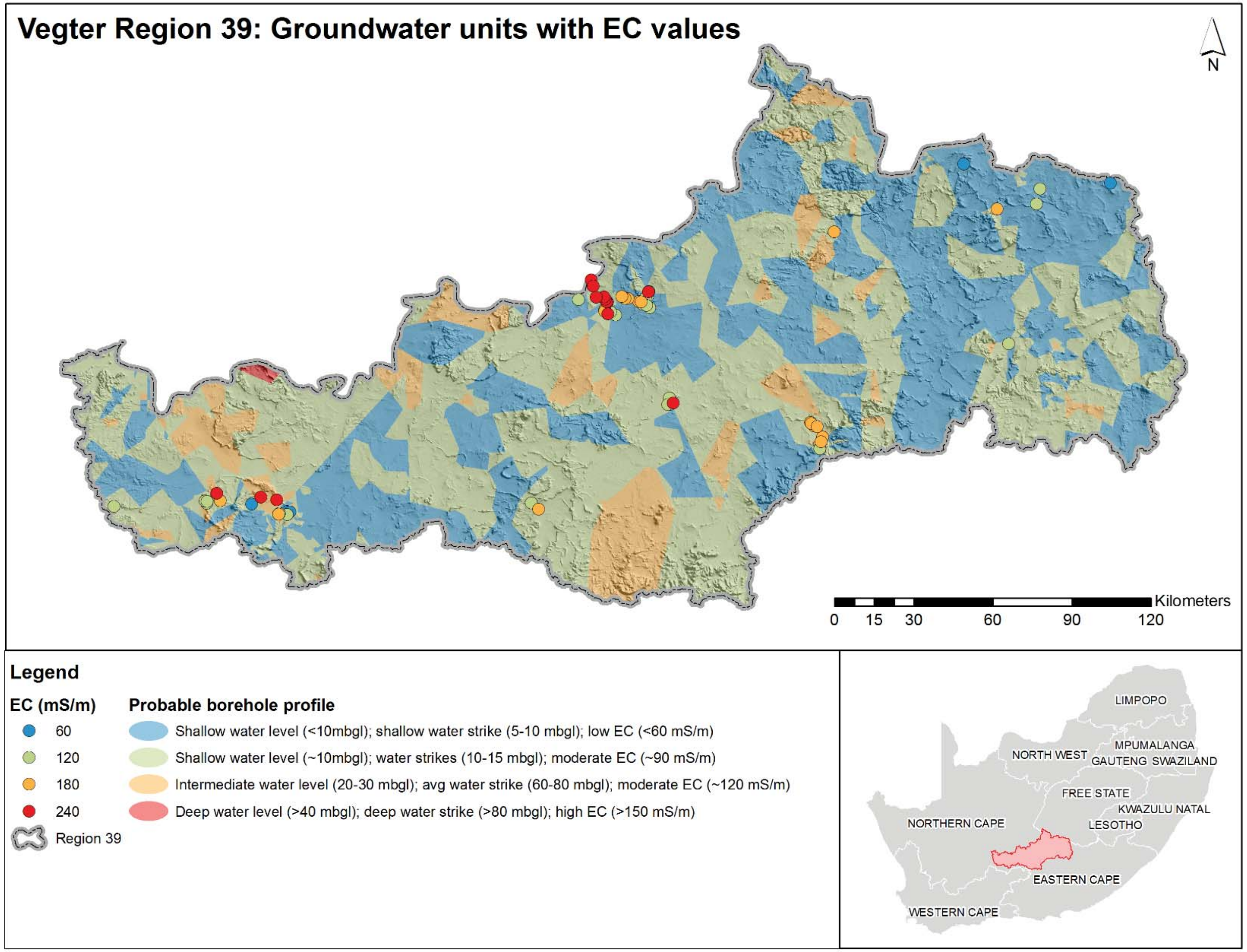


Figure 174: Sub-region map with probable borehole EC values

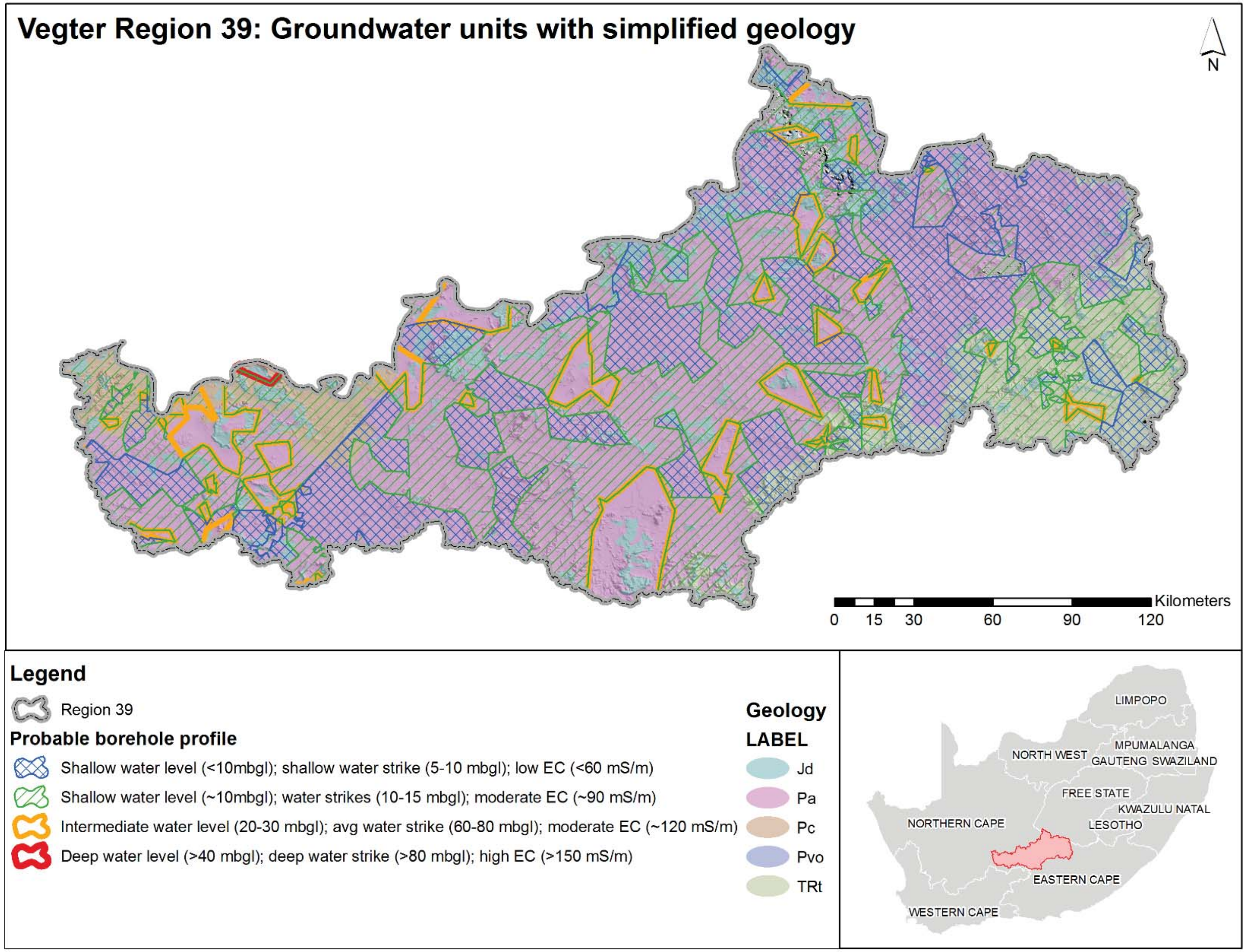


Figure 175: Sub-region comparison with the simplified surface geology

8 Conclusions and Recommendations

8.1 Summary

Approximately 50% of South Africa, is underlain by the so-called Karoo Supergroup of geological formations. A major characteristic of the Karoo Supergroup, which consists mainly of sandstone, mudstone, shale and siltstone, is their low permeability. The majority of boreholes drilled in Karoo formations therefore have very low immediate yields (<1 l/s). However, large volumes of groundwater are pumped from wellfields supplying towns, mines and the basements of buildings on a daily basis in areas underlain by the Karoo formations, which is not what one would expect from aquifers with a limited yield. The location of the Vegter Region 39 is in the south of the Karoo Basin. Victoria West, Hanover, Colesberg, Noupoort, Philippolis, Richmond, Bethulie and Springfontein.

There are numerous rivers within the region. The major rivers include the Orange, Seekoei and Ongers Rivers. The Van der Kloof and Gariep Dams are located in Region 39.

Groundwater Region No 39 falls in the heart of the proposed Karoo fracking area. According to the WRC (2012), the proposed fracking in the Karoo has been met with concern relating to potential impacts on water resources. These impacts include (O'Day and Reece, 2012):

- Contamination of groundwater.
- Stress on existing water supply.

Currently there are a number of ongoing research projects concerning the fracking. However, the current available groundwater information has not been statistically analysed according to Vegter's methodology. This approach will be useful to collate in a single reference the current knowledge and understanding of these hydrogeological systems which in turn can be used to manage and protect the aquifers within the study area.

Borehole information was obtained from the National Groundwater Archive (NGA). There are 2 aquifer types found in the regions, namely fractured and, intergranular and fractured. For most of the regions the borehole yields are less than 2 l/s. Groundwater use was obtained from the WARMS database. Recharge for the study area was also assessed.

The geostatistical analyses for the study as a whole are discussed and also the individual analysis of the different geological units as identified in the 1:1 000 000 simplified geological map of the area. Vegter's methodology is followed as closely as possible, but due to the absence of certain datasets not all Vegter analyses could be repeated. Groundwater-Surface water interaction.

Groundwater is a major contributor to flow in many streams and rivers and therefore this was determined per quaternary catchment.

Water use was calculated for each of the quaternary catchments. This is in turn used to calculate a water balance and the subsequent groundwater availability. The Reserve is then determined together with the groundwater stress index.

Possible activities and associated that can be found in the study area include:

- Agricultural activities which may cause groundwater pollution including:
    - Application of inorganic fertilizers
    - Application of sewage sludge as a soil amendment
    - Irrigation with wastewater
    - Application of pesticides and herbicides
    - Storage and disposal of animal wastes from dairies/feedlots/piggeries
    - Disposal of wastewater from abattoirs
    - Accidental spills of agrichemicals
- Towns

    The area is characterised by both formal and informal settlement types, with very different levels of service provision, types of services and potential groundwater impacts in each. Old leaking sewage pipelines, septic tanks in unsuitable locations, unlined maturation ponds at wastewater treatment works, unlined stormwater basins and leaking underground fuel storage tanks represent groundwater contamination threats from the more formal settlement areas.

    Uncontrolled sanitation and waste disposal practices are probably among the greatest threats in terms of groundwater contamination, because of the wide spatial extent across which these activities occur, and the likelihood of occurrence. Cemeteries can also be a source of groundwater pollution.

Typical potential pollution sources in the various catchments include:

- D61 catchments – Sheep farming and towns/villages
- D62 catchments – sheep, ostrich and game farming. There is also a solar plant at De Aar. A number of hazardous materials are used to clean and purify the semiconductor surface of solar cells. These chemicals, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane, and acetone. Thin-film cells contain a number of more toxic materials than those used in traditional silicon photovoltaic cells, including gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride. There are also towns/villages.
- D32 catchments – Sheep farming and towns/villages.
- D31 catchments – This is an arid area with livestock farming including cattle and game. Crop farming (e.g. pecan nuts) also occurs in the area. There are a number of towns/villages. The Van der Kloof Dam is also located in the area. An Eskom Hydroelectric Power Station is situated within the dam wall.
- D34 catchments – Livestock farming including sheep and game. Crop farming takes place along the Orange River. There are also towns/villages.
- D35 catchments – Livestock farming including game, sheep and horses. Crop farming takes place in the vicinity of the Gariep Dam. There are also towns/villages.

8.2 Delineation of Sub-Regions

A statistical analysis of various borehole parameters per surface geology type was performed. These analyses were taken into account when delineating the sub-regions. The two major anthropogenic influences effecting the skewness of data include:

- Only records of good yielding boreholes are normally kept, e.g. when drilling for water supply takes place, the "dry" boreholes don't get logged as these are not deemed important.
- Borehole density will also affect the proposed delineation as a high concentration of boreholes in certain regions will result in a more detailed delineation as opposed to regions where the borehole distribution is sparse.

Final factors taken into account in the delineation of sub-regions include: water levels, blow yields, water strike depth and water quality in terms of EC. The delineation class was calculated as:

$$Delineation\ Class = \frac{Level + (5 - Yield) + Depth + EC}{4}$$

8.3 Data Challenges

Data has been a major challenge during this study. Rainfall and surface water flow data was sparse and complete time series data sets were a challenge. There are numerous boreholes in the study area but once again the associated data sets are incomplete. It is recommended that DWS setup a regional monitoring system to be able to quantify the anthropogenic impacts on groundwater and surface water systems in the study area.

8.4 Management

It is important that the groundwater and surface water resources be managed. Management will focus on the ensuring there is sufficient groundwater and surface water of a sufficient quality to ensure the correct functioning of the lakes within the study area. It is envisaged that the management principles should be similar to Resource Quality Objectives discussed in Chapter 3 of the National Water Act (1998).

Typical characteristics of these principles include the following:

- They set limits that are simple and measurable.
- They set the limits of acceptable impact.
- They may be numeric or descriptive.

Setting management principals requires an understanding of water resources and their boundary conditions, uses of the resource, the importance of various uses and the agreed degree of modification of the resource (Colvin et al., 2003) as measured through the Classification (RDM process). When setting management principals, consideration must also be given to the consequences of modifying the hydrological regime. It is crucial that these management principals are directly linked to both the Classification and the Reserve to ensure their legal position in the event of disputes.

Capture zones must be delineated for the wetlands and rivers/streams. It is recommended that no abstraction or polluting activities take place within these zones.

Monitoring of all groundwater and surface water bodies is essential. Monitoring must be conducted by a suitably qualified person.

For more information concerning management and protection refer to:

Department of Water Affairs and Forestry (2008) A Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa, Edition 1. Pretoria.
Also online: http://www.dwaf.gov.za/Groundwater/Documents.aspx

Department of Water Affairs and Forestry (1991) Resource Directed Measures for Protection of Water Resources, Integrated Manual, Pretoria.

8.5 Suggested Monitoring

As part of the water management in the area, it is necessary to understand:

- The changes in groundwater and surface flow/levels within the area and to monitor how these change with time.
- Any pollution and how to monitor how the pollution changes with time.
- Assess performance of prevention measures, i.e. compliance with license conditions and catchment objectives.

8.5.1 Objectives of intended management action

The objectives of the management action defined above can be defined as:

- Identify, quantify and monitor surface and groundwater levels/flow in the area.
- Identify, quantify and monitor all point and diffuse pollution sources and associated plumes in the area.
- These objectives must adhere to the requirements of being specific, measurable and feasible.

8.5.2 Data requirements

The data requirements are dictated by:

- Area influenced by groundwater dewatering (due to for example agriculture).

- Groundwater discharge points.
- Groundwater and surface water abstraction points.
- Point and diffuse sources of pollution and associated pathways.

8.6 Recommendations for Future Research

The proposed delineation method, based on the work of Vegter (2001) provides a methodology in which aquifers can delineated. This allows the groundwater specialists to conduct studies/research on aquifer boundaries which deviates from the current approach of using surface water boundaries to delineate study areas. This approach can for example be applied in Groundwater Resource Directed studies, which include Reserve determinations.

This method is not subjective and repeatable. It is however depended on data availability. The method can also be applied at different scales, thereby becoming a planning tool for potential sites where field work can take place, for example borehole siting.

It is therefore recommended that a software tool be developed in which the sub-regions for each of the Vegter Regions are delineated. Thereafter the user can further refine the regions if data availability. The tool can also be used to identify areas where the potential to drill high yielding boreholes is good, thereby reducing the amount of field work that would need to be conducted.

This study can also be applied in conjunction to the work conducted by Cobbing et al. (2014), which documents the diverse factors influencing long-term success of groundwater schemes for domestic water supplies. The focus of this report is on the 24 priority municipalities as defined by the Department of Water Affairs and Sanitation.

9 Data Sources

Numerous reports were consulted during the project, including:

Botha, J. F., Verwey, J. P., Van der Voort, I., Vivier, J. J. P., Colliston, W. P. and Loock, J. C. (1998). Karoo Aquifers. Their Geology, Geometry and Physical Behaviour. WRC Report No 487/1/98. Water Research Commission, P.O. Box 824, Pretoria 0001.

Bredenkamp, D. B., Verhagen, B. Th. and Botha, L; (1998). Hydrogeological and isotopic assessment of the response of a fractured multi-layered aquifer to long-term abstraction. Final report on project K5/565 to the Water Research Commission.

Bredenkamp, D.B., Botha. L.J., Van Tonder, G.J., Van Rensburg, H.J. (1995). Manual on quantitative estimation of groundwater recharge and aquifer storativity, WRC Report TT 73/95, Water Research Commission, Pretoria

Cavé L, Beekman HE & Weaver J (2003). Impact of Climate Change on Groundwater Recharge Estimation. In Y Xu & HE Beekman (eds.) Groundwater Recharge Estimation in South Africa. UNESCO, Paris, 189–197.

Chevallier L. and Woodford A.C. (1999). Morpho-tectonics and mechanism of emplacement of the dolerite rings and sills of the Western Karoo, South Africa., S.Afr.J.Geol., Vol. 102 (1), pp. 43-54.

Chevallier L., Goedhart, M. and Woodford A.C. (2001). Influence of dolerite ring-structures on the occurrence of groundwater in Karoo Fractured Aquifers: a morpho-tectonic approach, Project Number K937, Water Research Commission, Pretoria, p146.

Cobbing, J.E., Eales, K., Gibson, J., Lenkoe, K. and Rossouw T. (2014). An appraisal of diverse factors influencing long-term success of groundwater schemes for domestic water supplies, focusing on priority areas in South Africa. Water Research Commission Report No 2158/1/14.

Department of Water Affairs and Forestry (DWAF). 2006. Groundwater Resource Assessment II: Methodology report. Department of Water Affairs, Pretoria, South Africa.

Donnenfeld, Z., Crookes C. and Hedden S. (2018). A delicate Balance – Water scarcity in South Africa. https://issafrica.s3.amazonaws.com/site/uploads/sar13-2.pdf. Date of access 1 November 2016.

Engelbrecht, J.F.P., (1993). An assessment of health aspects of the impact of Domestic and Industrial waste disposal activities on groundwater resources, Water Research Commission, Report No. 371/1/93, Pretoria.

Govender M., Naiken V., Chetty K., and Bulcock K. (2008) Towards improved estimates in water resources assessments: the use of hyperspectral and multispectral imagery to classify and map vegetation in Southern Africa. WRC Report No. 1684/1/08. Water Research Commission, Pretoria, South Africa.

Hallbauer D.K., Chevallier L. and Woodford A.C. (1995) The application of capillary ion analysis to the geochemistry of ground water from Western Karoo Aquifers. Ground Water Recharge and Rural Water Supply, 26-28 sept 1995, Midrand. Extended Abstract.

Herold, C.E. (1980). A model to compute on a monthly basis diffuse salt loads associated with runoff. WRCPWVS project, HRU Report No. 1/80, University of the Witwatersrand, Witwatersrand, South Africa.

Hodgson, F., Verhagen, B. Th. and van der Linde P. J; (1977). The use of groundwater chemistry in determining the relative age of groundwater occurrences in the southern Orange Free State. Unpub. Rep. IGS, UOFS.

Kirchner, J. O. G., Van Tonder, G. J. and Lukas, E., (1991). Exploitation Potential of Karoo Aquifers. WRC Report No 170/1/91. Water Research Commission, P.O. Box 824, Pretoria 0001.

McCarthy, M.J. (1979). A perspective view of Karoo dolerites and normal faulting in coastal Natal. Petros, Students Geological Society, University of Natal, 9, 44-52 pp.

Middleton, B.J. & Bailey, A.K. (2008). Water resources of South Africa, 2005 STUDY (WR2005). Water Research Commission Project No. K5/1491, Water Research Commission, Pretoria.

Murray R, Baker K, Ravenscroft P, Musekiwa C and Dennis R (2011). A Groundwater Planning Toolkit for the Main Karoo Basin: Identifying and quantifying groundwater development options incorporating the concept of wellfield yields and aquifer firm yields. WRC Report No: 1763/1/11 Water Research Commission, Pretoria.

National Water Act (1998). Act No 36. Republic of South Africa Government Gazette.

O'Day S and Reece JL (2012). Top Environmental Concerns in Fracking. Oil and Gas Monitor. http://www.oilgasmonitor.com/top-environmental-concerns-fracking/1557/. Accessed on 4 July 2014.

SANBI (2010) Wetland Cover for South Africa. South African National Biodiversity Institute 2 Cussonia Ave, Brummeria, Pretoria.

USGS (1998). Groundwater and Surface water: A single resource. U.S. Geological Survey Circular 1139. Denver, Colorado.

Vegter, J.R., (1992). An evaluation of ground water exploitation and its potential for urban use, De Aar, hydrogeological consulting report to the Directorate of Geohydrology, Department of Water Affairs and Forestry, Pretoria, South Africa.

Vegter, J.R., (1995). An explanation of a set of national groundwater maps, Water Research Commission, Report 483, TT 74/95, Pretoria.

Vegter, J.R. (2001). Groundwater Development in South Africa and an Introduction to the Hydrogeology of Groundwater Regions. Water Research Commission Report TT134/00, 106 pp.

Water Research Commission (WRC) (2004). Identification and prioritisation of groundwater contaminants and sources in South Africa's urban catchments. WRC Report No: K5/1326 Water Research Commission, Pretoria.

Water Research Commission (WRC) (2011). Implementing Uncertainty Analysis in Water Resource Assessment and Planning. Deliverable No. 1: Design of Surface – Groundwater Interaction Studies. Project Number KV/2056. Institute for Water Research, Rhodes University, 40 pp.

Water Research Commission (WRC) (2012). State of the Art: Fracking for Shale Gas Exploration in South Africa and the Impact on Water Resources. WRC Report No: KV 294/11, Water Research Commission, Pretoria.

Woodford A.C., Rosenwarne P. and Girman J. (date unknown) How much groundwater does South Africa have? www.srk.co.za/files/File/newsletters/groundwater/PDFs/1_A_Woodford.pdf. Date of access 1 November 2016.

Woodford A.C. and Chevallier L., (2000). Regional characterization and mapping of Karoo fractured aquifer systems – An integrated approach using a geographical information system and digital image processing, Water Research Commission, Project Report K653, Pretoria, p209.

Woodford AC & Chevallier L (eds.) (2002). Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Needs. WRC Report No. TT 179/02, Water Research Commission, Pretoria.

Woodford, A., Du Plooy, J., Chevallier, L., Dondo, C., Nhleko, L., Murray, E.C., Gqiba, D., Hughes, D. and Haigh, L. (2006). Flow Conceptualisation, Recharge and Storativity Determination in Karoo Aquifers, with special emphasis on Mzimvubu to Keiskamma and Mvoti to Umzimkulu Water Management Areas in the Eastern Cape and KwaZulu-Natal Provinces of South Africa. Inception Report. WRC Project K1565.

