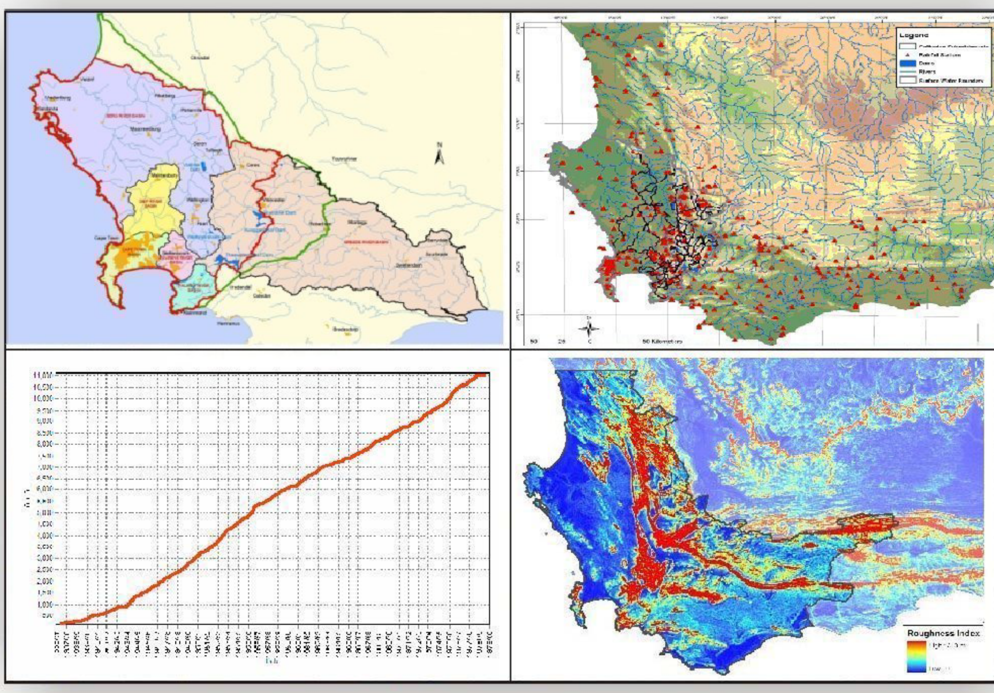
Ref No: P WMA19/000/00/0407

Department of Water Affairs and Forestry

Directorate: National Water Resource Planning

# The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models

## Report No.2 : Rainfall Data Preparation and MAP Surface




**FINAL** **July 2007**


Submitted by:
Ninham Shand (Pty) Ltd
in Association with
Umvoto Africa (Pty) Ltd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CONSULTING SERVICES

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

# DEPARTMENT OF WATER AFFAIRS AND FORESTRY

# THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

# REPORT No. 2 : RAINFALL DATA PREPARATION AND MAP SURFACE

***Final***

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Department of Water Affairs and Forestry
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THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS

# REPORT No. 2
# RAINFALL DATA PREPARATION AND MAP SURFACE

## APPROVAL

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| DWAF REF NO. | : | P WMA19/000/00/0407 |
| CONSULTANTS | : | Ninham Shand in association with Umvoto Africa |
| AUTHORS | : | V Jonker, L Hayes and J Beuster |
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|---|---|---|---|
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| 2 | Rainfall Data Preparation and MAP Surface | | |
| 3 | The Assessment of Flow Gauging Stations | | |
| 4 | Land Use and Water Requirements | Vol 1 | Data in Support of Catchment Modelling |
| | | Vol 2 | Invasive Alien Plant Mapping |
| | | Vol 3 | Water Use and Water Requirements |
| 5 | Update of Catchment Hydrology | Vol 1 | Berg River |
| | | Vol 2 | Upper Breede River |
| | | Vol 3 | Peripheral Rivers |
| 6 | Water Quality | Vol 1 | A Literature Review of Water Quality Related Studies in the Berg WMA, 1994 - 2006 |
| | | Vol 2 | Updating of the ACRU Salinity Model for the Berg River |
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| 8 | System Analysis Status Report | | |
| 9 | Groundwater Model | Vol 1 | Overview of Methodology and Results |
| | | Vol 2 | Data Availability and Evaluation |
| | | Vol 3 | Regional Conceptual Model |
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**THE ASSESSMENT OF WATER AVAILABILITY IN THE BERG CATCHMENT (WMA 19) BY MEANS OF WATER RESOURCE RELATED MODELS**

# RAINFALL DATA PREPARATION AND MAP SURFACE

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## ABBREVIATIONS

| | |
|---|---|
| DWAF | Department of Water Affairs and Forestry |
| GIS | Geographical Information System |
| WAAS | Water Availability Assessment Study |
| WCSA | Western Cape System Analysis |
| WMA | Water Management Area |
| WR-IMS | Water Resources Information Management System |
| WRPM | Water Resources Planning Model |
| WRYM | Water Resources Yield Model |

# 1. INTRODUCTION

Detailed in this report is the patching of the monthly rainfall records for the Berg WMA and contiguous areas. The patching of the monthly rainfall records is undertaken as a sub-task in the broader objective of the Berg (WMA 19) Water Availability Assessment Study (WAAS) to reconfigure existing or newly-configured water resource related models for allocable water quantification for both surface water and groundwater. As outlined in the Inception Report, this task comprises the forward extension of monthly point rainfall records from the last dates of the previous studies to September 2005 including the recent severe Western Cape drought in the analysis.

The Study Area comprises:

- The complete Berg River Catchment from its source in the Groot Drakenstein Mountains to its estuary at Laaiplek on the Atlantic West Coast.
- The Cape Town Basin, which includes the Eerste, Lourens and Sir Lowry's Pass Rivers (all of which drain into False Bay) as well as the groundwater resources for the Peninsula.
- The Diep River, which flows westerly from its source in the Riebeeck Kasteel mountains to its mouth in the northern suburbs of Cape Town.
- The complete Palmiet and Steenbras catchments in the south of the Study Area, which flow in a south-westerly direction to the south of False Bay.
- The Breede River, which flows easterly to the Indian Ocean, and of which the Upper and Middle Breede and the Upper Riviersonderend catchments are focus study areas.

The rainfall patching was performed for the region as a whole to ensure that all relevant spatial cross-dependencies influence the infilling process. This rainfall extension also included the Upper Breede River and Theewaterskloof Dam catchments.

# 2. WATER RESOURCES INFORMATION MANAGEMENT SYSTEM

The Water Resources Information Management System (WR-IMS) is a database management system that was developed by DWAF. The rainfall database covered by the WR-IMS comprises 12 748 rainfall stations across southern Africa, of which, the majority are located in South Africa. It also encompasses the WRYM Yield model and systems data with additional storage retrieval capabilities for metadata. The WR-IMS allows for the easy selection of rainfall stations through a GIS interface and includes various data visualizers which allow the rainfall data to be viewed diagnostically, including key statistics of any selected rainfall gauge and cumulative mass plots for particular gauges or a data grid of rainfall data.

Included in the WR-IMS is an interface to the ClassR and PatchR utilities which allow for the identification of outliers and appropriate groupings of source rainfall gauges in order to patch the missing records of selected rainfall gauges.

The WR-IMS was used in this study as the database management tool to patch the monthly rainfall records of rainfall stations located in the Berg, Breede and peripheral river catchments. The methodology followed, using the WR-IMS, was as follows:

- Identification of rainfall stations located inside and nearby the study area.
- Screening and testing of rainfall station records for stationarity.
- The ClassR and PatchR utilities were used to identify suitable groupings of stations, to identify outliers or errors in the rainfall data and to infill missing or suspect rainfall data.

Discussed below is the methodology followed for the selection of rainfall gauges and the screening of the monthly rainfall records.

## 3. SELECTION AND SCREENING OF MONTHLY RAINFALL RECORDS

With the aid of the WR-IMS all rainfall stations located within or near the study area were selected. Figure 3.1 shows all rainfall stations selected initially. The raw monthly rainfall records up to 2004 contained in the WR-IMS (its limit) were used in this study, and records up to September 2005 for live stations were obtained separately from the South African Weather Bureau (SAWB). As an initial screening, any rainfall gauge was eliminated that had less than 10 years of rainfall record or where the rainfall recorded ended prior to 1940. In addition, rainfall stations with excessive missing data were rejected from the study.

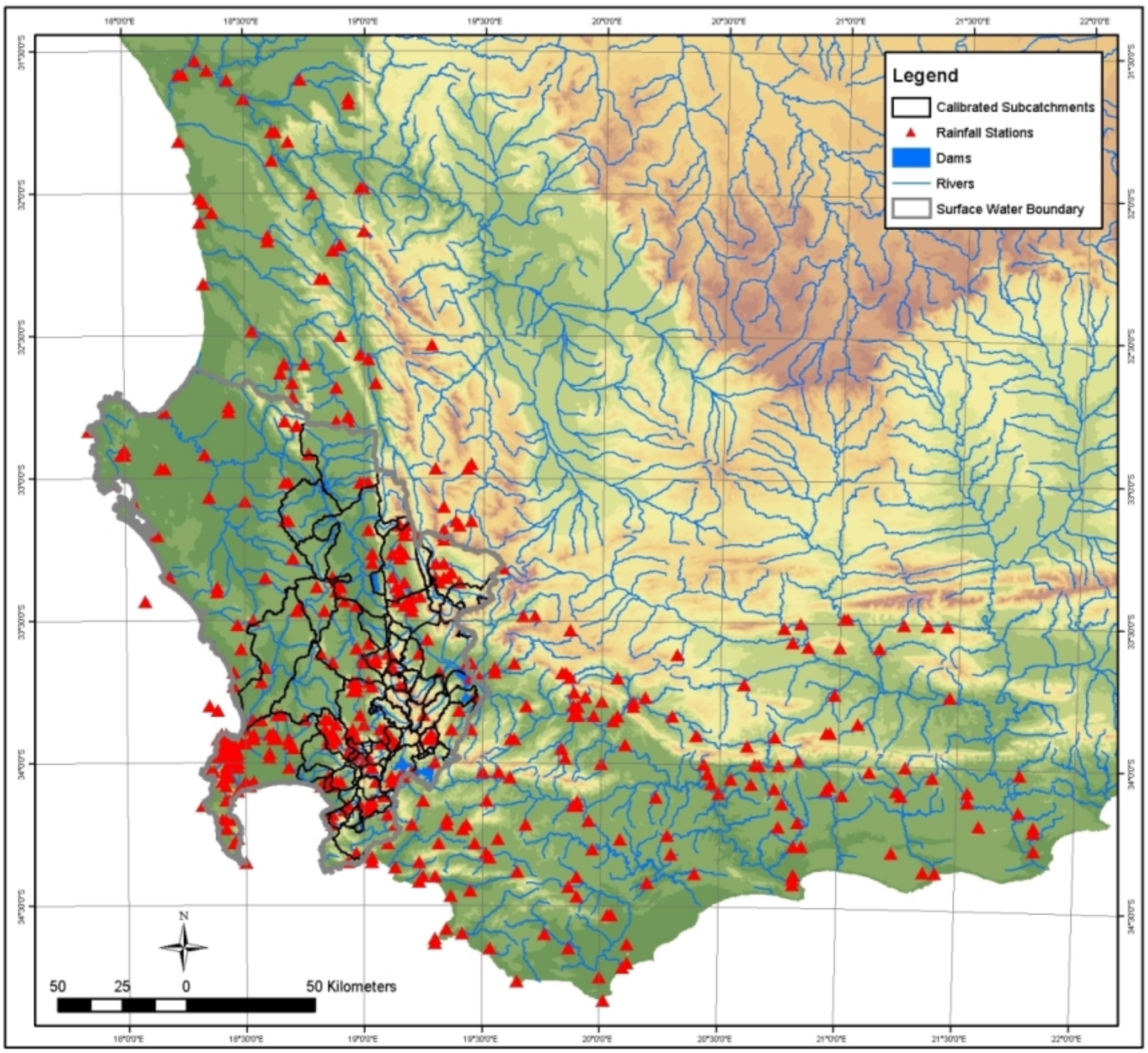


**Figure 3.1 Location of all rainfall stations in the WAAS Study Area**

Included in the WR-IMS is a patched monthly record for all rainfall gauges over southern Africa. These patched rainfall records were a deliverable of a Water Research Commission Project (Lynch, 2004). The records were infilled using a hierarchy of techniques at a daily level. Although these infilled rainfall records were not used in this study, in instances where rainfall records were suspect or no nearby rainfall station had a recorded value, the WRC rainfall values were used as a qualitative check on the raw monthly records.

Following this initial screening, tests of stationarity were conducted on all selected rainfall gauges. Cumulative mass plots were examined and rainfall station records were analysed. An example of a typical mass plot for a station is shown in Figure 3.2. The slope indicates some relatively small changes in stationarity, i.e. the slope appears to be steeper for the first half of the record, but in this case, these changes were not considered to be significant enough to reject the station record. Records with significant changes in the slope of the graph were eliminated. A diagnostic grid of the rainfall record was scanned, with the following indicators of errors examined more closely:

- Zero values in the wet months, these were compared to stations nearby.
- Annual totals which were more than double or less than half of the Mean Annual Precipitation of the rainfall station.
- Series of monthly recorded rainfall values of zero.
- Numerous recorded rainfall values in a rainfall station's record that appeared to be rounded to the nearest whole number.

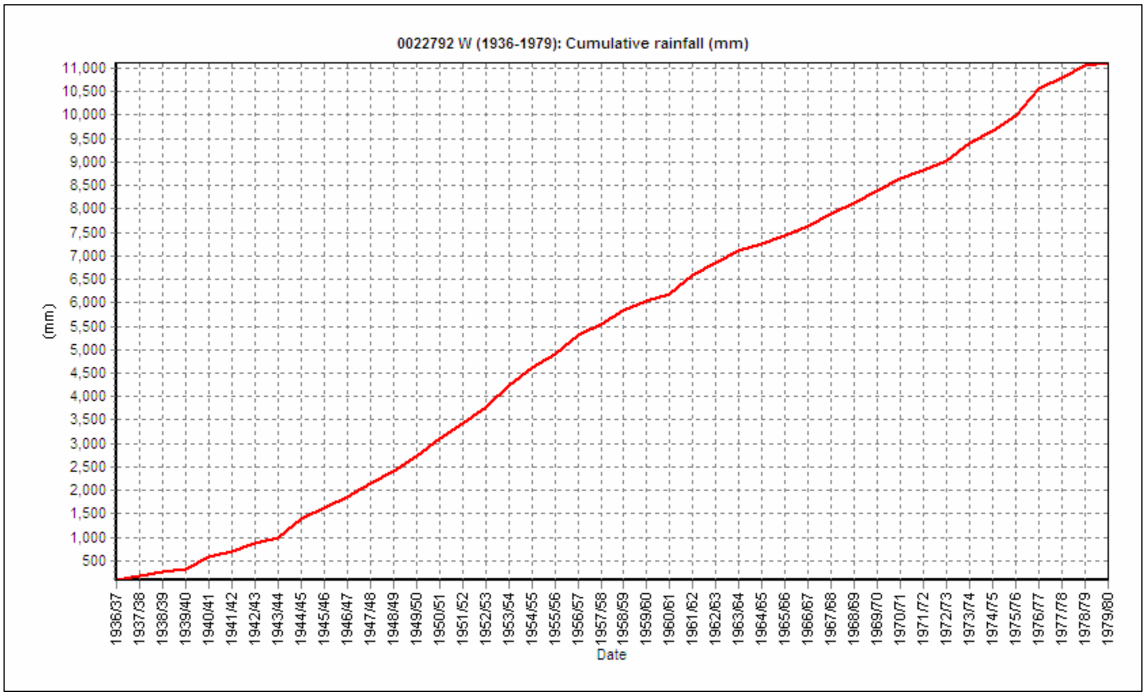


**Figure 3.2 Single mass plot of raw data for station 0022792W**

The WR-IMS contains a useful tool to assess the overlapping time period for selected groups of stations. Figure 3.3 shows an example of the bar chart indicating the overlapping years and the gaps in the record for a group of stations. Numerous rainfall gauge records had large portions of data that were found to have continuous zeros. Although, these rainfall records were not flagged in the raw rainfall records contained in the WR-IMS, they were flagged prior to using the ClassR and PatchR utilities, as it was found that they significantly influenced the groupings of the rainfall stations.

Once the rainfall stations had been selected and the rainfall data had been screened, ClassR and PatchR were used to group suitable rainfall stations together and infill missing or suspect values.

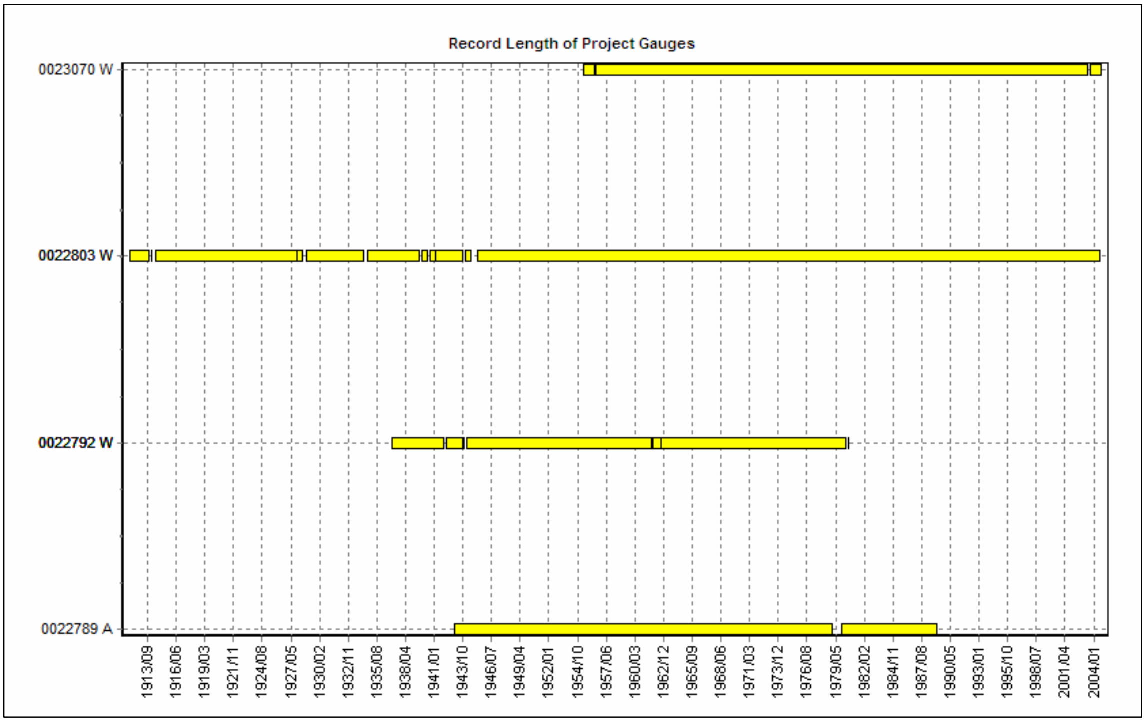


**Figure 3.3 Bar chart showing overlapping years**

## 4. CLASSR AND PATCHR METHODOLOGY

As previously mentioned, the WR-IMS contains an interface to the ClassR and PatchR utilities. The philosophy of patching of rainfall data adopted for this study was to use rainfall stations with sound data quality to infill missing or suspect data in other sound rainfall station records in an iterative process. The importance of performing the patching exercise for the region as a whole was recognised, thus all relevant spatial cross-dependencies are fed into the infilling process.

Initially, patched rainfall records used in previous studies were to be retained and only the extended portions of the records would be patched during this study. However, due to problems in recovering previously used patched rainfall files, the decision was taken to disregard the previously used patched files. Where available, these previously used patched files were compared against the newly created patched rainfall files and few differences between these were noted.

### 4.1 CLASSR

ClassR is a utility used to group hydro-meteorologically similar rainfall stations together. Given a number of rainfall station records, the CLASSR program performs an outlier analysis which enables the user to make a selection of well-correlated rainfall stations to be used in the patching process. This is achieved in the following way:

- Simple outlier detection by means of scaled absolute difference
- Biplot graphical method employing the Mahalanobis distance measure, and
- Cluster analysis which associates objects by their Euclidian distance.

