DIGITAL ADDENDA 5A – 5F

Contents

ADDENDUM 5A PRESENTATION OF SUPPLEMENTARY HYDROLOGICAL DATA USED FOR THE KAROO SHALE GAS SCIENTIFIC ASSESSMENT

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CATCHMENT BACKGROUND

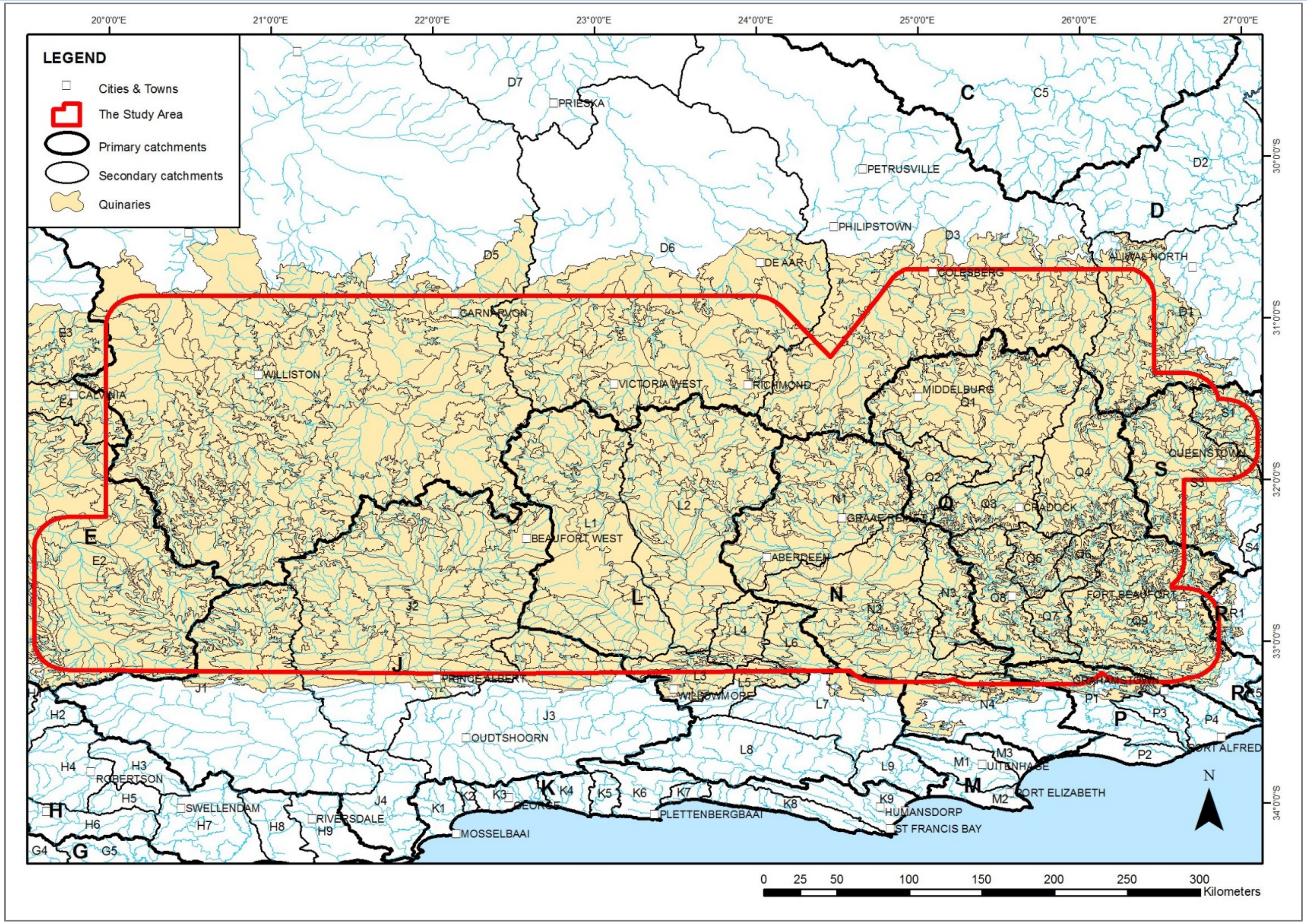


Figure 5A1.1: Map showing the distribution of Quinary catchments in the study area. Since the emphasis in these maps is on water resources / hydrology, the jagged outer boundaries designate the boundaries of all Quinary Catchments which are at least partially within the study area.