10 Appendix A Rainfall and Temperatures

10.1 Victoria West

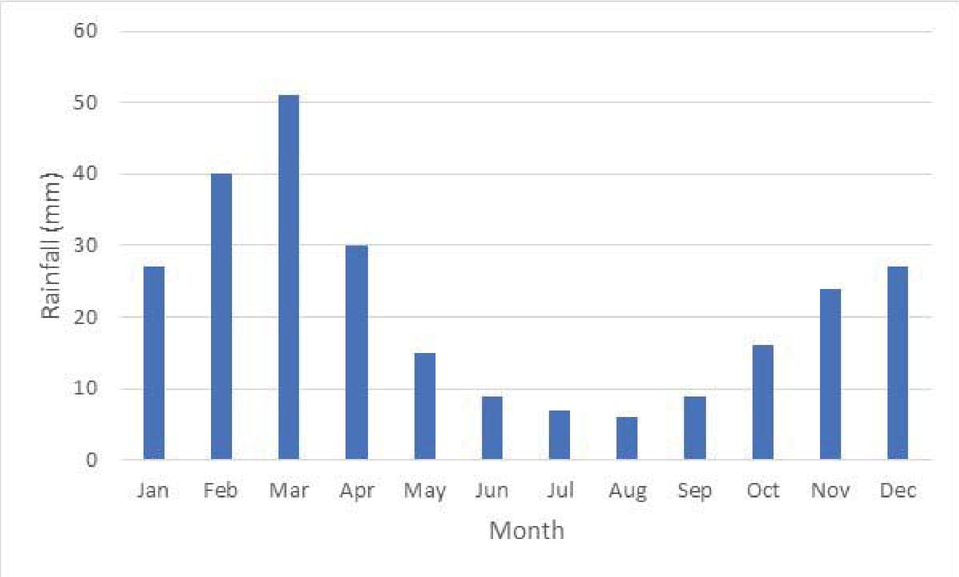


Figure 176: Monthly rainfall

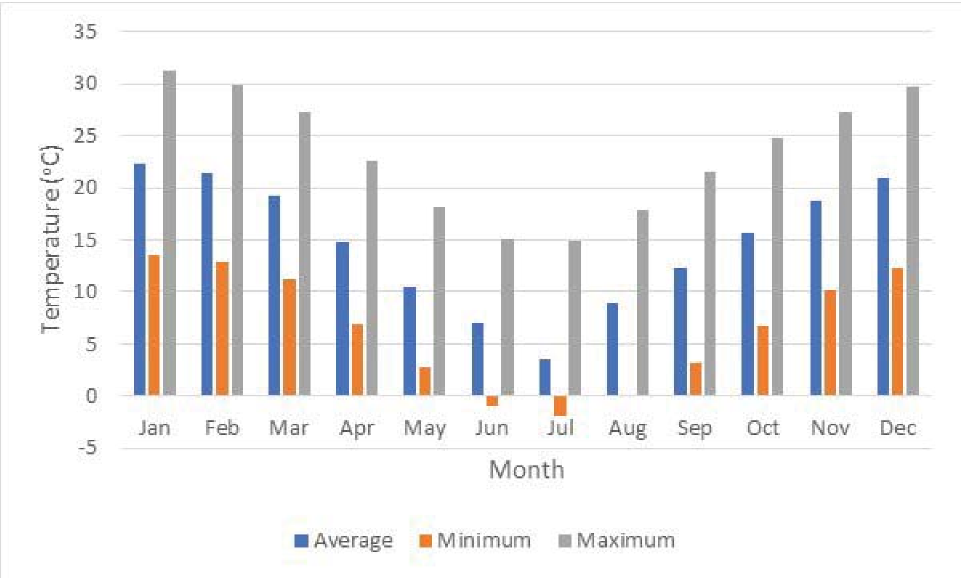


Figure 177: Monthly temperatures

10.2 Colesberg

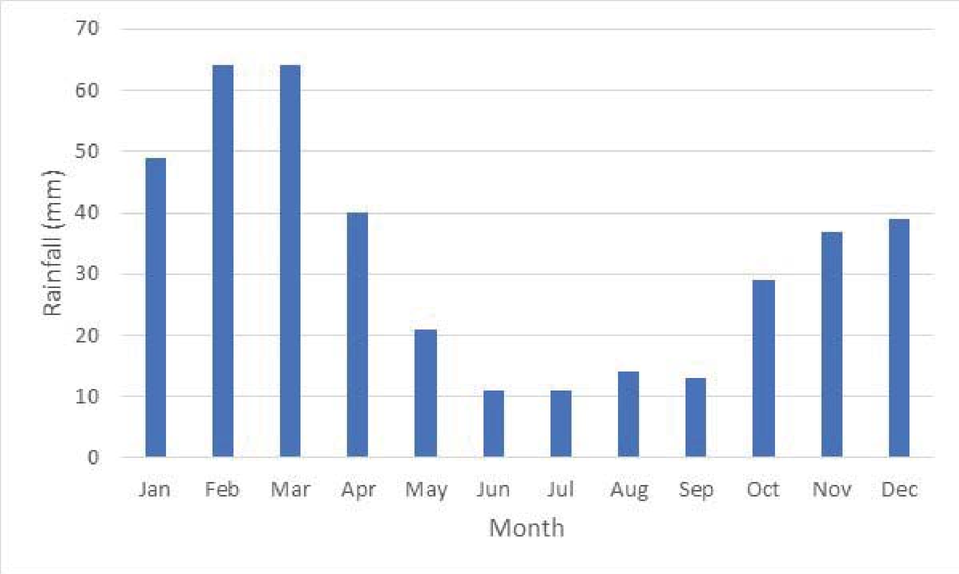


Figure 178: Monthly rainfall

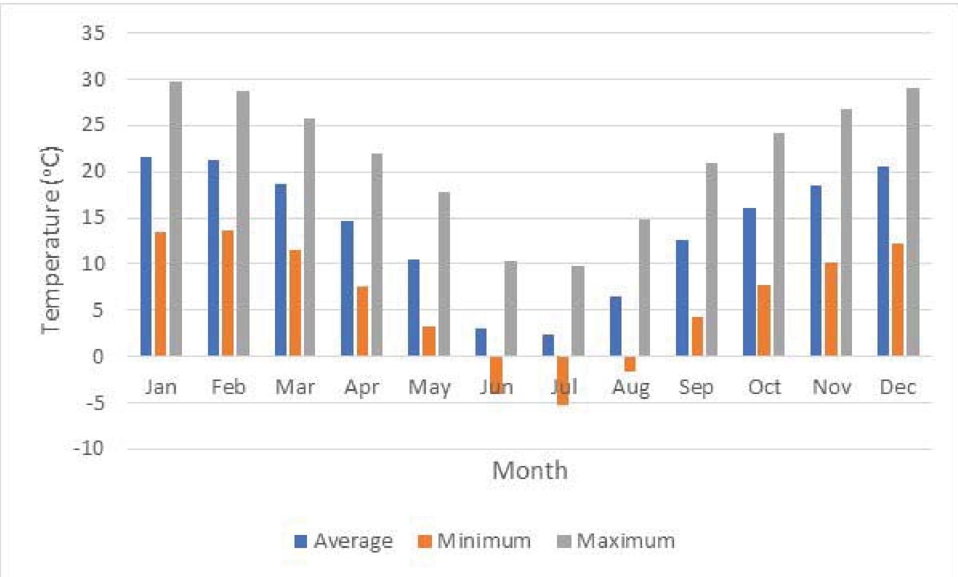


Figure 179: Monthly temperatures

10.3 Hanover

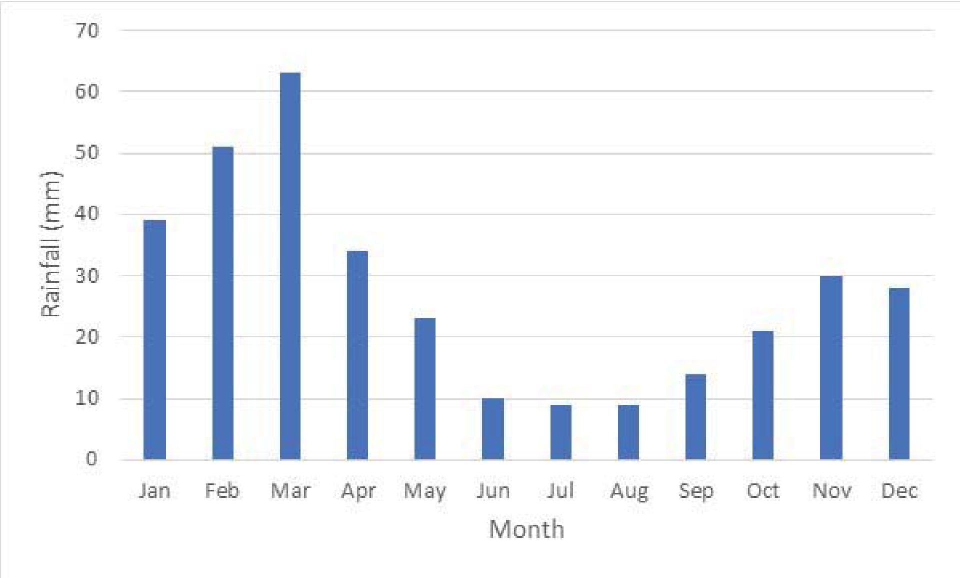


Figure 180: Monthly rainfall

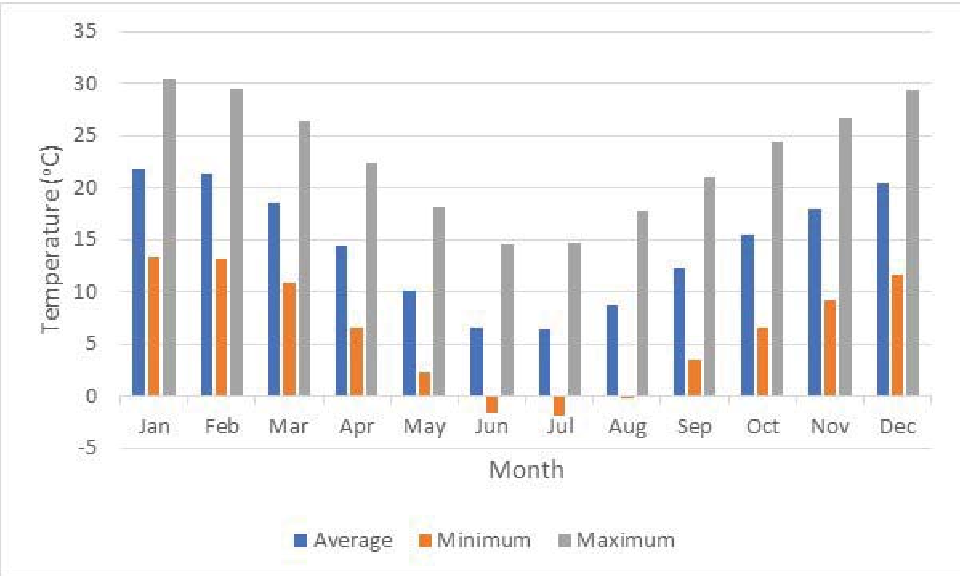


Figure 181: Monthly temperatures

10.4 Noupoort

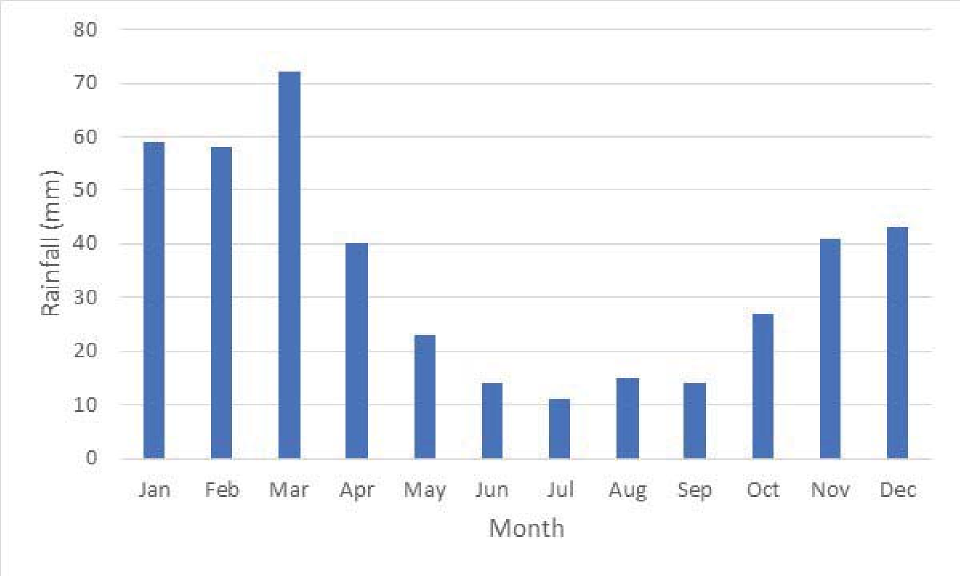


Figure 182: Monthly rainfall

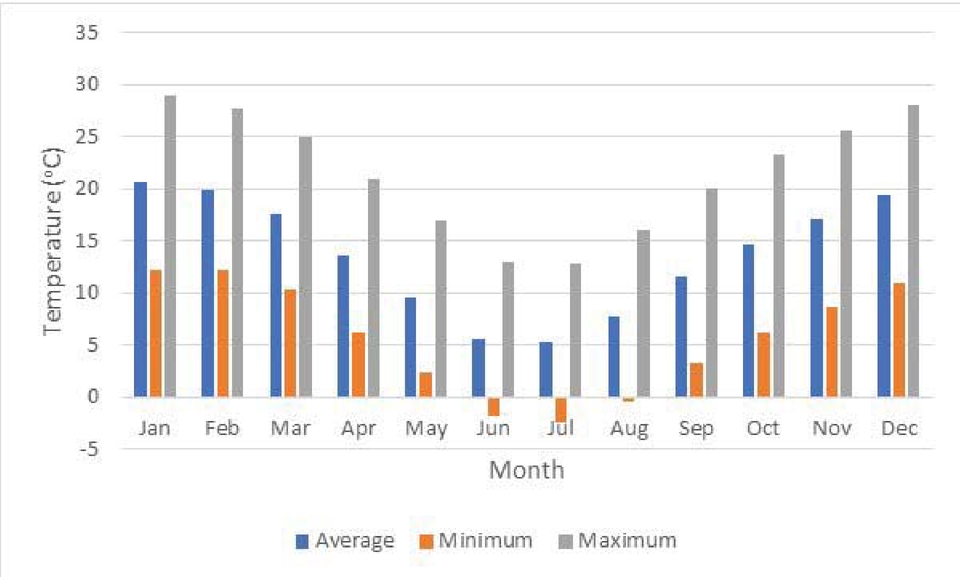


Figure 183: Monthly temperatures

10.5 Philippolis

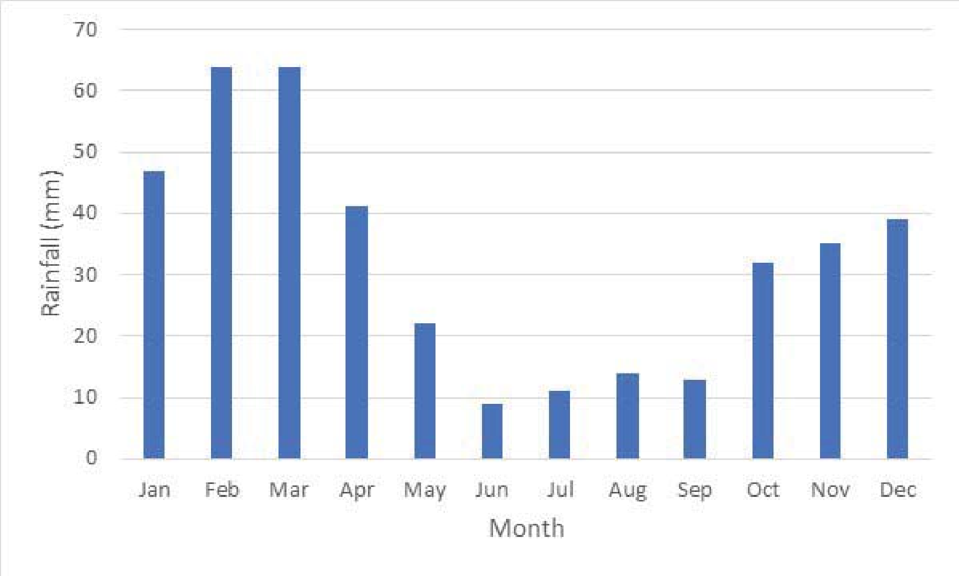


Figure 184: Monthly rainfall

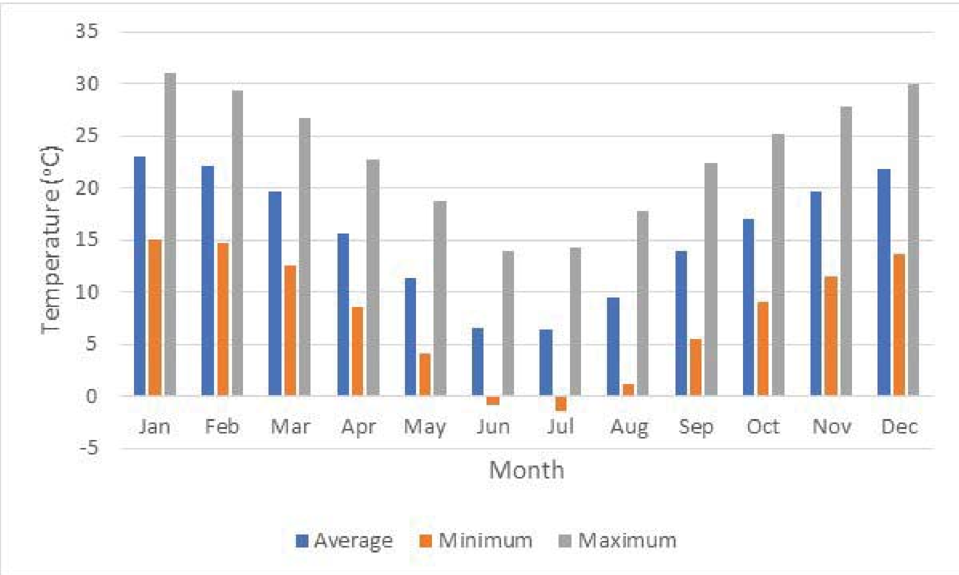


Figure 185: Monthly temperatures

10.6 Richmond

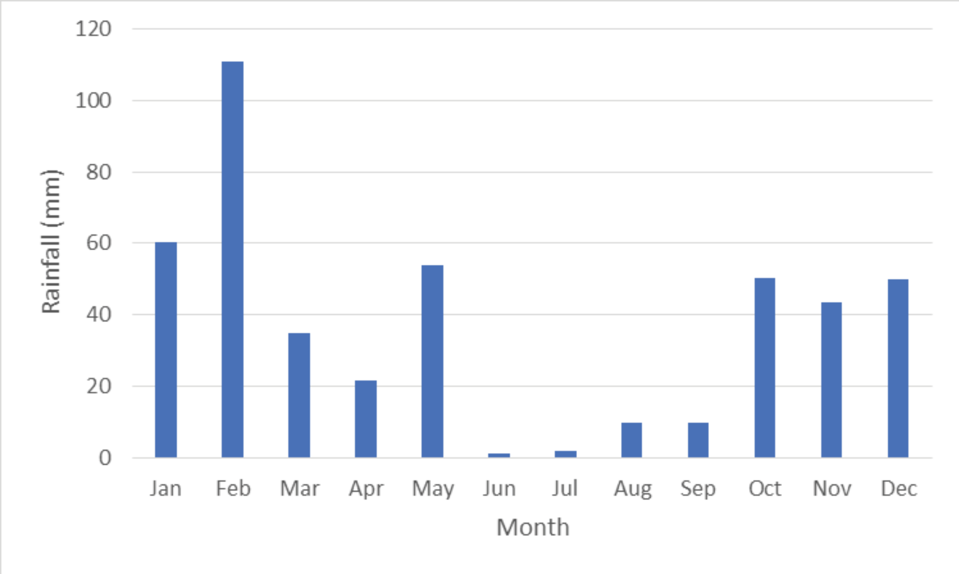


Figure 186: Monthly rainfall

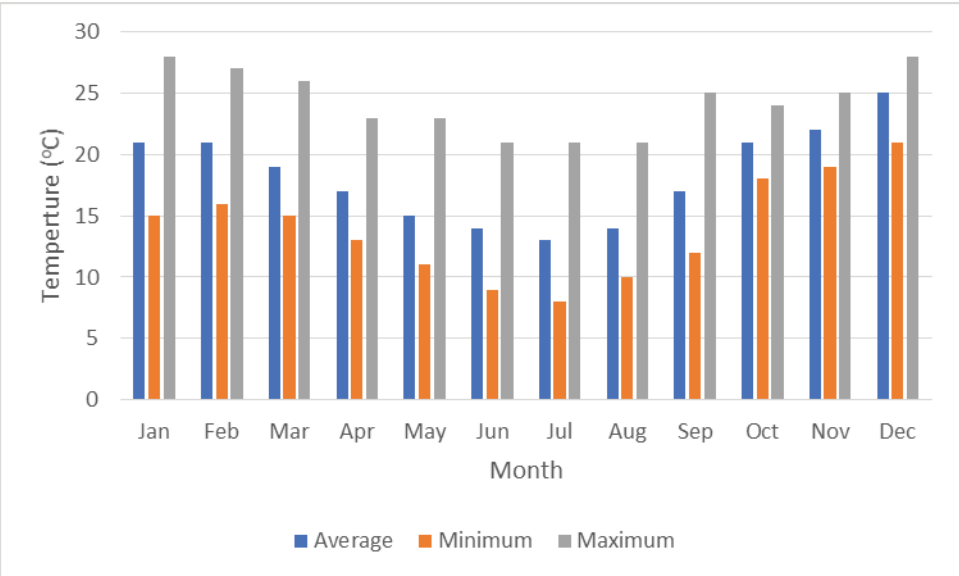