A number of rainfall gauges in an area are identified and included in the ClassR utility. The software is initially used in performing a rough patch in order to allow the stations to cluster into groups that are closely related. The rainfall stations are then re-selected according to the identified clusters and

ClassR is re-run. This process is repeated until satisfactory results are obtained. The rainfall gauges included in the final cluster to be used in PatchR need to satisfy the following criteria:

- The number of intact years needs to at least 2.5 times greater than the number of rainfall stations included in the cluster.
- The first of the two singular values in the biplot must be at least 10 times larger than the second singular value.
- The percentage of total variance must be high, close to 100%, but at least 80%.
- Outliers are identified, however, the outliers are only flagged if completely confident that the rainfall value is an outlier.

ClassR was re-run if there was non-compliance with any of the above specifications. Once satisfied with the grouping of rainfall stations, the months were grouped into seasons. Up to four “seasons” can be accommodated by PatchR per run, with a minimum of two seasons. Ten different definitions of seasons were identified in the ClassR process for the Berg WMA and these are shown in Table 4.1.

The grouping of rainfall stations, the number of seasons and associated months are used as input to PatchR. The final grouping of rainfall stations for patching is presented in Table 4.2.

**Table 4.1 Seasonal distributions obtained using ClassR**

| Season code | NO.OF MONTHS | Season | Months |
|---|---|---|---|
| 1 | 8 | Dry | September - April |
| | 4 | Wet | May - August |
| 2 | 6 | Dry | October - March |
| | 1 | | April |
| | 5 | Wet | May - September |
| 3 | 9 | Dry | September - May |
| | 3 | Wet | June - August |
| 4 | 7 | Dry | October - April |
| | 5 | Wet | May - September |
| 5 | 7 | Dry | September - March |
| | 5 | Wet | April - August |
| 6 | 7 | Dry | September - March |
| | 2 | Wet | April, May |
| | 3 | Wet | June - August |
| 7 | 6 | Dry | October - March |
| | 6 | Wet | April - September |
| 8 | 8 | Dry | September - April |
| | 1 | Wet | May |
| | 3 | Wet | June - August |
| 9 | 7 | Dry | September - March |
| | 1 | Wet | April |
| | 4 | Wet | May - August |
| 10 | 2 | Wet | September, October |
| | 5 | Dry | November - March |
| | 1 | Dry | April |
| | 4 | Wet | May - August |

**Table 4.2 Final grouping of rainfall gauges for patching**

| No. | No. of Gauges | Gauges | Start Year | End Year | Number of intact years | Season Code |
|---|---|---|---|---|---|---|
| B1A | 4 | 0022803W, 0022792W, 0023070W, 0022789A | 1929 | 2004 | 19 | 1 |
| B1B | 3 | 0022759W, 0023070W, 0022825W | 1927 | 2004 | 15 | 2 |
| B2A | 3 | 0022440W, 0022368W, 0022521W | 1900 | 2004 | 22 | 1 |
| C1A | 4 | 0042281A, 0042582W, 0042531A, 0042532A | 1909 | 2004 | 13 | 1 |
| C1B | 4 | 0042669W, 0042588W, 0043139W, 0042621W | 1943 | 2004 | 11 | 3 |
| C1C | 3 | 0042802W, 0042650W, 0043109W | 1931 | 1985 | 10 | 4 |
| C1D | 4 | 0042250W, 0042281A, 0042582W, 0042789W | 1933 | 2004 | 15 | 4 |
| E1A | 6 | 0021260W, 0021330W, 0021230W, 0021441W, 0021655W, 0005605W | 1924 | 1977 | 26 | 5 |
| E1B | 3 | 0021204W, 0021325W, 0005545W | 1959 | 1991 | 19 | 1 |
| E1C | 3 | 0005664A, 0021325W, 0021204W | 1941 | 1993 | 9 | 1 |
| E2 | 5 | 0005612W, 0005611A, 0005640W, 0005759W, 0005730W | 1960 | 1988 | 20 | 1 |
| E3B | 3 | 0021778W, 0021809W, 0006065W | 1936 | 2003 | 33 | 6 |
| M1A | 4 | 0020846W, 0040653W, 0040682W, 0041417W | 1979 | 2000 | 11 | 3 |
| M1B | 3 | 0021230W, 0021260W, 0021441W | 1924 | 1978 | 33 | 1 |
| M1C | 3 | 0041388W, 0020846W, 0041347W | 1993 | 2004 | 8 | 4 |
| M1D | 3 | 0041533W, 0041388W, 0041279W | 1993 | 2002 | 7 | 4 |
| M1E | 4 | 0062768W, 0062678A, 0041871W, 0041301W | 1970 | 1988 | 16 | 1 |
| M1F | 3 | 0041841W, 0062768W, 0040192W | 1993 | 2004 | 6 | 1 |
| M1G | 4 | 0062379A, 0061766W, 0061286W, 0040875W | 1983 | 2000 | 10 | 7 |
| M1H | 4 | 0041684W, 0062444W, 0041713W, 0041060W | 1937 | 1965 | 10 | 1 |
| M1I | 3 | 0061286W, 0040875W, 0020791W | 1988 | 2003 | 7 | 8 |
| M1J | 4 | 0061298W, 0040875W, 0041279W, 0041347W | 1973 | 2003 | 23 | 1 |
| M2A | 5 | 0062379W, 0041060W, 0041713W, 0041836W, 0041347A | 1941 | 1975 | 15 | 1 |
| M2B | 4 | 0040604W, 0041347A, 0041417A, 0040682W | 1949 | 1983 | 18 | 1 |
| M2C | 5 | 0062444W, 0040604W, 0040682W, 0041417W, 0040653W | 1914 | 2000 | 23 | 1 |
| M2D | 3 | 0041681W, 0041713W, 0041279W | 1970 | 1982 | 9 | 1 |
| M2E | 4 | 0061736W, 0061766W, 0061256W, 0020841W | 1964 | 1981 | 12 | 9 |
| P1A | 4 | 0005771W, 0006167W, 0005880W, 0005849W | 1955 | 1972 | 10 | 1 |
| P1B | 3 | 0005829W, 0006223W, 0006038A | 1975 | 1988 | 5 | 1 |
| P1C | 3 | 0006051A, 0006167W, 0006192W | 1949 | 1991 | 25 | 1 |
| P1D | 4 | 0006039W, 0006167W, 0005759W, 0005730W | 1959 | 1988 | 18 | 3 |
| P2 | 3 | 0006214W, 0006332W, 0022539W | 1932 | 1995 | 37 | 1 |
| P3 | 3 | 0022504W, 0022440W, 0022539W | 1974 | 1990 | 7 | 1 |
| V1A | 3 | 0042358W, 0042355W, 0042227W | 1984 | 2004 | 10 | 7 |
| V1B | 4 | 0042415W, 0042357A, 0042227W, 0042326W | 1929 | 1961 | 19 | 4 |

| No. | No. of Gauges | Gauges | Start Year | End Year | Number of intact years | Season Code |
|---|---|---|---|---|---|---|
| V1C | 3 | 0042227W, 0042355W, 0042233W | 1967 | 1986 | 6 | 1 |
| V1D | 3 | 0042357W, 0042257W, 0042198W | 1968 | 1982 | 8 | 1 |
| V1E | 4 | 0042011W, 0041871W, 0041713W, 0041279W | 1964 | 1977 | 9 | 1 |
| W1A | 4 | 0022005W, 0022069W, 0021825W, 0021860A | 1961 | 1974 | 6 | 4 |
| W1B | 4 | 0021823W, 0022038W, 0022113W, 0022004W | 1931 | 1985 | 34 | 8 |
| W1C | 4 | 0022205A, 0022204W, 0021795A, 0021860A | 1943 | 1970 | 21 | 10 |
| W1D | 3 | 0021878B, 0021816A, 0022004W | 1974 | 1985 | 10 | 1 |
| W1E | 3 | 0021879W, 0022005W, 0022038W | 1988 | 2003 | 5 | 4 |

## 4.2 PATCHR

PatchR uses a linear regression in combination with expectation maximization to infill missing or suspect values which have been flagged in the input rainfall record. PatchR performs a multiple patch on all rainfall stations contained within a group; the rainfall sequnece is lengthened to the earliest and latest date that occurs in the input rainfall records. This process of infilling and extension of rainfall sequences is done as an iterative procedure.

PatchR was typically used in two or more passes with problems identified in the first pass, and final patching conducted in the second pass. The criteria that the PatchR output had to meet are given below:

- As a rule of thumb, the number of iterations performed by the software needed to be less then 25,; if more than 15 iterations occurred, the rainfall station grouping was revisited as a conservative check.
- In the B-matrix of statistics, values smaller than – 0.5 and greater than 1.5, were not accepted. The ideal bracket was between –0.3 and 1.0.

Outliers were identified from the PatchR output once the above criteria were met. These outliers were flagged in the raw monthly rainfall records and PatchR was re-run to create the final patched file. For the purposes of this study, all extended rainfall sequences were deleted and the resulting patched sequence had the same period of record as the original raw data file. The MAP and the start and end year for the trimmed sequence were checked and corrected where necessary.

Using the above methodology, 98 rainfall station records in the Berg WAAS study area were patched. Figure 4.1 illustrates the location of these rainfall stations and the station details are included in Table 4.3. In patching the rainfall records for the Berg Catchment various problems were encountered. These problems are discussed in detail below. Following this, the rainfall stations patched in each of the other sub-catchments are detailed.

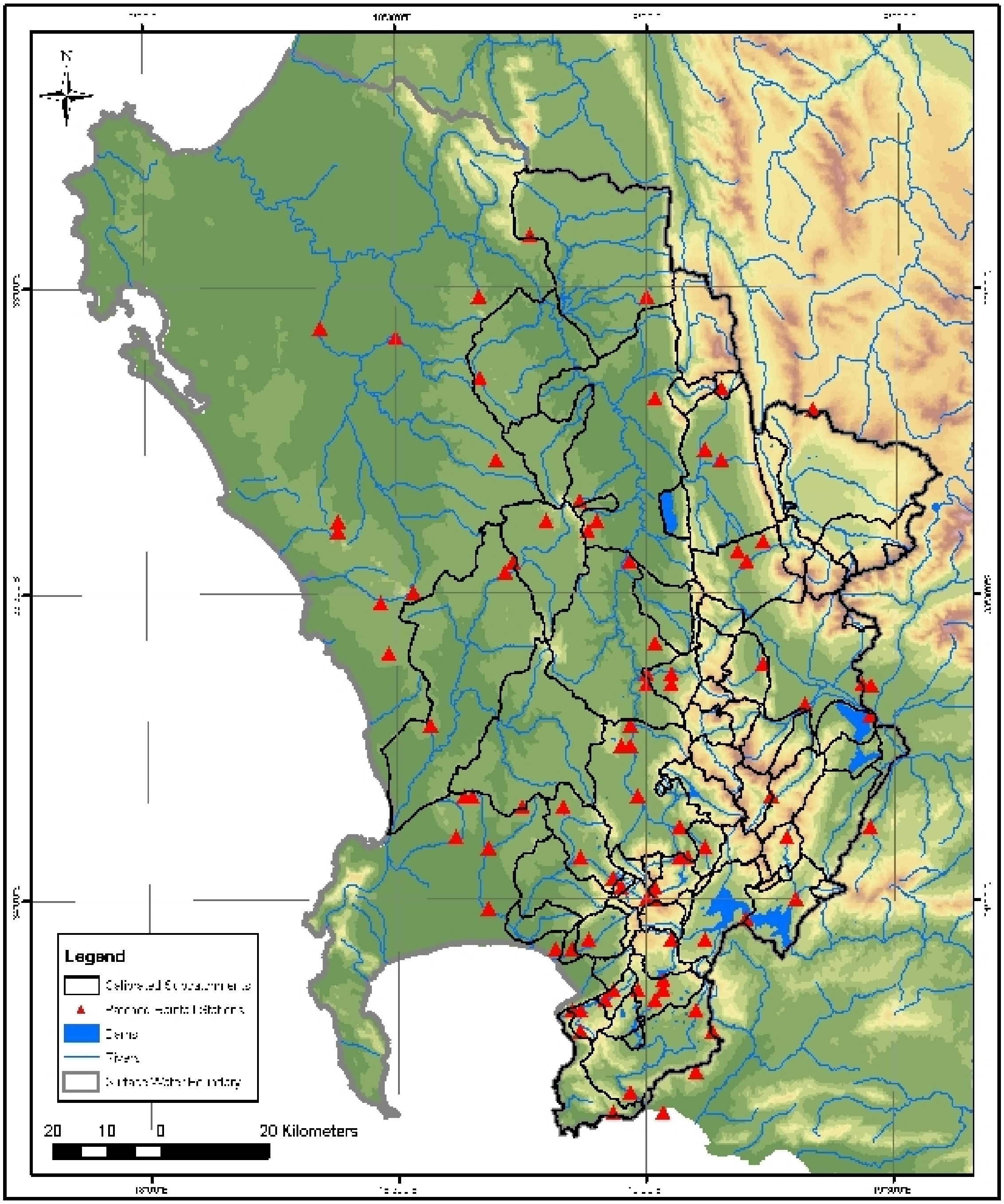


**Figure 4.1 Location of patched rainfall stations in the Berg WAAS study area**

**Table 4.3 Final statistics of patched rainfall station records**

| No. | Gauge number | Name | Latitude | Longitude | Start | End | MAP (mm) | SD (mm) | CV |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0005545 W | Somerset west - dyn | -34° 5' | 18°49' | 1958 | 1995 | 592 | 116 | 0.20 |
| 2 | 0005605 W | Somerset west - pol | -34° 5' | 18°51' | 1927 | 1977 | 627 | 144 | 0.23 |
| 3 | 0005611 A | Steenbrasdam 5/611 | -34°11' | 18°51' | 1955 | 2003 | 967 | 182 | 0.19 |
| 4 | 0005612 W | Steenbras no ii - rsv | -34°13' | 18°52' | 1954 | 2004 | 1242 | 225 | 0.18 |
| 5 | 0005640 W | Steenbras no 111 - rsv | -34°11' | 18°52' | 1959 | 2004 | 981 | 180 | 0.18 |
| 6 | 0005664 A | Somerset west lourensford | -34° 4' | 18°53' | 1941 | 1968 | 487 | 238 | 0.49 |
| 7 | 0005730 W | Steenbras no iv - rsv | -34°10' | 18°55' | 1955 | 1994 | 1159 | 199 | 0.17 |
| 8 | 0005759 W | Steenbras no v - rsv | -34° 9' | 18°56' | 1955 | 1987 | 927 | 171 | 0.18 |
| 9 | 0005771 W | Bettys bay | -34°21' | 18°56' | 1966 | 2004 | 1056 | 196 | 0.19 |
| 10 | 0005829 W | Oudebos - bos | -34°19' | 18°58' | 1974 | 2004 | 1232 | 238 | 0.19 |
| 11 | 0005849 W | Steenbras no vii - rsv | -34° 9' | 18°59' | 1955 | 1985 | 1036 | 186 | 0.18 |
| 12 | 0005880 W | Morning star | -34°10' | 19° 1' | 1927 | 1972 | 1067 | 216 | 0.20 |
| 13 | 0006038 A | Elgin (nivv) | -34° 8' | 19° 2' | 1962 | 1987 | 1001 | 216 | 0.22 |
| 14 | 0006039 W | Grabouw - bos | -34° 9' | 19° 2' | 1928 | 2004 | 1018 | 192 | 0.19 |
| 15 | 0006051AW | Kleinmond - pol | -34°21' | 19° 2' | 1948 | 1993 | 692 | 173 | 0.25 |
| 16 | 0006065 W | Nieuweberg - bos | -34° 4' | 19° 3' | 1927 | 2004 | 1595 | 419 | 0.26 |
| 17 | 0006167 W | Highlands - bos | -34°17' | 19° 6' | 1938 | 1991 | 928 | 169 | 0.18 |
| 18 | 0006192 W | Lebanon - bos | -34°11' | 19° 6' | 1938 | 1991 | 677 | 139 | 0.21 |
| 19 | 0006214 W | Rus - en - vrede | -34° 4' | 19° 7' | 1932 | 1994 | 820 | 229 | 0.28 |
| 20 | 0006223 W | Haasvlakte - bos | -34°13' | 19° 8' | 1971 | 2004 | 678 | 161 | 0.24 |
| 21 | 0006332 W | Rustfontein | -34° 2' | 19°12' | 1932 | 2004 | 794 | 215 | 0.27 |
| 22 | 0020841 W | Mamre - col | -33°31' | 18°28' | 1964 | 1980 | 369 | 117 | 0.32 |
| 23 | 0020846 W | Atlantis | -33°36' | 18°29' | 1979 | 2004 | 451 | 89 | 0.20 |
| 24 | 0021105 W | Koeberg | -33°43' | 18°34' | 1967 | 1989 | 463 | 112 | 0.24 |
| 25 | 0021204 W | Bellville - sar kwekery | -33°54' | 18°37' | 1948 | 1990 | 523 | 133 | 0.26 |
| 26 | 0021230 W | Altydgedacht | -33°50' | 18°38' | 1927 | 2004 | 589 | 112 | 0.19 |
| 27 | 0021260 W | Durbanville - pol | -33°50' | 18°39' | 1927 | 1992 | 600 | 129 | 0.21 |
| 28 | 0021325 W | Kuilsrivier | -33°55' | 18°41' | 1949 | 1993 | 630 | 157 | 0.25 |
| 29 | 0021330 W | Eersterivier - bos | -34° 1' | 18°41' | 1927 | 1979 | 520 | 116 | 0.22 |
| 30 | 0021441 W | Kraaifontein - bos | -33°51' | 18°45' | 1927 | 1978 | 527 | 114 | 0.22 |
| 31 | 0021591 A | Elsenburg | -33°51' | 18°50' | 1963 | 1986 | 596 | 141 | 0.24 |
| 32 | 0021655 W | Stellenbosch | -33°56' | 18°52' | 1927 | 1985 | 719 | 140 | 0.19 |
| 33 | 0021778 W | Jonkershoek - bos | -33°58' | 18°56' | 1927 | 2004 | 1076 | 198 | 0.18 |
| 34 | 0021795 A | Bellevue (niww) | -33°45' | 18°57' | 1941 | 1987 | 944 | 198 | 0.21 |
| 35 | 0021809 W | Jonkershoek - 2d | -33°59' | 18°57' | 1936 | 2004 | 1463 | 278 | 0.19 |
| 36 | 0021823 W | Paarl | -33°43' | 18°58' | 1927 | 2004 | 895 | 202 | 0.23 |
| 37 | 0021825 W | Paarl - agr | -33°45' | 18°58' | 1959 | 1997 | 915 | 204 | 0.22 |
| 38 | 0021860 A | Bien donne (nivv) | -33°50' | 18°59' | 1940 | 1987 | 812 | 166 | 0.20 |
| 39 | 0021878BW | Wellington - mun | -33°38' | 19° 0' | 1963 | 1987 | 628 | 134 | 0.21 |
| 40 | 0021879 W | Wellington-mun | -33°39' | 19° 0' | 1987 | 2004 | 692 | 131 | 0.19 |
| 41 | 0021900 W | Jonkershoek - 3m | -34° 0' | 19° 0' | 1971 | 1990 | 2050 | 494 | 0.24 |
| 42 | 0022004 W | Jonkershoek - 3m | -33°35' | 19° 1' | 1942 | 1969 | 878 | 183 | 0.21 |
| 43 | 0022005 W | Welbedacht | -33°35' | 19° 1' | 1931 | 2003 | 623 | 125 | 0.20 |
| 44 | 0022029 W | Jonkershoek - virgin pea | -33°59' | 19° 1' | 1974 | 1998 | 2276 | 626 | 0.27 |
| 45 | 0022030 W | Jonkershoek - jonkersnek | -34° 0' | 19° 1' | 1972 | 1998 | 3149 | 600 | 0.19 |
| 46 | 0022038 W | Vrugbaar | -33°38' | 19° 3' | 1927 | 2004 | 763 | 147 | 0.19 |
| 47 | 0022069 W | Onverwacht | -33°39' | 19° 3' | 1927 | 1993 | 755 | 161 | 0.21 |
| 48 | 0022113 W | La motte - bos | -33°53' | 19° 4' | 1927 | 2002 | 838 | 215 | 0.26 |
| 49 | 0022113 W | La motte - bos | -33°53' | 19° 4' | 1927 | 2003 | 835 | 215 | 0.26 |
| 50 | 0022116 W | Driefontein - bos | -33°56' | 19° 4' | 1927 | 1960 | 1842 | 402 | 0.22 |