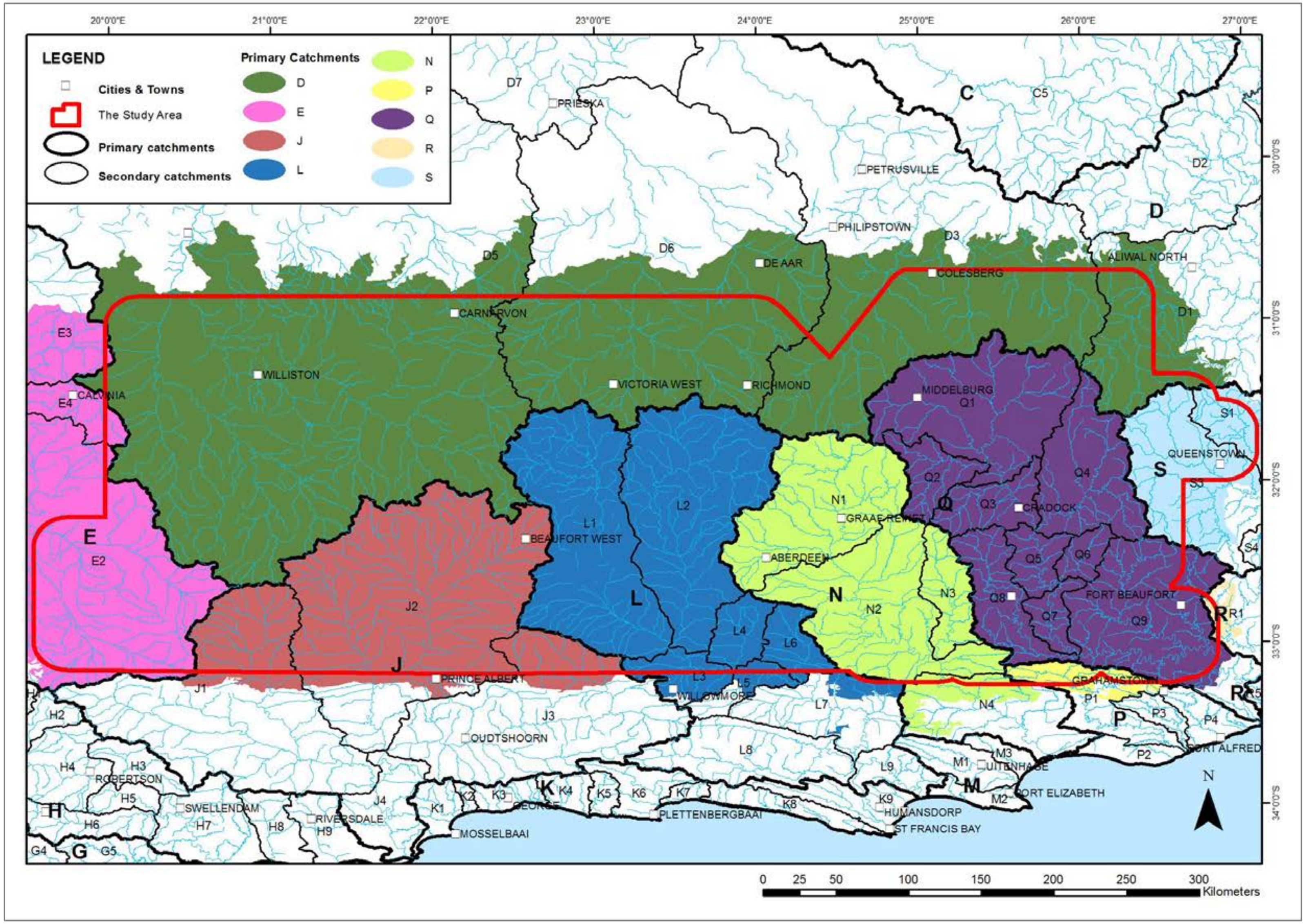


Figure 5A1.2: Map showing the study area in the context of Primary, Secondary and Quaternary Catchments.

BASIC RAINFALL AND EVAPORATION FIGURES

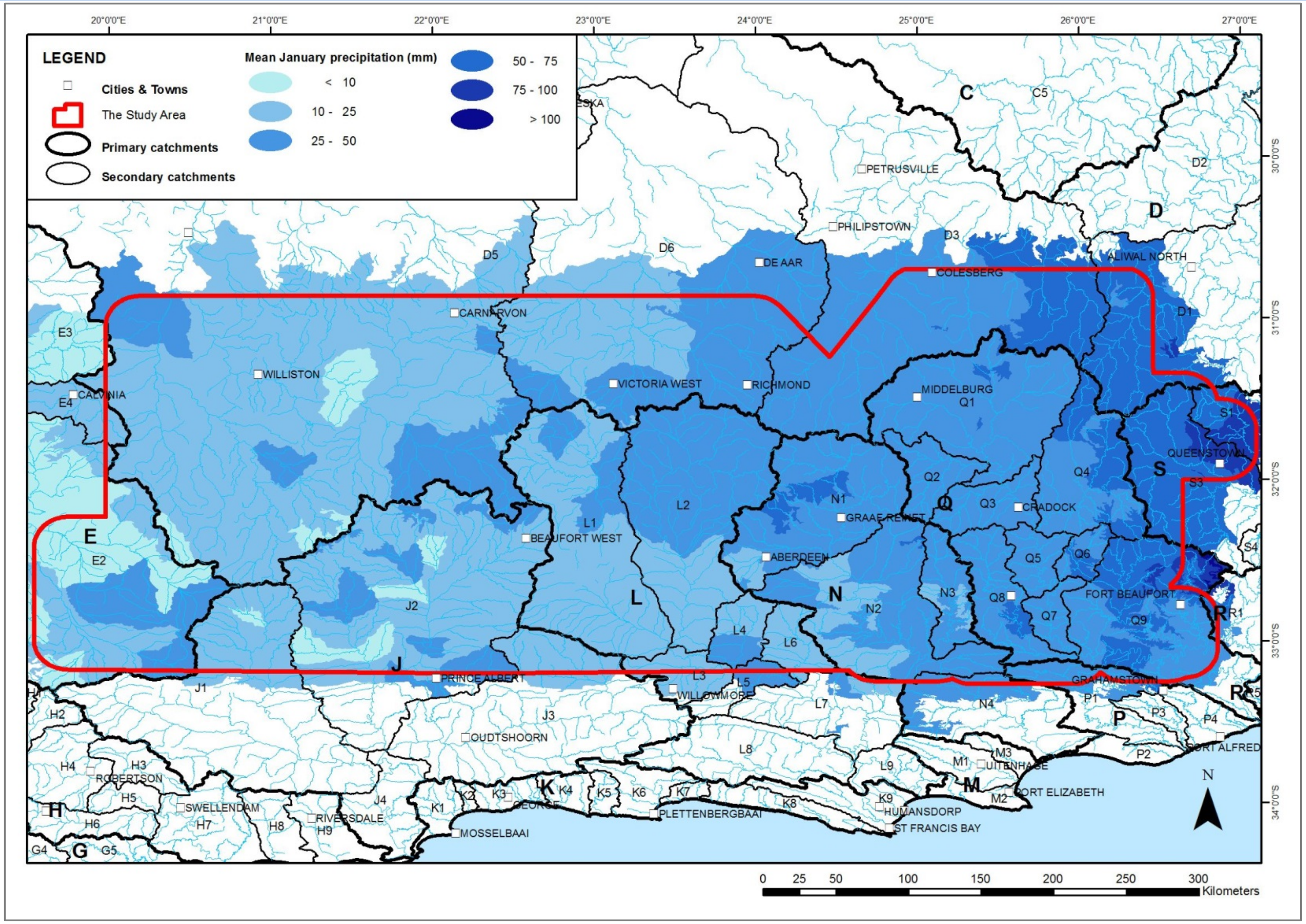
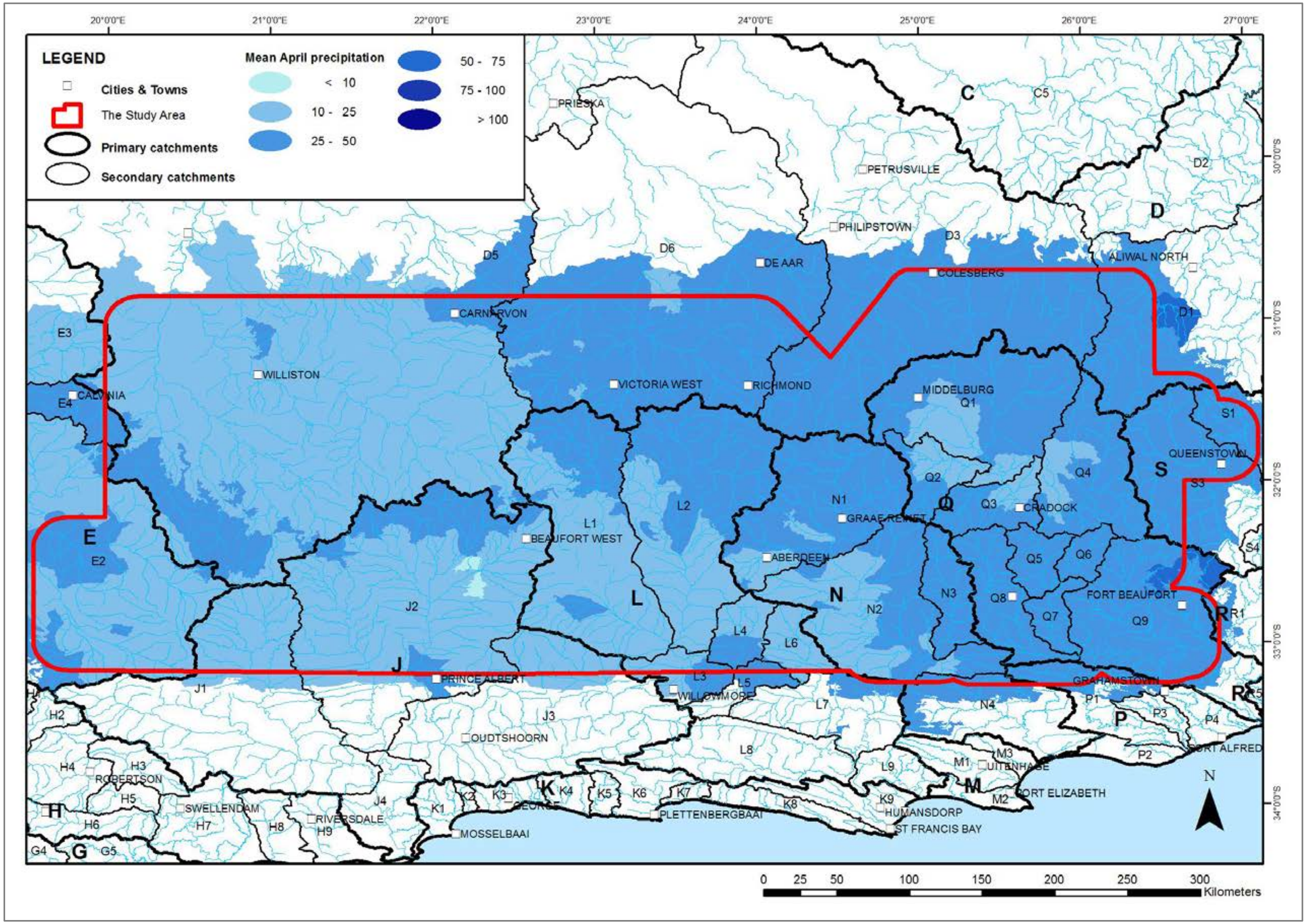