Figure 187: Monthly temperatures

10.7 Bethulie

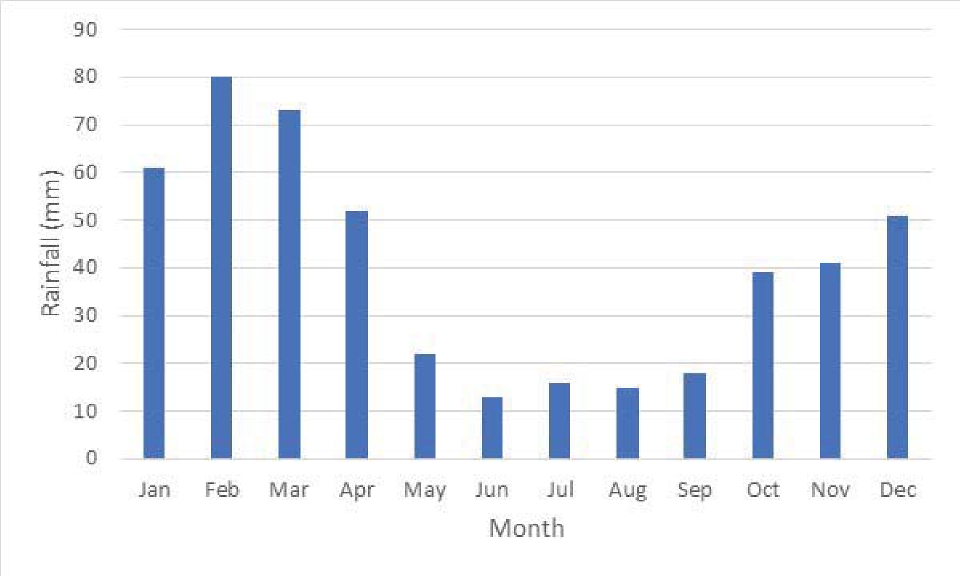


Figure 188: Monthly rainfall

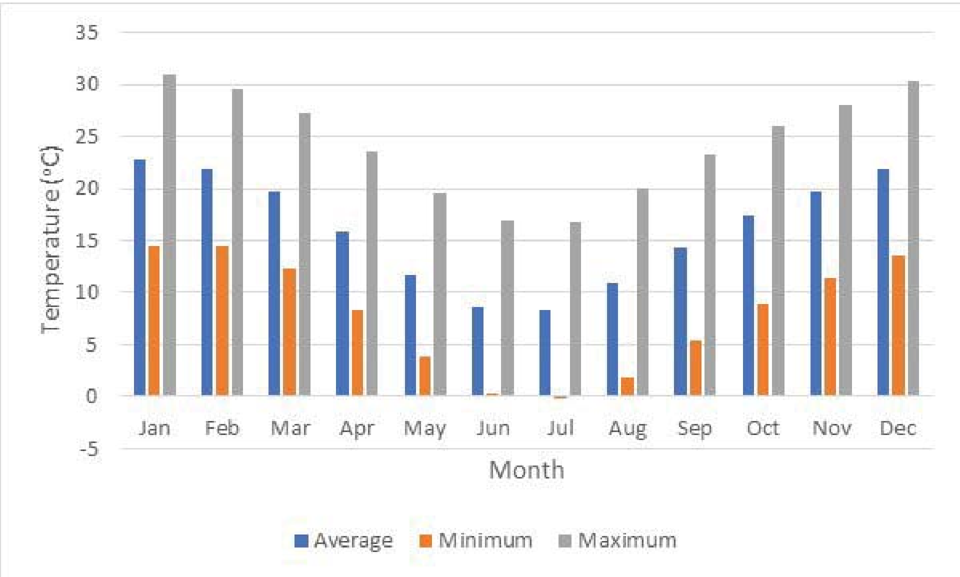


Figure 189: Monthly temperatures

10.8 Springfontein

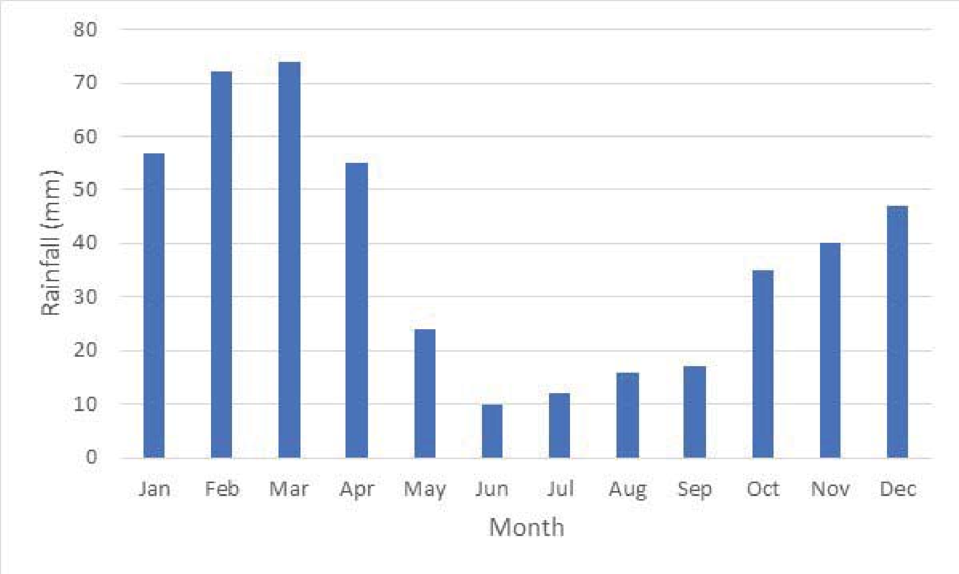


Figure 190: Monthly rainfall

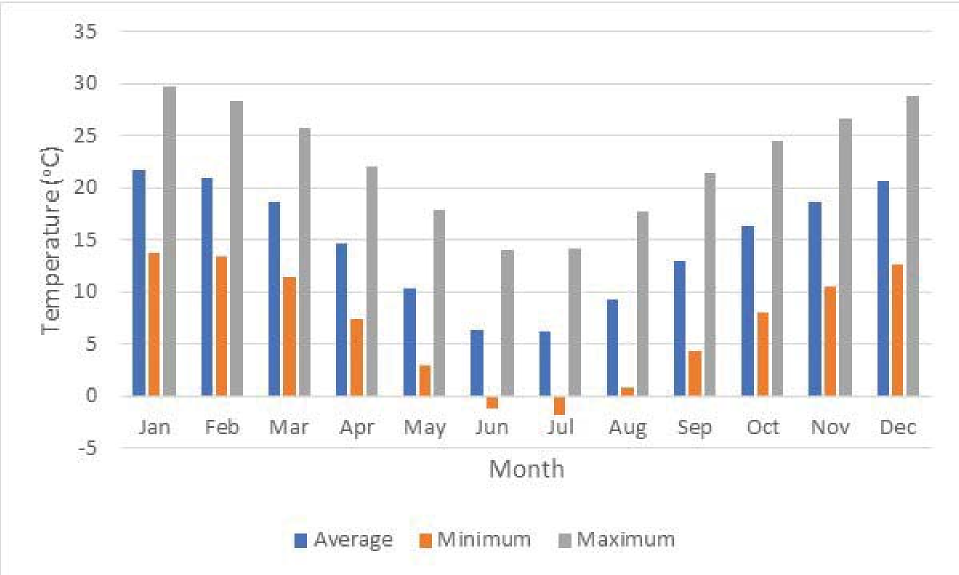


Figure 191: Monthly temperatures

11 Appendix B: Hydrographs

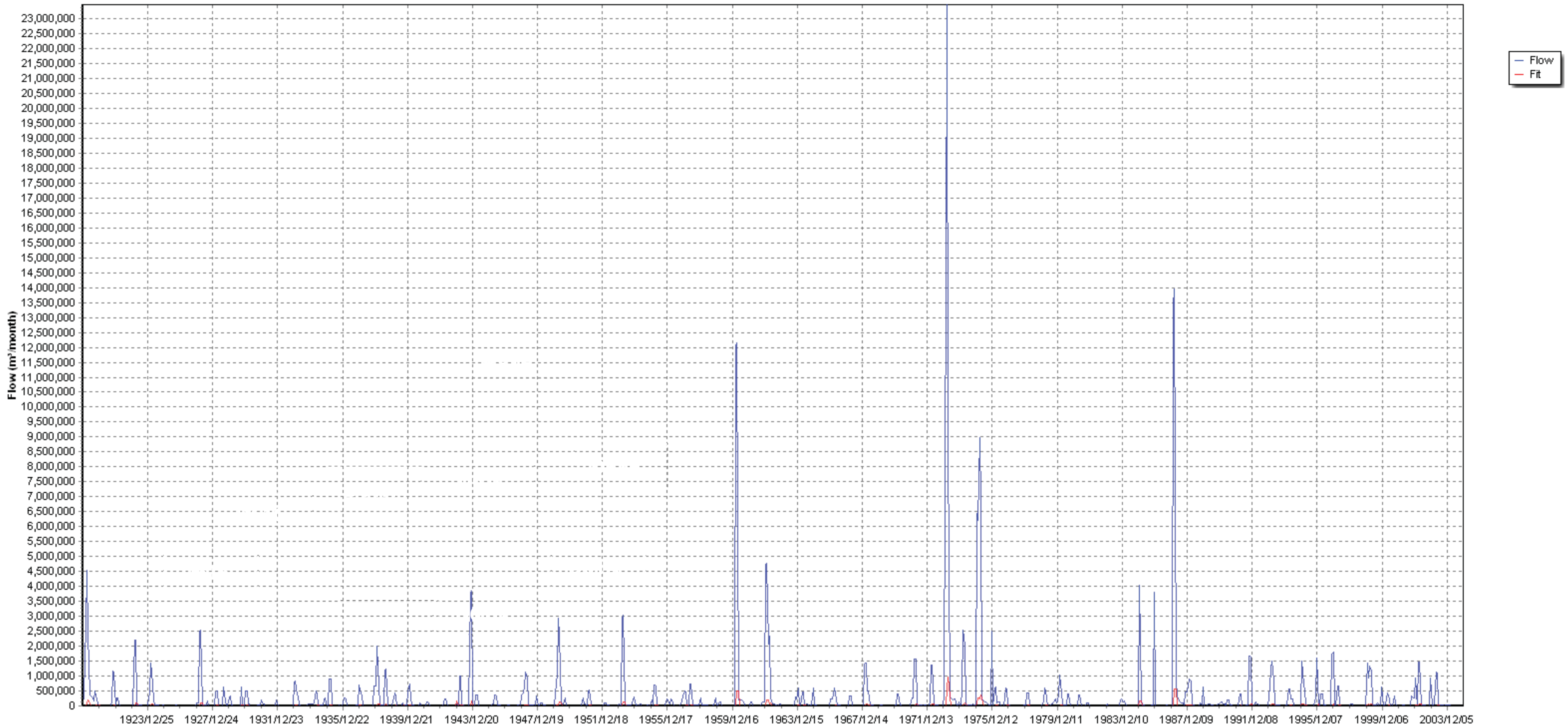


Figure 192: Groundwater contribution to baseflow (D61A)

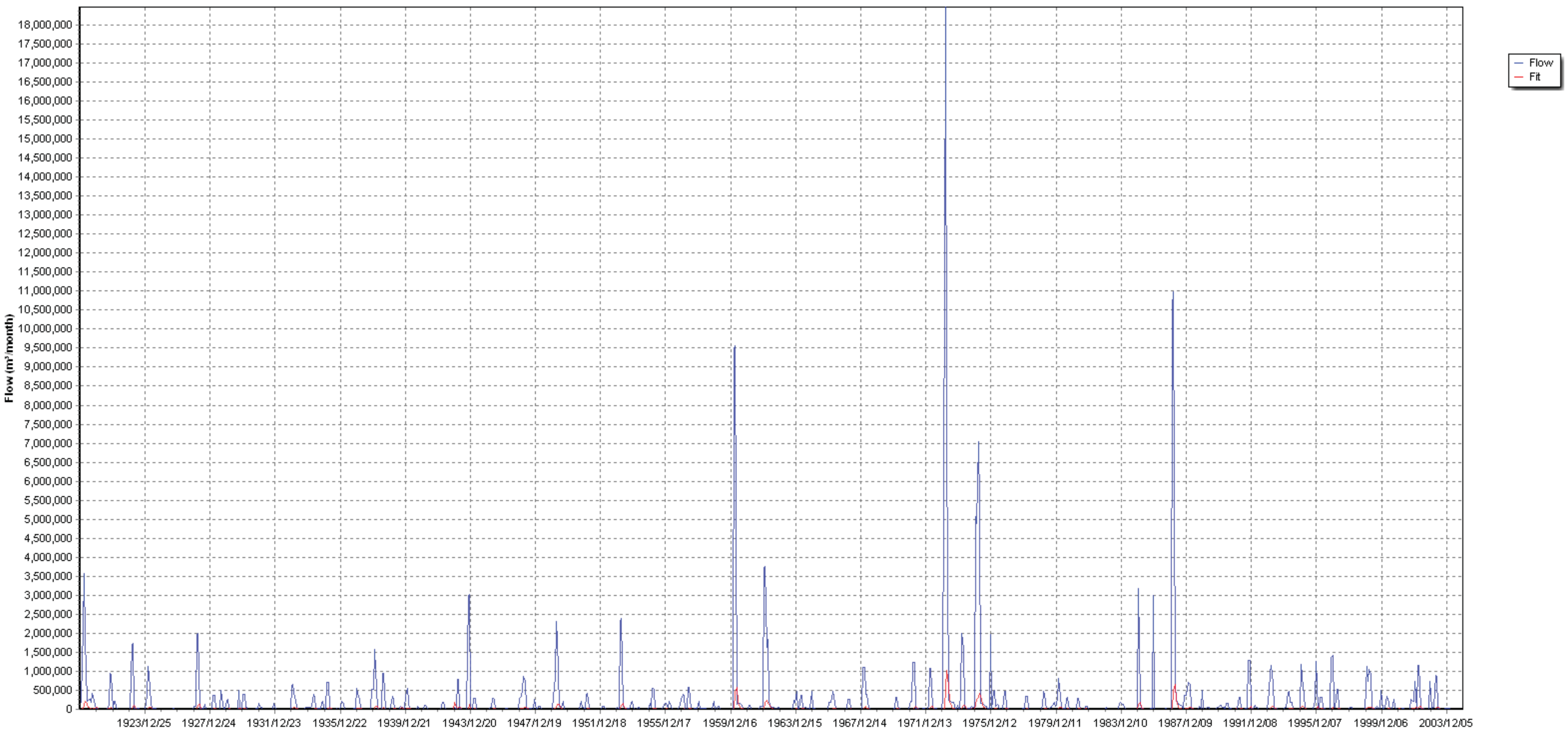


Figure 193: Groundwater contribution to baseflow (D61B)

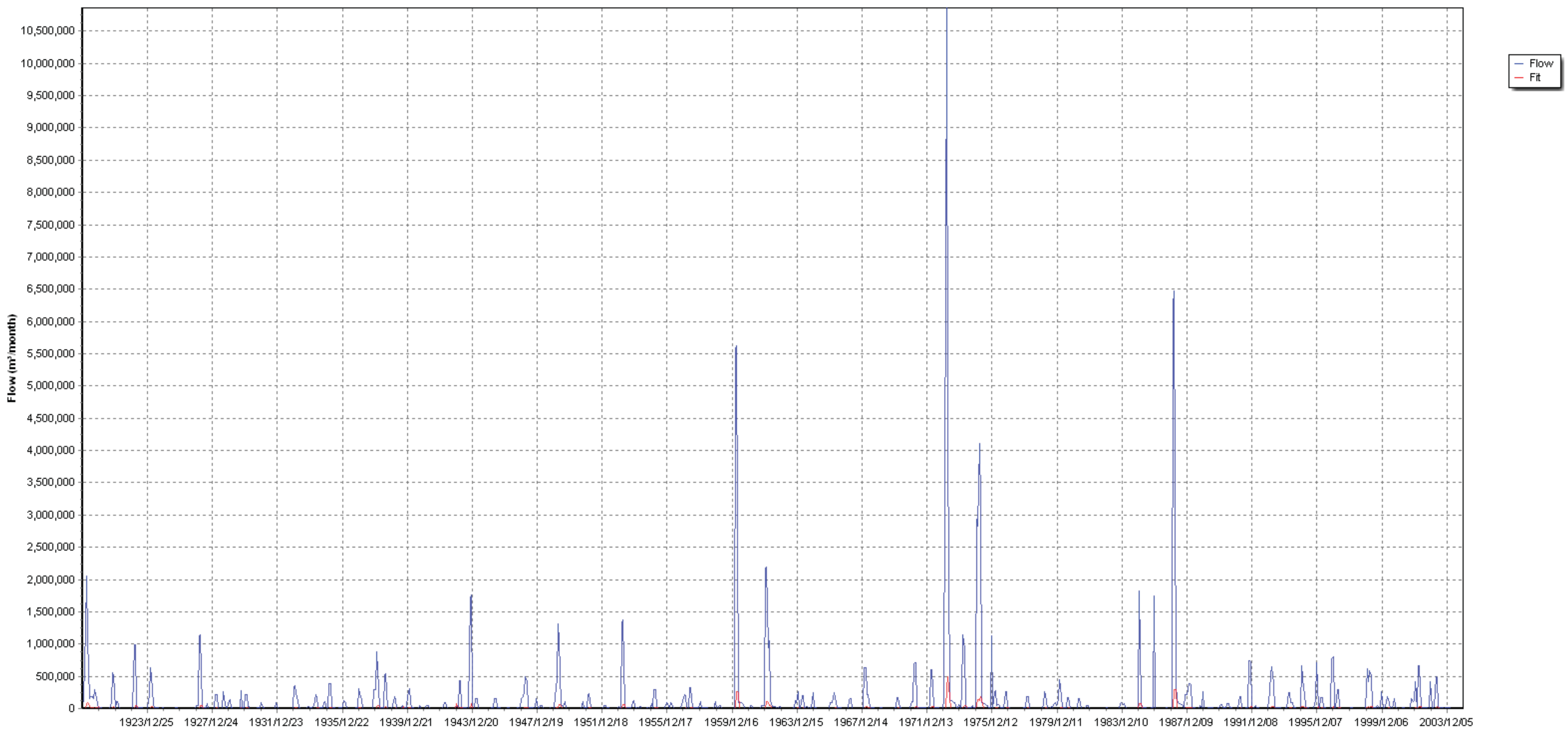


Figure 194: Groundwater contribution to baseflow (D61C)

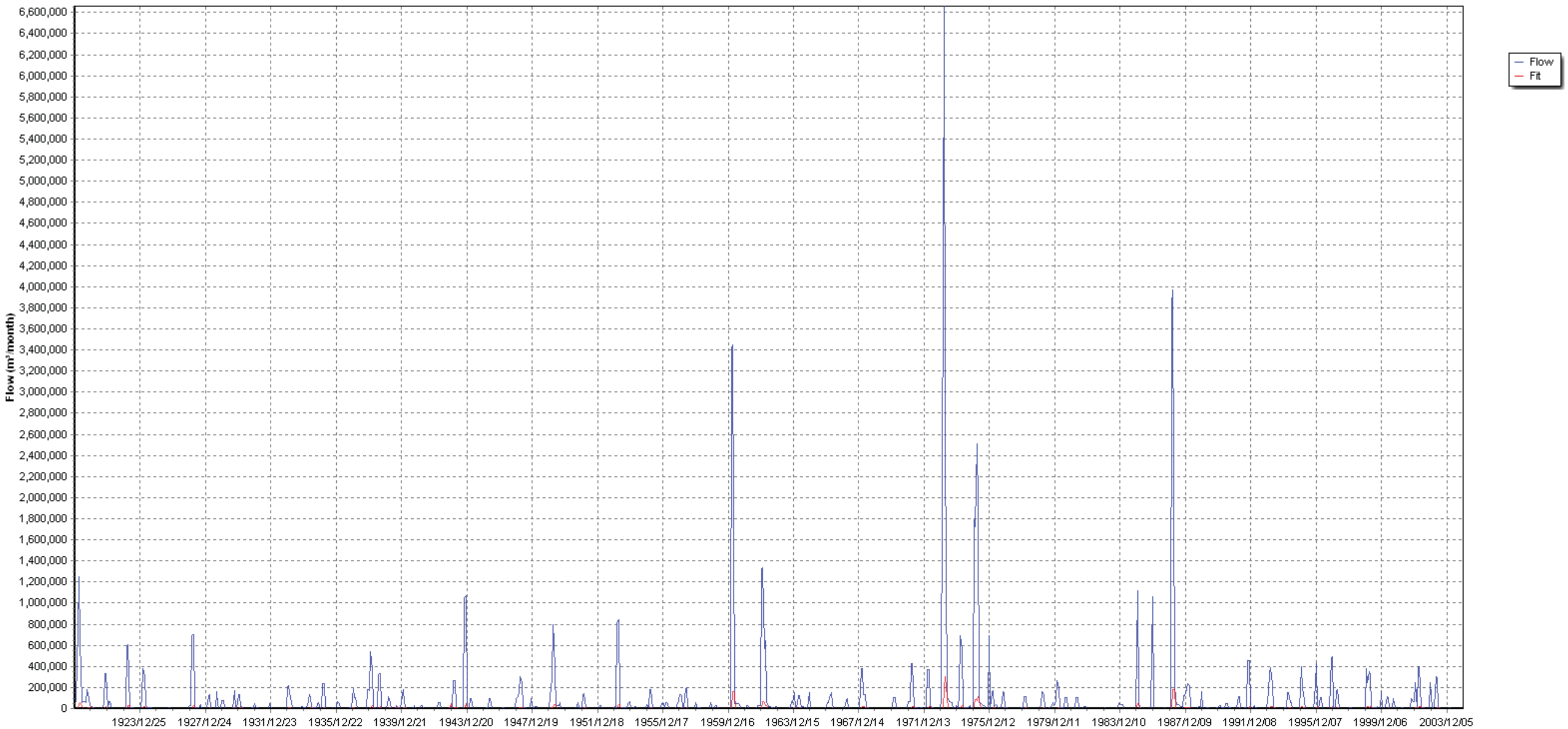


Figure 195: Groundwater contribution to baseflow (D61D)

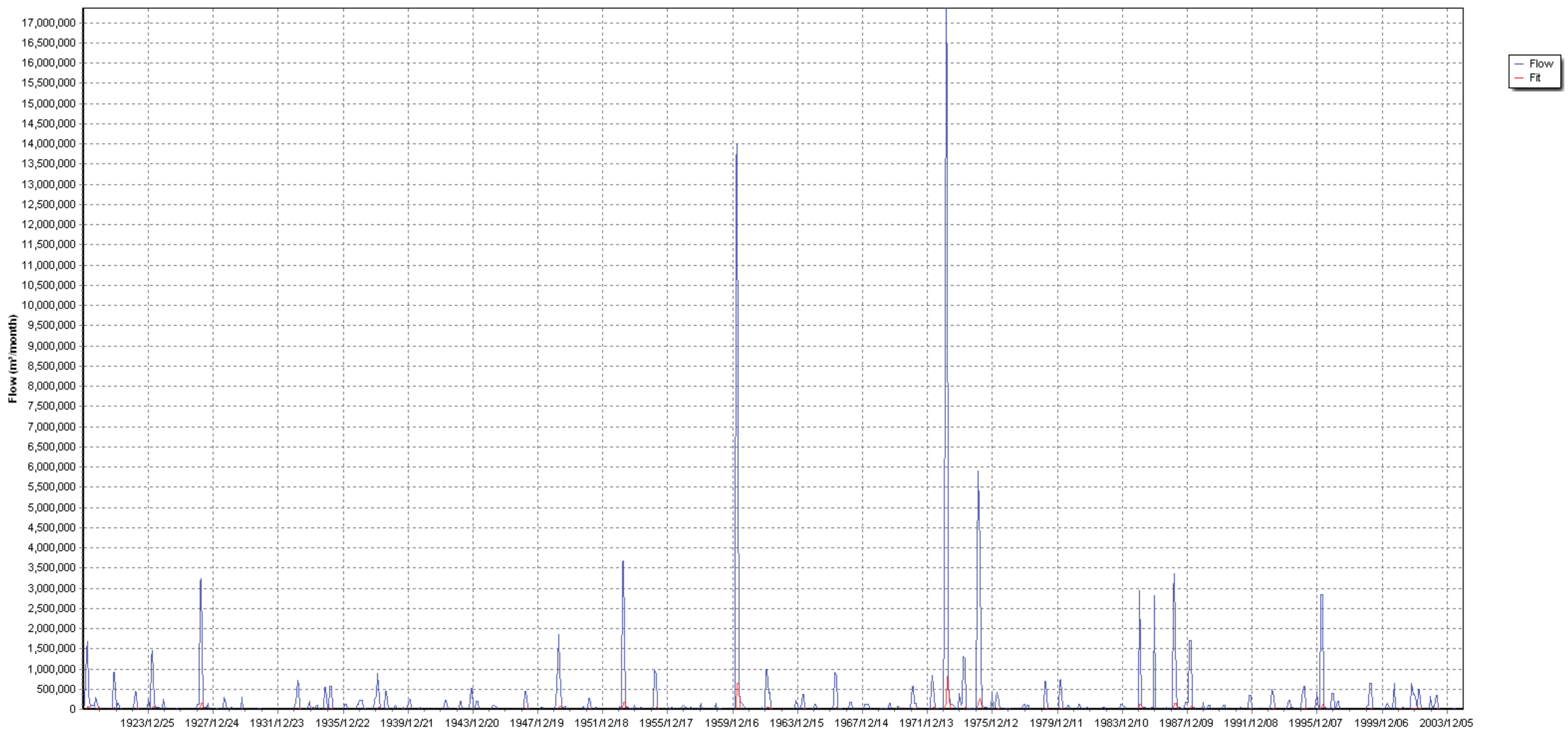


Figure 196: Groundwater contribution to baseflow (D61E)

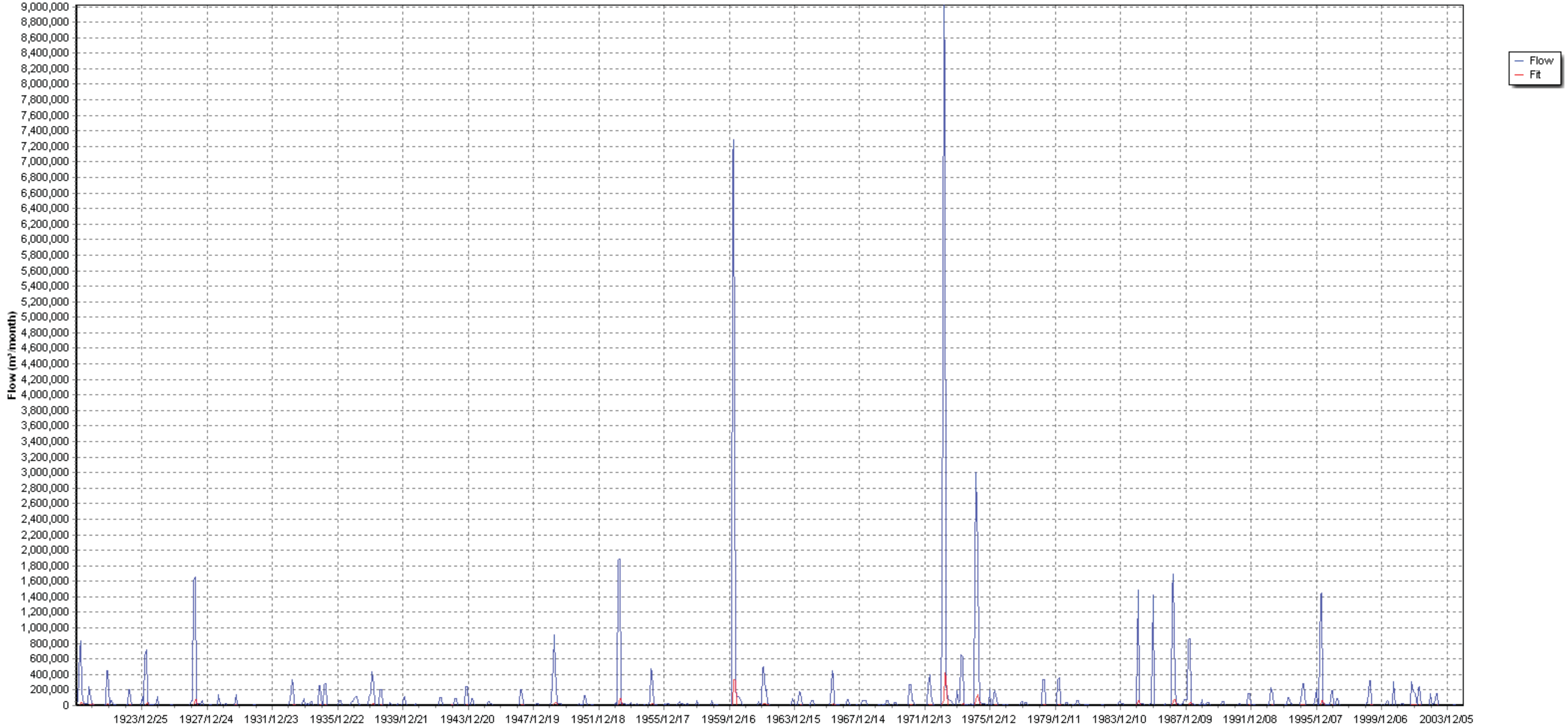


Figure 197: Groundwater contribution to baseflow (D61F)