| No. | Gauge number | Name | Latitude | Longitude | Start | End | MAP (mm) | SD (mm) | CV |
|---|---|---|---|---|---|---|---|---|---|
| 51 | 0022143 A | La motte - bos | -33°53' | 19° 5' | 1961 | 2004 | 1985 | 457 | 0.23 |
| 52 | 0022204 W | Franschhoek | -33°55' | 19° 7' | 1941 | 1969 | 880 | 180 | 0.20 |
| 53 | 0022368 W | Swartvlei | -33°37' | 19°14' | 1932 | 1976 | 1009 | 269 | 0.27 |
| 54 | 0022440 W | Stettynskloof | -33°50' | 19°15' | 1952 | 2004 | 916 | 343 | 0.37 |
| 55 | 0022504 W | Welgegund | -33°54' | 19°17' | 1932 | 2000 | 760 | 224 | 0.29 |
| 56 | 0022521 W | Rawsonville - pol | -33°41' | 19°19' | 1927 | 2004 | 613 | 212 | 0.35 |
| 57 | 0022539 W | Villiersdorp | -34° 0' | 19°18' | 1927 | 2004 | 623 | 163 | 0.26 |
| 58 | 0022759 W | Worcester - tnk | -33°39' | 19°26' | 1927 | 2004 | 257 | 79 | 0.31 |
| 59 | 0022789 A | Veldreserwe | -33°39' | 19°27' | 1942 | 1987 | 237 | 81 | 0.34 |
| 60 | 0022792 W | Brandvlei dam | -33°42' | 19°27' | 1938 | 1978 | 265 | 103 | 0.39 |
| 61 | 0022803 W | Doornrivier | -33°53' | 19°27' | 1929 | 2004 | 247 | 82 | 0.33 |
| 62 | 0040604 W | Hopefield - pol | -33° 4' | 18°21' | 1927 | 2004 | 318 | 81 | 0.26 |
| 63 | 0040653 W | The towers | -33°24' | 18°23' | 1927 | 2004 | 482 | 106 | 0.22 |
| 64 | 0040682 W | Darling - pol | -33°23' | 18°23' | 1949 | 2004 | 462 | 101 | 0.22 |
| 65 | 0040875 W | Vlakvlei | -33° 5' | 18°30' | 1955 | 2004 | 314 | 90 | 0.29 |
| 66 | 0041060 W | Burgherspost | -33°30' | 18°32' | 1927 | 1975 | 559 | 131 | 0.23 |
| 67 | 0041279 W | Moorreesburg - pol | -33° 9' | 18°40' | 1964 | 2004 | 385 | 98 | 0.26 |
| 68 | 0041301 W | Koringberg | -33° 1' | 18°40' | 1967 | 1997 | 372 | 99 | 0.27 |
| 69 | 0041347 A | Langgewens (wrs) | -33°17' | 18°42' | 1930 | 1988 | 395 | 83 | 0.21 |
| 70 | 0041347 W | Langgewens - agr | -33°17' | 18°42' | 1958 | 2004 | 396 | 94 | 0.24 |
| 71 | 0041388 W | Malmesbury e | -33°28' | 18°43' | 1993 | 2004 | 366 | 94 | 0.26 |
| 72 | 0041417 A | Malmesbury | -33°27' | 18°44' | 1927 | 1983 | 446 | 113 | 0.25 |
| 73 | 0041417 W | Malmesbury - tnk | -33°27' | 18°44' | 1927 | 2000 | 463 | 117 | 0.25 |
| 74 | 0041533 W | Lelyfontein | -33°23' | 18°48' | 1988 | 2004 | 391 | 92 | 0.24 |
| 75 | 0041681 W | Riebeek - wes - pol | -33°21' | 18°52' | 1969 | 1997 | 577 | 140 | 0.24 |
| 76 | 0041684 W | Kloovenburg | -33°24' | 18°53' | 1927 | 1964 | 688 | 138 | 0.20 |
| 77 | 0041713 W | Riebeek - kasteel - mun | -33°23' | 18°54' | 1937 | 1982 | 660 | 156 | 0.24 |
| 78 | 0041836 W | Rondeheuwel | -33°27' | 18°58' | 1941 | 1978 | 465 | 102 | 0.22 |
| 79 | 0041871 W | Porterville - mun | -33° 1' | 19° 0' | 1958 | 2004 | 496 | 101 | 0.20 |
| 80 | 0042011 W | Saron - col | -33°11' | 19° 1' | 1964 | 1978 | 444 | 122 | 0.27 |
| 81 | 0042166 W | Mont pellier | -33°16' | 19° 7' | 1927 | 1950 | 537 | 105 | 0.20 |
| 82 | 0042227 W | Tulbagh - pol | -33°17' | 19° 9' | 1927 | 2004 | 474 | 114 | 0.24 |
| 83 | 0042250 W | Avalon | -33°10' | 19° 9' | 1984 | 2004 | 1127 | 294 | 0.26 |
| 84 | 0042257 W | Obiqua - tnk | -33°17' | 19° 9' | 1961 | 2004 | 445 | 125 | 0.28 |
| 85 | 0042326 W | Kluitjieskraal - bos | -33°26' | 19°11' | 1927 | 2004 | 645 | 148 | 0.23 |
| 86 | 0042357 A | La plaisante | -33°27' | 19°12' | 1929 | 1987 | 568 | 153 | 0.27 |
| 87 | 0042357 W | La plaisante | -33°27' | 19°12' | 1927 | 1981 | 562 | 161 | 0.29 |
| 88 | 0042415 W | Waverley mills | -33°25' | 19°14' | 1927 | 1960 | 616 | 110 | 0.18 |
| 89 | 0042582 W | Bokveldskloof | -33°12' | 19°20' | 1933 | 2004 | 685 | 193 | 0.28 |
| 90 | 0043139 W | Klondyke | -33°19' | 19°35' | 1952 | 2003 | 586 | 142 | 0.24 |
| 91 | 0062444 W | Piketberg - pol | -32°55' | 18°46' | 1927 | 2004 | 444 | 104 | 0.23 |
| 92 | 9112301 | | | | 1966 | 1988 | 984 | 241 | 0.24 |
| 93 | 9158101 | | -34°11' | 18°51' | 1928 | 1988 | 955 | 201 | 0.21 |
| 94 | 9158102 | | -34°12' | 18°52' | 1928 | 1988 | 1276 | 241 | 0.19 |
| 95 | 9158104 | | -34°10' | 18°56' | 1928 | 1988 | 1083 | 210 | 0.19 |
| 96 | 9995017 | | -34° 8' | 19° 8' | 1963 | 1988 | 1013 | 222 | 0.22 |
| 97 | 90200004 | | | | 1936 | 1986 | 2116 | 529 | 0.25 |
| 98 | 90300001 | | | | 1968 | 1988 | 1022 | 247 | 0.24 |

# 5. RAINFALL PATCHING RESULTS

## 5.1 PROBLEMS ENCOUNTERED

Various problems were encountered during the patching process for the Berg WMA, which are discussed below. These problems do not differ from those commonly experienced by practitioners when using rainfall records.

In the mountainous areas of the Berg WMA, such as the Jonkershoek, Upper Berg and Palmiet areas, there are few rainfall stations. The rainfall stations, which are located there, have short records and contain numerous missing or suspect values. Thus, patching of these rainfall stations proved difficult, as no sound rainfall gauges with similar statistics exist in the area. After various iterations, the patched rainfall files ultimately produced reasonably representative rainfall for mountainous zones, however, they do not cover the entire time period of interest.

Another problem encountered with the rainfall stations in the mountainous areas was that ClassR and PatchR are unable to accommodate monthly rainfall values larger than 999.9 mm. A monthly total as large as this in the Western Cape is unusual. A few of these appeared in the rainfall records, and those identified were carefully scrutinized; however, it was concluded that they were genuine records. To solve this problem, the rainfall values larger than 999.9 mm were replaced with 999.99 mm in the raw monthly rainfall records. The ClassR and PatchR utilities were then used, and once the final patched file had been obtained, the monthly rainfall values larger than 999.9 mm were replaced with their original value in the raw rainfall record.

## 5.2 BERG RIVER CATCHMENT

The stations with patched rainfall records in the Berg catchment are illustrated in Figure 5.1. Thirty-seven rainfall stations were patched in total. Twenty of these stations were used in the previous WCSA study and 17 new stations have been added for the WAAS.

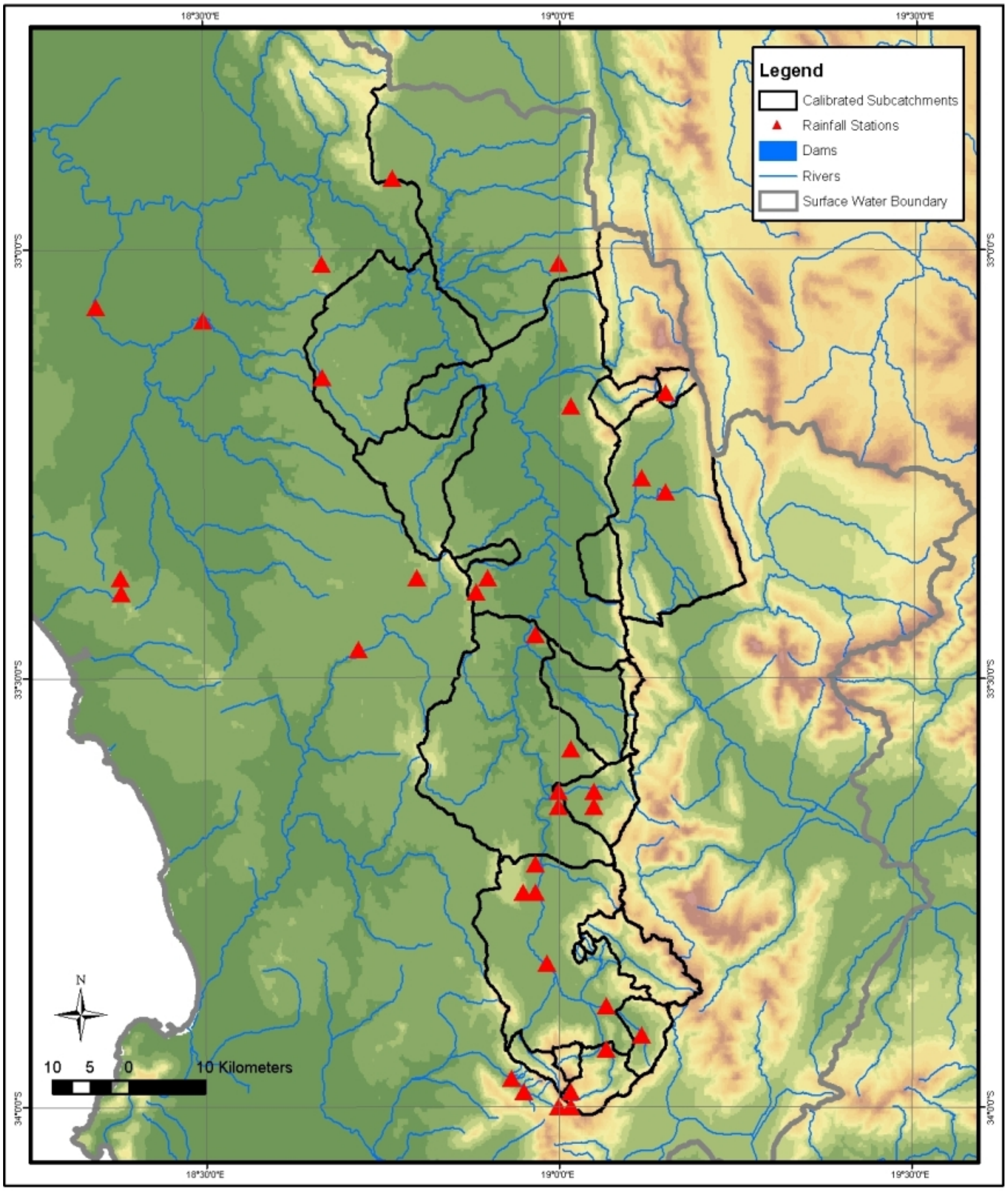


**Figure 5.1 Location of patched rainfall stations in the Berg catchment**

## 5.3 EERSTE, LOURENS AND SIR LOWRY'S PASS CATCHMENTS

The stations with patched rainfall records in the Eerste, Lourens and Sir Lowry's Pass catchments are shown in Figure 5.2. There are 21 patched stations in total; 12 of these stations were used in the previous WCSA study and 9 new stations have been added in the current study.

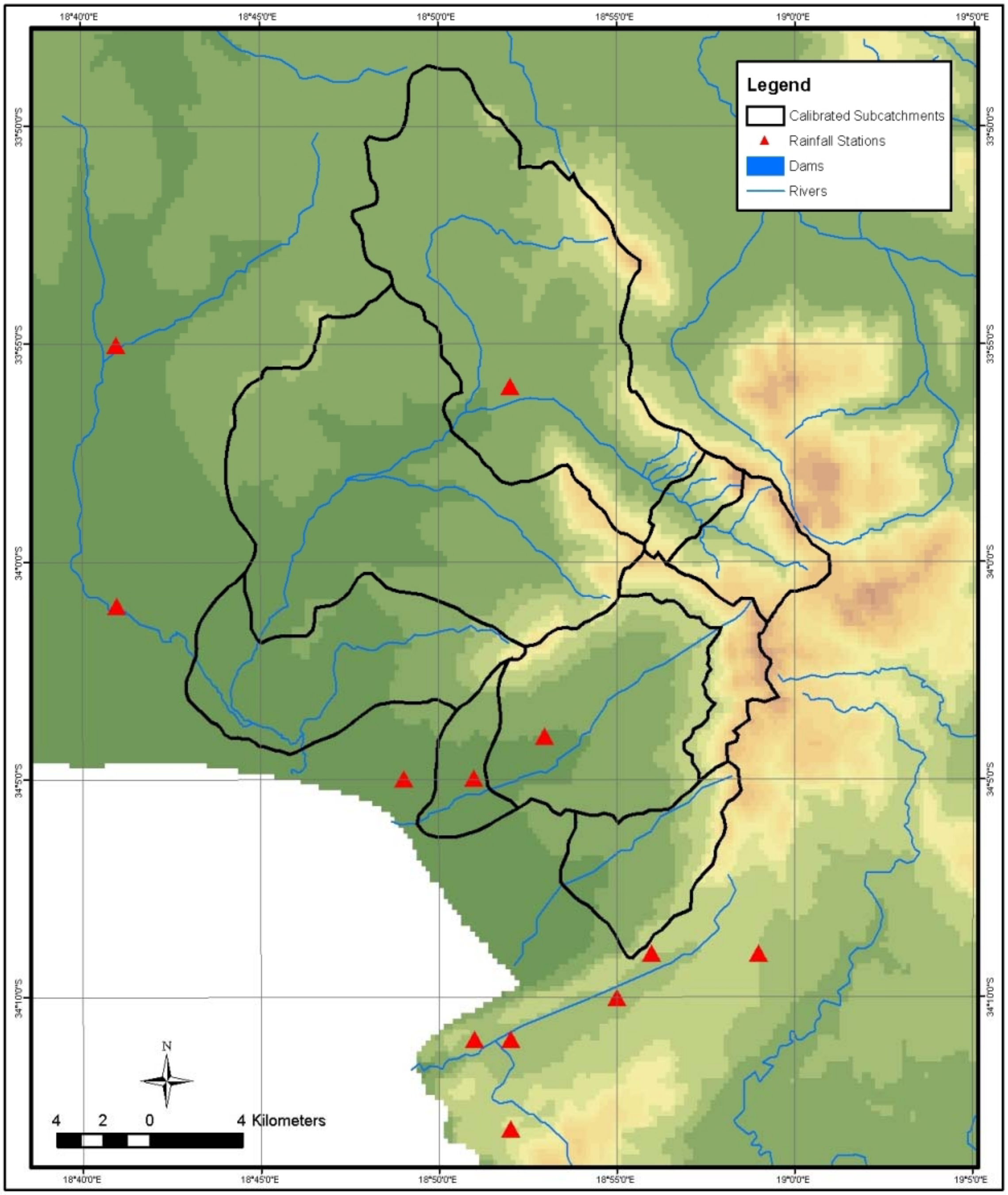


**Figure 5.2 Location of patched rainfall stations in the Eerste, Lourens and Sir Lowry's Pass catchments**

## 5.4 DIEP RIVER

The stations with patched rainfall records in the Diep River catchment are shown in Figure 5.3. There are 19 patched stations in total; 11 of these stations were used in the previous WCSA study and 8 new stations have been added in the current study.

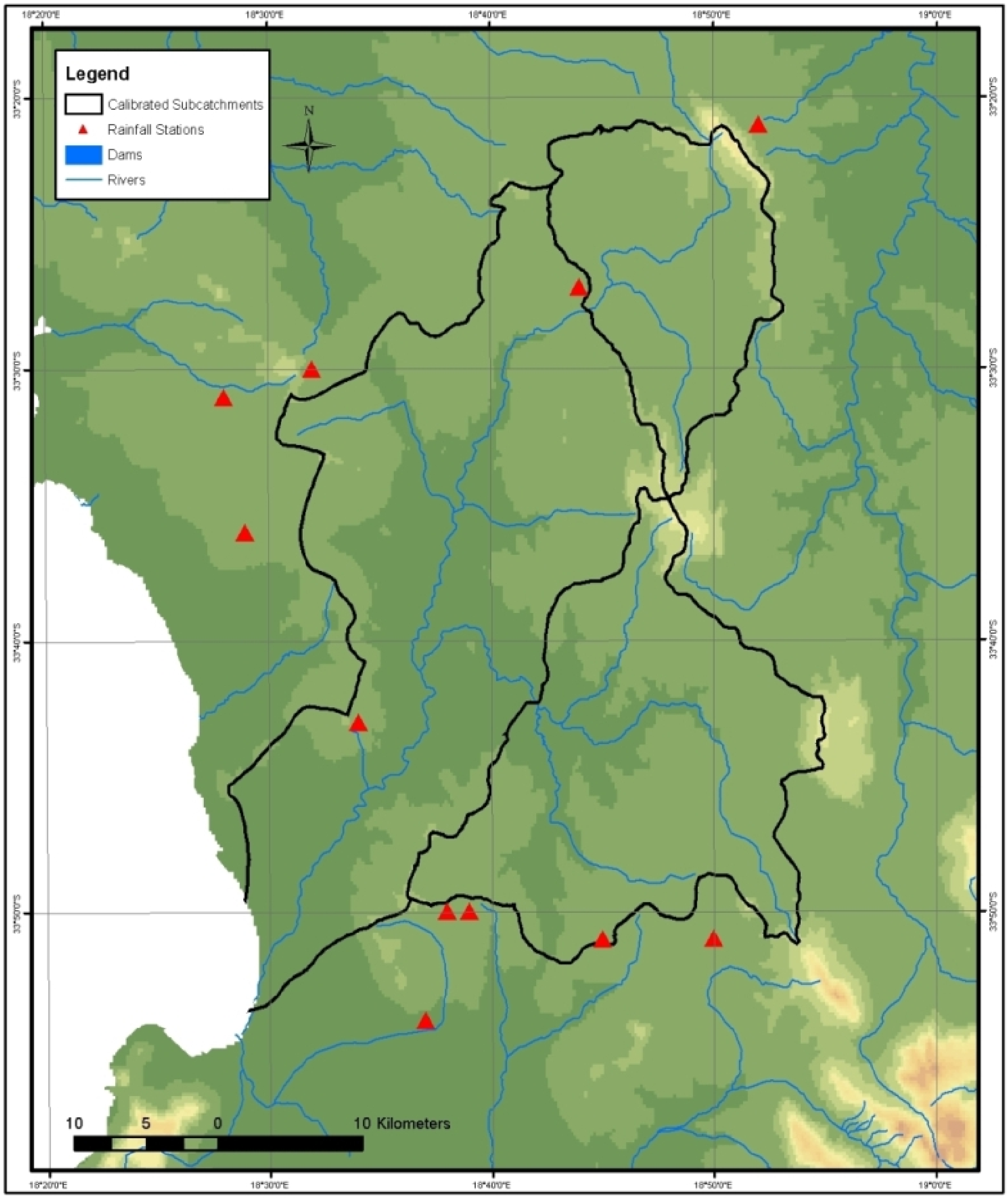


**Figure 5.3 Location of patched rainfall stations in the Diep River catchment**

## 5.5 PALMIET AND STEENBRAS

The stations with patched rainfall records in the Palmiet and Steenbras catchments are shown in Figure 5.4. There are 20 patched stations in total; 12 of these stations were used in the previous WCSA study and 8 new stations have been added in the current study.