Figure 5A1.3:

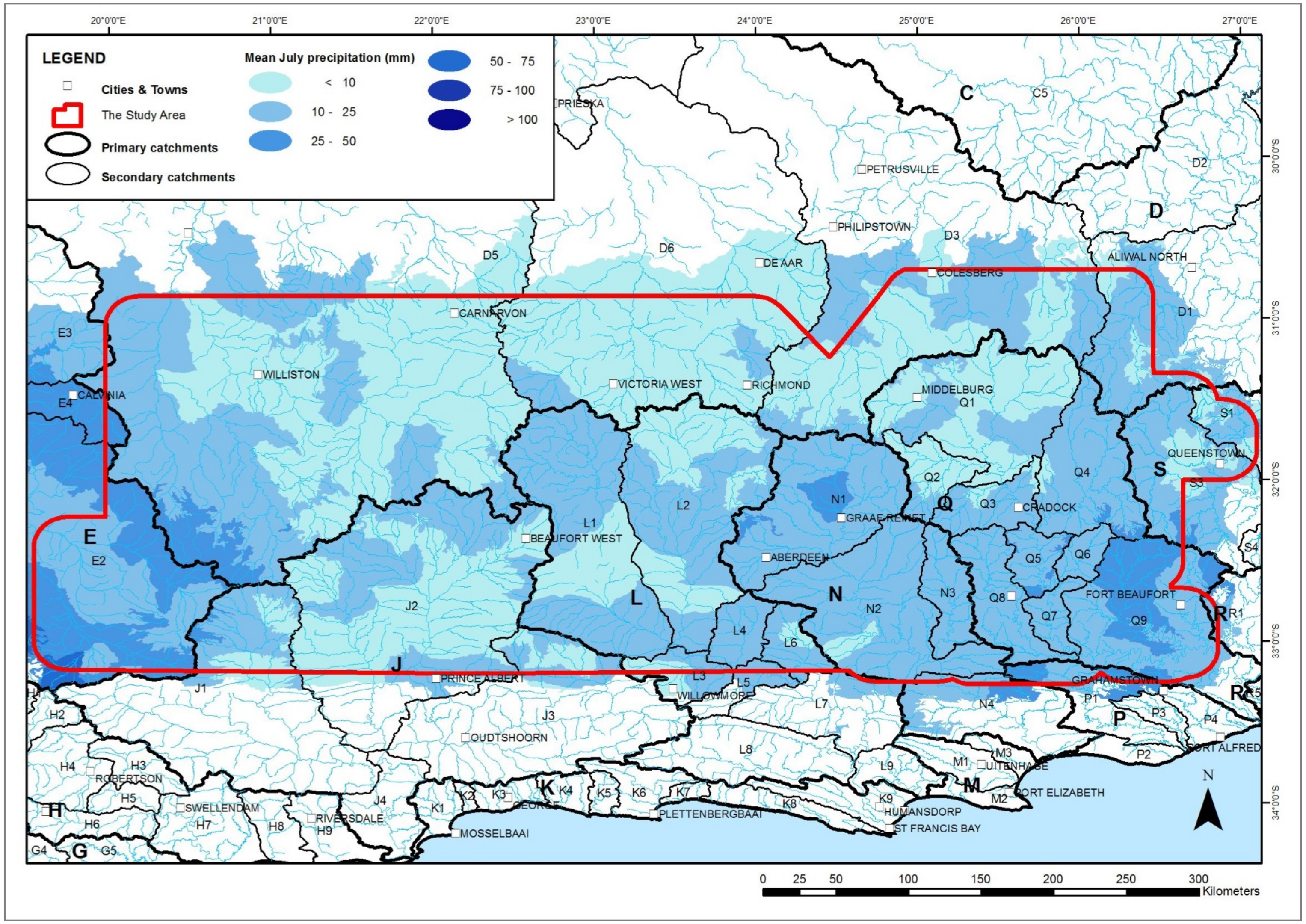
A. Mean January Precipitation (Summer)