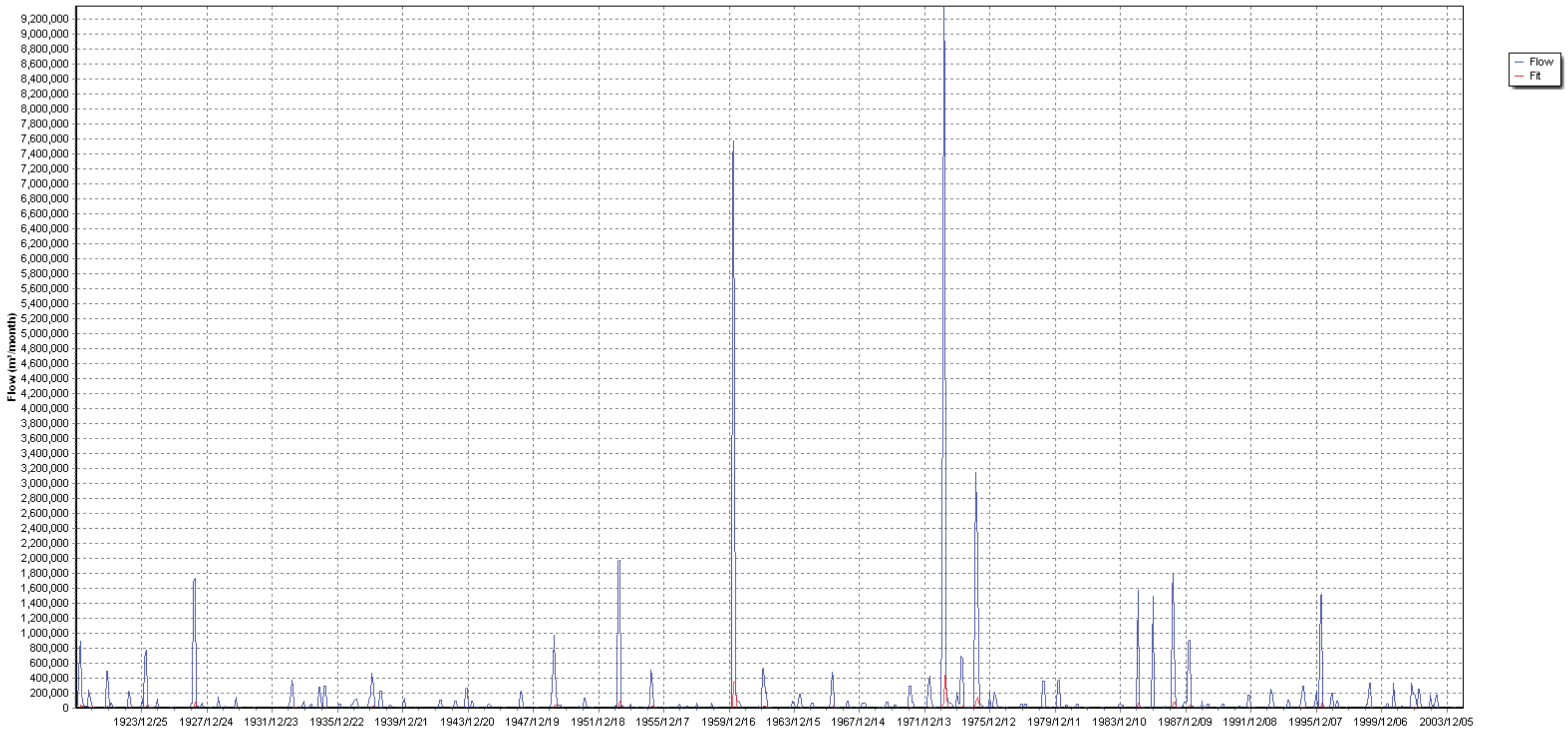


Figure 198: Groundwater contribution to baseflow (D61G)

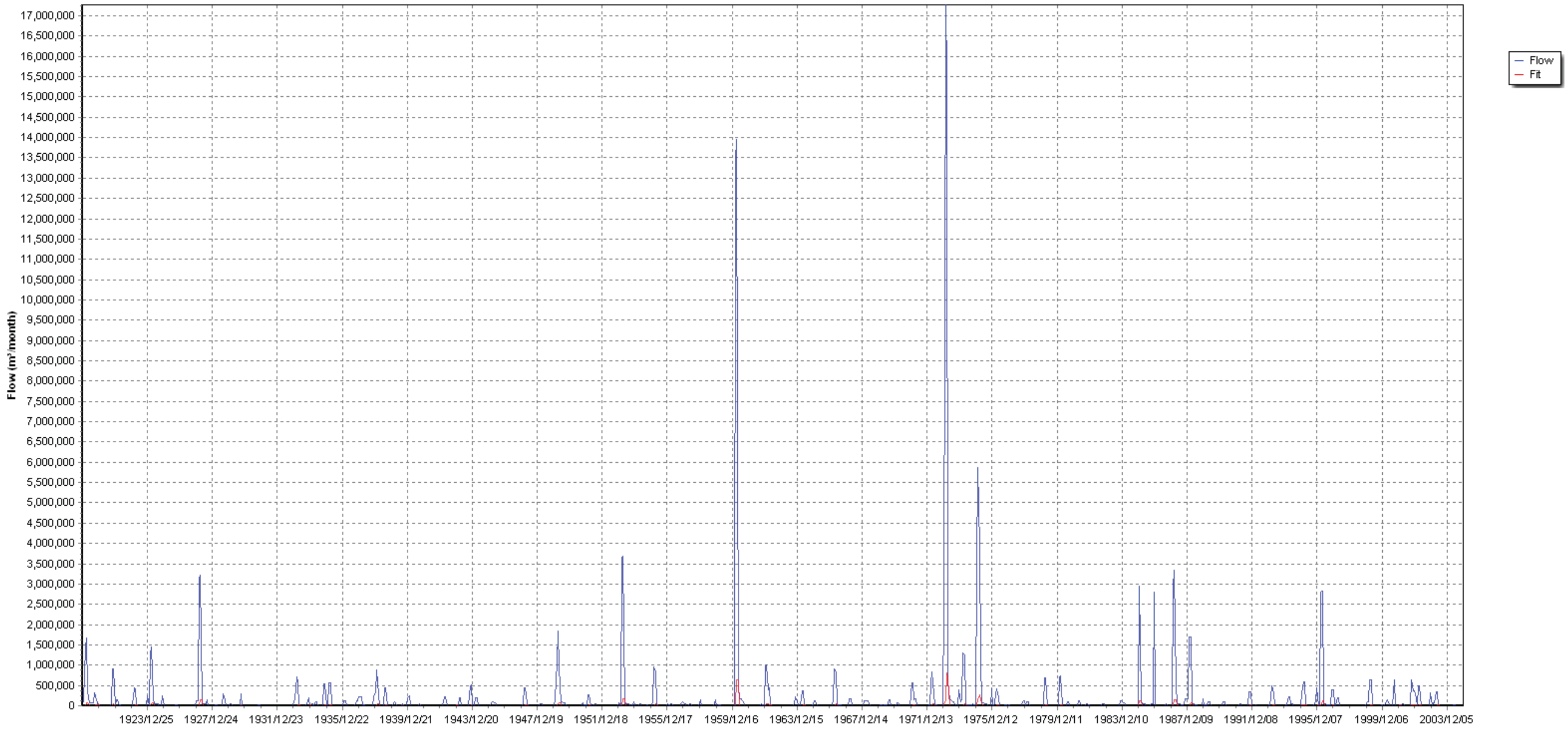


Figure 199: Groundwater contribution to baseflow (D61H)

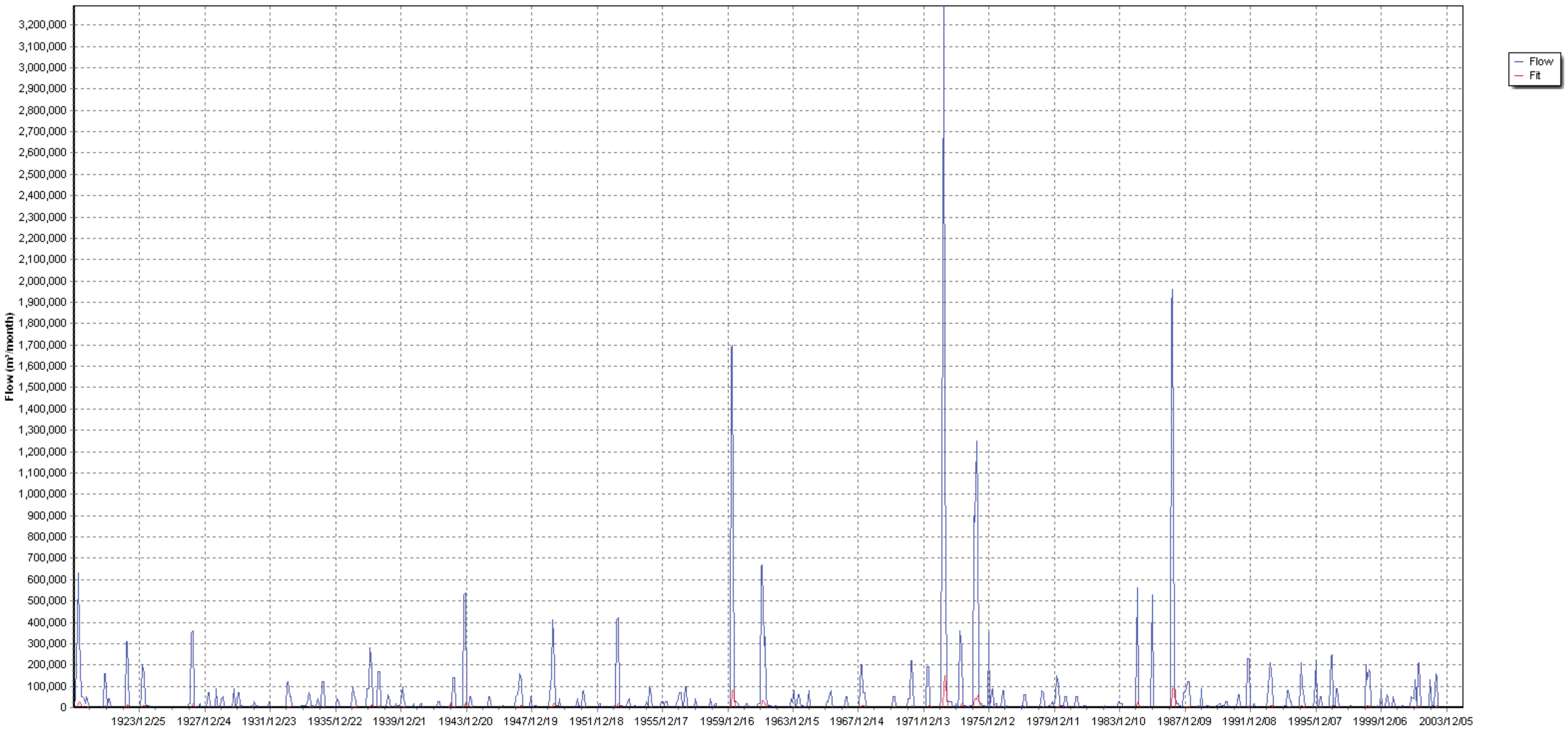


Figure 200: Groundwater contribution to baseflow (D61L)

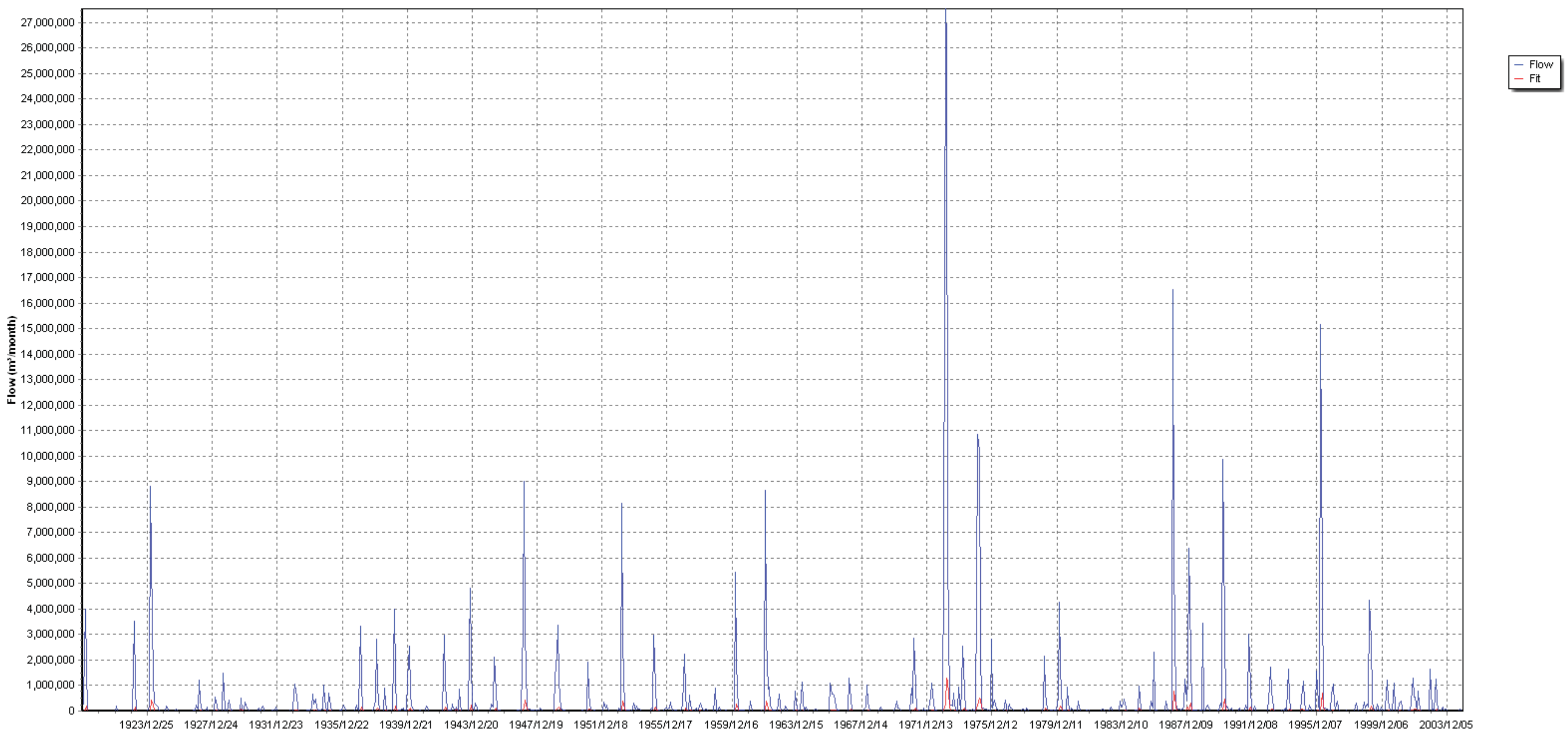


Figure 201: Groundwater contribution to baseflow (D62C)

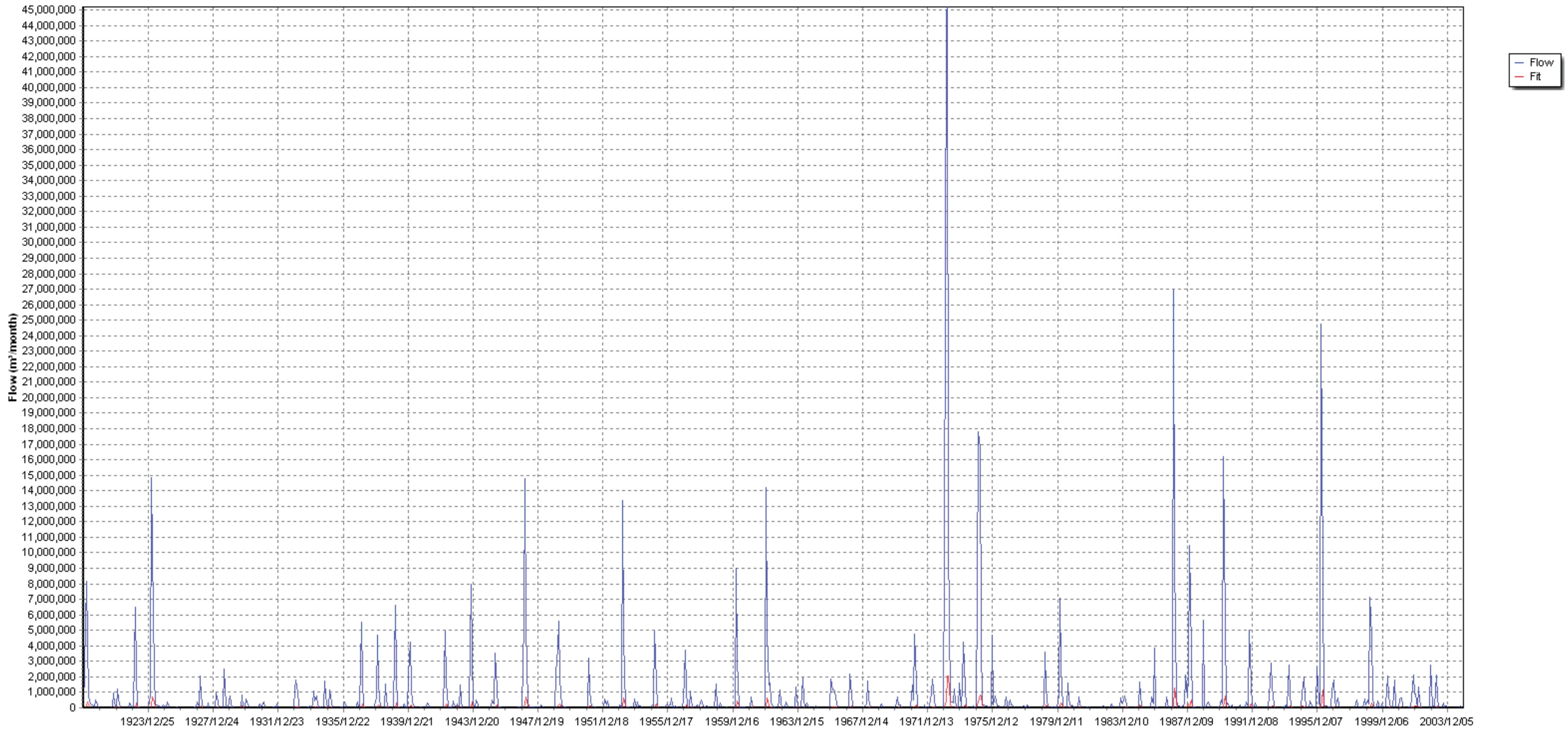


Figure 202: Groundwater contribution to baseflow (D62D)

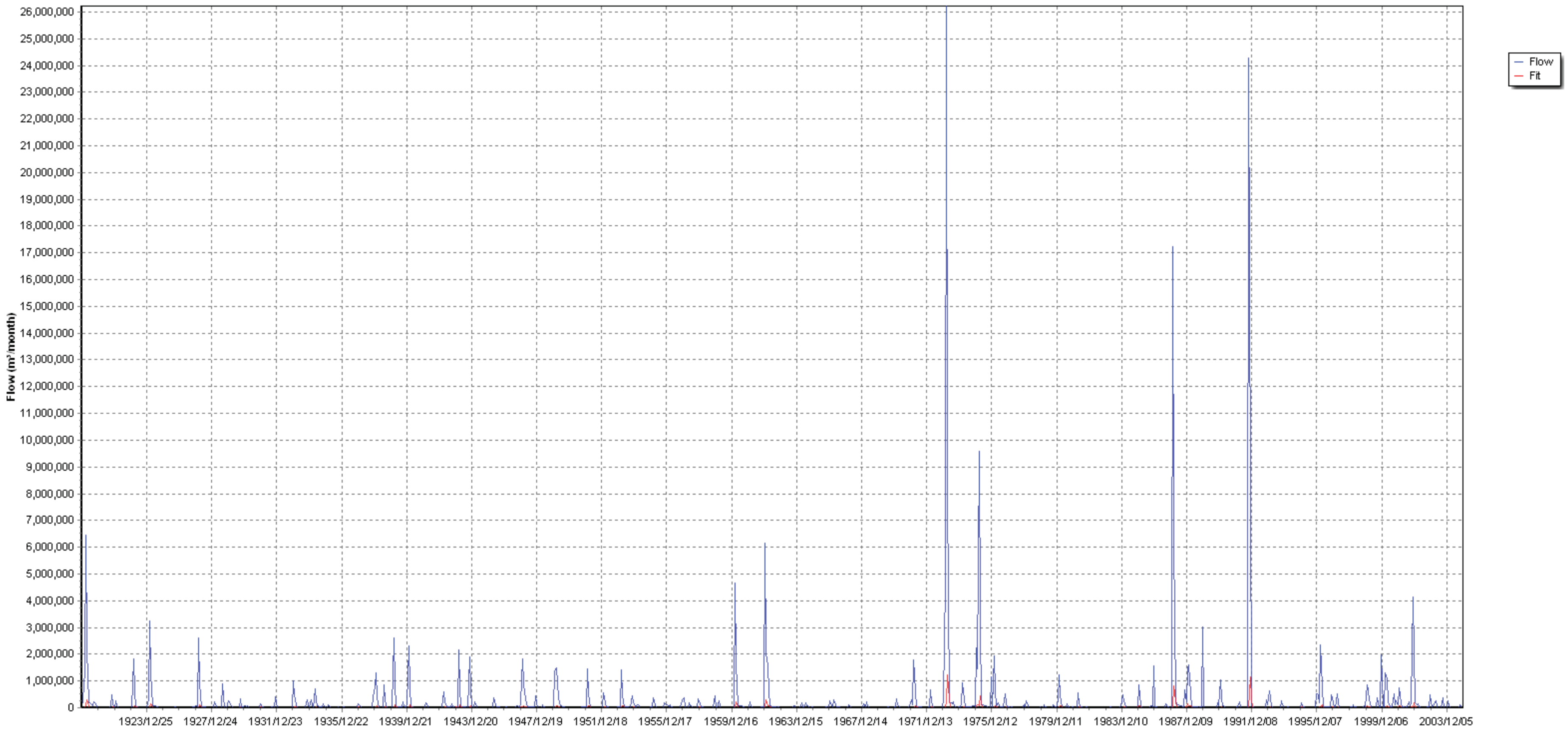


Figure 203: Groundwater contribution to baseflow (D32A)

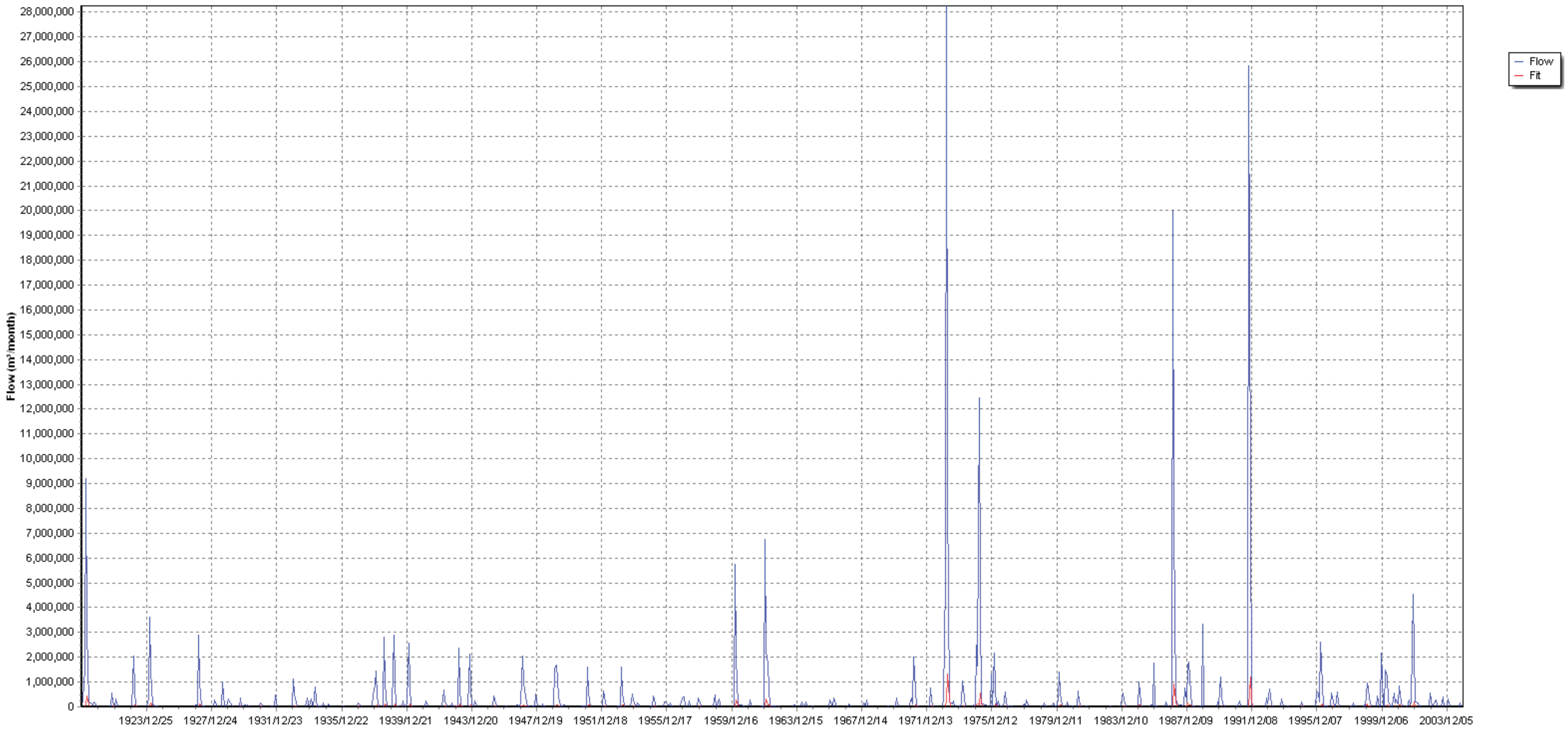


Figure 204: Groundwater contribution to baseflow (D32B)