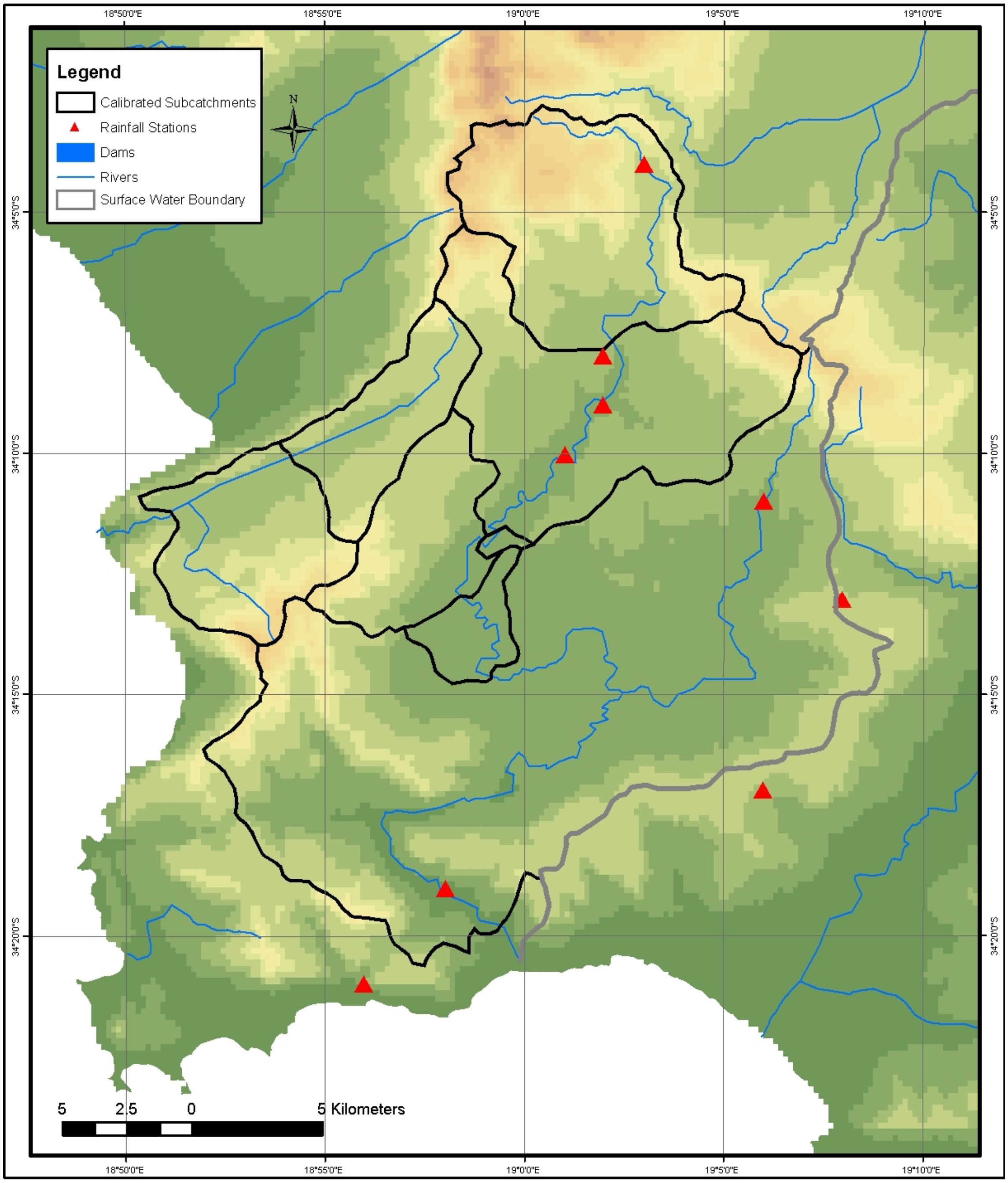


**Figure 5.4 Location of patched rainfall stations in the Palmiet and Steenbras catchments**

## 5.6 BREEDE AND RIVIERSONDEREND

The stations with patched rainfall records in the Breede and Riviersonderend catchments are shown in Figure 5.5. There are 26 patched stations in total; 9 in the Breede and 15 in the Riviersonderend. Nineteen of these stations were used in the previous WCSA study and 7 new stations have been added in the current study.

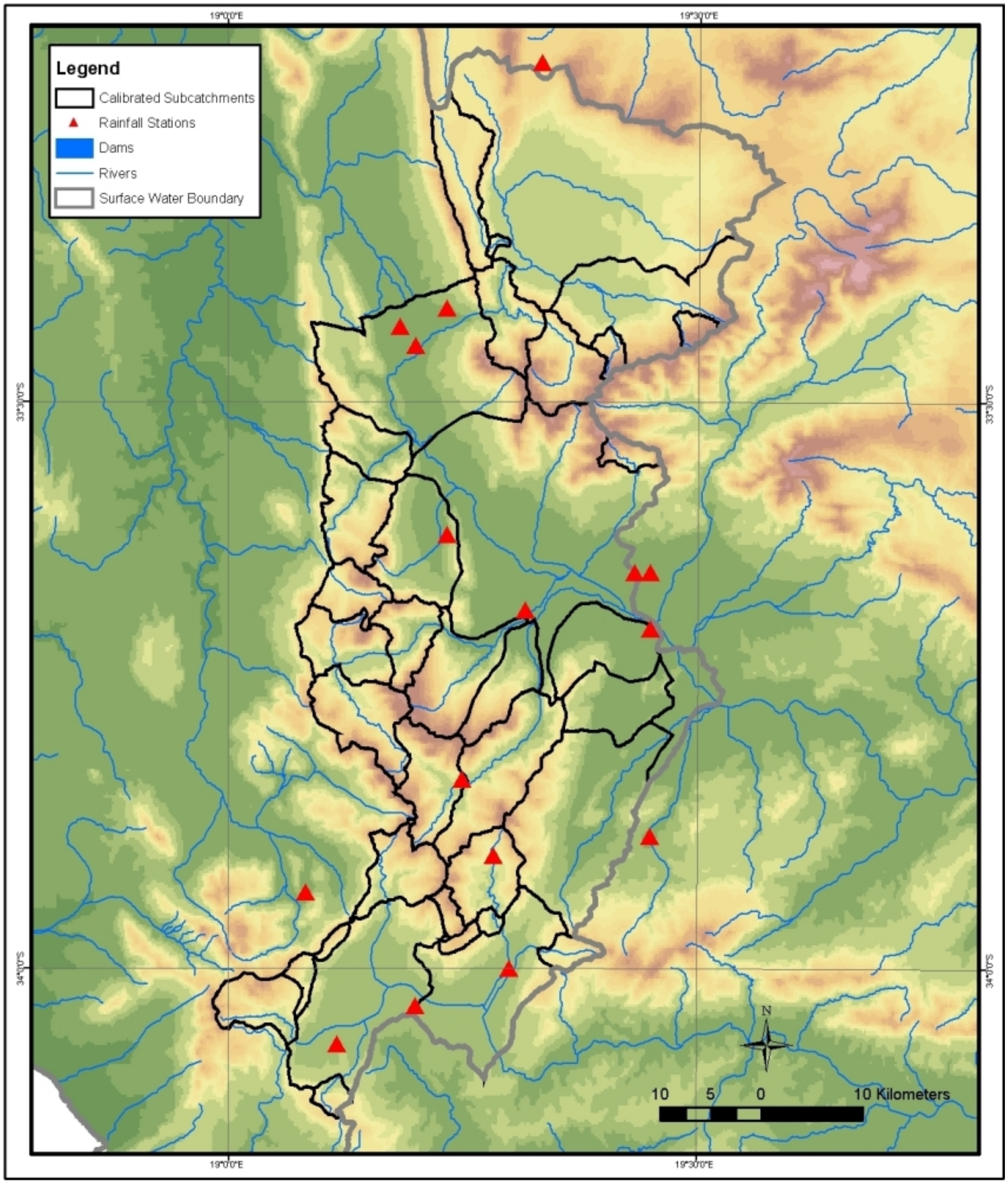


**Figure 5.5 Location of patched rainfall stations in the Breede and Riviersonderend catchments**

# 6. DEVELOPMENT OF AN UPDATED MEAN ANNUAL RAINFALL MAP FOR THE SOUTH-WESTERN CAPE

## 6.1 INTRODUCTION

Reliable and realistic estimates of long term mean annual rainfall are important inputs to distributed hydrological and geohydrological modelling, determination of water requirements and other aspects of surface and groundwater assessments. This information has in the past been obtained from the 1:250 000 rainfall map series of South Africa that was published in 1965 by the Department of Water Affairs and Forestry. In 1989 the Computing Centre for Water Research (CCWR) produced a new mean annual rainfall (MAP – mean annual precipitation) map as part of a Water Research Commission project (Dent *et al*, 1989). The map was produced by developing regression models to relate continuous physiographic data to point (station) measurements of MAP, and using these models to automate production of MAP isohyets for South Africa, Lesotho and Swaziland. The map was produced as a series of transparent 1:250 000 map overlays, and electronically as a 1 minute x 1 minute grid of mean annual rainfall values. The map was included in the *South African Atlas of Agrohydrology and -Climatology* (Schulze, 1997), and an updated version of the map was released in 2003.

To automate the generation of the 1 minute x 1 minute rainfall surface, Southern Africa was divided into 34 rectangular areas. An iterative procedure was used to develop regression equations for each of these areas and to “edge-match” the surface along the boundaries of these areas. Two rectangular areas (Areas 1 and 9) and two sets of regression equations were used to develop the rainfall surface in the South-western Cape, in an area that includes the catchments of the Berg River, the Breede River, the Cape Town Basin, and the Overberg coastal catchments. The rainfall surface in this region has been used to provide estimates of MAP for hydrological modelling of the catchments of the Breede River (BRHS and BRBS), and the Berg, Palmiet, Eerste, Lourens Rivers (WCSA). During these studies, it became apparent that the rainfall surface contains a number of anomalies which include under-estimates of MAP in most of the mountain catchments, and inadequate representation of the variability of MAP over the complex topography of the Boland and Overberg regions.

The anomalies in the Western Cape portion of the 1 minute x 1 minute rainfall surface were considered to be serious enough to warrant the re-generation of a more realistic surface for use in the WAAS hydrology. Based on a review of the methods and rainfall station data that were used to generate the 1 minute x 1 minute surface, the anomalies were attributed to a range of factors, including:

- A lack of rainfall stations with long records in mountain catchments,
- The relatively coarse resolution of the 1 minute by 1 minute altitude grid (about 1.6 km square in the Western Cape);
- Inaccurate rainfall station coordinates. Until recently, the rainfall station coordinates in the Western Cape were recorded to the nearest minute. This means that the recorded position could be up to 800 m removed from the actual position of the station. Due to the steep topography in the Western Cape Mountains, a horizontal shift of this order could be associated with a change in altitude of hundreds of meters;
- It is not clear whether the barrier effect of the Western Cape fold mountains was adequately represented in the regression equations that were developed for the region. It was felt that the

re-definition and inclusion of this variable may improve modelling of rain shadows in the lee of these mountain ranges.

The intention was to address these issues by utilising more accurate rainfall station position information, a high resolution terrain model, incorporation of additional stations in certain mountain catchments, introduction of barrier distance as an independent variable to derive a new rainfall surface.

## 6.2 GENERAL APPROACH

The approach that was followed to develop the updated rainfall surface is similar to the one used by Dent *et al* to generate the original 1 minute x 1 minute surface, i.e. development of a regression model that relates MAP to one or more physiographic variables, followed by interpolation of residuals, and combination of the two surfaces to form a composite mean annual rainfall surface. A detailed discussion and motivation for the use of regression techniques to relate MAP to physiographic variables, rather than the use of simpler, direct interpolation methods, can be found in Dent et al. The current approach differed from the CCWR approach in two main aspects, namely:

- The 1 minute x 1 minute surface is comprised of about 34 rectangular regions. Separate regression models were developed for each of these regions. (The area covered by the current revision falls within two regions.) Discontinuities at regional boundaries were then smoothed out by iterative adjustment of regression expressions on either side of the boundaries, and shifting of some boundaries to avoid areas with highly variable topography. For the current assignment, an attempt was made to improve on this approach by delineating three irregularly shaped climatically homogenous regions in the South-western Cape, and developing separate regression models for each of these areas. However, when compared to an approach where one model was developed for the South-western Cape, the multi-model approach did not result in an overall improvement in goodness-of-fit and caused unacceptably large discontinuities along regional boundaries. A single regression model was therefore adopted for the South-western Cape.
- The residual component of the 1 minute x 1 minute surface was derived by direct interpolation of residuals at station points. For the current assignment, a semi-variogram model was developed and used to weigh the influence of residual values at surrounding stations on estimates of residuals at interpolated grid points. This approach allows for the statistical modelling of "unexplained" local spatial autocorrelation that remain after the regression.

The physiographic variables that were considered for inclusion into the regression equations were altitude, aspect, rain-bearing wind direction, exposure, roughness and continentality. The variables are discussed in more detail in Section 6.4.

## 6.3 SELECTION OF RAINFALL STATIONS

The selection of rainfall stations for use in the surface model had to be done with care, as the inclusion (or rejection) of a single station in an area where few other stations are present, could make a significant difference to the interpolated surface. The process that was followed to select a set of 321 stations for inclusion in the South-western Cape rainfall surface was as follows:

- A candidate set of stations was compiled by using data from the following databases:
  - Agricultural Research Council (ARC)
  - CSIR. This dataset provided rainfall records for 14 research stations in mountain catchments, and was considered to be particularly important for improving estimates of MAP at higher altitudes.

  - o South African Weather Service (SAWS) with accurate coordinates. At the time of this work, the SAWS were re-establishing precise coordinates of their stations by means of a GPS survey. Accurate coordinates were available for 115 SAWS stations in the South-western Cape.
  - o Water Resource Information Management System (WRIMS). The WRIMS database contains a combination of SAWS and ARC stations. Station coordinates are provided to the nearest minute.
- The quality of the rainfall records was evaluated and a subset of stationary, patched records was selected as candidates for use in the rainfall surface. (Refer to Section 3)
- Stations with record lengths of less than 20 years were removed from the candidate set.
- ARC and SAWS stations with inaccurate coordinates (nearest minute), were weeded by determining the maximum ground elevation difference in a 200m diameter circle around the recorded station position. Elevations were determined from the 90m x 90m SRTM DEM. Stations with elevation differences of more than 40m were discarded.
- Where one or more stations plotted within 400m of an accurately coordinated SAWS station, the former were discarded.
- The remaining set of ARC and SAWS stations with inaccurate coordinates contained numerous instances of two or more stations plotting on the same position. The station with the longest record was retained, and the "duplicates" were removed.

The distribution of the 321 selected stations is shown in Figure 6.1. The stations are listed in Appendix A.

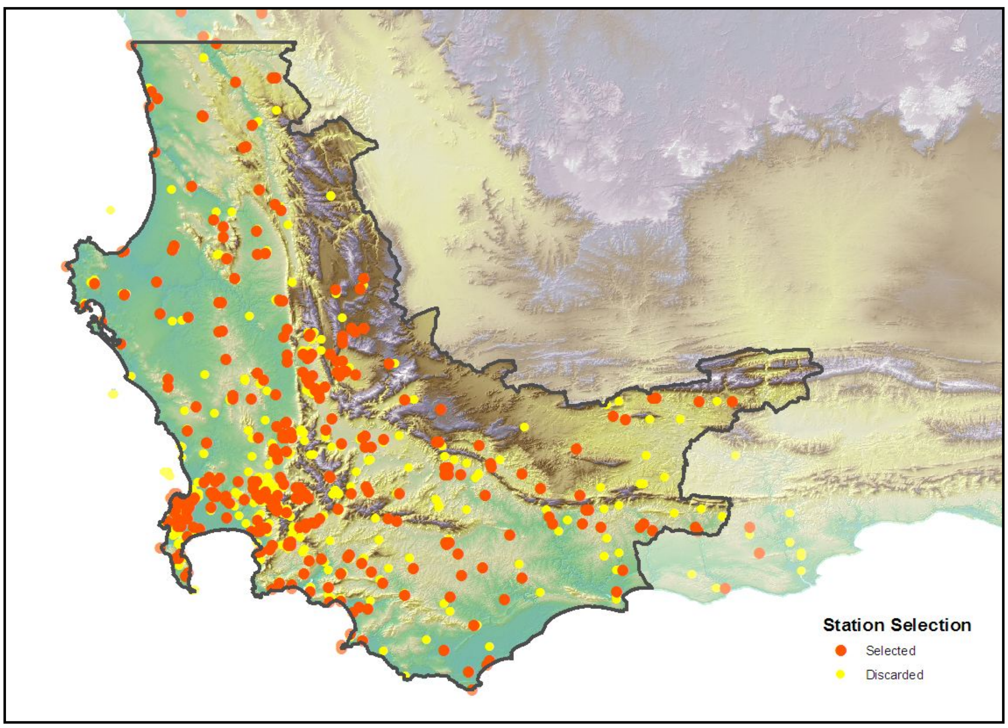


**Figure 6.1 Distribution of Selected Rainfall Stations**

## 6.4 PHYSIOGRAPHIC DATA SETS

### 6.4.1 Selection of Independent Variables

The physiographic variables that were considered for inclusion into the regression equations were altitude, aspect, rain-bearing wind direction, exposure, roughness and continentality. These are the same variables that were considered for the development of the earlier CCWR and Agro-Hydrology Atlas MAP surfaces. It was felt that this collection of variables was diverse enough to describe most of the major factors that influence rainfall distribution in the Western Cape. It was also decided to avoid non-linear transformation of these variables to keep the ratio of independent variables to data points as low as possible, and also to avoid unstable predictions in areas with sparse distributions of rainfall stations.

### 6.4.2 Altitude

The NASA Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) was used to provide altitude data and to derive most of the secondary physiographic variables that were required for the rainfall surface modelling (see Figure 6.2). The SRTM data is available for over 80% of the globe, and have a resolution of 90m at the equator, and about 100m in the South-western Cape.