Precipitation in the Cardinal Months of January (Representing Summer), April (Autumn), July (Winter) and October (Representing Spring)

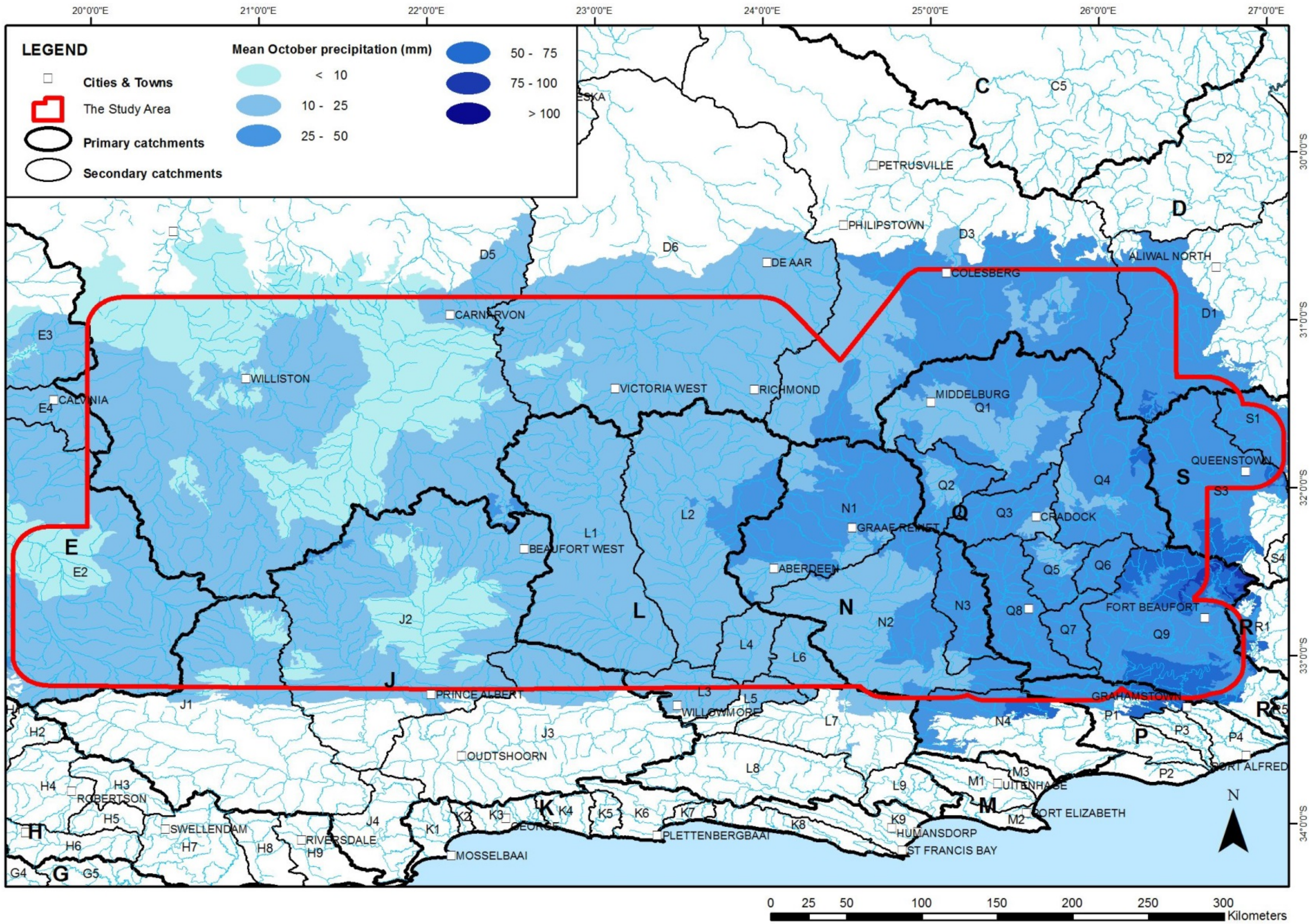
Noticeable in these maps is the west to east gradient of increasing monthly rainfall, and that in April a band of higher rainfall exists where the escarpment is located.



B. Mean April Precipitation (Autumn)



C. Mean July Precipitation (Winter)



D. Mean October Precipitation (Spring)

Figure 5A1.3 (A-D):

Precipitation in the Cardinal Months of January (Representing Summer), April (Autumn), July (Winter) and October (Representing Spring)

Noticeable in these maps is the west to east gradient of increasing monthly rainfall, that in April a band of higher rainfall exists where the escarpment is located and that in winter the west displays the highest rainfall. Original Data Source: Schulze (2012).