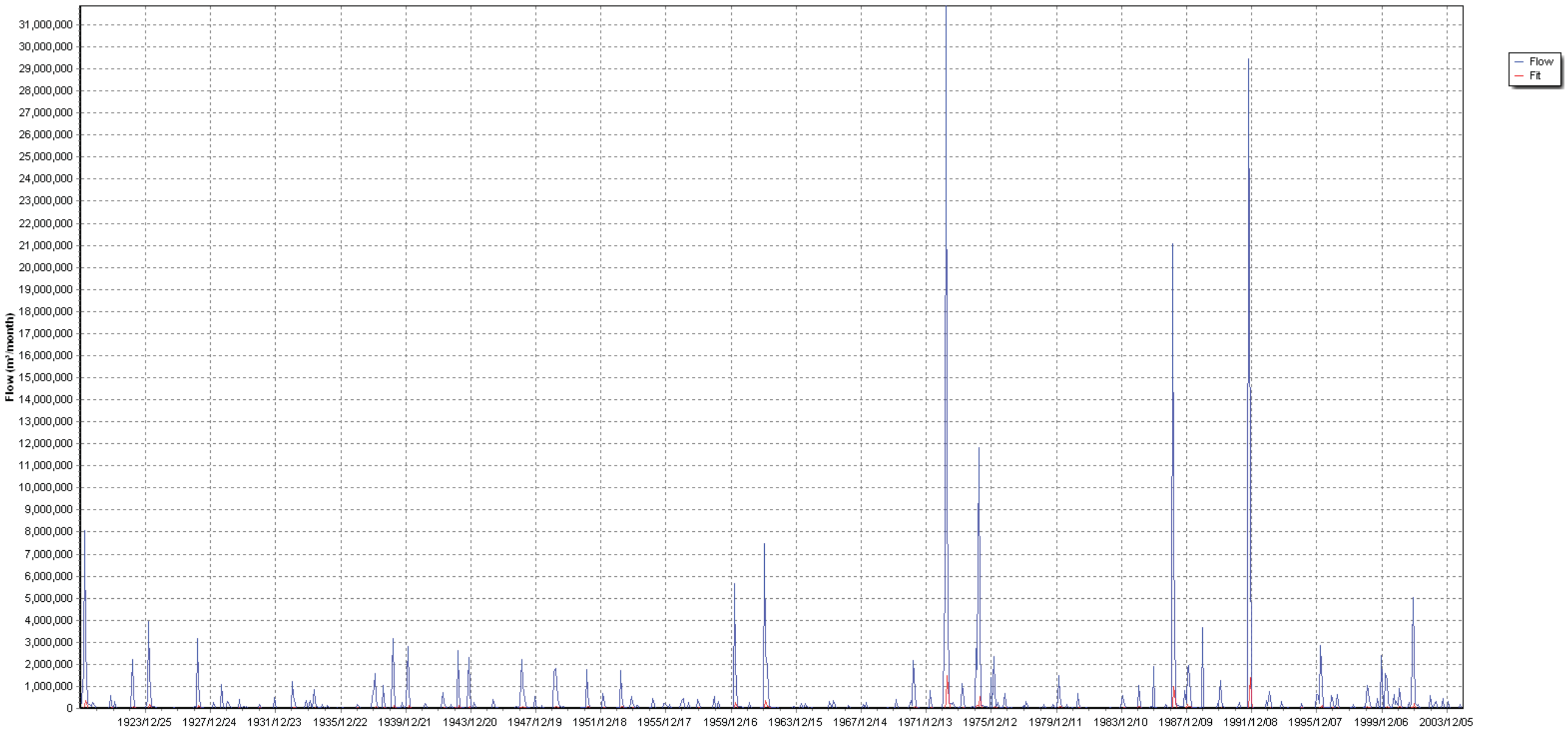


Figure 205: Groundwater contribution to baseflow (D32C)

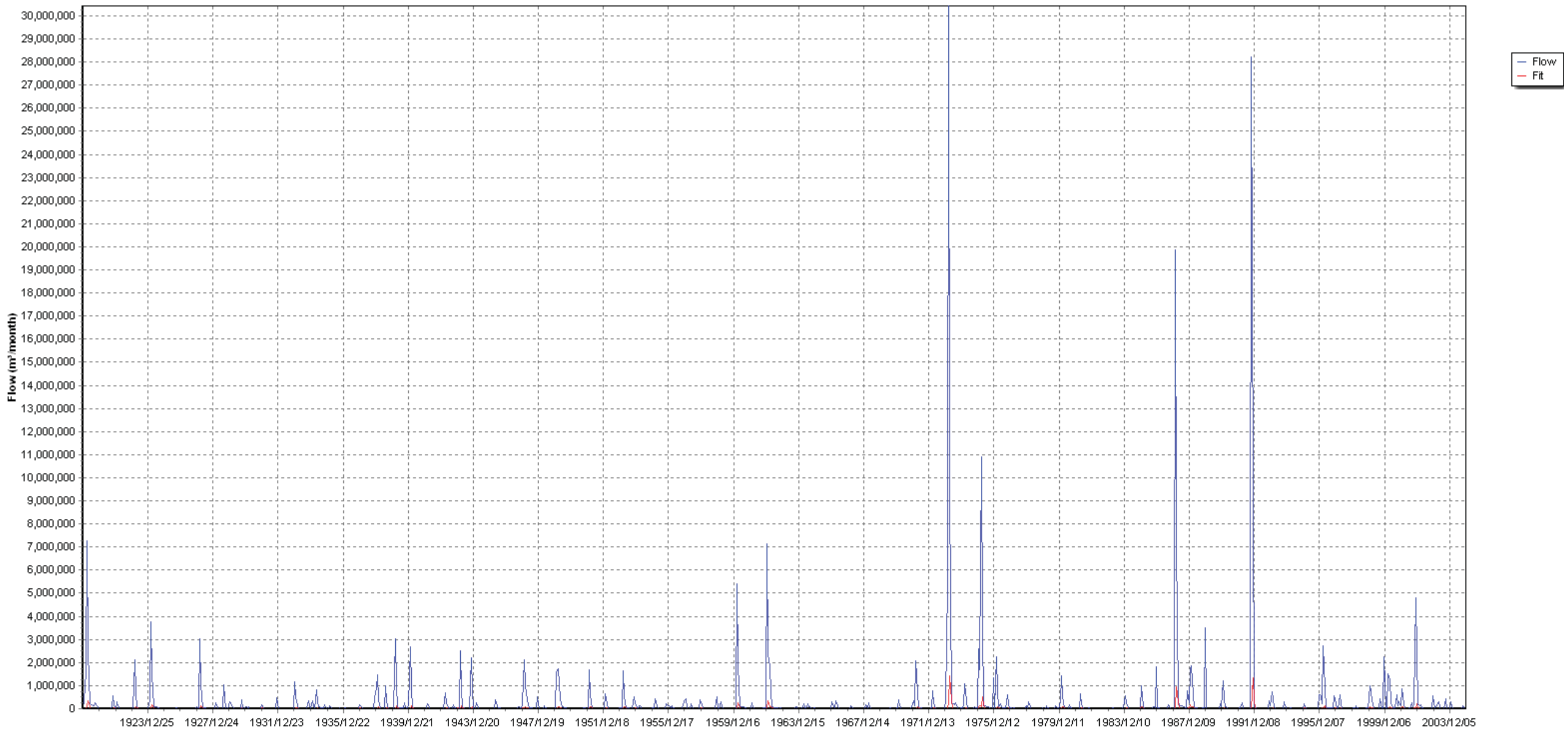


Figure 206: Groundwater contribution to baseflow (D32D)

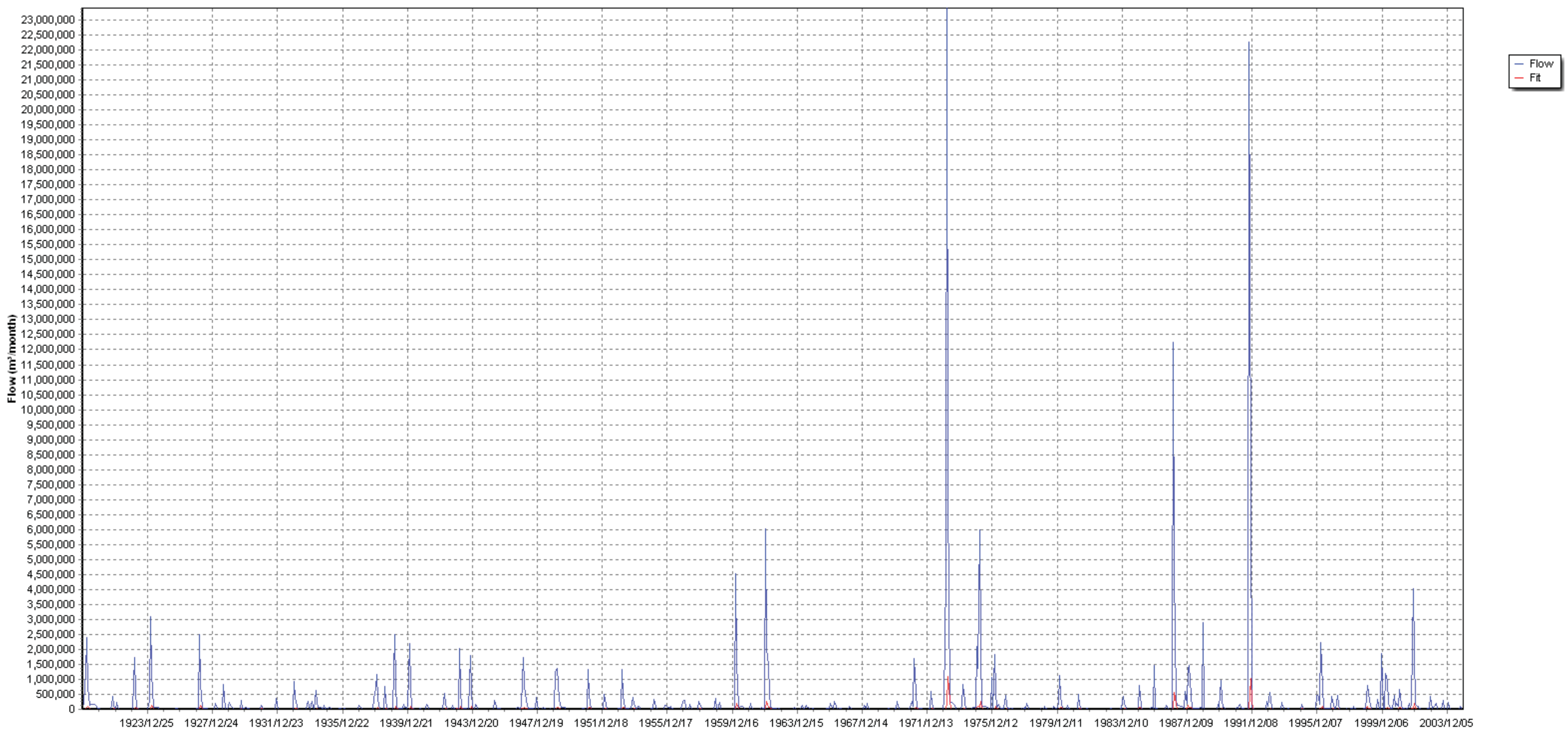


Figure 207: Groundwater contribution to baseflow (D32E)

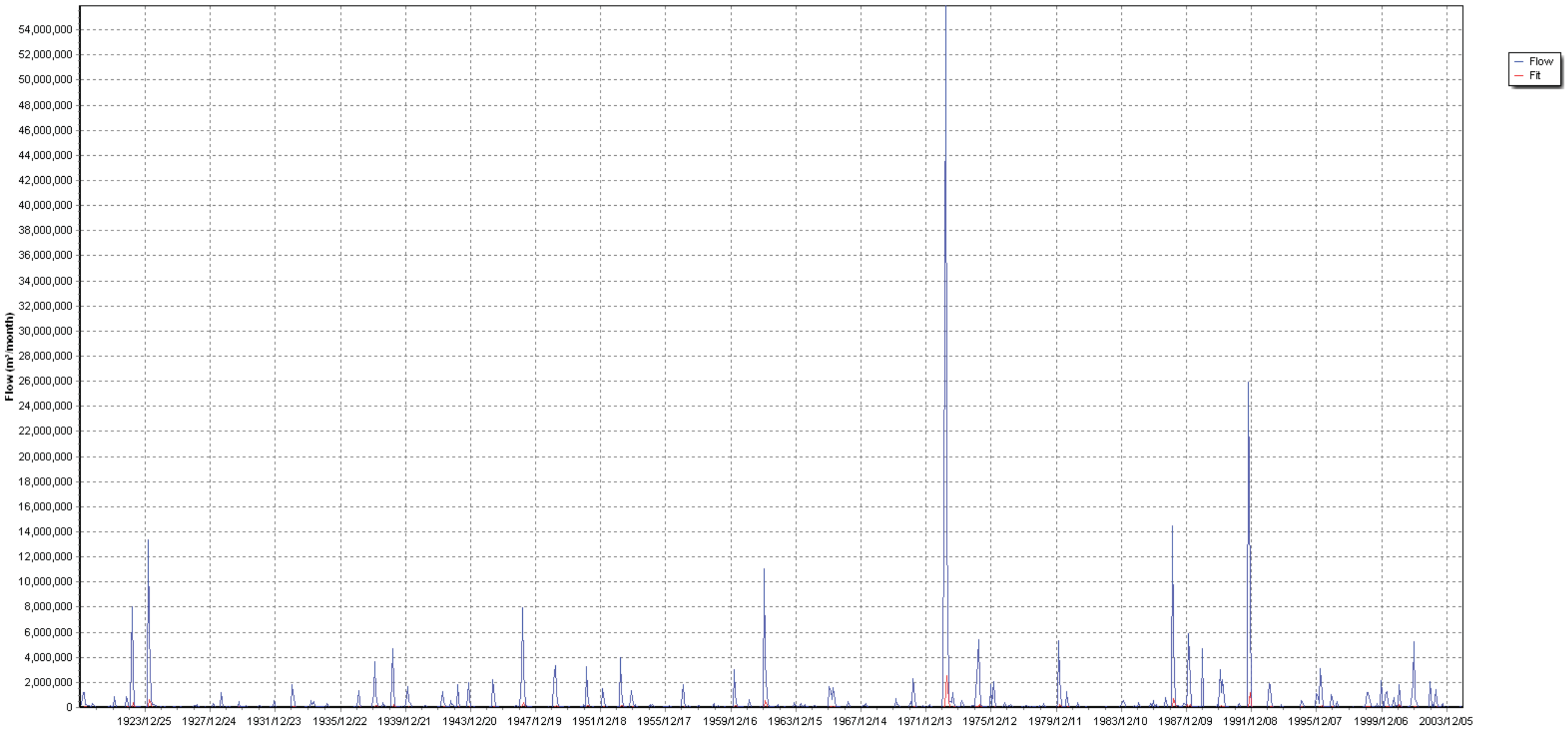


Figure 208: Groundwater contribution to baseflow (D32F)

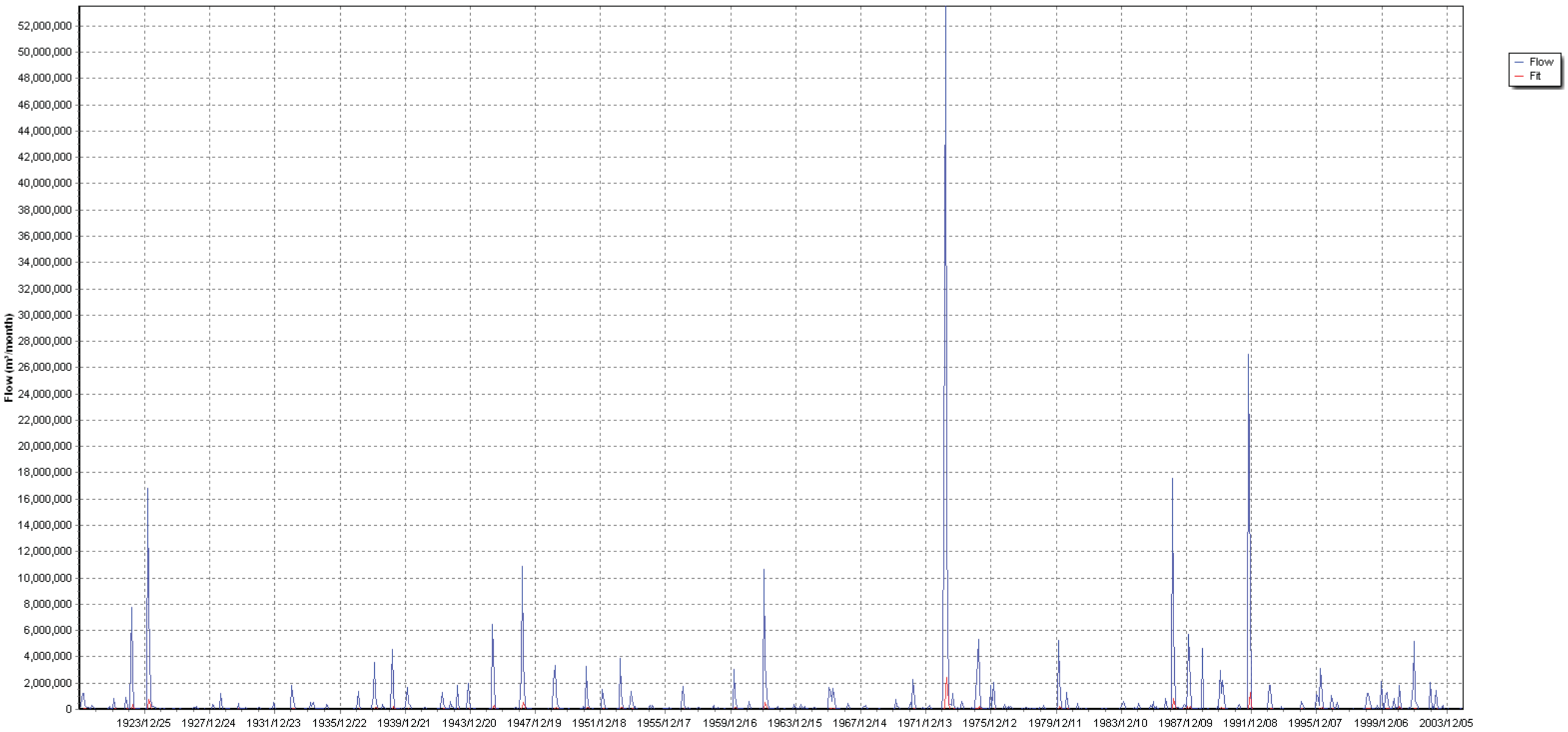


Figure 209: Groundwater contribution to baseflow (D32G)

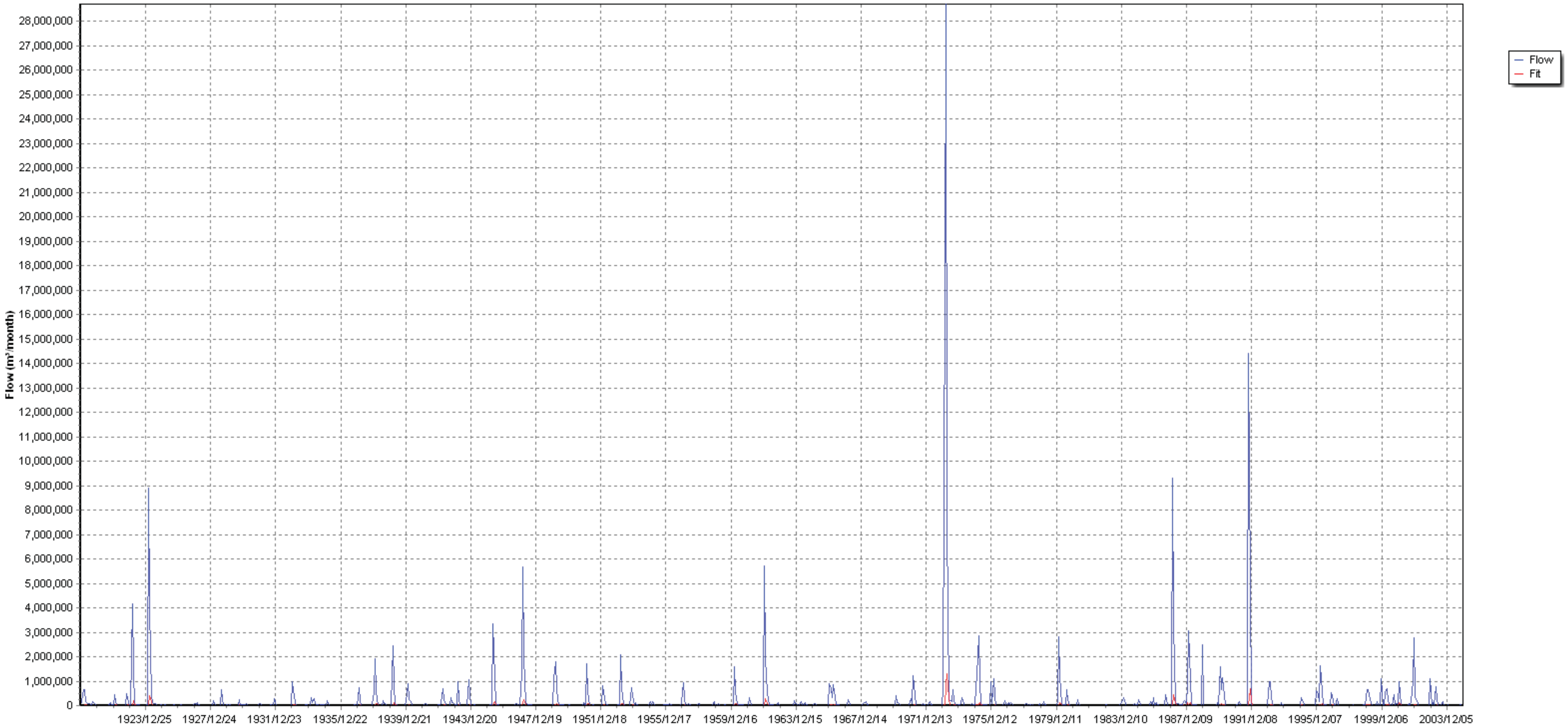


Figure 210: Groundwater contribution to baseflow (D32H)

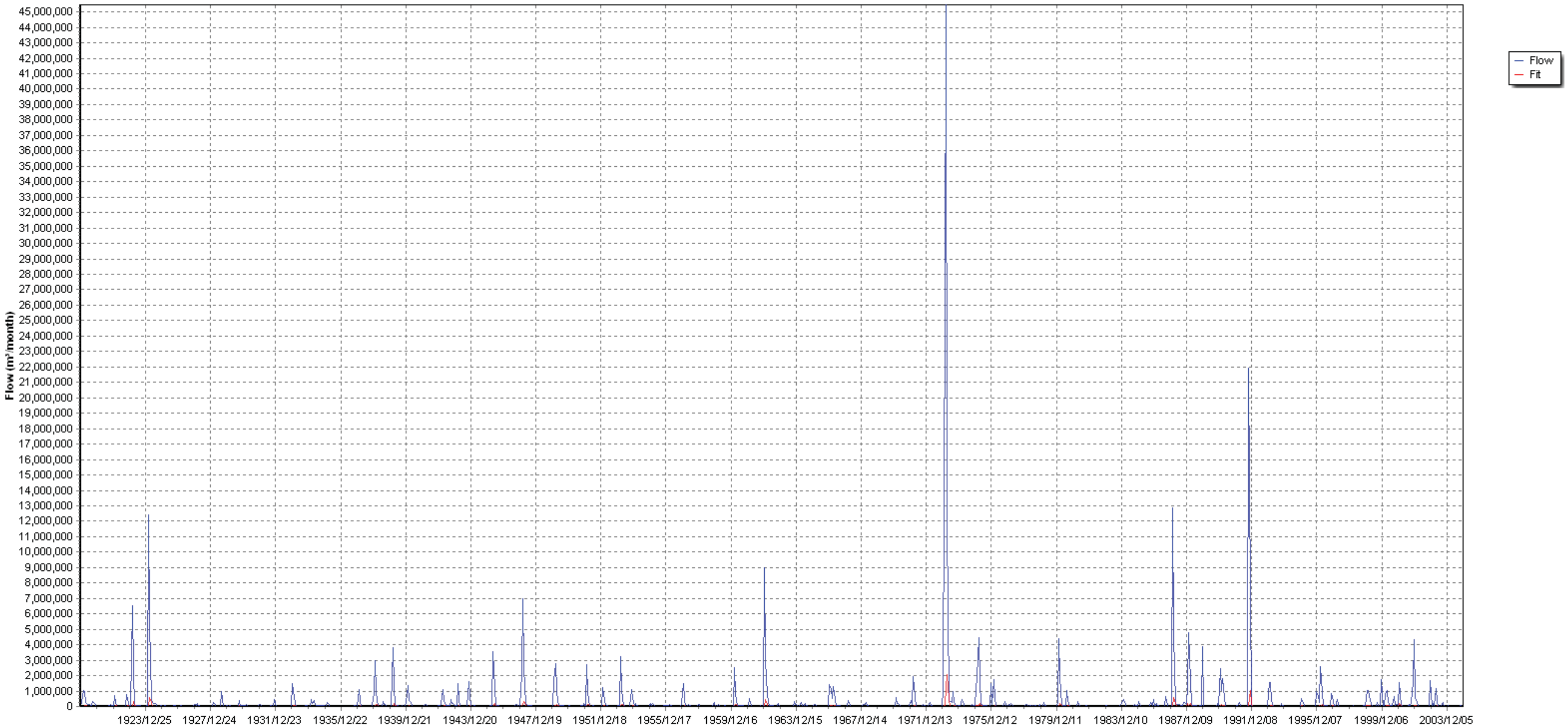


Figure 211: Groundwater contribution to baseflow (D32J)