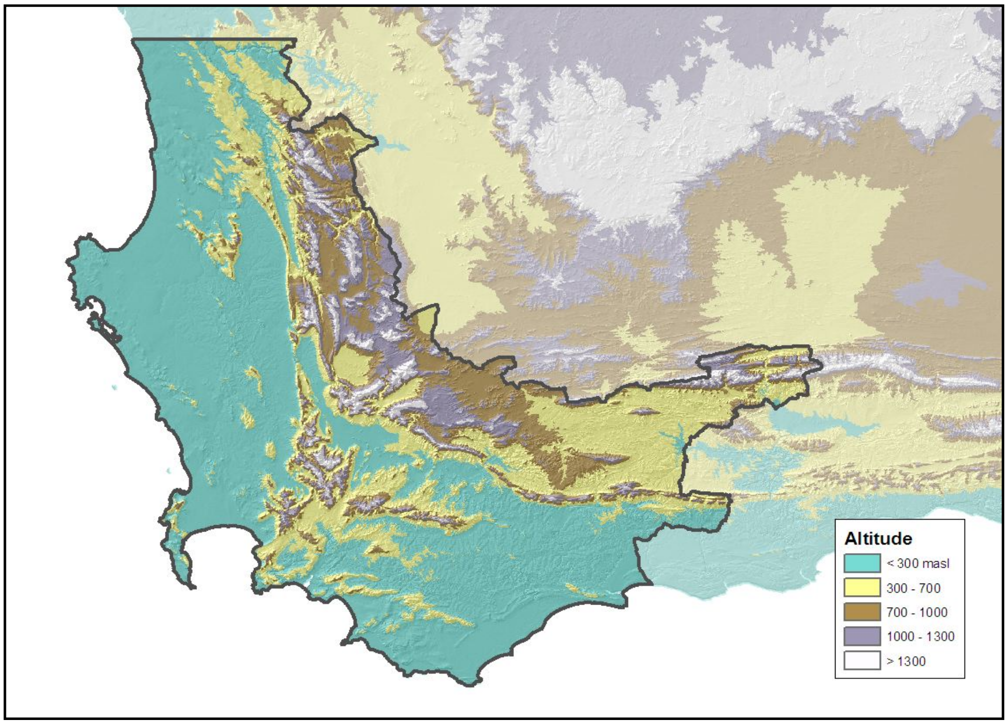


**Figure 6.2 Altitude**

### 6.4.3 Continentality

In the South-western Cape, mean annual rainfall tends to be higher in the coastal areas than further inland. This effect is most notable within about 300 km of the coast, and has been documented by Whitmore (1989) and others. Continentality (distance from the coast) was derived by calculating the euclidean distance (in km) of the centre-points of a grid of 100m x 100m cells from the coastline. The resultant dataset is shown in Figure 6.3.

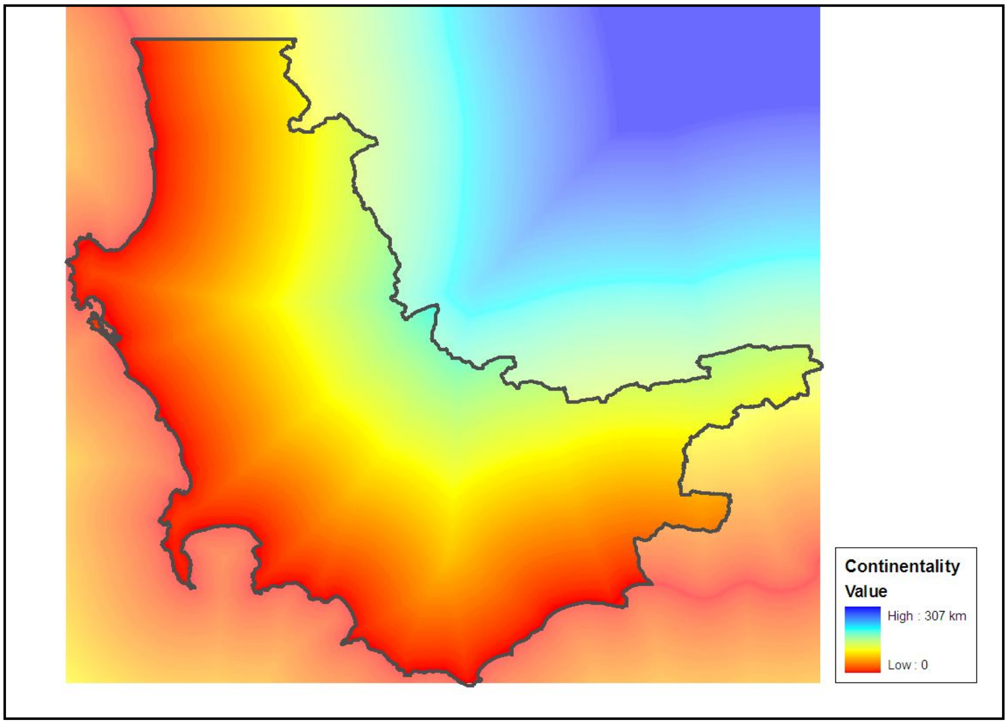


**Figure 6.3 Continentality**

### 6.4.4 Roughness

Roughness of terrain causes updraughts and turbulence which may affect rainfall (Dent, 1989). A roughness index was derived by calculating the standard deviation of altitudes in a 1km x 1km mask, i.e. by evaluating 100 grid cell values at a time. The roughness index values are shown in Figure 6.4.

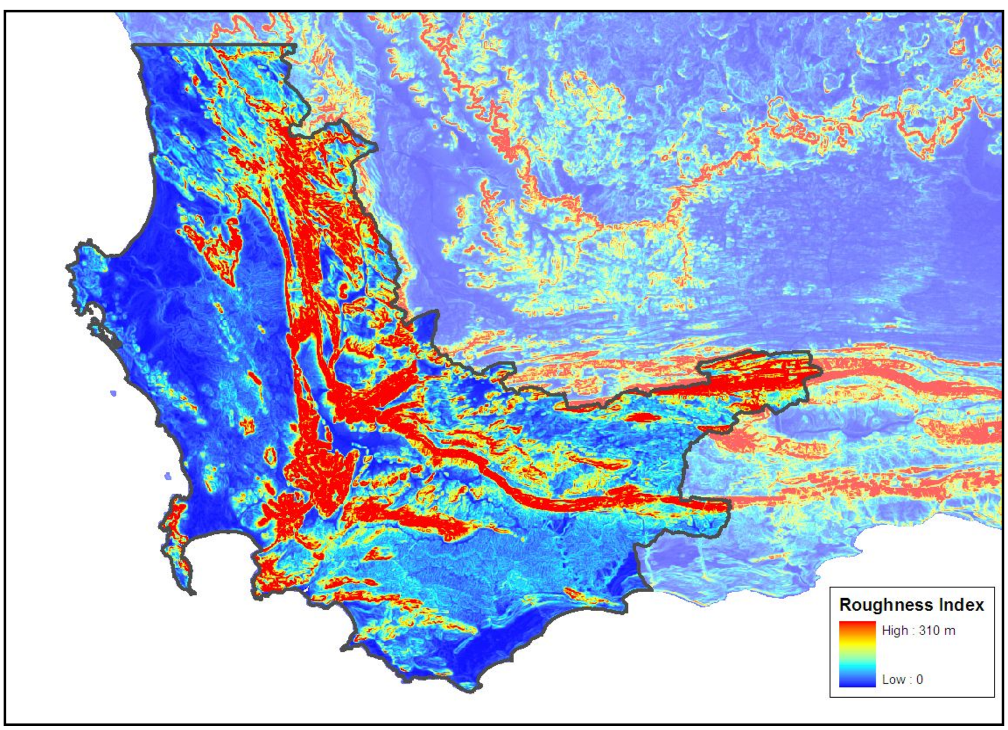


**Figure 6.4 Roughness Index**

### 6.4.5 Aspect and Rain-bearing Wind Index

Winter rainfall in the South-western Cape typically occurs in the form of a procession of cold fronts that sweep over the region from the west. Rainbearing wind directions vary from north to west to south, peaking in a north-westerly direction. An attempt was made to account for this effect by introducing a rain-bearing wind index to the regression model. The index was based on a weighted classification of aspect. Aspect is defined as slope direction, or the compass direction a hill faces. It can be calculated from a DEM by identifying the steepest downslope direction from each cell to its neighbours. The index dataset was developed as follows:

- The 100m resolution DEM was used to calculate aspects.
- The aspect grid was smoothed by calculating the mean of a 1km x 1km neighbourhood;
- The smoothed aspect grid was reclassified by assigning rain-bearing index values to 8 aspect sectors as shown in Table 6.1 and on Figure 6.5.

**Table 6.1 Rain-bearing Wind Index**

| Aspect | Index |
|---|---|
| NNW – NNE | 5 |
| NNE – ENE | 1 |
| ENE – ESE | 0 |
| ESE – SSE | 1 |
| SSE – SSW | 5 |
| SSW – WSW | 5 |
| WSW – WNW | 7 |
| WNW – NNW | 10 |

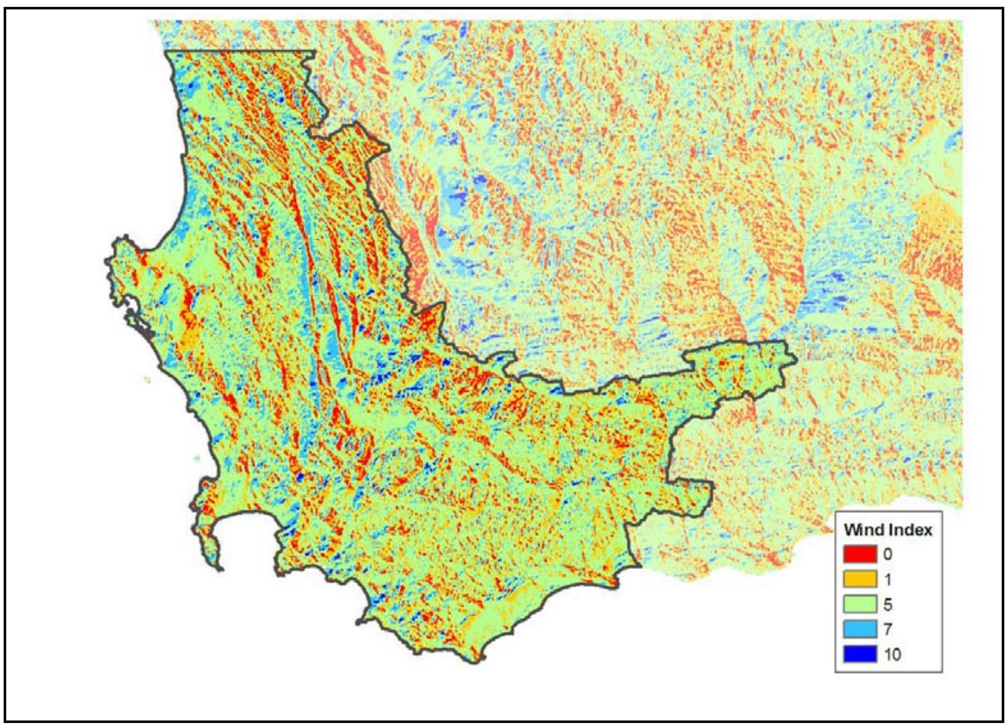


**Figure 6.5 Rain-bearing Wind Index**

### 6.4.6 Exposure

Terrain that is exposed above the surrounding countryside tends to receive more rainfall than less exposed areas (Hutchinson 1968, Hughes 1982). An exposure index was derived by calculating a "normalised" elevation as follows:

Exposure Index = (Point elevation - average neighbourhood elevations) / (standard deviation of neighbourhood elevations)

A 10km x 10km neighbourhood was used to determine the exposure index. The exposure index values are shown in Figure 6.6.

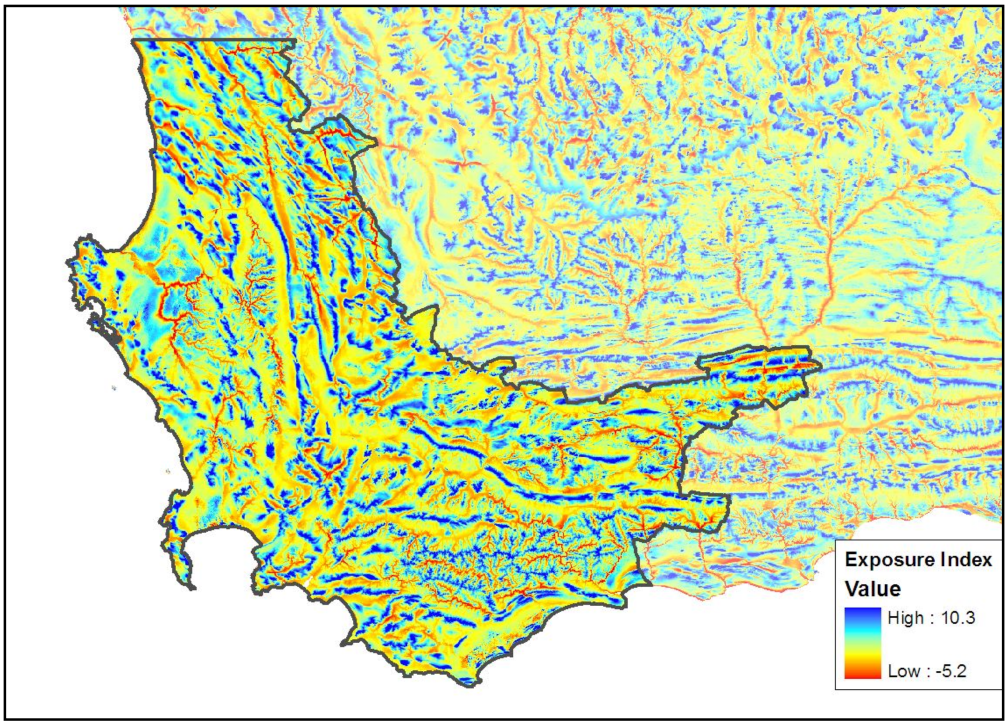


**Figure 6.6 Exposure Index**

### 6.4.7 Distance from Barrier Features

The Cederberg, Koue Bokkeveld, Du Toitskloof and Langeberg mountain ranges are arranged in an arc about 60 to 80 kilometres inland from the coast. These mountains, and the Drakenstein and Peninsula mountain ranges in the south-west form barriers that cause uplift and precipitation. This effect was introduced to the modelling by digitising the spines of the mountain ranges, and calculating euclidean distances (in km) of the centre-points of a grid of 100m x 100m cells from the barrier features. The spatial effect is illustrated on Figure 6.7.

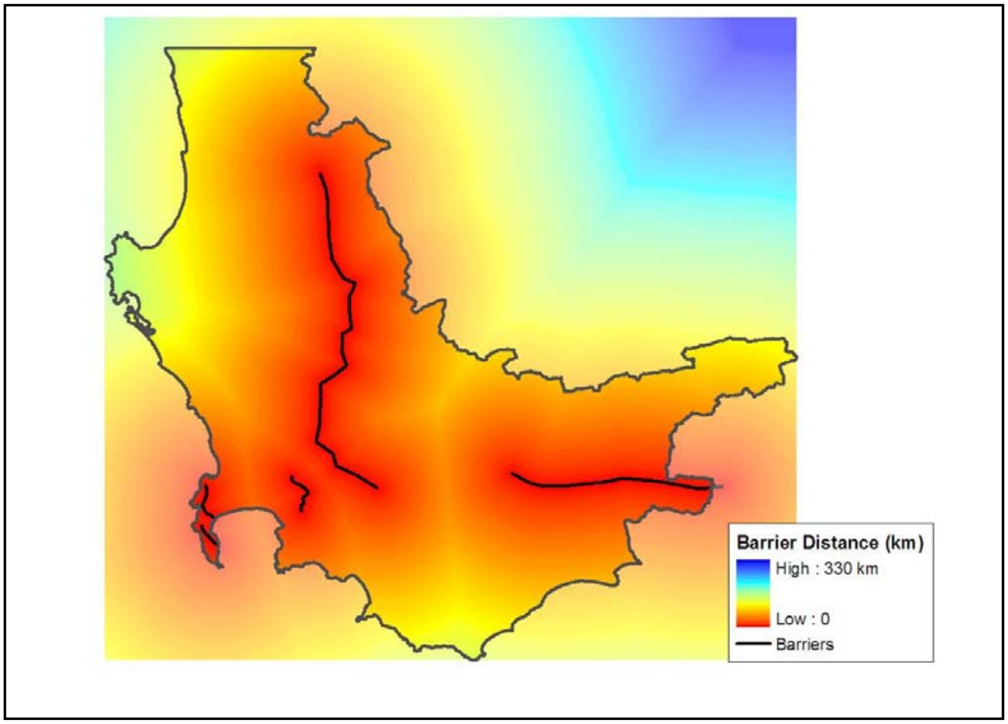


**Figure 6.7 Barrier Distance**

## 6.5 REGRESSION ANALYSIS

The set of candidate physiographic variables and the measured point MAP values were used to develop a regression surface that explains a portion of the variability of rainfall in the region.

Values of the physiographic (independent) variables were determined at each of the rainfall station locations by superimposing the station points on the physiographic variable rasters, and transferring the raster cell values to the rainfall station point shapefile (Appendix A). To minimise bias in the final composite surface, two randomly selected subsets of rainfall stations were used to develop the regression surface and the residual surface. It was not possible to divide the rainfall stations into two completely separate subsets, as it would not have been possible to maintain adequate sample sizes. As a compromise, the stations were divided into three equally sized, randomly selected subsets A, B and C. Subsets A and B (215 stations in total) were used to develop the regression surface, while B and C were used to develop the residual surface. One of the consequences of this decision was that the final composite surface would not be "shrink-fitted" to the complete set of measured MAPs. Forward stepwise regression was used to select independent variables and to construct the deterministic model. A maximum p-value1 of 0.01 was used to determine entry of an independent variable into the regression equation. This threshold resulted in the selection of roughness, continentality, altitude and barrier distance as predictors of MAP and an R2 value of 0.41, indicating that the regression equation explained about 41% of the spatial variance ("drift") of MAP. By relaxing the p-value threshold to 0.02, it was possible to include the exposure index (but not the rain-bearing wind index) into the regression equation, but the marginal improvement of the R2 value to 0.42 indicated that this was not warranted. The final selection of independent variables and estimates of the regression coefficients are shown in Table 6.2. The final selection of four independent variables is

[1] The p-value provides an indication of the statistical significance of an independent variable's predictive capability.

well within the guideline that states that in order to avoid an unstable regression; one should have at least 10 to 20 times as many observations as there are variables. Descriptive statistics for all of the steps in the forward stepwise selection procedure are shown in Appendix B.

**Table 6.2 Regression Coefficients**

| Source | Coefficient | Std Error | Std Beta | -95% C.I. | +95% C.I. | T | P-value |
|---|---|---|---|---|---|---|---|
| Intercept | 710.037 | 41.919 | | 627.401 | 792.673 | 16.938 | 0.000 |
| Roughness | 3.363 | 1.035 | 0.200 | 1.322 | 5.404 | 3.248 | 0.001 |
| Continentality | -3.786 | 0.720 | -0.377 | -5.205 | -2.366 | -5.256 | 0.000 |
| Altitude | 0.286 | 0.104 | 0.208 | 0.082 | 0.490 | 2.759 | 0.006 |
| Barrier Dist. | -5.271 | 0.675 | -0.440 | -6.602 | -3.940 | -7.807 | 0.000 |

## 6.6 THE RESIDUAL SURFACE

The regression equation was used to calculate predicted values of MAPs at each of the station points. Residuals were then calculated by subtracting predicted values from measured MAPs. The distribution of residuals (plotted on a normal probability scale) is shown in Figure 6.8. As can be expected, the distribution of the residuals indicates that there is still a fair amount of unexplained drift in the residuals. At the high end of the plot, there are four stations that at first glance appear to be outliers. An inspection of these stations showed that one of the stations is located in Newlands, one in the Jonkershoek valley, and two in the catchment upstream of the new Berg River Dam. As all of these stations have long record periods (>45 years), are considered to be of good quality, and are located in very high rainfall areas, it was decided not to exclude these stations, and to let their residual values influence the surface in these areas.

To account for some of the remaining drift in the residuals, it was decided to construct the residual surface with a kriging method, rather than with a non-statistical interpolation method. Ordinary kriging can be used to model spatial trends, and also takes the effect of spatial auto-correlation into account. The method would for example tend to group correlated residuals on the same side of a physiographic barrier for use in interpolation, rather than interpolating between uncorrelated residuals that are located on both sides of such a barrier. The effect of decreasing autocorrelation with increasing distance is simulated by means of a semi-variogram model. The semi-variogram model that was fitted to the residuals of subsets B and C is shown in Figure 6.9. The model has a sill value2 of about 170 km.