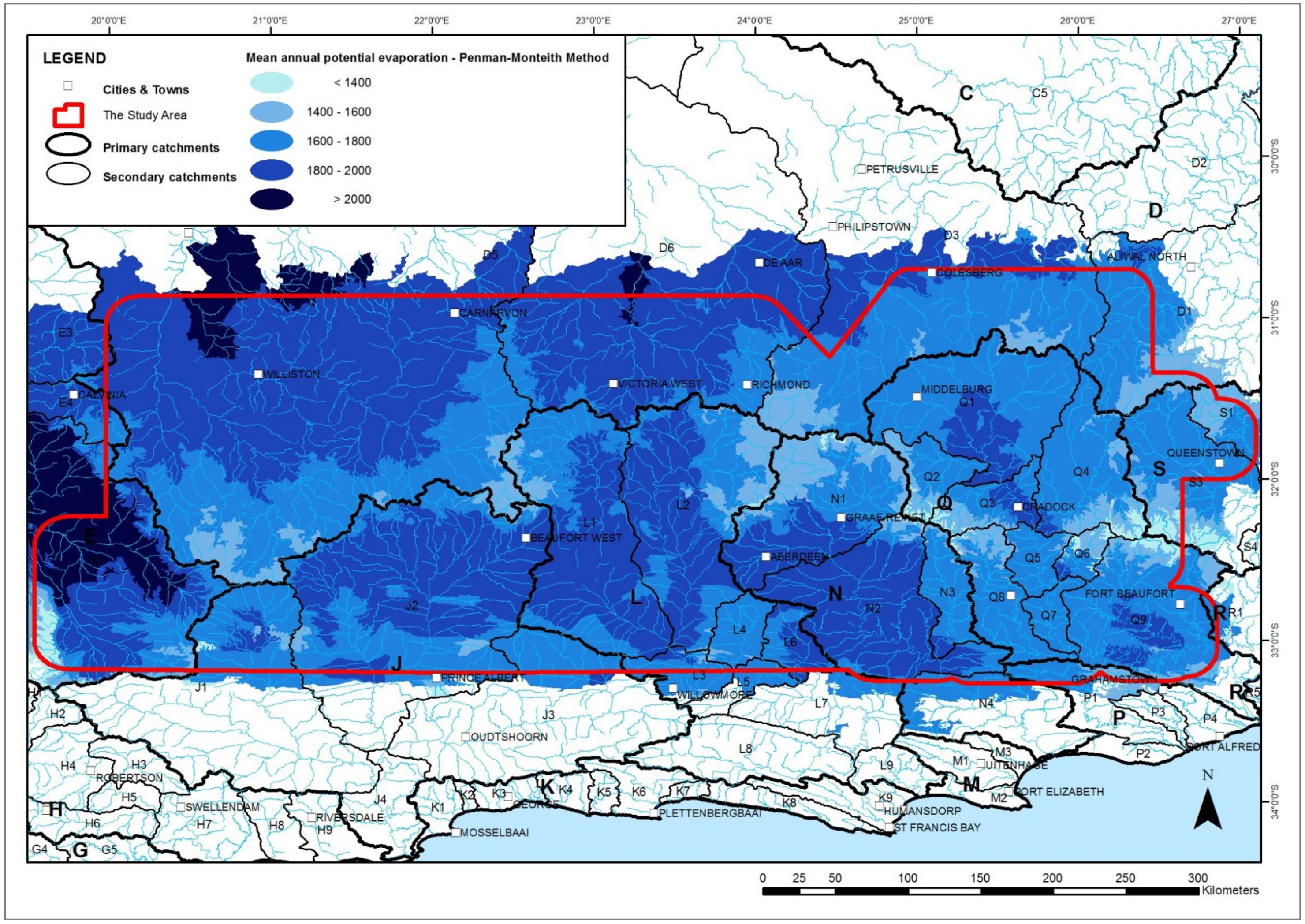


Figure 5A1.4:
Mean Annual Potential Evaporation (PE)
PE is an index of the atmospheric demand of water from a vegetated surface that contains sufficient soil water. PE is directly related to solar radiation and wind, and inversely related to relative humidity, Annual values are high, at generally over 1 600 mm and in parts of the arid west even > 2 000 mm. The band of relatively lower PE running through the centre occurs over the cooler higher lying east-west mountain range. Original Data Source: Schulze (2012).