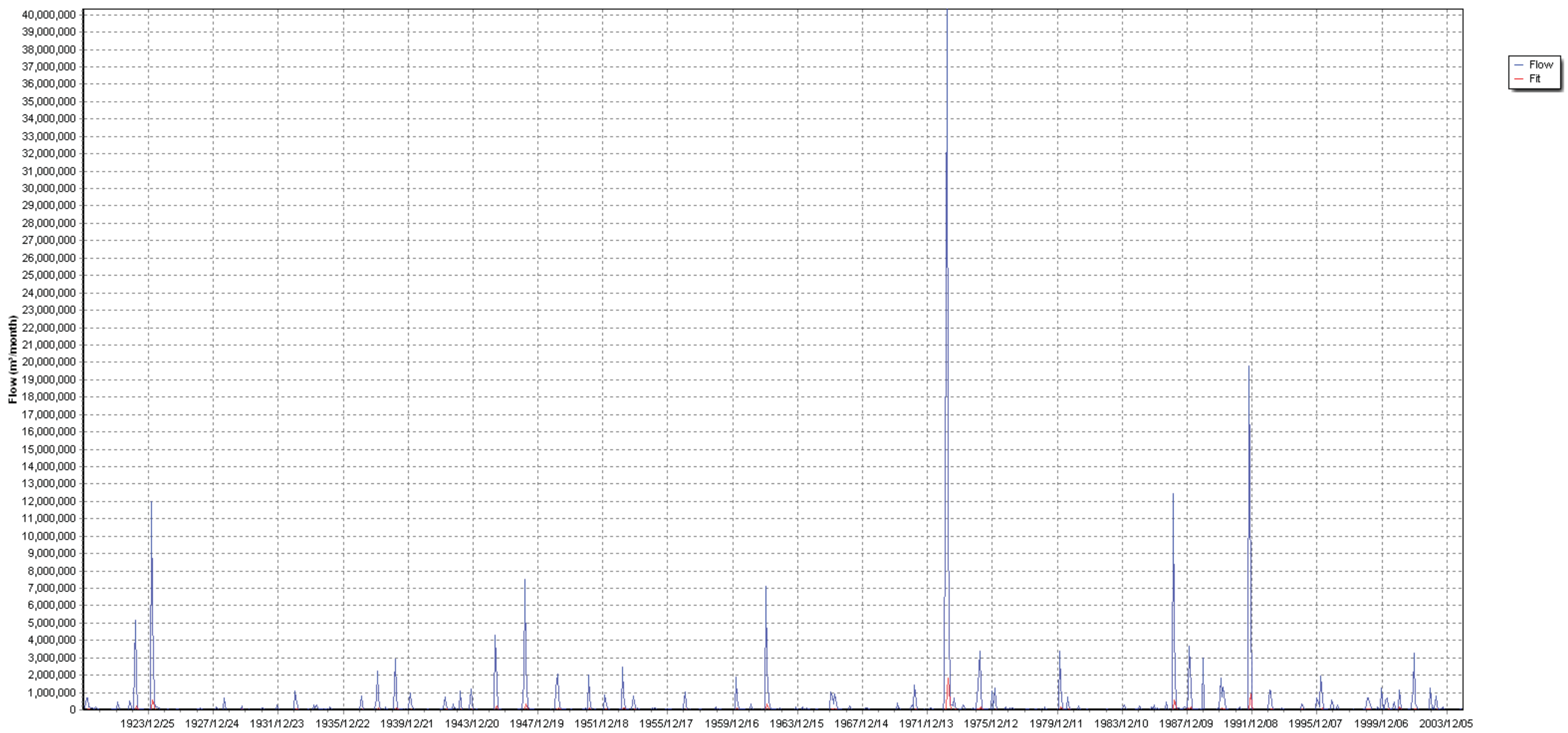


Figure 212: Groundwater contribution to baseflow (D32K)

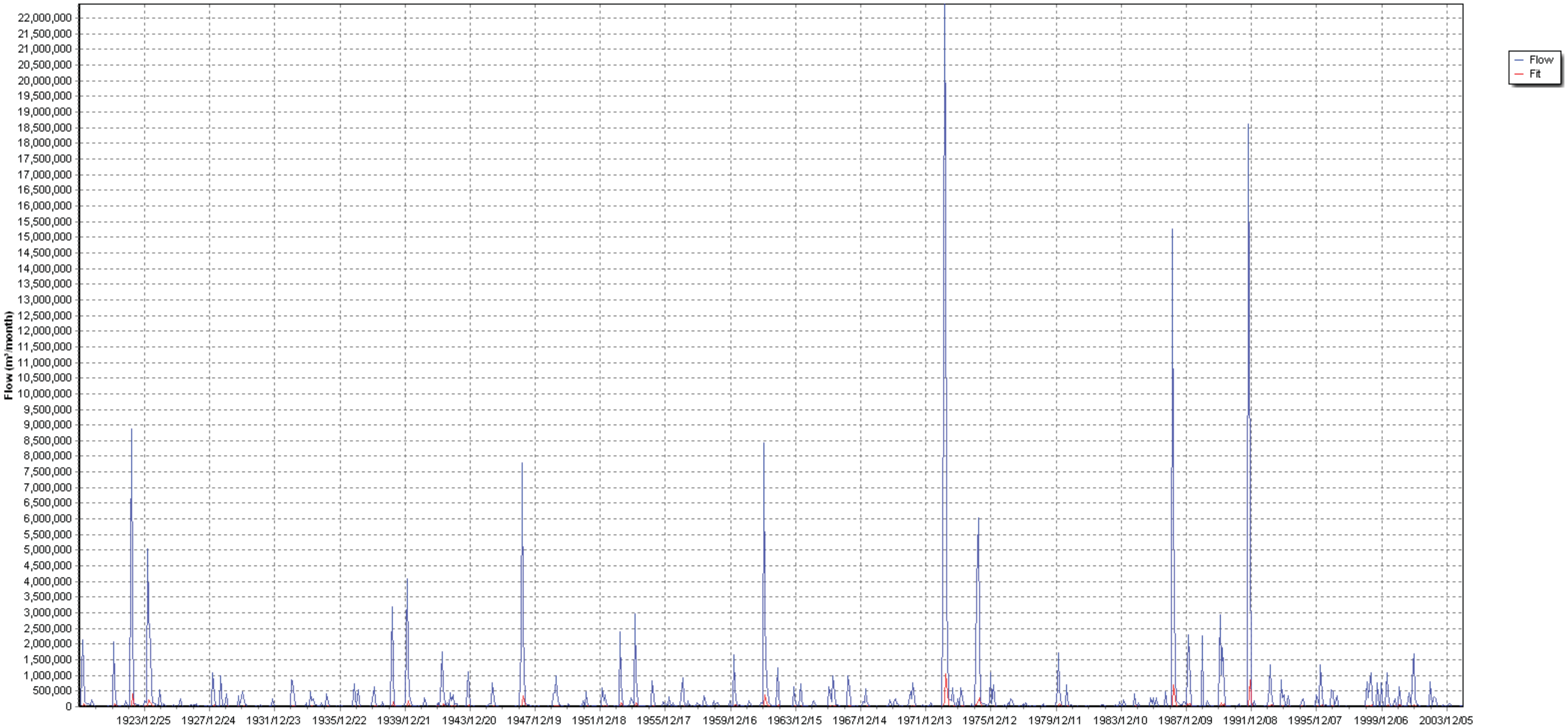


Figure 213: Groundwater contribution to baseflow (D31B)

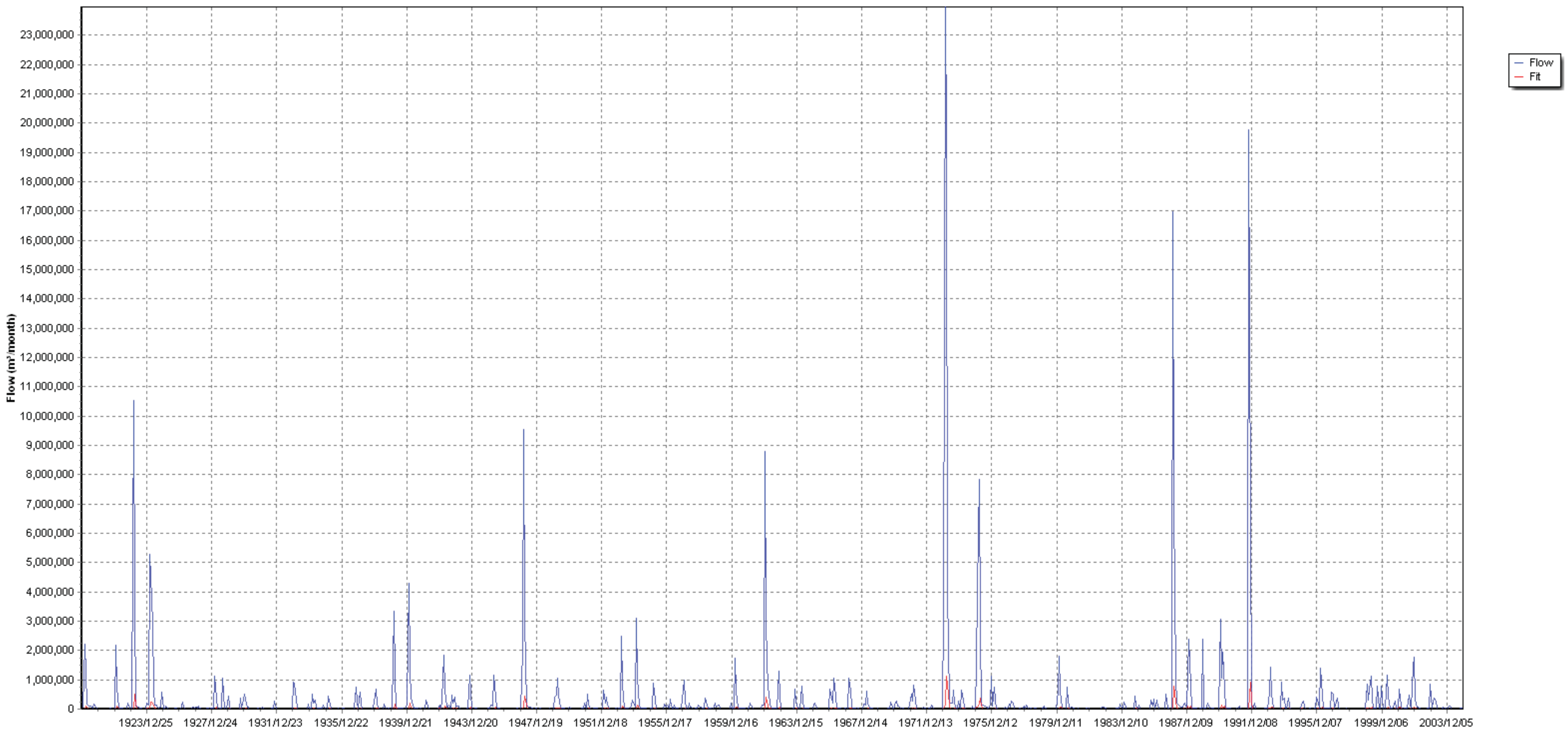


Figure 214: Groundwater contribution to baseflow (D31C)

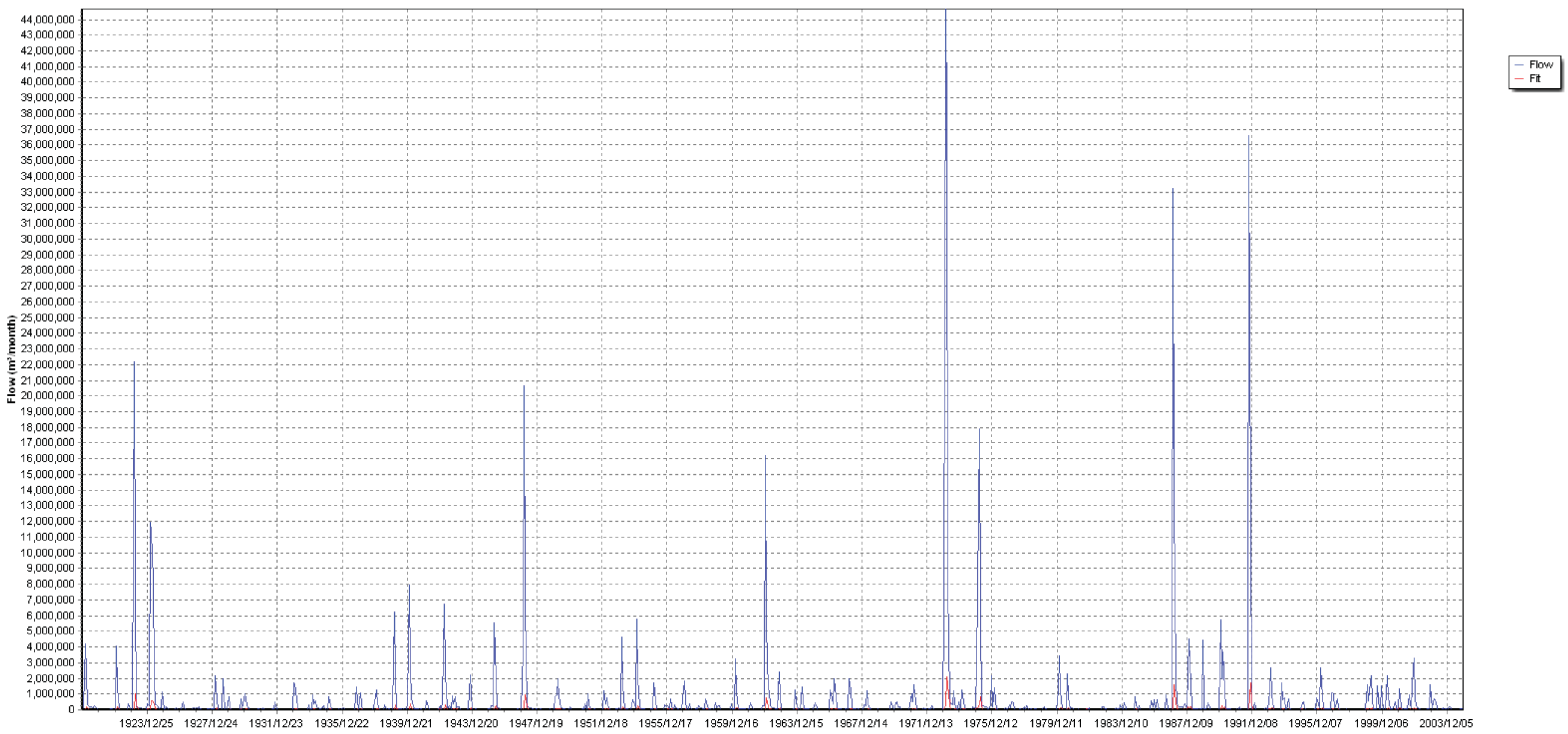


Figure 215: Groundwater contribution to baseflow (D31E)

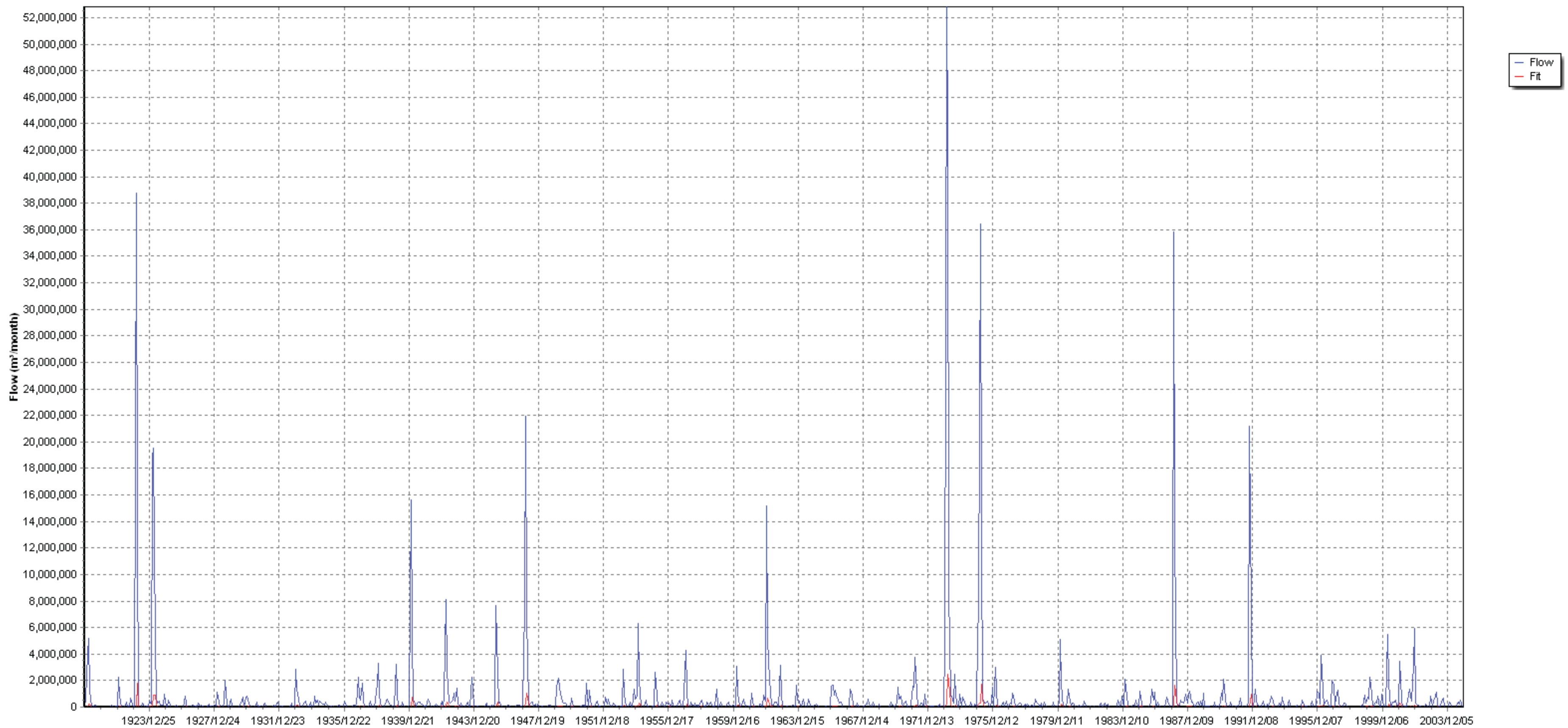


Figure 216: Groundwater contribution to baseflow (D34A)

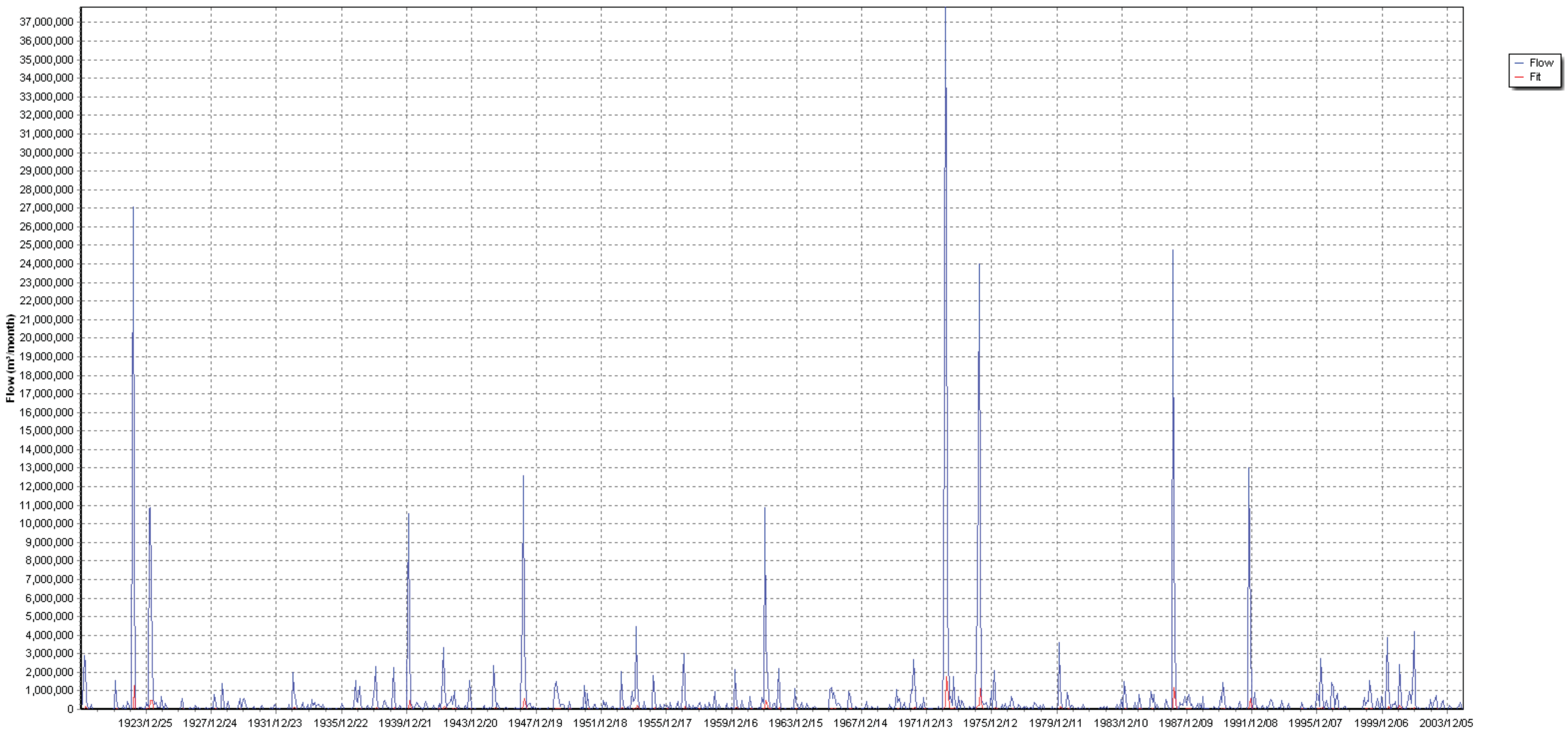


Figure 217: Groundwater contribution to baseflow (D34B)

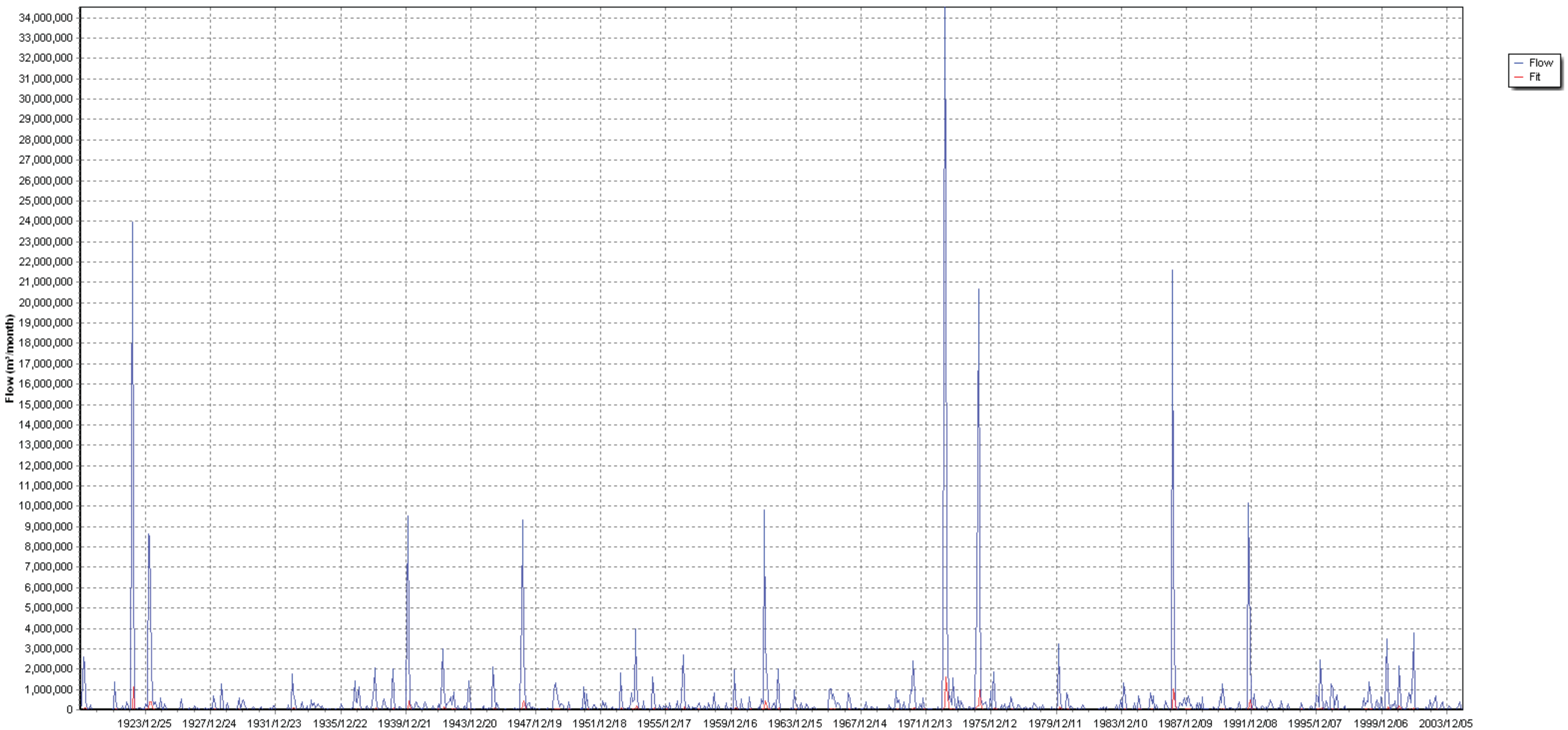


Figure 218: Groundwater contribution to baseflow (D34C)