[2] The sill value is the distance ("range") at which the semi-variogram levels off. Pairs of observations that are further apart than the range, are not spatially auto-correlated.

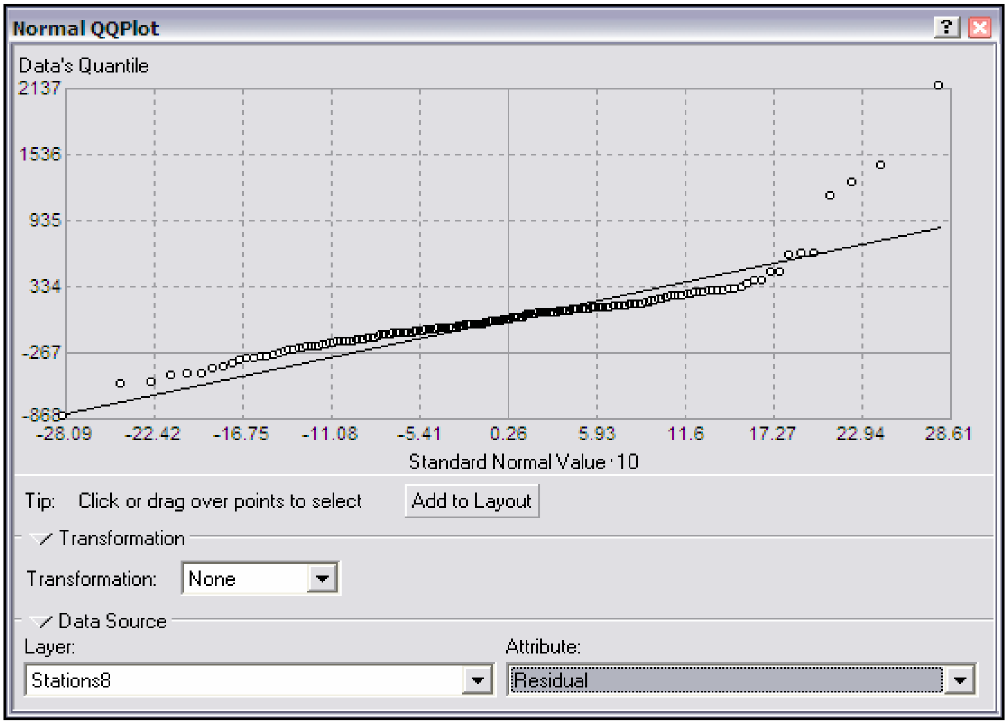


**Figure 6.8 Distribution of Residual Values**

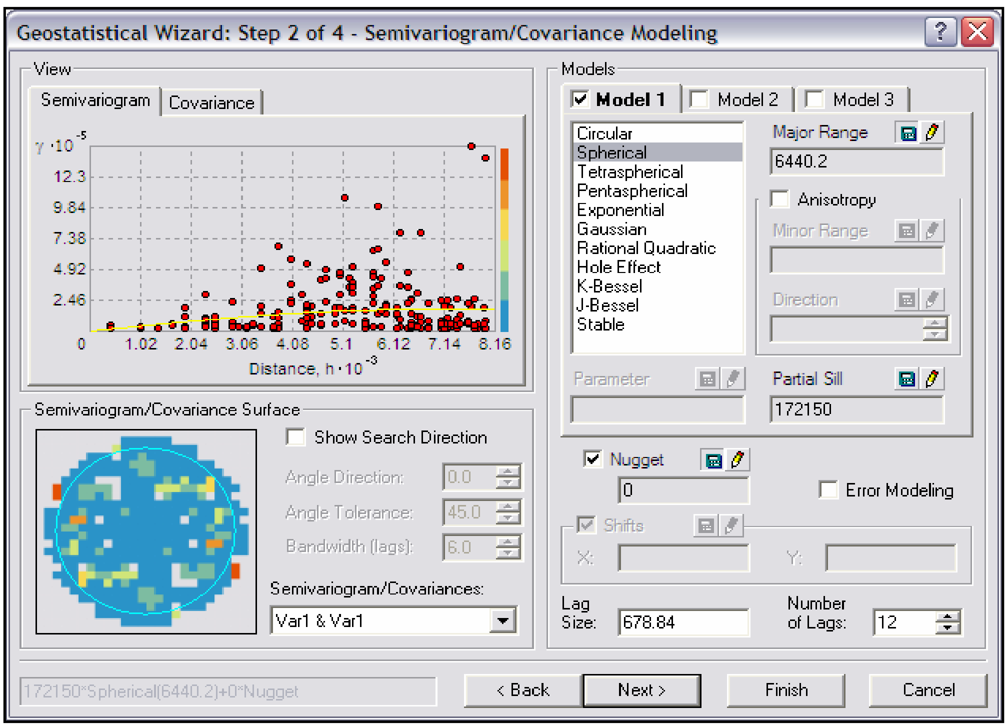


**Figure 6.9 Semi-variogram Fitted to Residuals**

Residual values are interpolated between groups of station points, without the smoothing effect of a spatially continuous variable. The resultant surface is therefore composed of angular planes, as shown in Figure 6.10, and can introduce discontinuities into the final composite surface. This effect was reduced by passing a 5km x 5km smoothing filter over the residual surface. The smoothing effect is illustrated in Figure 6.10.

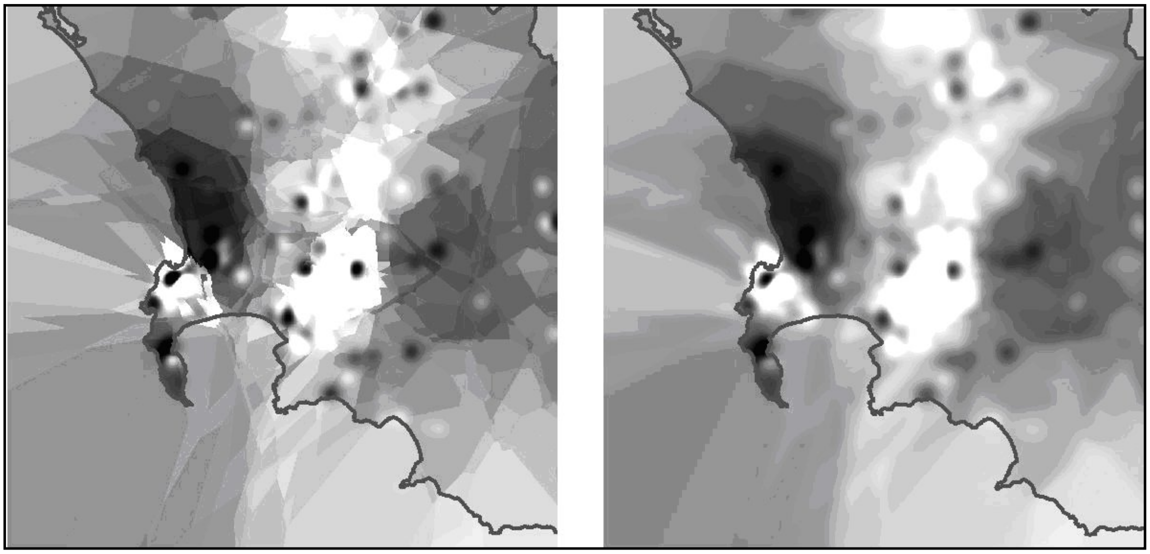

**Figure 6.10 Unsmoothed (left) and Smoothed (right) Residual Surfaces**

## 6.7 THE COMPOSITE SURFACE

The interpolated regression and residual surfaces were added together (summed) to produce a composite surface. Predicted MAPs over a very small part (0.7%) of the modeled area were less than 60 mm per year and negative in some instances. These values were set equal to 60 mm. The maximum predicted value was 3 238 mm in the Jonkershoek valley, which is of the same order as the maximum measured MAP of 3 348 mm at a research station in the same valley. The characteristics of the revised surface and a comparison of the revised surface and the Atlas surface are presented in Section 6.8.

## 6.8 DISCUSSION AND CONCLUSIONS

The new composite rainfall surface and the 2003 Agro-Hydrology Atlas are shown side-by-side in Figure 6.11 so that a visual comparison can be made.

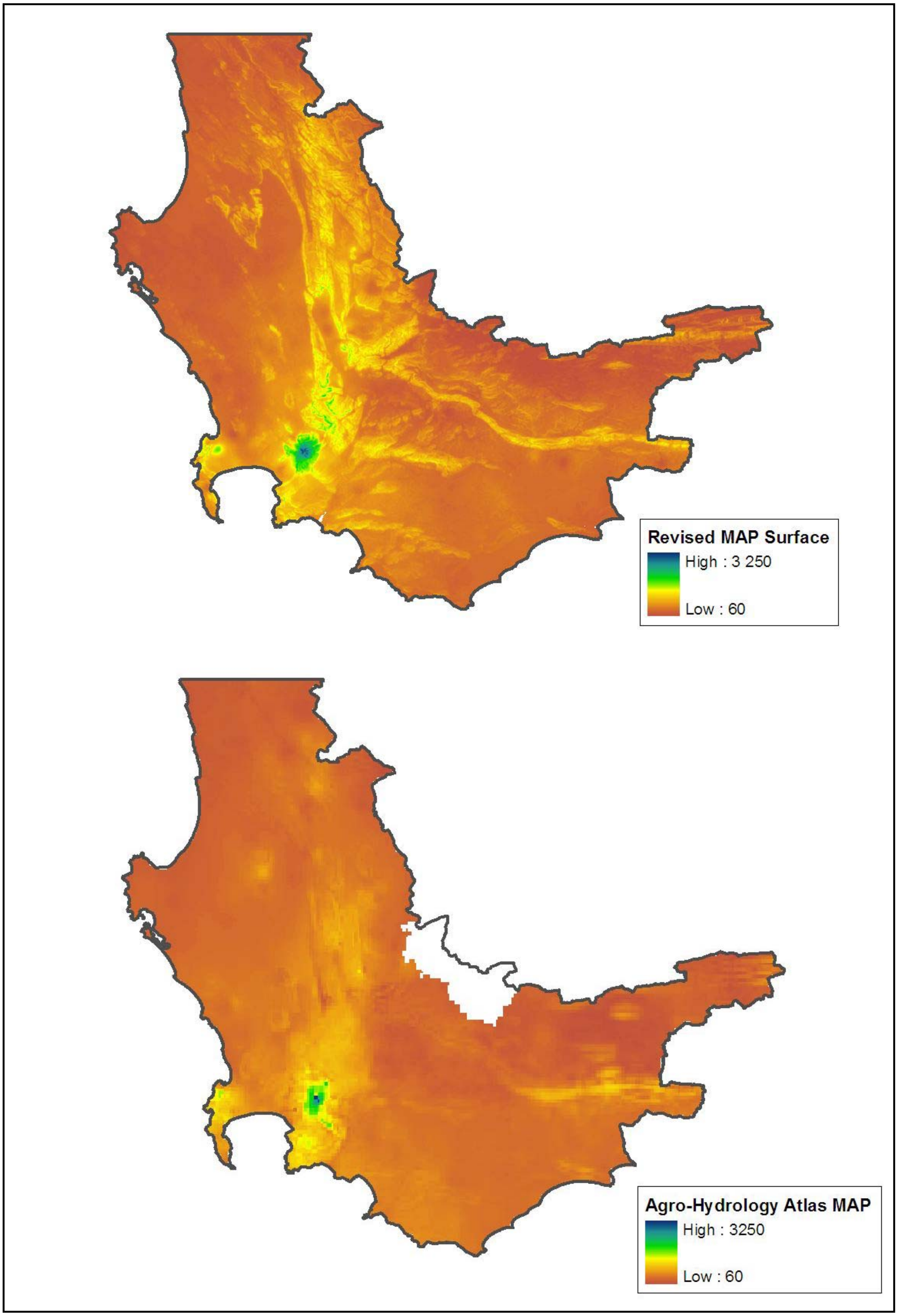


**Figure 6.11 Comparison of the Revised MAP Surface (Top) and the Atlas Surface (Bottom)**

Figure 6.12 shows the arithmetic difference (Revised minus Atlas) between the two surfaces. It can be seen that the revised surface consistently predicts higher MAPs in the higher lying areas, and predicts lower values in the West Coast, Overberg and Little Karoo areas.

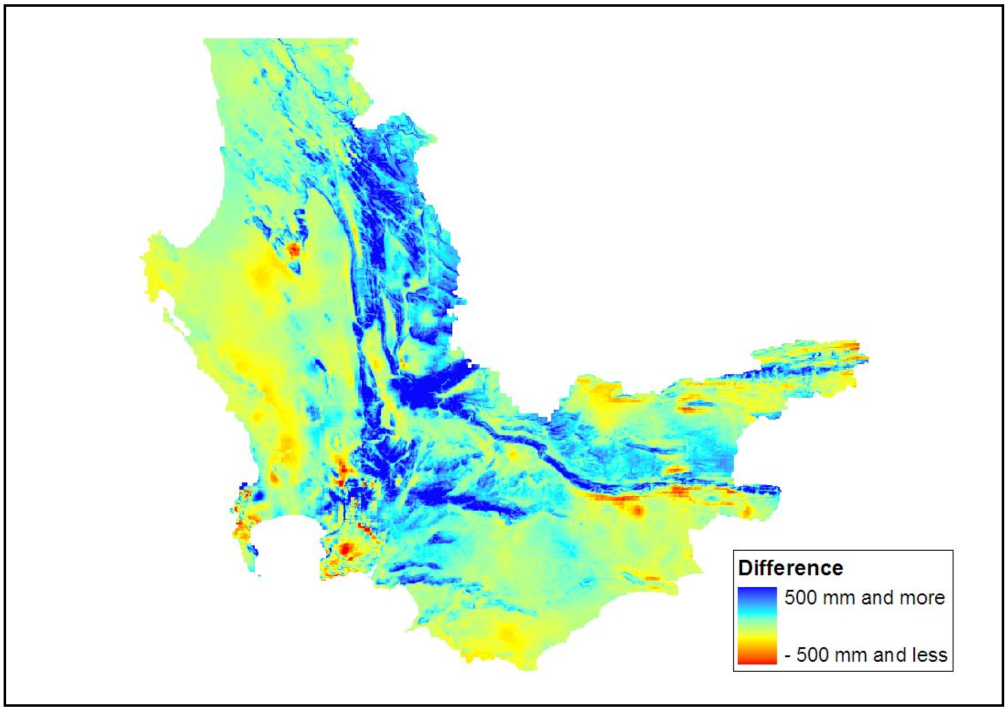


**Figure 6.12 Difference (mm) Between the Revised MAP Surface and the Atlas Surface**

The revised rainfall surface was used to determine predicted values at each of the 321 stations (subsets A,B and C). These values were subtracted from the measured MAP values to determine prediction errors as a percentage of measured values. The comparison indicated that 75% of the predictions differ by less than 20% from the measured MAP values, and 65% of the predictions differ by less than 10%. The distribution of these errors is shown in Figure 6.13.

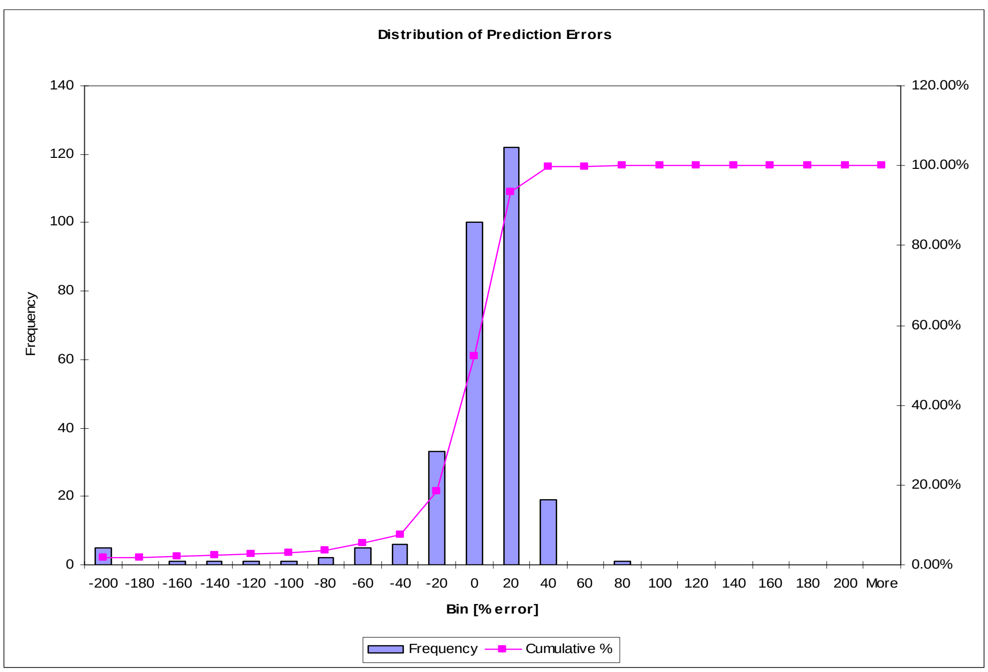


**Figure 6.13 Distribution of Prediction Errors**

# 7. WAY FORWARD

The rainfall data analysis undertaken for the Berg WAAS has provided rainfall sequences that will be used to generate catchment rainfall files for the purposes of hydrological modelling. The methodology for this process will be included in the catchment modelling reports.