HYDROLOGY – MAPS SHOWING STREAMFLOW DATA

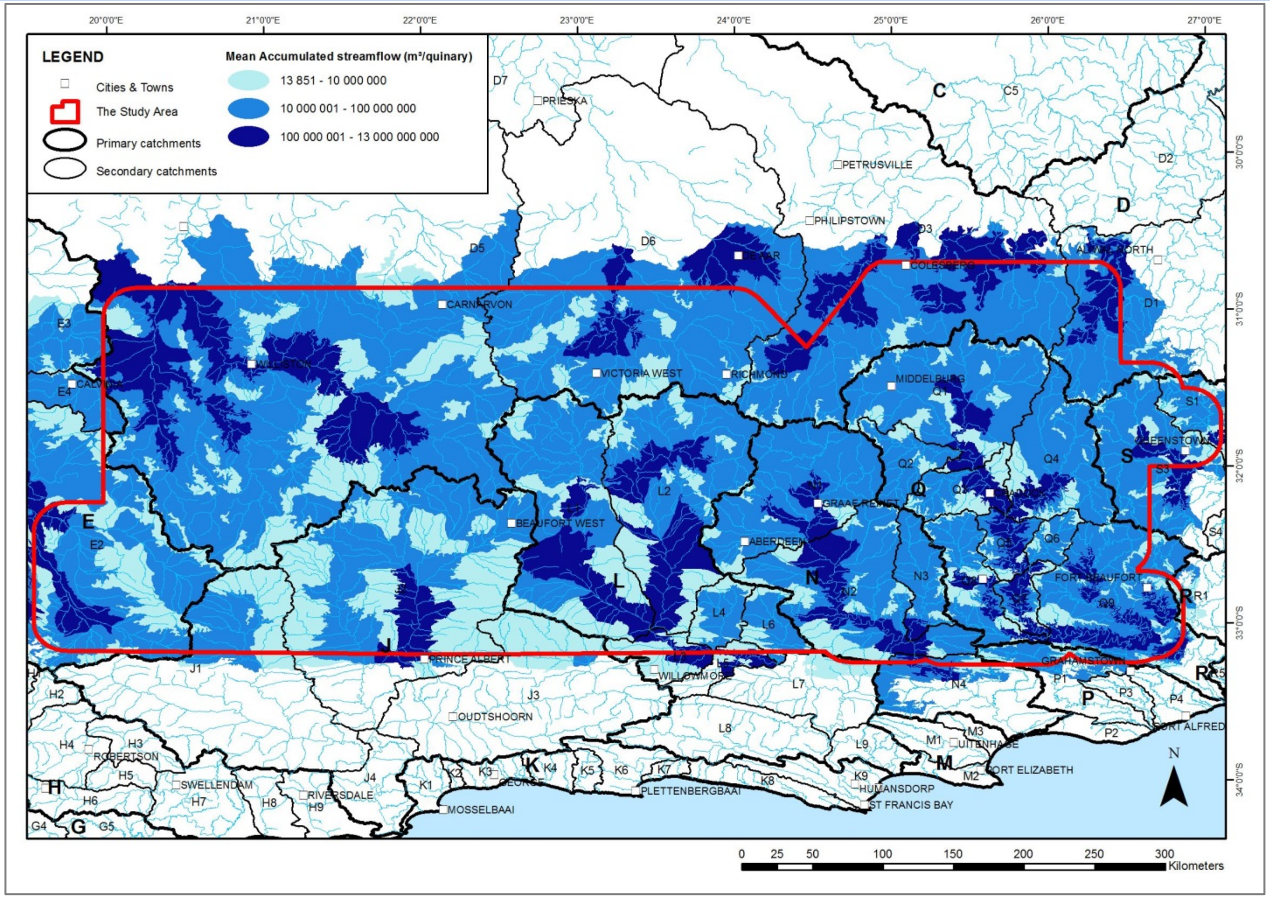


Figure 5A1.5:
Mean Annual Accumulated Streamflow (m^3/Quinary)
For each Quinary catchment, daily values of runoff were generated with the ACRU daily time-step physical-conceptual, multi-soil level and multi-purpose hydrological model (Schulze, 1995 and updates) using as inputs daily rainfall and daily potential evaporation and the catchment's actual soil properties of soil water at saturation, field capacity and wilting point plus saturated drainage rates for both the topsoil and the subsoil, and where runoff is the sum of daily stormflow (when it occur) and baseflow. The streamflow at the exit of a Quinary is then the runoff generated within that specific Quinary plus the accumulation of runoffs from all upstream Quinaries. Note that from the darker coloration one can clearly see how, for the bigger rivers, the streamflow gets larger and larger as one cascades downstream. Original Data Source: Schulze (2012).

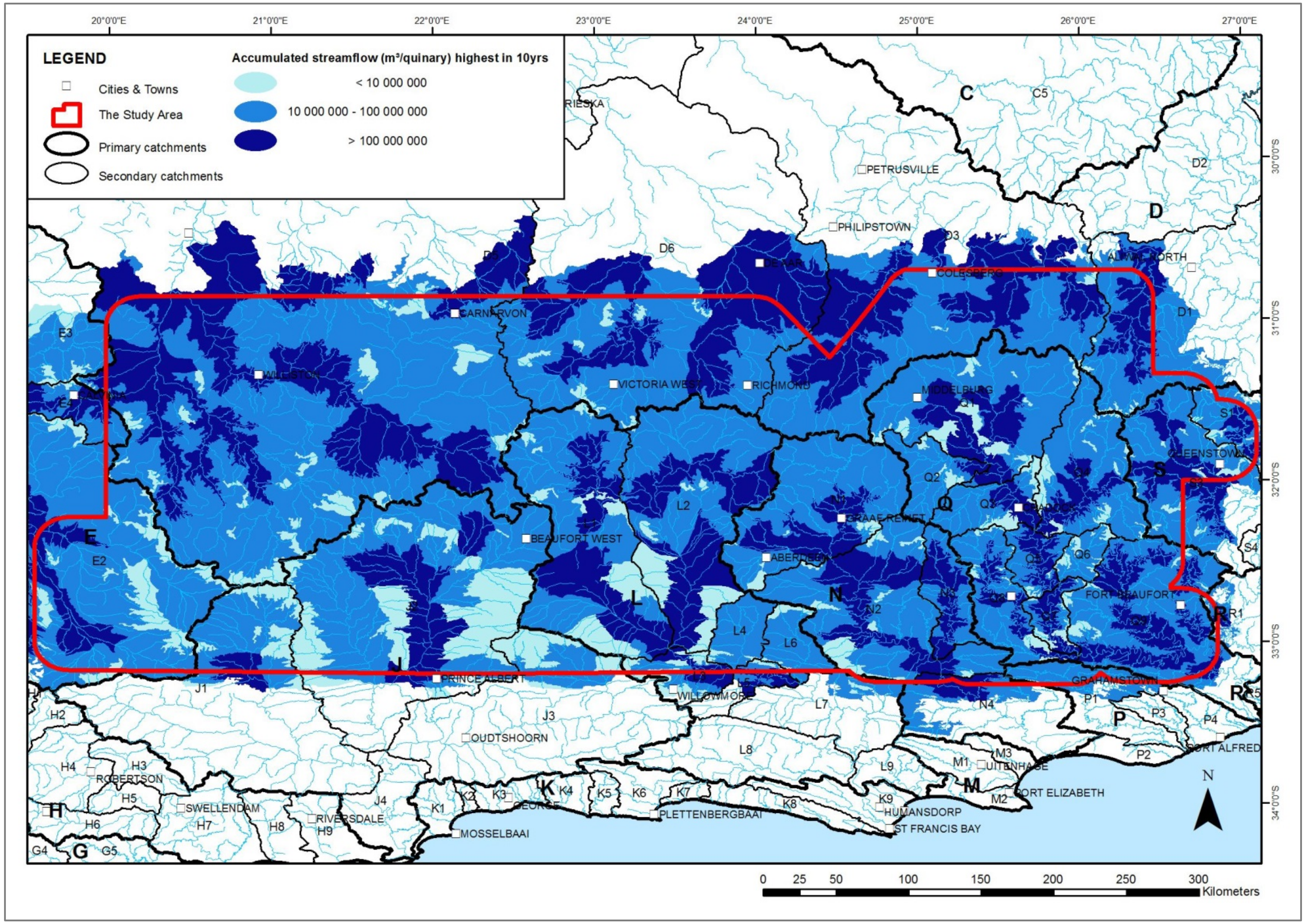


Figure 5A1.6:
Accumulated Streamflow (m^3/Quinary) – Highest in 10 Years
In wet years the streamflows are considerably higher than in years with average streamflows, illustrated here for the year with the highest flows in 10 years.
Original Data Source: Schulze (2012).