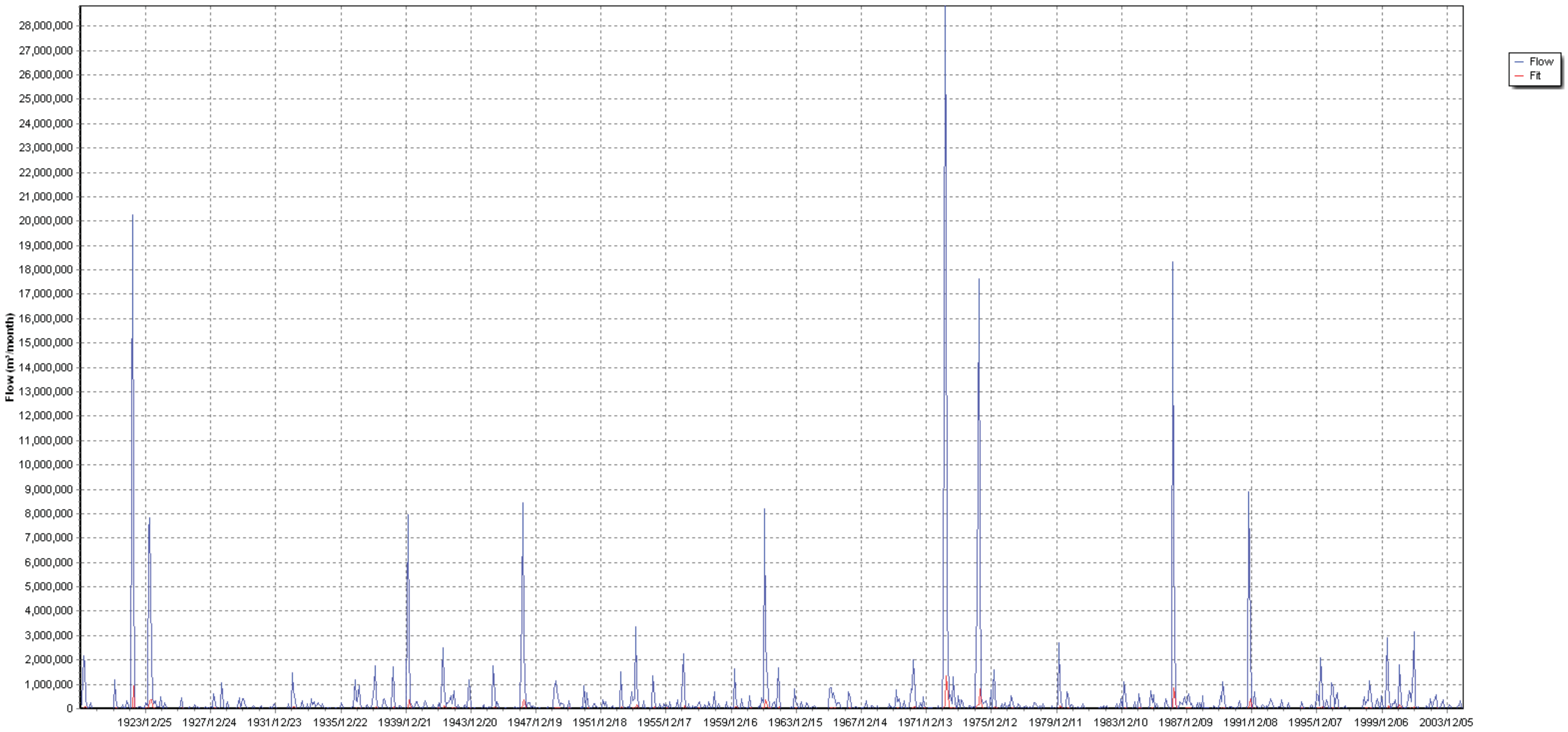


Figure 219: Groundwater contribution to baseflow (D34D)

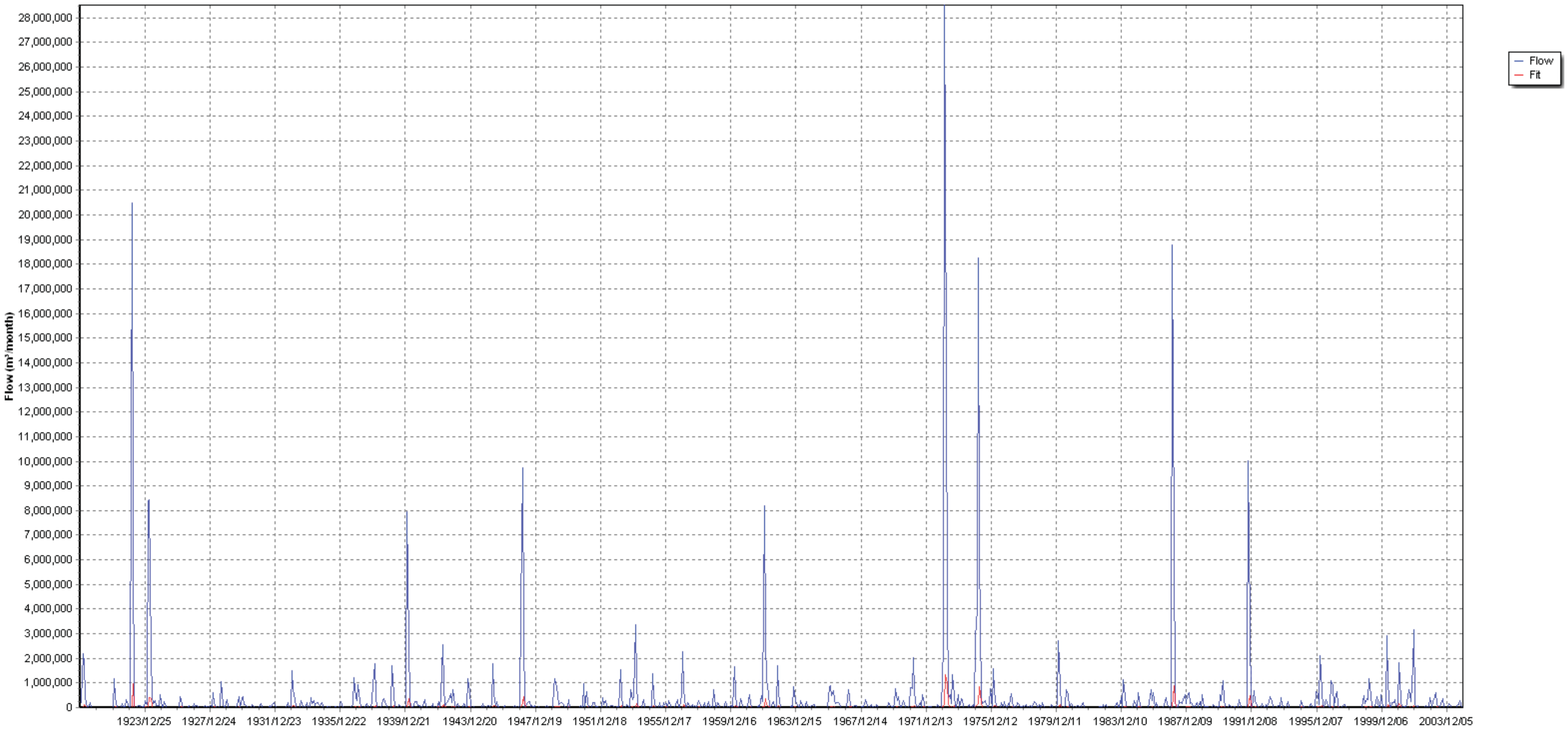


Figure 220: Groundwater contribution to baseflow (D34E)

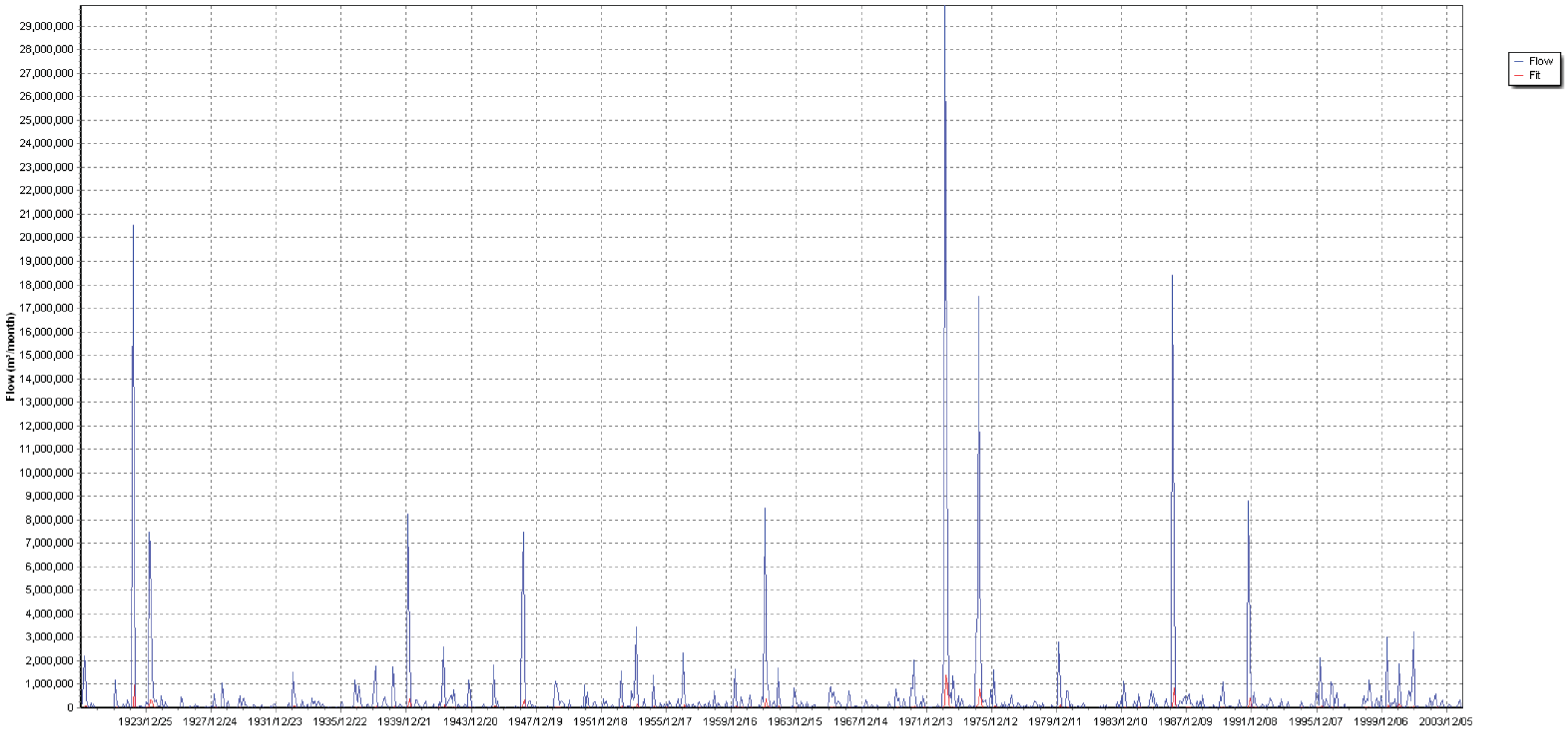


Figure 221: Groundwater contribution to baseflow (D34F)

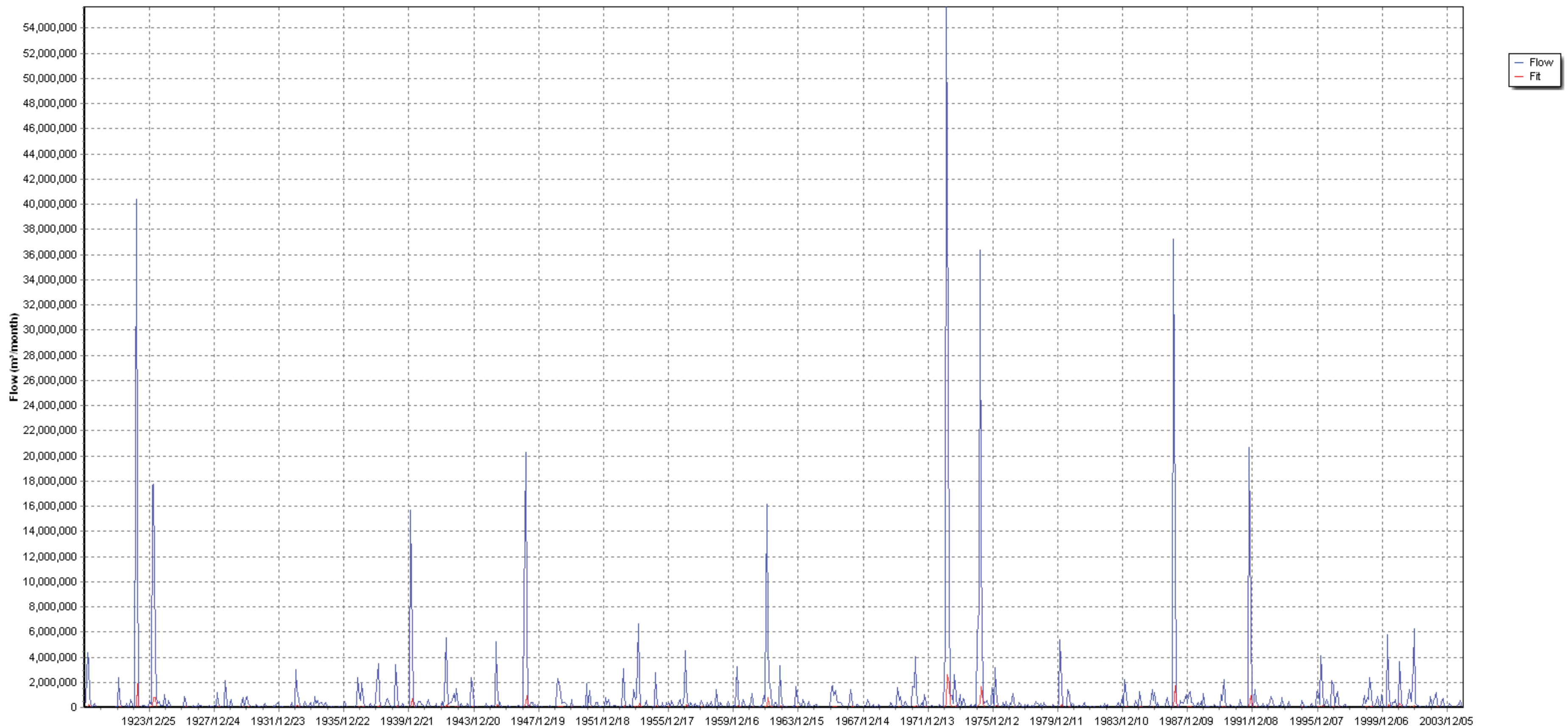


Figure 222: Groundwater contribution to baseflow (D34G)

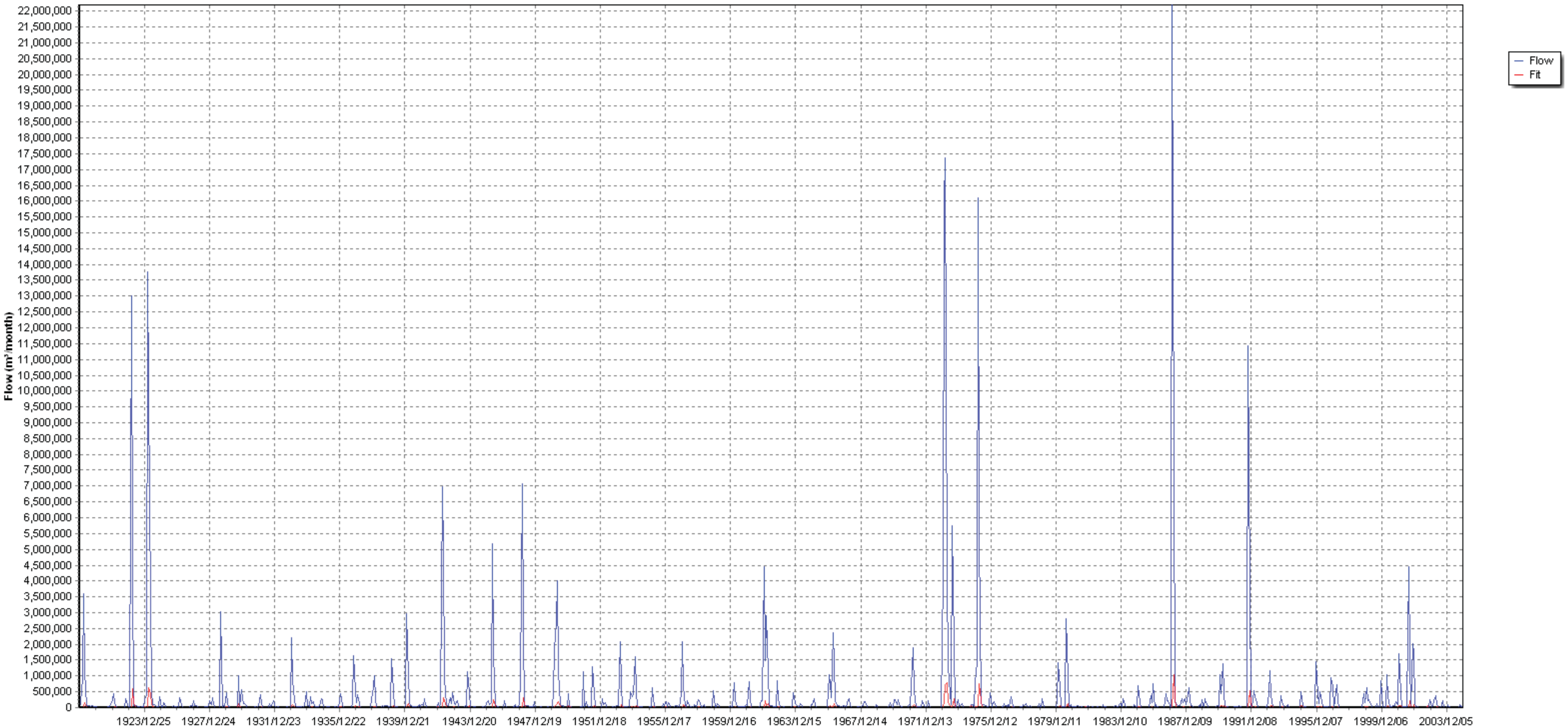


Figure 223: Groundwater contribution to baseflow (D35A)

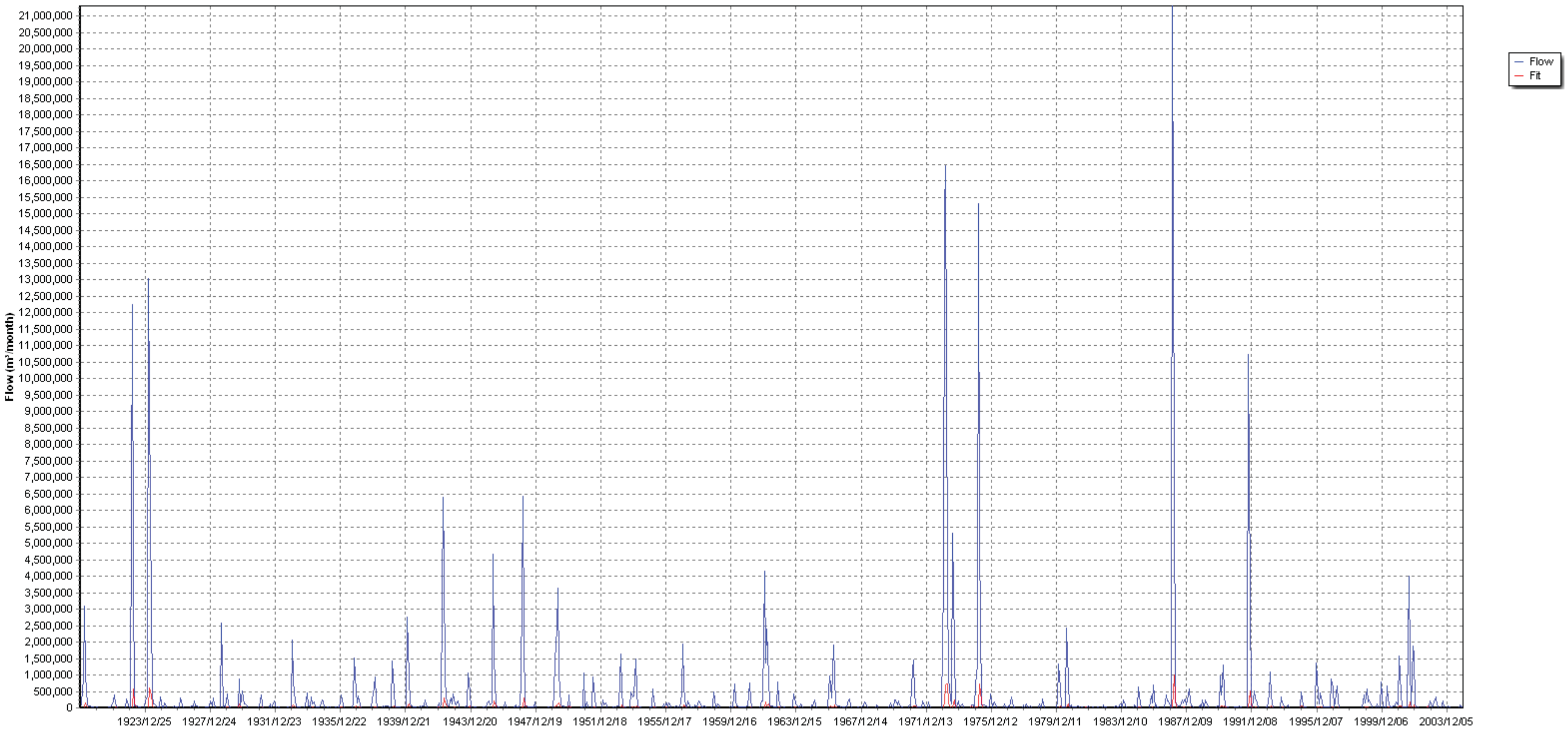


Figure 224: Groundwater contribution to baseflow (D35B)

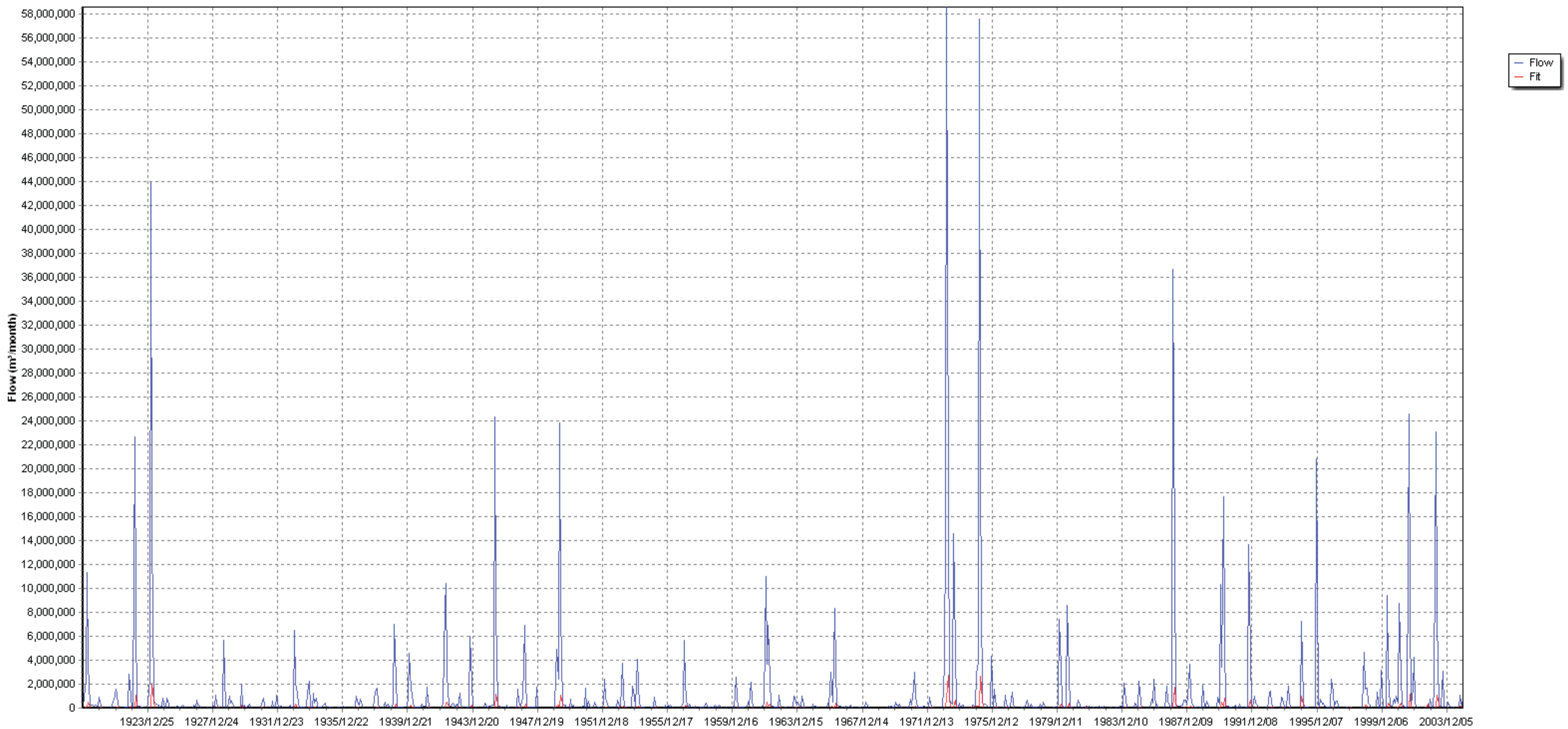


Figure 225: Groundwater contribution to baseflow (D35C)