# APPENDIX A : RAINFALL STATIONS

| Station | Length (Years) | Number | MAP | Wind Index | Rough-ness | Continen-tality | Altitude | Expo-sure | Barrier Distance | Subset |
|---|---|---|---|---|---|---|---|---|---|---|
| Aan de Doorns, Worcester | 37 | 20043 | 251.0 | 7 | 7.9 | 75.9 | 220.0 | -0.15 | 28.95 | B |
| ALBERTINIA - POL | 81 | 0011132W | 438.1 | 5 | 11.6 | 17.6 | 183.0 | 0.15 | 25.87 | A |
| ALTYDGEDACHT | 82 | 0021230W | 571.0 | 5 | 13.5 | 15.0 | 183.0 | 0.14 | 23.69 | B |
| ATLANTIS | 86 | 0020846W | 133.0 | 5 | 3.1 | 8.3 | 121.0 | 0.18 | 39.32 | B |
| AVALON | 22 | 0042250W | 1101.0 | 5 | 62.2 | 86.0 | 529.0 | -0.77 | 9.46 | A |
| BELLVILLE | 32 | 0021234W | 118.4 | 5 | 9.6 | 13.8 | 76.0 | -0.13 | 18.83 | B |
| BELLVILLE - BOS | 49 | 0021235W | 466.8 | 5 | 2.6 | 17.1 | 61.0 | -0.27 | 21.06 | B |
| Bethlehem | 15 | 20091 | 1531.0 | 10 | 91.7 | 24.5 | 376.0 | -0.57 | 3.93 | A |
| BETTYS BAY | 52 | 0005771W | 1097.0 | 5 | 41.5 | 0.2 | 34.0 | -1.28 | 29.53 | A |
| BIEN DONNE (NIVV) | 50 | 0021860A | 811.5 | 5 | 5.1 | 33.1 | 141.0 | -0.59 | 11.14 | A |
| BIEN DONNE PP | 8 | 30006 | 783.0 | 1 | 2.6 | 32.2 | 119.0 | -0.78 | 10.24 | A |
| BIZWENI | 100 | 0005605A | 653.0 | 5 | 5.5 | 3.6 | 38.0 | -0.64 | 11.24 | A |
| BIZWENI | 29 | 0005635W | 336.7 | 5 | 9.8 | 4.7 | 46.0 | -0.74 | 9.63 | B |
| BLYDSKAP | 70 | 0007699W | 384.2 | 5 | 6.4 | 61.1 | 157.0 | -0.65 | 41.46 | A |
| BOKVELDSKLOOF | 71 | 0042582W | 685.0 | 5 | 13.9 | 99.3 | 1030.0 | -0.65 | 3.71 | A |
| BONFOI | 4 | 30081 | 811.0 | 5 | 24.3 | 15.9 | 171.0 | 0.14 | 13.30 | A |
| BONNIEVALE - SKL | 58 | 0024146W | 268.3 | 5 | 14.4 | 69.2 | 145.0 | -0.68 | 12.62 | A |
| BONTEBOKPARK | 44 | 0008813W | 526.7 | 5 | 16.7 | 43.4 | 110.0 | 0.24 | 9.10 | B |
| BONTEBOKSKLOOF | 47 | 0009214W | 49.4 | 5 | 18.4 | 41.0 | 213.0 | 0.08 | 10.04 | B |
| BOSKLOOF | 71 | 0007263W | 464.0 | 5 | 23.6 | 29.8 | 128.0 | -0.80 | 49.56 | A |
| BOTHASHALT | 33 | 0022471W | 826.5 | 5 | 47.8 | 49.7 | 543.0 | -1.24 | 6.36 | A |
| BREDASDORP ZOET. VALLEI | 73 | 0002885A | 468.8 | 5 | 3.4 | 4.9 | 12.0 | -0.17 | 92.41 | B |
| BULSHOEK - IRR | 91 | 0107510W | 170.4 | 5 | 42.7 | 46.6 | 90.0 | -1.34 | 57.78 | A |
| BURGHERSPOST | 48 | 0041060W | 559.4 | 0 | 35.5 | 17.8 | 183.0 | -0.05 | 51.91 | A |
| CALEDON - TNK | 24 | 0006734W | 483.0 | 1 | 15.1 | 22.8 | 236.0 | -0.46 | 28.60 | A |
| CAMPAMENTO | 34 | 0021326W | 562.7 | 7 | 3.9 | 15.6 | 69.0 | -0.29 | 22.30 | B |
| CAPE TOWN - CITY HOSPITA | 81 | 0020744W | 246.6 | 1 | 14.7 | 0.2 | 16.0 | -0.58 | 6.30 | A |
| CAPE TOWN - FIRE STATION | 88 | 0020776W | 558.3 | 1 | 33.3 | 2.6 | 53.0 | -0.50 | 3.68 | B |
| CAPE TOWN - GREEN POINT | 108 | 0020714W | 515.0 | 5 | 4.9 | 0.6 | 30.0 | -0.50 | 6.22 | A |
| CAPE TOWN - GROOTE SCHUU | 37 | 0020838FW | 1181.0 | 5 | 4.1 | 6.7 | 45.0 | -0.23 | 5.94 | A |
| CAPE TOWN - KLOOFSTREET | 118 | 0020746CW | 835.4 | 1 | 15.8 | 3.1 | 28.0 | -0.66 | 2.73 | B |
| CAPE TOWN - MAITLAND - C | 99 | 0021055W | 491.0 | 5 | 2.7 | 6.0 | 15.0 | -0.27 | 10.32 | A |
| CAPE TOWN - SEA POINT - | 114 | 0020685W | 299.2 | 10 | 15.5 | 0.1 | 23.0 | -0.65 | 4.65 | A |

| Station | Length (Years) | Number | MAP | Wind Index | Rough-ness | Continen-tality | Altitude | Expo-sure | Barrier Distance | Subset |
|---|---|---|---|---|---|---|---|---|---|---|
| CAPE TOWN SLANGKOP | 85 | 0004549W | 47.8 | 7 | 18.9 | 2.6 | 8.0 | -0.74 | 5.41 | A |
| CERES - MUN | 95 | 0042532AW | 575.0 | 5 | 2.8 | 89.6 | 456.0 | -0.73 | 5.51 | B |
| Chiltern Damwal, Vyeboom | 34 | 20079 | 867.0 | 5 | 8.9 | 29.6 | 309.0 | -0.48 | 13.20 | B |
| CITRUSDAL | 41 | 0063005W | 319.0 | 5 | 6.7 | 65.0 | 165.0 | -0.91 | 14.10 | A |
| Citrusdal Proefplaas | 32 | 20019 | 398.0 | 0 | 19.4 | 61.6 | 198.0 | -0.68 | 16.70 | A |
| CLANWILLIAM DAM | 21 | 0084642W | 252.7 | 5 | 29.6 | 49.6 | 152.0 | -0.48 | 35.43 | B |
| CLAREMONT - PARADISE EST | 71 | 0020839W | 1272.8 | 0 | 7.3 | 8.2 | 30.0 | -0.46 | 4.80 | A |
| D F MALANLUGHAWE | 85 | 0021178AW | 73.9 | 5 | 2.8 | 11.7 | 46.0 | 0.42 | 17.21 | A |
| DE DOORNS - POL | 103 | 0043329W | 181.2 | 10 | 11.3 | 104.3 | 465.0 | -0.86 | 39.55 | A |
| DE GRENDEL | 46 | 0021111W | 390.4 | 7 | 17.0 | 9.7 | 122.0 | 0.02 | 19.09 | B |
| DE KEUR | 47 | 0063538A | 624.1 | 5 | 8.7 | 101.8 | 942.0 | -0.59 | 0.20 | A |
| DE MOND - BOS | 33 | 0003192A | 411.3 | 5 | 3.6 | 0.9 | 5.0 | -0.78 | 83.92 | B |
| Deelville, Prince Alfred Ha | 24 | 20099 | 563.0 | 5 | 5.2 | 91.7 | 480.0 | -0.49 | 7.53 | A |
| DIE ERF | 10 | 0042700W | 265.6 | 1 | 19.1 | 106.5 | 990.0 | -0.56 | 10.27 | A |
| DIEPKLOOF | 56 | 0011065W | 463.2 | 5 | 17.4 | 29.8 | 225.0 | 1.15 | 12.12 | A |
| DOORNRIVIER | 93 | 0022803W | 226.0 | 0 | 20.2 | 57.9 | 347.0 | -0.86 | 8.39 | A |
| DOORNRIVIER | 73 | 0022803A | 245.9 | 7 | 4.3 | 60.5 | 283.0 | -1.03 | 10.27 | B |
| DUNGHYE PARK | 59 | 0007050W | 415.7 | 5 | 18.3 | 23.0 | 122.0 | -1.02 | 39.97 | A |
| DURBANVILLE - POL | 93 | 0021260W | 599.6 | 1 | 11.6 | 17.1 | 157.0 | 0.02 | 26.40 | A |
| DWARSRIVIER TNK | 22 | 0042358W | 578.0 | 7 | 8.7 | 75.3 | 265.0 | -0.60 | 4.96 | A |
| Eendekuil SAPD | 39 | 0062671W | 304.0 | 5 | 8.8 | 54.9 | 100.0 | -1.30 | 26.43 | B |
| EERSTERIVIER - BOS | 81 | 0021330W | 519.6 | 5 | 1.8 | 6.3 | 30.0 | -0.17 | 23.93 | A |
| ELANDSBAAI | 28 | 0083618W | 208.0 | 5 | 4.0 | 0.6 | 14.0 | -0.93 | 74.77 | B |
| ELANDSFONTEIN | 80 | 0084558W | 506.0 | 5 | 14.5 | 44.4 | 421.0 | -0.77 | 31.89 | A |
| Elgin Proefplaas | 33 | 20018 | 1039.0 | 1 | 19.3 | 16.7 | 305.0 | -0.81 | 7.37 | A |
| ELIM | 30 | 0083634W | 244.9 | 5 | 4.4 | 6.6 | 90.0 | 0.20 | 82.07 | B |
| FRANSCHHOEK | 32 | 0022205A | 854.6 | 7 | 7.9 | 34.3 | 272.0 | -0.93 | 8.09 | B |
| FRANSCHOEK | 32 | 0022174A | 854.7 | 5 | 7.6 | 34.3 | 230.0 | -0.88 | 8.47 | B |
| GENADENDAL - COL | 63 | 0007062W | 453.7 | 5 | 35.3 | 49.4 | 305.0 | -0.65 | 13.80 | A |
| GOUDA | 50 | 0042048W | 511.1 | 5 | 2.3 | 69.3 | 84.0 | -0.42 | 18.50 | B |
| GRAAFWATER | 81 | 0084159W | 215.0 | 5 | 3.0 | 26.3 | 174.0 | -0.59 | 57.69 | A |
| GRABOUW - BOS | 82 | 0006039A | 1082.9 | 5 | 8.8 | 16.5 | 276.0 | -0.81 | 8.81 | A |
| HEIDELBERG C/K - POL | 127 | 0009815W | 407.1 | 5 | 30.1 | 30.7 | 84.0 | -1.42 | 14.75 | A |

| Station | Length (Years) | Number | MAP | Wind Index | Rough-ness | Continen-tality | Altitude | Expo-sure | Barrier Distance | Subset |
|---|---|---|---|---|---|---|---|---|---|---|
| HELDERBERG NATURE RESERV | 13 | 0005634W | 773.7 | 5 | 20.2 | 5.9 | 150.0 | -0.20 | 9.60 | B |
| Heldervue | 49 | 20100 | 809.0 | 5 | 30.9 | 45.2 | 755.0 | 1.12 | 42.85 | A |
| HELDERVUE | 81 | 0062379AW | 157.5 | 5 | 30.9 | 45.2 | 755.0 | 1.12 | 42.75 | B |
| HERMANUS - MUN | 71 | 0006415W | 624.0 | 5 | 7.1 | 0.1 | 24.0 | -0.84 | 43.91 | B |
| HIGHLANDS - BOS | 55 | 0006167W | 928.1 | 1 | 38.2 | 7.2 | 366.0 | 0.75 | 24.53 | B |
| HILLCREST: AWS | 4 | 30611 | 345.0 | 5 | 41.7 | 12.1 | 313.0 | 1.80 | 22.83 | B |
| HLS Boland, Agter-Paarl | 37 | 20031 | 502.0 | 1 | 8.6 | 40.0 | 149.0 | -0.21 | 20.75 | A |
| Hooggeleë | 5 | 20032 | 380.0 | 5 | 14.2 | 39.9 | 351.0 | 1.90 | 40.09 | A |
| HOPEFIELD - POL | 99 | 0040604W | 318.0 | 7 | 9.2 | 24.3 | 40.0 | -0.83 | 81.22 | A |
| JONASKRAAL | 16 | 0007714A | 407.2 | 0 | 20.4 | 39.2 | 159.0 | 0.21 | 61.71 | B |
| JONKERSHOEK - 2D | 70 | 0021809W | 1471.0 | 1 | 30.3 | 18.0 | 314.0 | -1.31 | 2.98 | B |
| JONKERSHOEK - 3M | 55 | 0022004W | 878.3 | 5 | 12.3 | 55.2 | 209.0 | 0.13 | 7.50 | A |
| JONKERSHOEK - BOS | 81 | 0021778W | 1076.1 | 5 | 34.9 | 18.3 | 244.0 | -1.19 | 2.02 | B |
| JONKERSHOEK - BOS | 26 | 0021793W | 718.9 | 0 | 83.0 | 43.5 | 365.0 | 0.56 | 11.73 | B |
| KAAP AGULHAS - VRT | 105 | 0003020W | 362.6 | 1 | 4.9 | -10.0 | 8.0 | -0.95 | 100.68 | A |
| KERSEFONTEIN | 82 | 0061594W | 172.8 | 5 | 3.7 | 24.9 | 5.0 | -1.17 | 79.74 | B |
| KLAASVOOGDSRIVIER | 40 | 0023890W | 265.0 | 5 | 5.7 | 85.1 | 179.0 | -0.44 | 26.55 | A |
| KLAPMUTS | 61 | 0021621W | 744.6 | 5 | 9.6 | 26.7 | 169.0 | -0.72 | 10.41 | B |
| KLAWER - IRR | 35 | 0107197W | 158.0 | 5 | 11.8 | 34.5 | 42.0 | -0.82 | 86.49 | A |
| KLEINFONTEIN | 74 | 0008367W | 324.7 | 0 | 14.3 | 45.4 | 168.0 | -0.34 | 19.37 | B |
| KLEINMOND - POL | 45 | 0006051AW | 691.9 | 5 | 2.1 | 0.8 | 15.0 | -0.79 | 29.52 | A |
| KLIPDALE - SAR | 66 | 0007828W | 336.5 | 5 | 6.7 | 46.2 | 170.0 | -1.11 | 49.01 | A |
| KLIPHOEK | 27 | 0062248W | 317.7 | 5 | 10.0 | 32.3 | 65.0 | -1.00 | 48.30 | B |
| KLUITJIESKRAAL - BOS | 106 | 0042326W | 650.0 | 5 | 5.3 | 75.2 | 269.0 | -0.46 | 0.28 | A |
| KNOLVLEI - BOS | 38 | 0042264W | 507.5 | 0 | 19.7 | 74.0 | 215.0 | -0.82 | 4.10 | A |
| KOEKENAAP - IRR | 67 | 0106512W | 120.3 | 7 | 4.1 | 18.3 | 68.0 | 0.48 | 126.60 | B |
| KOGELFONTEIN | 33 | 0004702A | 585.8 | 5 | 35.4 | 3.3 | 163.0 | -0.18 | 0.78 | B |
| KOMPAGNIESDRIFT | 22 | 0006343W | 493.0 | 1 | 20.2 | 17.8 | 91.0 | -0.77 | 25.27 | B |
| KORINGBERG | 35 | 0041301W | 372.5 | 1 | 41.1 | 53.5 | 130.0 | -0.18 | 51.38 | B |
| KRAAIFONTEIN - BOS | 55 | 0021441W | 527.2 | 7 | 9.5 | 25.1 | 122.0 | -0.28 | 17.94 | A |
| KUILSRIVIER | 44 | 0021325W | 630.4 | 5 | 2.4 | 17.3 | 50.0 | -0.86 | 22.30 | A |
| LA PLAISANTE | 60 | 0042357A | 568.3 | 5 | 2.5 | 75.9 | 262.0 | -0.59 | 3.00 | A |
| LA PLAISANTE | 58 | 0042357W | 562.3 | 5 | 2.5 | 75.9 | 290.0 | -0.35 | 3.00 | B |

| Station | Length (Years) | Number | MAP | Wind Index | Rough-ness | Continen-tality | Altitude | Expo-sure | Barrier Distance | Subset |
|---|---|---|---|---|---|---|---|---|---|---|
| LAAIPLEK-POL | 27 | 0061286W | 210.0 | 5 | 2.4 | 1.6 | 7.0 | 0.09 | 95.31 | B |
| LADISMITH-BUFFELSVLEI | 85 | 0046059W | 195.0 | 1 | 4.1 | 97.4 | 381.0 | -0.79 | 52.02 | B |
| LAMBERTSBAAI - POL | 39 | 0083515W | 144.9 | 5 | 3.2 | 1.3 | 22.0 | -0.75 | 84.48 | A |
| Landau, Wellington | 34 | 20072 | 505.0 | 5 | 5.8 | 50.3 | 122.0 | 0.10 | 12.20 | A |
| LANGEBAAN - POL | 94 | 0040035W | 251.0 | 7 | 11.2 | 3.1 | 14.0 | -1.05 | 101.76 | A |
| LANGEBAANWEG | 104 | 0061298W | 172.0 | 5 | 2.1 | 13.4 | 31.0 | -0.88 | 96.72 | B |
| LANGGEWENS - AGR | 85 | 0041347W | 396.4 | 5 | 7.4 | 42.7 | 175.0 | -0.05 | 43.03 | A |
| Longdown | 22 | 20080 | 23.0 | 5 | 16.3 | 30.9 | 341.0 | 0.23 | 14.67 | A |
| LOURENSFORD | 37 | 0005694W | 930.6 | 5 | 8.1 | 8.2 | 122.0 | -0.79 | 6.60 | B |
| MALABAR FARM | 60 | 0042669W | 379.2 | 5 | 6.4 | 105.9 | 998.0 | -0.39 | 8.96 | A |
| Malmesbury | 5 | 20064 | 566.0 | 5 | 12.6 | 36.1 | 152.0 | -0.55 | 34.51 | B |
| MIDDELDEURVLEI | 36 | 0062768W | 301.0 | 5 | 4.9 | 62.2 | 168.0 | -0.08 | 23.17 | B |
| MIDDELVLEI - BOS | 27 | 0006232W | 595.9 | 7 | 5.5 | 3.0 | 30.0 | -0.54 | 34.26 | A |
| MIDDELVOETPAD | 35 | 0024101W | 169.3 | 5 | 30.0 | 93.7 | 366.0 | -0.74 | 28.73 | B |
| MIERKOM - BOS | 16 | 0006658W | 555.9 | 5 | 8.2 | 2.3 | 45.0 | -0.24 | 54.02 | A |
| MON DESIR | 38 | 0010036W | 399.5 | 5 | 8.5 | 29.0 | 145.0 | -0.38 | 16.22 | B |
| MONT PELLIER | 33 | 0042166W | 537.1 | 5 | 4.2 | 77.9 | 151.0 | -0.57 | 11.00 | B |
| MONTAGUE POLICE | 9 | 0024228A | 338.2 | 5 | 17.5 | 81.1 | 285.0 | -0.63 | 16.16 | B |
| MOORREESBURG - POL | 42 | 0041279W | 382.0 | 1 | 5.5 | 48.3 | 149.0 | -0.77 | 53.88 | A |
| MOORREESBURG KO-OP | 34 | 20066 | 408.0 | 7 | 11.6 | 49.9 | 158.0 | -0.77 | 52.48 | A |
| MOUTONSHOEK | 20 | 0062374W | 544.9 | 0 | 18.4 | 39.5 | 137.0 | -0.95 | 43.69 | B |
| MUIZENBERG - PAVILION | 31 | 0004816AW | 970.1 | 0 | 55.9 | 1.2 | 15.0 | -0.60 | 1.97 | B |
| NIVV PROEF | 102 | 0021655A | 723.1 | 5 | 32.3 | 20.0 | 197.0 | -0.26 | 5.31 | A |
| Nooitgedacht | 11 | 20128 | 881.0 | 7 | 54.0 | 7.7 | 343.0 | 0.69 | 11.86 | A |
| NOOITGEDACHT | 46 | 0006887W | 482.0 | 0 | 17.5 | 22.1 | 208.0 | -0.51 | 33.38 | A |
| NOOITGEDACHT | 20 | 0021593W | 495.8 | 5 | 11.5 | 22.7 | 145.0 | -0.84 | 9.39 | A |
| NOOITGEDACHT - CERES | 28 | 20052 | 777.0 | 5 | 15.8 | 98.4 | 1040.0 | -0.26 | 4.39 | A |
| ODESSA | 22 | 0042789W | 264.3 | 5 | 8.6 | 111.5 | 960.0 | -0.70 | 15.11 | B |
| ONVERWACHT | 70 | 0022069W | 755.3 | 5 | 16.5 | 53.9 | 230.0 | -0.54 | 4.12 | B |
| ONVERWACHT | 61 | 0022099W | 702.3 | 5 | 16.5 | 53.9 | 262.0 | -0.43 | 4.12 | B |
| Oude Hemel en Aarde | 13 | 20090 | 719.0 | 5 | 27.0 | 6.8 | 243.0 | -0.48 | 37.59 | B |
| OUDEBOS - BOS | 31 | 0005829W | 1197.0 | 5 | 34.6 | 2.5 | 60.0 | -1.15 | 26.10 | A |
| OUDEMUUR | 26 | 0107867W | 162.6 | 7 | 3.6 | 67.2 | 192.0 | -1.34 | 51.34 | B |