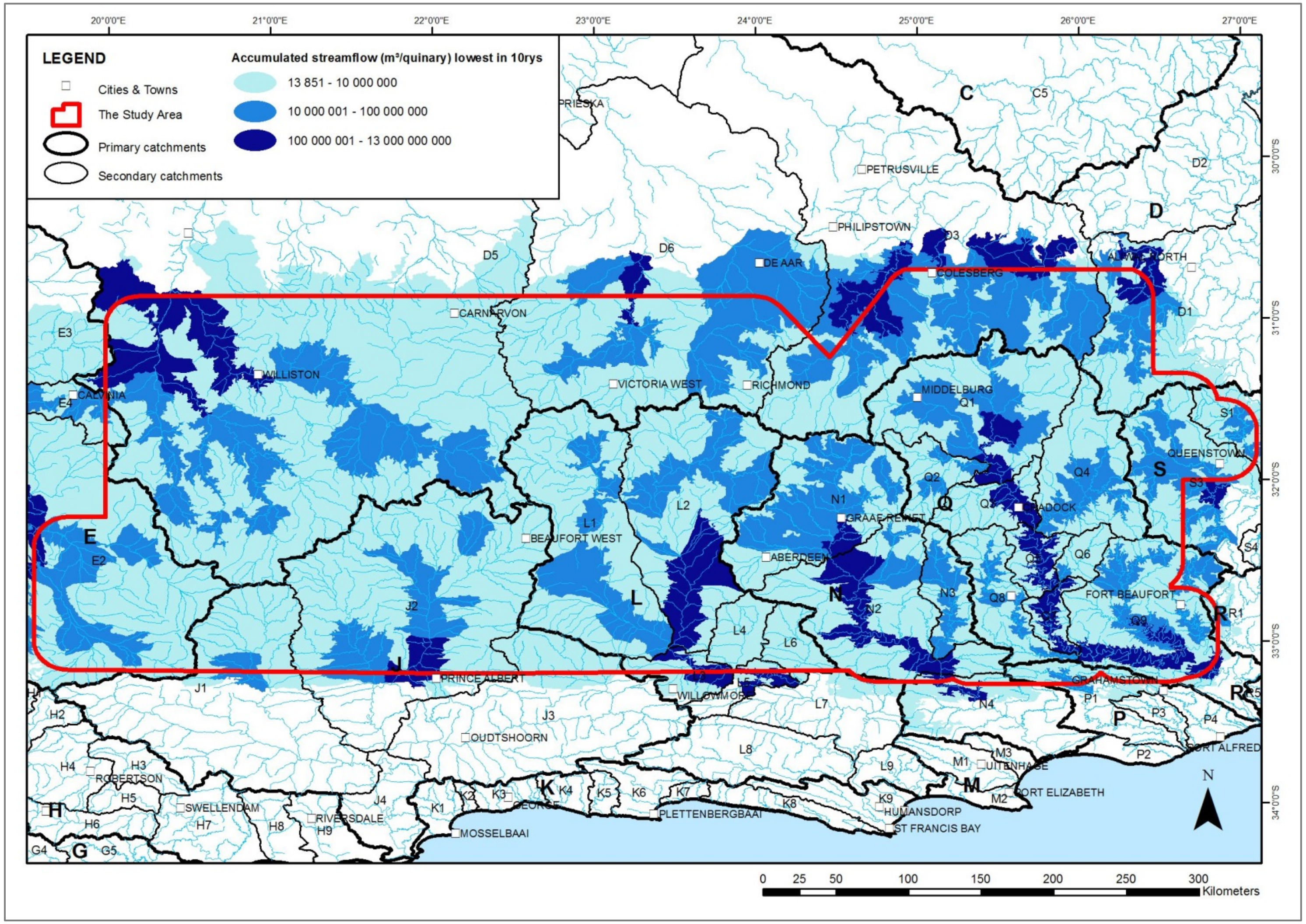


Figure 5A1.7:
Accumulated Streamflow (m^3/Quinary) – Lowest in 10 Years
Similarly, in dry years the streamflows are considerably lower than in years with average streamflows, illustrated here for the year with the lowest flows in 10 years. Note that in the study area the differences in flows between wet and dry years is vast, indicative of the high variability of streamflows and thus high uncertainty of assured supplies of water from local sources. Original Data Source: Schulze (2012).