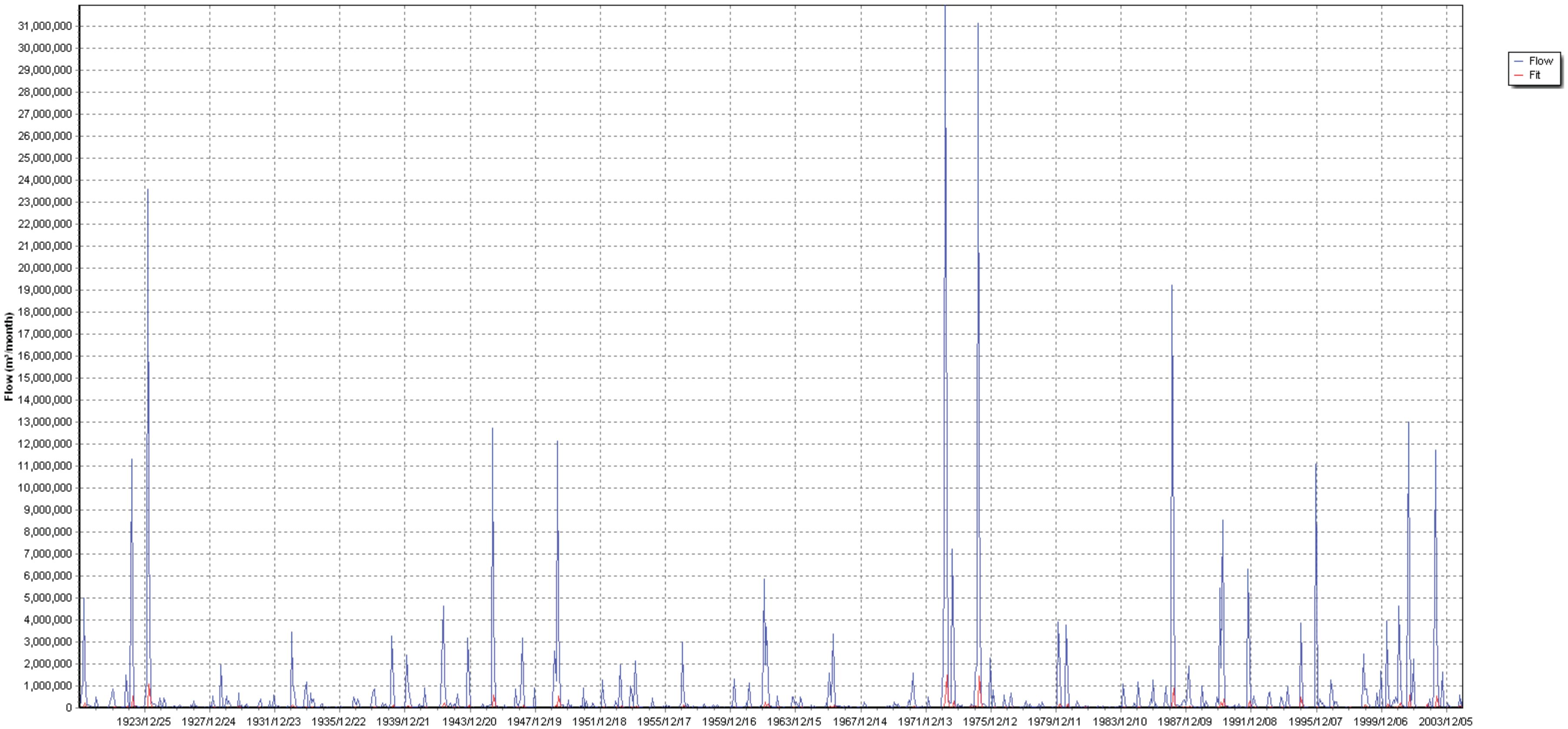


Figure 226: Groundwater contribution to baseflow (D35D)

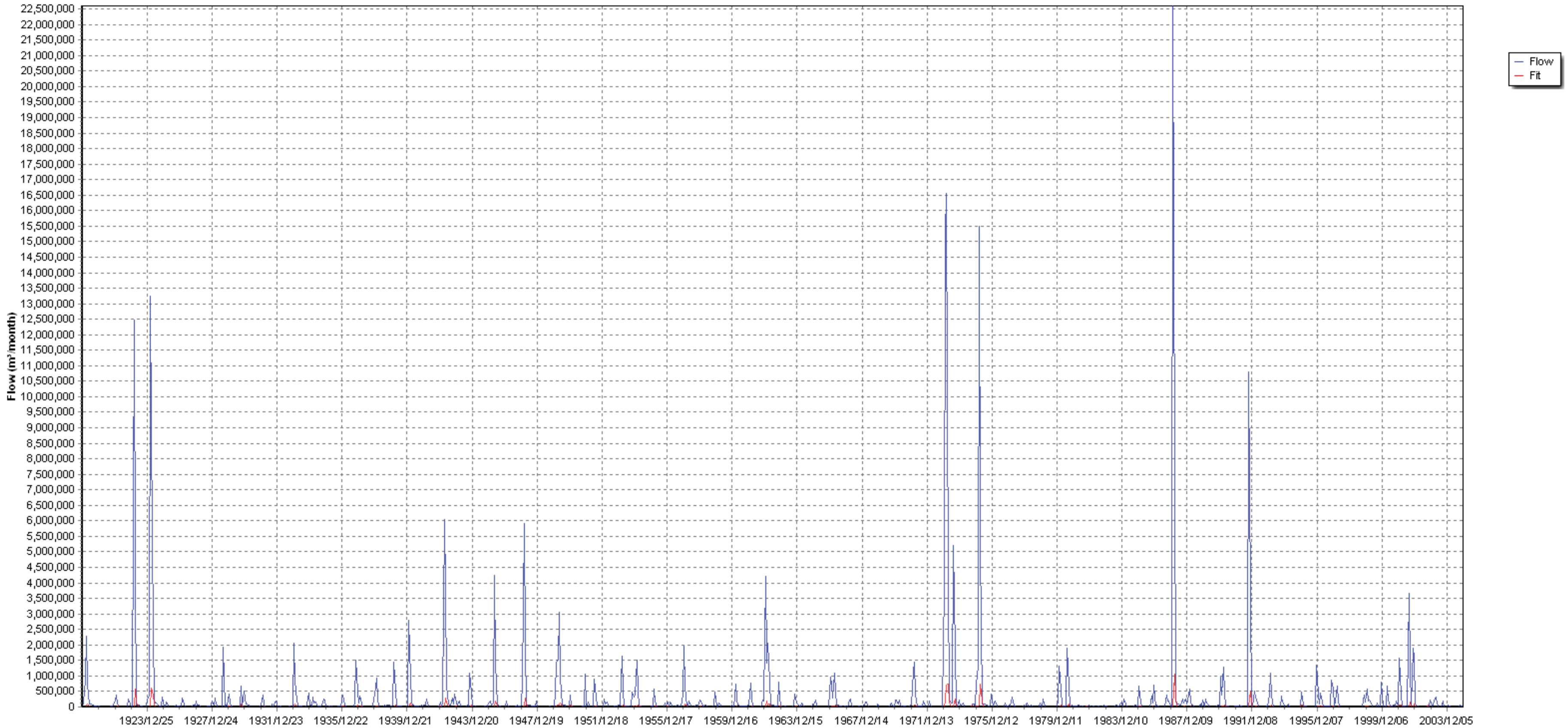


Figure 227: Groundwater contribution to baseflow (D35E)

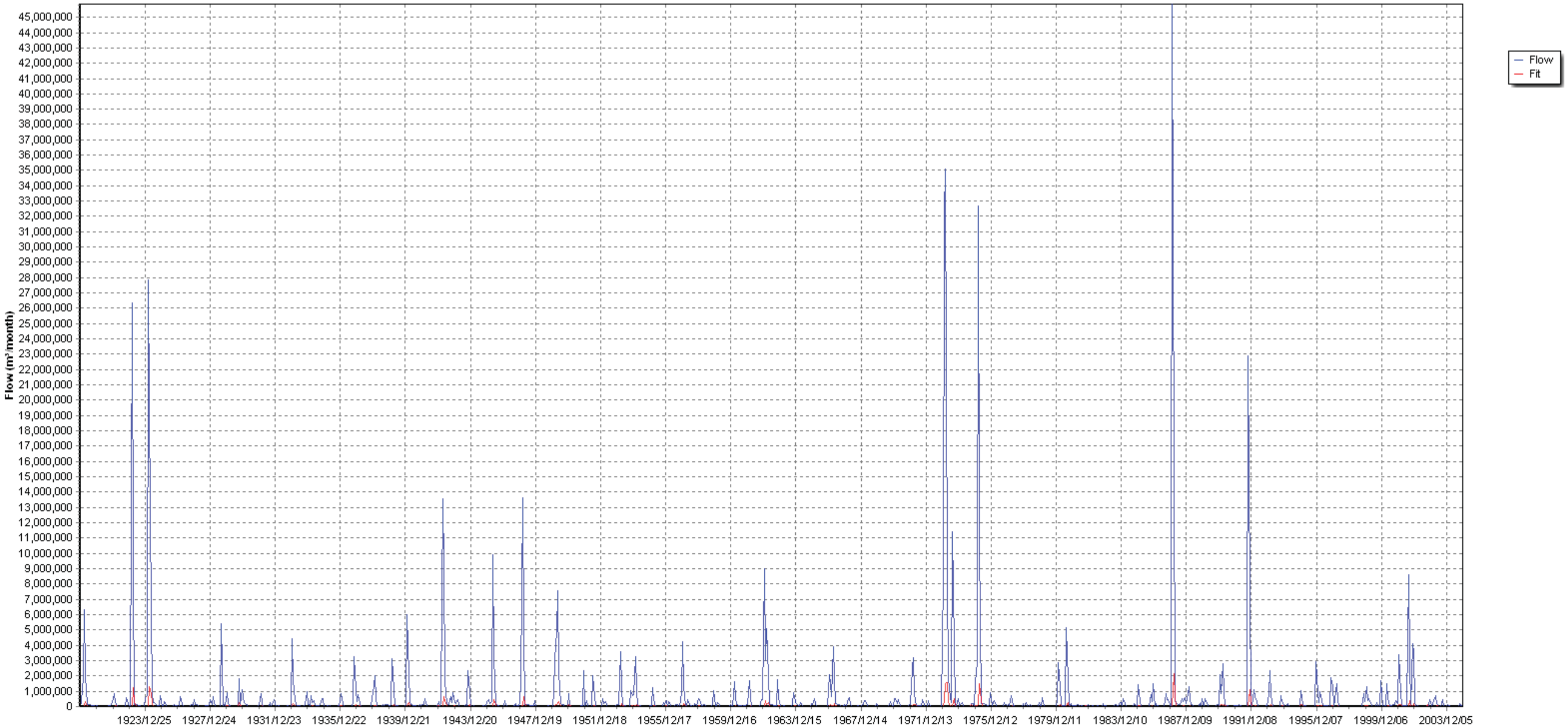


Figure 228: Groundwater contribution to baseflow (D35F)

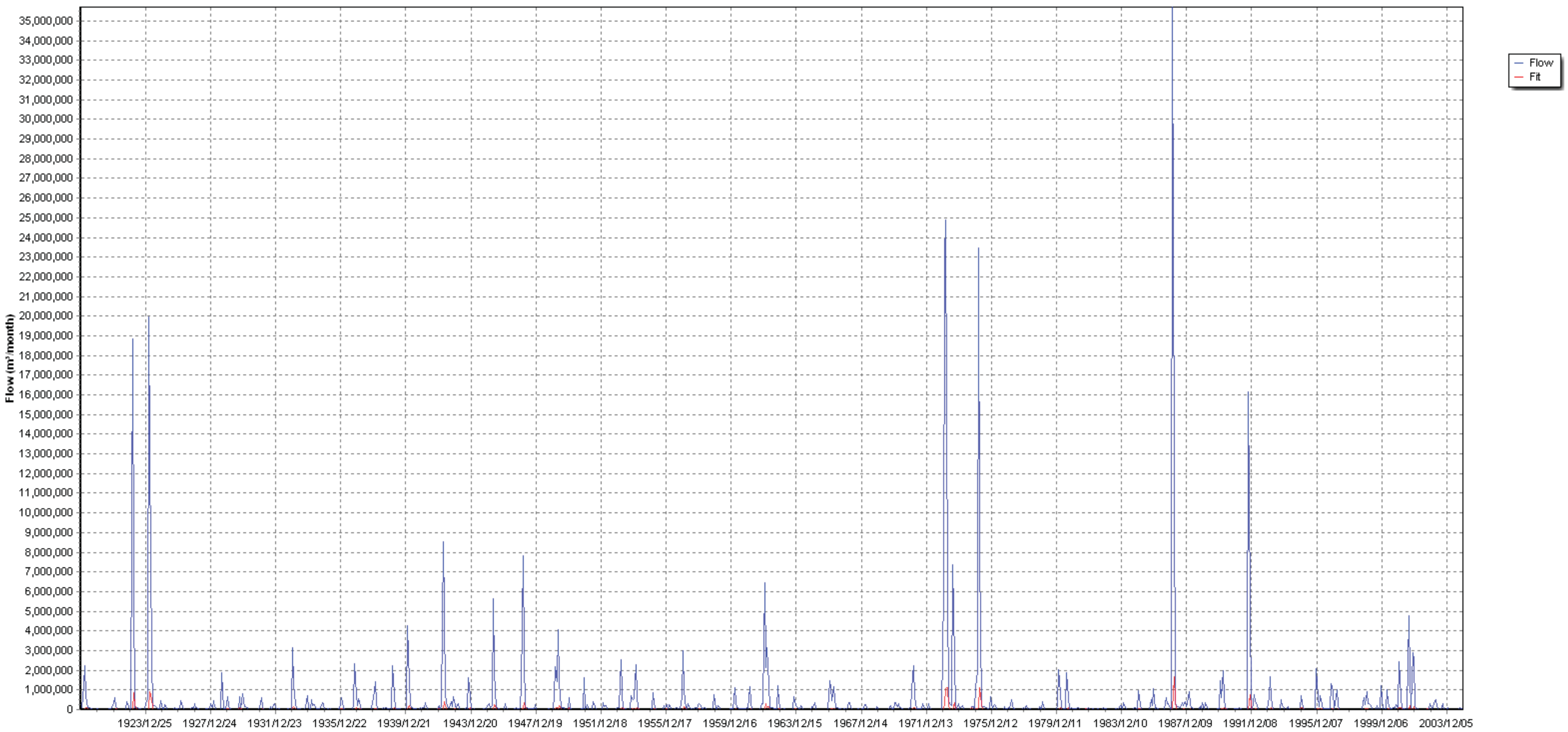


Figure 229: Groundwater contribution to baseflow (D35G)

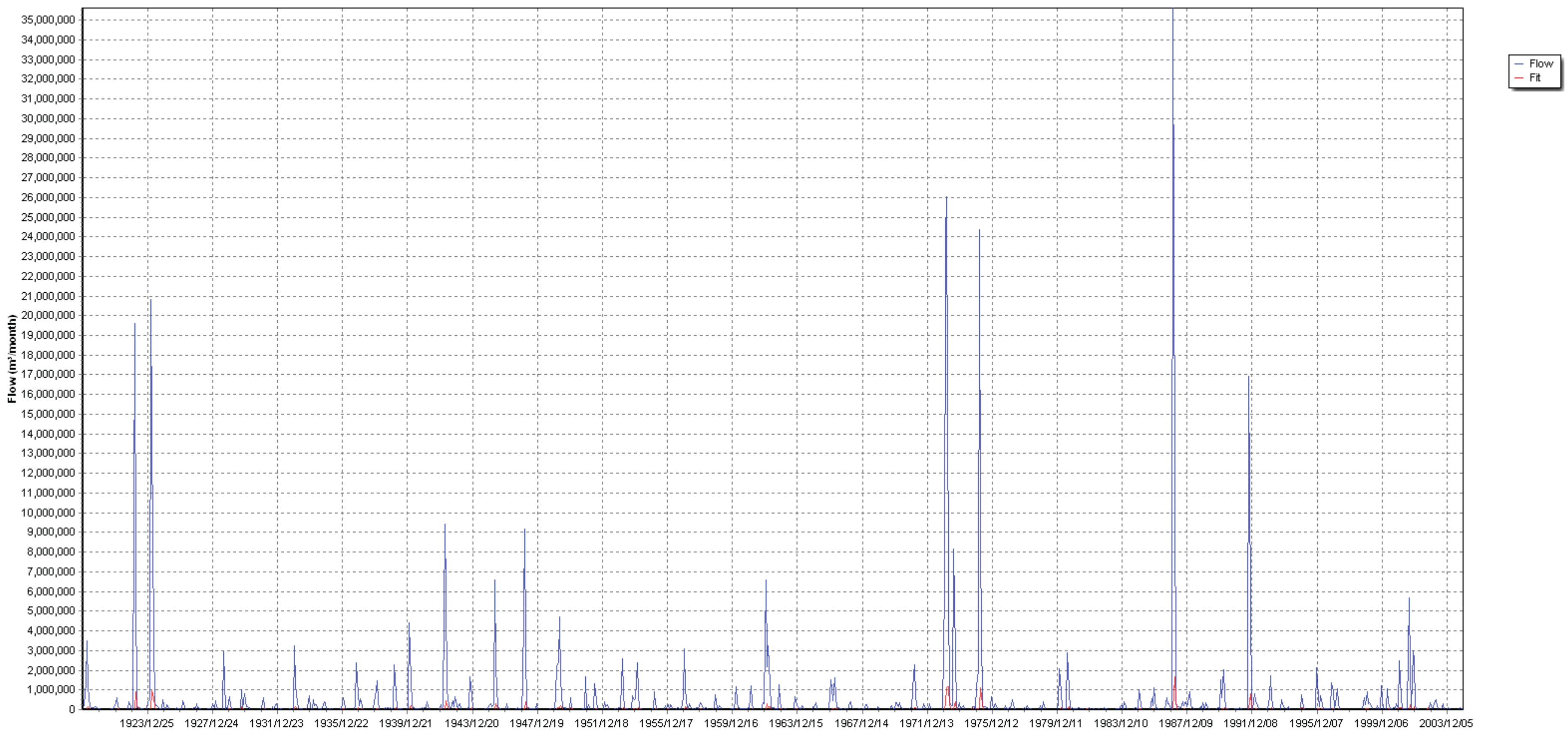


Figure 230: Groundwater contribution to baseflow (D35H)

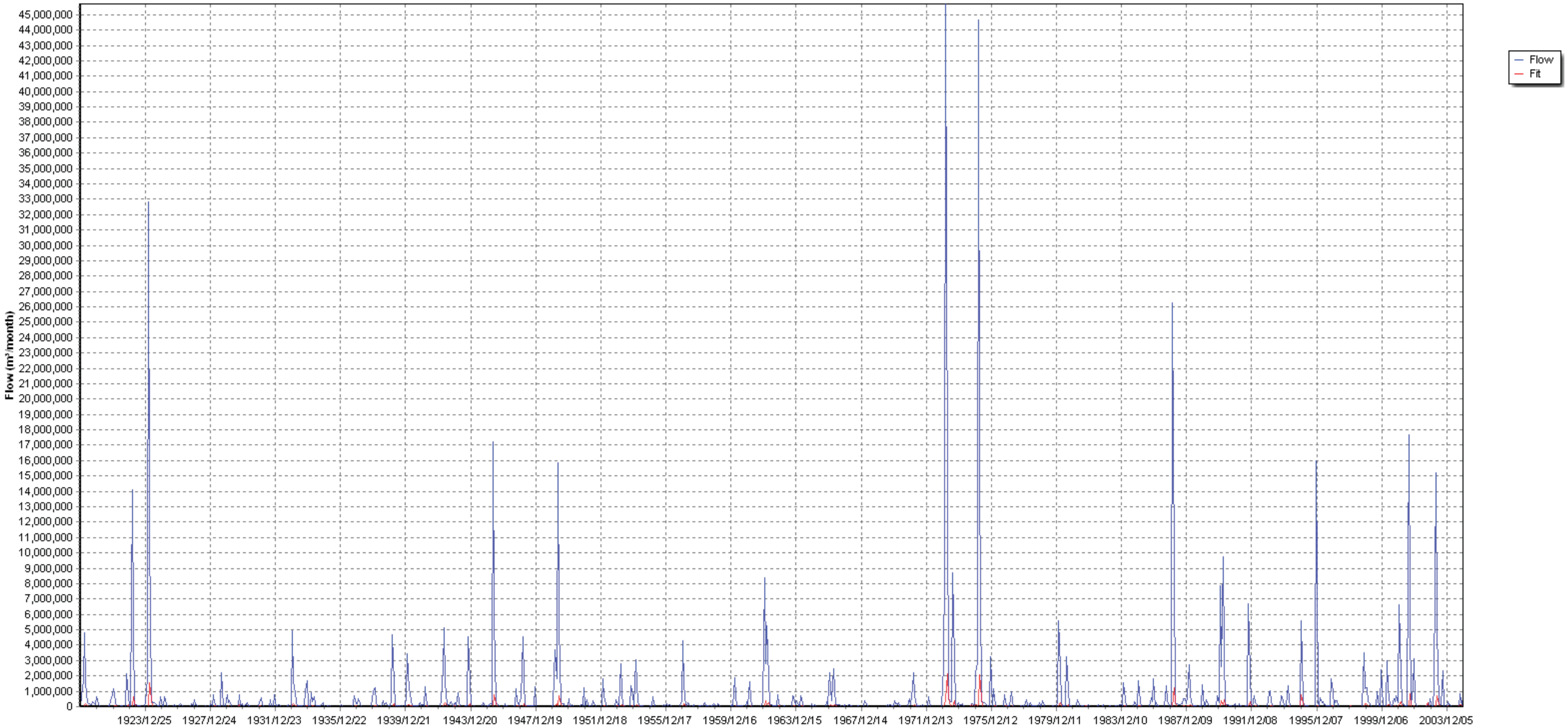


Figure 231: Groundwater contribution to baseflow (D35J)

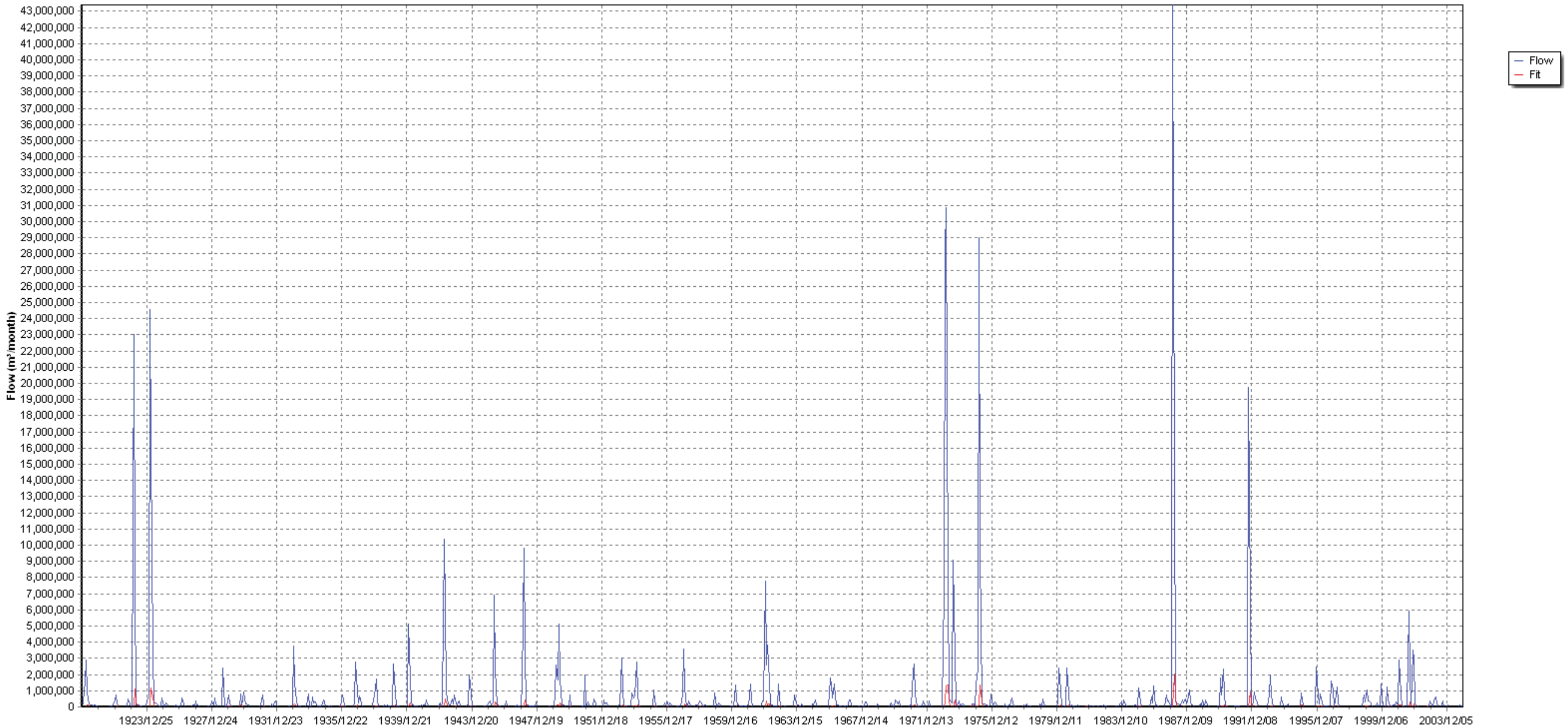


Figure 232: Groundwater contribution to baseflow (D35K)