| Station | Length (Years) | Number | MAP | Wind Index | Rough-ness | Continen-tality | Altitude | Expo-sure | Barrier Distance | Subset |
|---|---|---|---|---|---|---|---|---|---|---|
| Paardekloof, Witzenbergvall | 21 | 20152 | 986.0 | 7 | 30.5 | 90.4 | 895.0 | 0.04 | 2.90 | B |
| PAARL - AGR | 60 | 0021825W | 914.5 | 1 | 7.2 | 40.6 | 145.0 | -0.58 | 9.60 | A |
| PHILADELPHIA POLISIE | 70 | 0021130A | 362.0 | 0 | 8.4 | 13.9 | 70.0 | -0.61 | 36.05 | B |
| Piketberg SAPD | 124 | 0062444W | 472.0 | 0 | 22.8 | 53.0 | 230.0 | -0.11 | 40.44 | B |
| PLAATJESKRAAL | 72 | 0008470W | 397.2 | 5 | 18.5 | 23.5 | 168.0 | -0.24 | 38.38 | B |
| PLUMSTEAD | 44 | 0004811W | 790.0 | 5 | 4.4 | 8.8 | 24.0 | -0.35 | 5.66 | B |
| POLPERRO | 21 | 0022009W | 797.4 | 5 | 8.4 | 52.6 | 152.0 | -0.41 | 7.16 | B |
| PORT BEAUFORT | 20 | 0009563W | 291.7 | 0 | 4.0 | 3.5 | 41.0 | -0.49 | 46.35 | B |
| PORTERVILLE - MUN | 91 | 0041871W | 495.9 | 5 | 4.9 | 79.1 | 137.0 | -0.54 | 23.80 | B |
| PORTERVILLE KO-OP | 34 | 20068 | 517.0 | 7 | 12.7 | 80.5 | 145.0 | -0.76 | 22.48 | A |
| PRINCE ALFRED HAMLET - P | 34 | 0042588W | 553.2 | 5 | 1.8 | 94.2 | 496.0 | -0.56 | 9.20 | B |
| PROTEM - SAR | 59 | 0008136W | 404.6 | 1 | 11.1 | 41.6 | 268.0 | 1.29 | 40.66 | A |
| RABIESDAL | 16 | 0023235P | 297.0 | 1 | 14.3 | 63.6 | 274.0 | -0.58 | 20.09 | A |
| RAWSONVILLE - POL | 96 | 0022521W | 613.3 | 1 | 2.9 | 65.4 | 259.0 | 0.31 | 19.87 | B |
| REMHOOGTE | 53 | 0042281AW | 979.0 | 5 | 26.5 | 85.5 | 371.0 | -0.91 | 9.08 | B |
| RIEBEEK - KASTEEL - MUN | 46 | 0041713W | 659.7 | 0 | 10.4 | 54.1 | 122.0 | -0.51 | 21.34 | A |
| RIEBEEK - WES - POL | 29 | 0041681W | 577.2 | 1 | 21.9 | 53.0 | 168.0 | -0.50 | 25.84 | B |
| Riebeek-Wes Koöp | 23 | 20063 | 560.0 | 1 | 21.9 | 53.0 | 168.0 | -0.50 | 25.84 | A |
| RIVERSDAL | 85 | 0010425AW | 72.1 | 0 | 4.7 | 35.0 | 116.0 | -1.12 | 11.21 | B |
| RIVERSDALE | 103 | 0010456W | 428.6 | 0 | 20.9 | 33.8 | 116.0 | -1.01 | 12.81 | B |
| ROBERTSON | 85 | 0023708AW | 35.5 | 5 | 4.3 | 88.4 | 204.0 | -0.47 | 33.59 | B |
| ROBERTSON - AGR | 28 | 0023710W | 260.1 | 5 | 4.5 | 84.6 | 159.0 | -0.91 | 33.94 | A |
| ROBERTSON - MUN | 62 | 0023619W | 273.8 | 5 | 4.5 | 87.5 | 162.0 | -0.76 | 35.08 | B |
| ROBERTSON - TNK | 109 | 0023678W | 323.0 | 5 | 4.5 | 87.5 | 183.0 | -0.60 | 35.08 | B |
| ROBERTSVLEI - BOS | 45 | 0022148W | 1947.0 | 5 | 20.7 | 30.5 | 250.0 | -0.86 | 8.98 | B |
| RONDEHEUWEL | 38 | 0041836W | 464.9 | 5 | 7.8 | 56.3 | 73.0 | -0.69 | 13.11 | B |
| RONDEKOP | 66 | 0046058W | 176.1 | 1 | 4.7 | 97.4 | 410.0 | -0.71 | 51.92 | B |
| RONDEVLEI | 53 | 0004874W | 660.0 | 5 | 1.4 | 3.7 | 3.0 | -0.45 | 7.61 | A |
| Rustenberg Landgoed, Stelle | 8 | 21862 | 861.0 | 7 | 24.6 | 22.9 | 310.0 | -0.21 | 3.18 | A |
| RUSTFONTEIN | 73 | 0006332W | 787.0 | 5 | 23.4 | 34.3 | 320.0 | -0.40 | 15.55 | A |
| SALDANHA - POL | 65 | 0060780W | 329.9 | 1 | 7.9 | 0.4 | 8.0 | -0.75 | 112.40 | B |
| SANDVLEI | 28 | 0107759W | 196.1 | 5 | 4.3 | 66.9 | 213.0 | -0.34 | 86.92 | B |
| SARON - COL | 101 | 0042011W | 443.7 | 7 | 13.4 | 73.9 | 120.0 | -0.44 | 21.18 | A |

| Station | Length (Years) | Number | MAP | Wind Index | Rough-ness | Continen-tality | Altitude | Expo-sure | Barrier Distance | Subset |
|---|---|---|---|---|---|---|---|---|---|---|
| SCHEEPERSRUST | 23 | 0024684W | 301.9 | 5 | 35.6 | 62.7 | 381.0 | -1.26 | 8.42 | A |
| SIMONSTOWN - MUN | 125 | 0004762W | 317.0 | 0 | 49.5 | 1.7 | 60.0 | -1.09 | 2.22 | B |
| SMITSWINKELBAAI | 39 | 0004826W | 600.0 | 5 | 23.4 | 1.2 | 15.0 | -1.24 | 2.88 | A |
| Sneeuwkop, Koue-Bokkeveld | 25 | 20131 | 488.0 | 0 | 45.6 | 113.1 | 966.0 | -0.84 | 13.88 | A |
| SOMERSET WEST - POL | 100 | 0005605W | 627.3 | 5 | 5.5 | 3.6 | 46.0 | -0.56 | 11.24 | B |
| SOUTRIVIER | 64 | 0023602W | 277.0 | 1 | 6.7 | 111.3 | 1137.0 | -0.53 | 55.20 | A |
| SPRINGFONTEIN - STANFORD | 5 | 30549 | 591.0 | 0 | 20.7 | 6.2 | 34.0 | -0.54 | 51.13 | B |
| Stagmanskop, Citrusdal | 25 | 20127 | 475.0 | 1 | 27.0 | 53.1 | 587.0 | 0.52 | 22.11 | A |
| STEENBRAS NO 1 - RSV | 80 | 0005611AW | 644.0 | 5 | 23.9 | 0.0 | 399.0 | 0.27 | 15.21 | A |
| STELLENBOSCH - TNK | 47 | 0021625A | 827.3 | 1 | 16.7 | 19.6 | 119.0 | -0.71 | 6.90 | A |
| STETTYNSKLOOF | 53 | 0022440W | 915.0 | 5 | 88.0 | 49.9 | 451.0 | -1.49 | 6.15 | B |
| SUURBRAAK - COL | 15 | 0009241W | 612.2 | 5 | 26.3 | 46.6 | 150.0 | -0.79 | 2.80 | A |
| SWARTVLEI | 45 | 0022368W | 1008.9 | 7 | 27.0 | 65.9 | 274.0 | -0.27 | 12.60 | B |
| TABLE MOUNTAIN - DEVILS | 54 | 0020807W | 311.7 | 0 | 104.3 | 4.3 | 431.0 | 0.95 | 3.86 | B |
| TABLE MOUNTAIN - DISA HE | 47 | 0020719W | 1524.6 | 5 | 79.4 | 4.7 | 747.0 | 1.64 | 1.30 | B |
| TABLE MOUNTAIN - HOUSE | 92 | 0020719CW | 1115.0 | 5 | 41.5 | 4.7 | 745.0 | 1.64 | 1.00 | B |
| TABLE MOUNTAIN - MOLTENO | 116 | 0020746AW | 585.0 | 0 | 27.6 | 3.4 | 97.0 | -0.48 | 2.09 | A |
| THE TOWERS | 113 | 0040653W | 476.0 | 1 | 25.9 | 10.3 | 260.0 | 1.13 | 61.11 | B |
| TOKAI - BOS | 98 | 0004723A | 967.1 | 0 | 25.6 | 8.3 | 84.0 | -0.53 | 2.71 | A |
| TOKAI - BOS | 107 | 0004723W | 865.0 | 1 | 8.3 | 7.2 | 56.0 | -0.52 | 4.10 | A |
| TULBAGH | 22 | 0042198W | 507.6 | 5 | 9.6 | 79.9 | 150.0 | -0.69 | 7.81 | A |
| TULBAGH - POL | 126 | 0042227W | 474.0 | 7 | 12.0 | 79.0 | 163.0 | -0.57 | 8.70 | B |
| TUSSENBEIDE | 87 | 0006527W | 497.0 | 5 | 18.1 | 13.7 | 189.0 | -0.52 | 35.61 | A |
| TWEEVLEI | 23 | 0008355W | 290.8 | 5 | 9.1 | 22.9 | 76.0 | -0.04 | 51.62 | A |
| TYGERHOEK (WRS) | 51 | 0007699A | 435.0 | 7 | 12.5 | 62.6 | 157.0 | -0.63 | 39.94 | B |
| UILENKRAAL - BOS | 31 | 0001726W | 500.6 | 5 | 3.0 | 2.1 | 45.0 | -0.30 | 68.50 | A |
| VANRHYNSDORP - TNK | 120 | 0107396W | 146.0 | 5 | 6.0 | 51.1 | 122.0 | -0.73 | 99.49 | A |
| VELDRESERWE | 46 | 0022789A | 237.3 | 5 | 3.4 | 77.0 | 232.0 | -0.30 | 31.67 | B |
| VERDWAALSKLOOF | 12 | 0007792W | 302.0 | 1 | 16.2 | 55.8 | 226.0 | -0.04 | 40.84 | B |
| VOELVLEI | 37 | 0002639W | 496.4 | 0 | 3.8 | 11.3 | 30.0 | 0.10 | 84.17 | A |
| VOGELVLEI | 30 | 0042529W | 758.0 | 5 | 4.2 | 91.5 | 472.0 | -0.90 | 6.20 | A |
| VREDENBURG - POL | 70 | 0060864W | 323.2 | 1 | 10.2 | 9.5 | 120.0 | 1.08 | 110.76 | B |
| VREDENDAL | 85 | 0106880AW | 75.5 | 5 | 2.8 | 27.7 | 32.0 | -0.75 | 103.36 | A |

| Station | Length (Years) | Number | MAP | Wind Index | Rough-ness | Continen-tality | Altitude | Expo-sure | Barrier Distance | Subset |
|---|---|---|---|---|---|---|---|---|---|---|
| Vredenhof, Noorder-Paarl | 23 | 20141 | 740.0 | 0 | 43.0 | 45.2 | 154.0 | -0.53 | 12.08 | B |
| VRUGBAAR | 100 | 0022038W | 757.0 | 5 | 14.3 | 55.9 | 175.0 | -0.70 | 5.00 | B |
| WALKERS BAY - BOS | 53 | 0006534W | 659.0 | 5 | 15.7 | 0.9 | 28.0 | -0.80 | 46.93 | B |
| WARMBOKVELD | 34 | 0042621W | 593.6 | 5 | 3.4 | 93.2 | 485.0 | -0.62 | 9.08 | B |
| WELBEDACHT | 74 | 0022005W | 620.0 | 5 | 11.9 | 55.5 | 190.0 | -0.06 | 7.30 | A |
| WELGEMOED | 34 | 0043109W | 589.1 | 5 | 17.1 | 112.2 | 1175.0 | 0.30 | 30.15 | B |
| WELLINGTON - MUN | 26 | 0021878BW | 627.7 | 5 | 6.5 | 52.4 | 116.0 | -0.56 | 9.00 | B |
| WELTEVREDE | 24 | 0025206A | 352.5 | 1 | 15.1 | 54.6 | 421.0 | -0.91 | 4.84 | B |
| WILGENHOUTENDRIFT | 18 | 0062340W | 340.8 | 7 | 4.9 | 37.7 | 122.0 | -0.65 | 43.51 | A |
| ZANDDRIFT | 21 | 0022174W | 892.0 | 1 | 41.0 | 33.7 | 230.0 | -0.82 | 9.12 | B |
| ZEEKOEVLEI | 39 | 0005034W | 661.2 | 5 | 2.4 | 1.6 | 10.0 | -0.98 | 9.07 | B |
| ZOAR - COL | 41 | 0046809W | 244.9 | 7 | 74.8 | 93.3 | 515.0 | -1.00 | 53.90 | A |
| ZORGVLIET | 21 | 0025634W | 64.0 | 5 | 25.5 | 86.4 | 457.0 | -0.21 | 40.39 | B |
|  | 62 | 5B | 1469.0 | 5 | 125.6 | 20.2 | 655.0 | 0.10 | 0.22 | A |
|  | 62 | 13B | 1376.0 | 5 | 78.3 | 19.1 | 427.0 | -1.04 | 1.72 | A |
|  | 62 | 2B+2C | 1474.0 | 5 | 31.3 | 18.1 | 305.0 | -1.36 | 2.83 | B |
|  | 14 | 0004732W | 845.0 | 1 | 22.5 | 3.3 | 293.0 | 0.66 | 0.28 | B |

# APPENDIX B : STEPWISE FORWARD LINEAR REGRESSION

**Linear Regression Results for:**
**Y = OneArea!$G$1:$G$216**
**X = OneArea!$H$1:$M$216**
**Independent variable entry method: Forward Stepwise**
**P to enter = 0.010**

### Descriptive Statistics

| Variable | Mean | Std Dev. | N |
|---|---|---|---|
| MAP | 545.894 | 319.182 | 215 |
| WindIdx | 4.079 | 2.326 | 215 |
| RoughIdx | 17.820 | 19.001 | 215 |
| Cont_km | 39.171 | 31.783 | 215 |
| AltFinal | 231.330 | 232.004 | 215 |
| ExpIdx | -0.433 | 0.595 | 215 |
| Barrier_km | 26.928 | 26.612 | 215 |

### Pearson Correlations

| | MAP | WindIdx | RoughIdx | Cont_km | AltFinal | ExpIdx | Barrier_km |
|---|---|---|---|---|---|---|---|
| MAP | 1.000 | -0.006 | 0.415 | -0.203 | 0.158 | -0.006 | -0.488 |
| WindIdx | -0.006 | 1.000 | -0.093 | 0.100 | 0.022 | -0.069 | -0.003 |
| RoughIdx | 0.415 | -0.093 | 1.000 | -0.090 | 0.315 | 0.145 | -0.262 |
| Cont_km | -0.203 | 0.100 | -0.090 | 1.000 | 0.601 | -0.142 | -0.154 |
| AltFinal | 0.158 | 0.022 | 0.315 | 0.601 | 1.000 | 0.215 | -0.258 |
| ExpIdx | -0.006 | -0.069 | 0.145 | -0.142 | 0.215 | 1.000 | 0.041 |
| Barrier_km | -0.488 | -0.003 | -0.262 | -0.154 | -0.258 | 0.041 | 1.000 |

### Significance for Pearson Correlations

| | MAP | WindIdx | RoughIdx | Cont_km | AltFinal | ExpIdx | Barrier_km |
|---|---|---|---|---|---|---|---|
| MAP | - | 0.933 | 0.000 | 0.003 | 0.020 | 0.934 | 0.000 |
| WindIdx | 0.933 | - | 0.175 | 0.143 | 0.753 | 0.316 | 0.963 |
| RoughIdx | 0.000 | 0.175 | - | 0.189 | 0.000 | 0.034 | 0.000 |
| Cont_km | 0.003 | 0.143 | 0.189 | - | 0.000 | 0.037 | 0.024 |
| AltFinal | 0.020 | 0.753 | 0.000 | 0.000 | - | 0.002 | 0.000 |
| ExpIdx | 0.934 | 0.316 | 0.034 | 0.037 | 0.002 | - | 0.548 |
| Barrier_km | 0.000 | 0.963 | 0.000 | 0.024 | 0.000 | 0.548 | - |

### Step 1: Summary

| $R^2$ | R | Adj. $R^2$ | S.E. of Estimate |
|---|---|---|---|
| 0.238 | 0.488 | 0.234 | 279.316 |

### Step 1: ANOVA

| Source | Sum Sq. | D.F. | Mean Sq. | F | Prob. |
|---|---|---|---|---|---|
| Regression | ######## | 1 | ######## | 66.447 | 0.000 |
| Residual | ######## | 213 | ######## | | |
| Total | ######## | 214 | | | |

### Step 1: Regression Coefficients

| Source | Coefficient | Std Error | Std Beta | -95% C.I. | +95% C.I. | t | Prob. |
|---|---|---|---|---|---|---|---|
| Intercept | 703.383 | 27.132 | | 649.902 | 756.864 | 25.925 | 0.000 |
| Barrier_km | -5.848 | 0.717 | -0.488 | -7.263 | -4.434 | -8.152 | 0.000 |

**Step 2: Summary**

| $R^2$ | R | Adj. $R^2$ | S.E. of Estimate |
|---|---|---|---|
| 0.326 | 0.571 | 0.320 | 263.231 |

**Step 2: ANOVA**

| Source | Sum Sq. | D.F. | Mean Sq. | F | Prob. |
|---|---|---|---|---|---|
| Regression | ######## | 2 | ######## | 51.321 | 0.000 |
| Residual | ######## | 212 | ######## | | |
| Total | ######## | 214 | | | |

**Step 2: Regression Coefficients**

| Source | Coefficient | Std Error | Std Beta | -95% C.I. | +95% C.I. | t | Prob. |
|---|---|---|---|---|---|---|---|
| Intercept | 585.034 | 34.017 | | 517.979 | 652.089 | 17.198 | 0.000 |
| RoughIdx | 5.177 | 0.981 | 0.308 | 3.242 | 7.111 | 5.275 | 0.000 |
| Barrier_km | -4.879 | 0.701 | -0.407 | -6.260 | -3.498 | -6.964 | 0.000 |

**Step 3: Summary**

| $R^2$ | R | Adj. $R^2$ | S.E. of Estimate |
|---|---|---|---|
| 0.385 | 0.621 | 0.376 | 252.075 |

**Step 3: ANOVA**

| Source | Sum Sq. | D.F. | Mean Sq. | F | Prob. |
|---|---|---|---|---|---|
| Regression | ######## | 3 | ######## | 44.036 | 0.000 |
| Residual | ######## | 211 | ######## | | |
| Total | ######## | 214 | | | |

**Step 3: Regression Coefficients**

| Source | Coefficient | Std Error | Std Beta | -95% C.I. | +95% C.I. | t | Prob. |
|---|---|---|---|---|---|---|---|
| Intercept | 708.106 | 42.565 | | 624.199 | 792.012 | 16.636 | 0.000 |
| RoughIdx | 4.595 | 0.949 | 0.274 | 2.725 | 6.465 | 4.843 | 0.000 |
| Cont_km | -2.488 | 0.554 | -0.248 | -3.580 | -1.396 | -4.492 | 0.000 |
| Barrier_km | -5.445 | 0.683 | -0.454 | -6.791 | -4.099 | -7.976 | 0.000 |

**Step 4: Summary**

| $R^2$ | R | Adj. $R^2$ | S.E. of Estimate |
|---|---|---|---|
| 0.407 | 0.638 | 0.395 | 248.217 |

**Step 4: ANOVA**

| Source | Sum Sq. | D.F. | Mean Sq. | F | Prob. |
|---|---|---|---|---|---|
| Regression | ######## | 4 | ######## | 35.964 | 0.000 |
| Residual | ######## | 210 | ######## | | |
| Total | ######## | 214 | | | |

**Step 4: Regression Coefficients**

| Source | Coefficient | Std Error | Std Beta | -95% C.I. | +95% C.I. | t | Prob. |
|---|---|---|---|---|---|---|---|
| Intercept | 710.037 | 41.919 | | 627.401 | 792.673 | 16.938 | 0.000 |
| RoughIdx | 3.363 | 1.035 | 0.200 | 1.322 | 5.404 | 3.248 | 0.001 |
| Cont_km | -3.786 | 0.720 | -0.377 | -5.205 | -2.366 | -5.256 | 0.000 |
| AltFinal | 0.286 | 0.104 | 0.208 | 0.082 | 0.490 | 2.759 | 0.006 |
| Barrier_km | -5.271 | 0.675 | -0.440 | -6.602 | -3.940 | -7.807 | 0.000 |