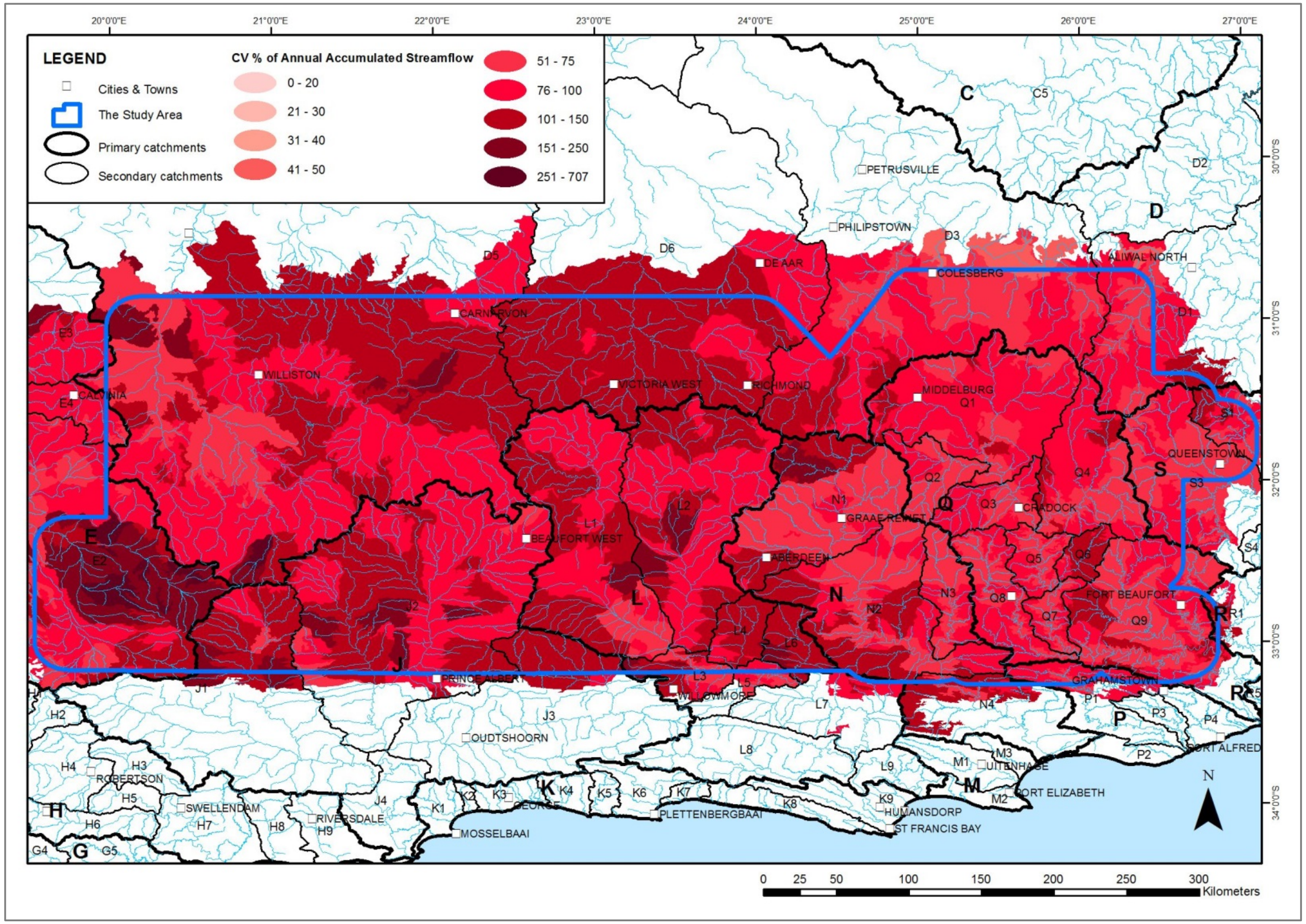


Figure 5A1.8:*Coefficient of Variation (%) of Annual Accumulated Streamflows*
As indicated above, there is a very high inter-annual variability in streamflows, shown by CVs in the range of 50-250%. Note that the CV of annual streamflow is considerably higher than that of annual rainfall, indicative of the non-linear response of runoff to rainfall, leading to an amplification of variability of the hydrological cycle, which is particularly prevalent in semi-arid regions. Original Data Source: Schulze (2012).

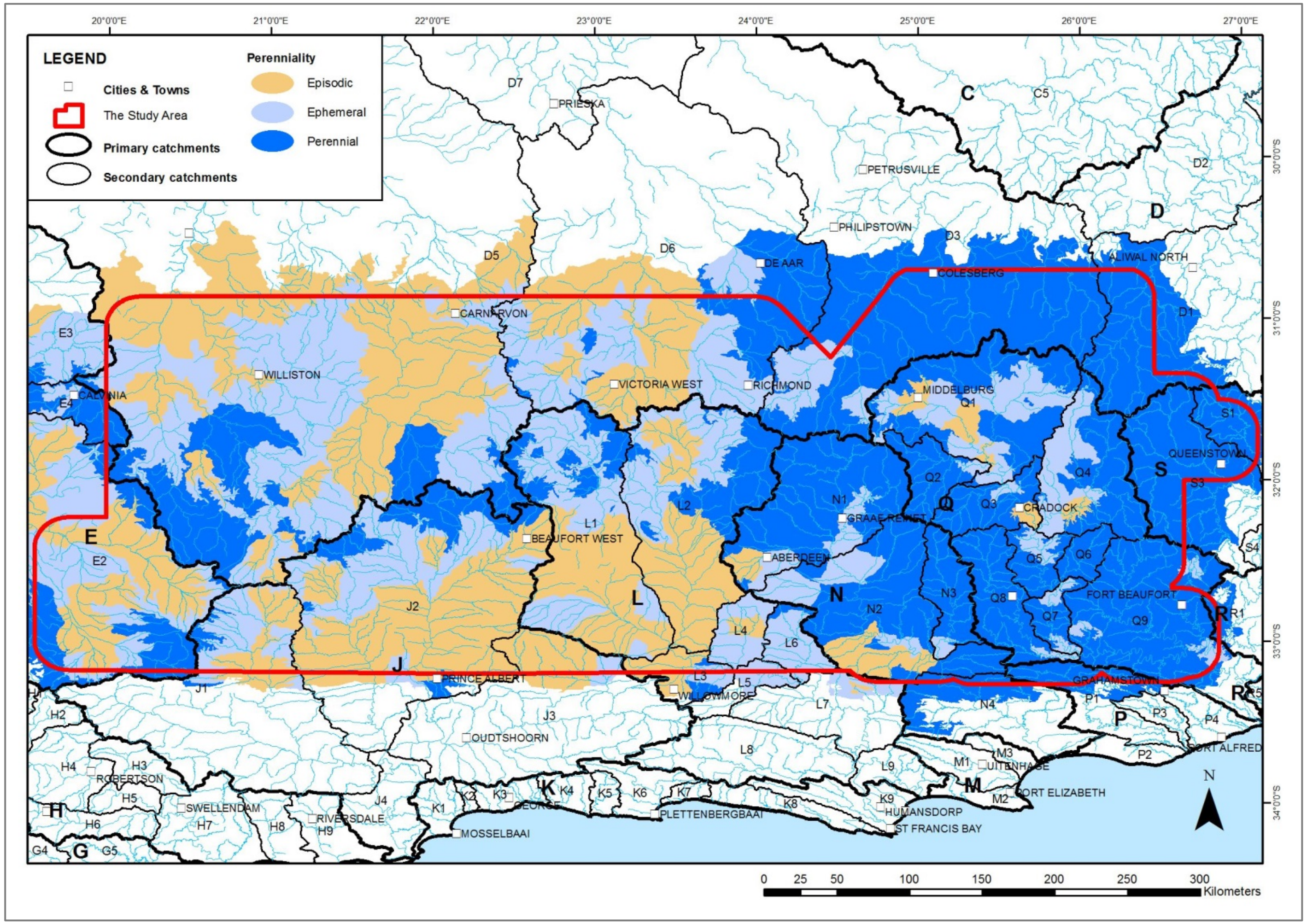


Figure 5A1.9:*Areas of Perennial, Ephemeral and Episodic Flows*
Perennial flows are defined here as effective runoff (i.e. runoff generated minus channel flow losses to evaporation) from individual Quinaries for at least 11 months in a year with average flows, while ephemeral streams are defined as exhibiting flows in at least 3 months and episodic streams have, in an average year, anything from zero flows to flows in two months only. The study area exhibits perennial flows in the east and along the high mountain Quinaries, with both areas of both ephemeral and episodic streams clearly evident. The latter two place great uncertainty on surface water availability in many parts of the study area.
Information Source: New unpublished research by Schulze and Schütte (2016).

HYDROLOGY: RECHARGE INTO THE SOIL PROFILE

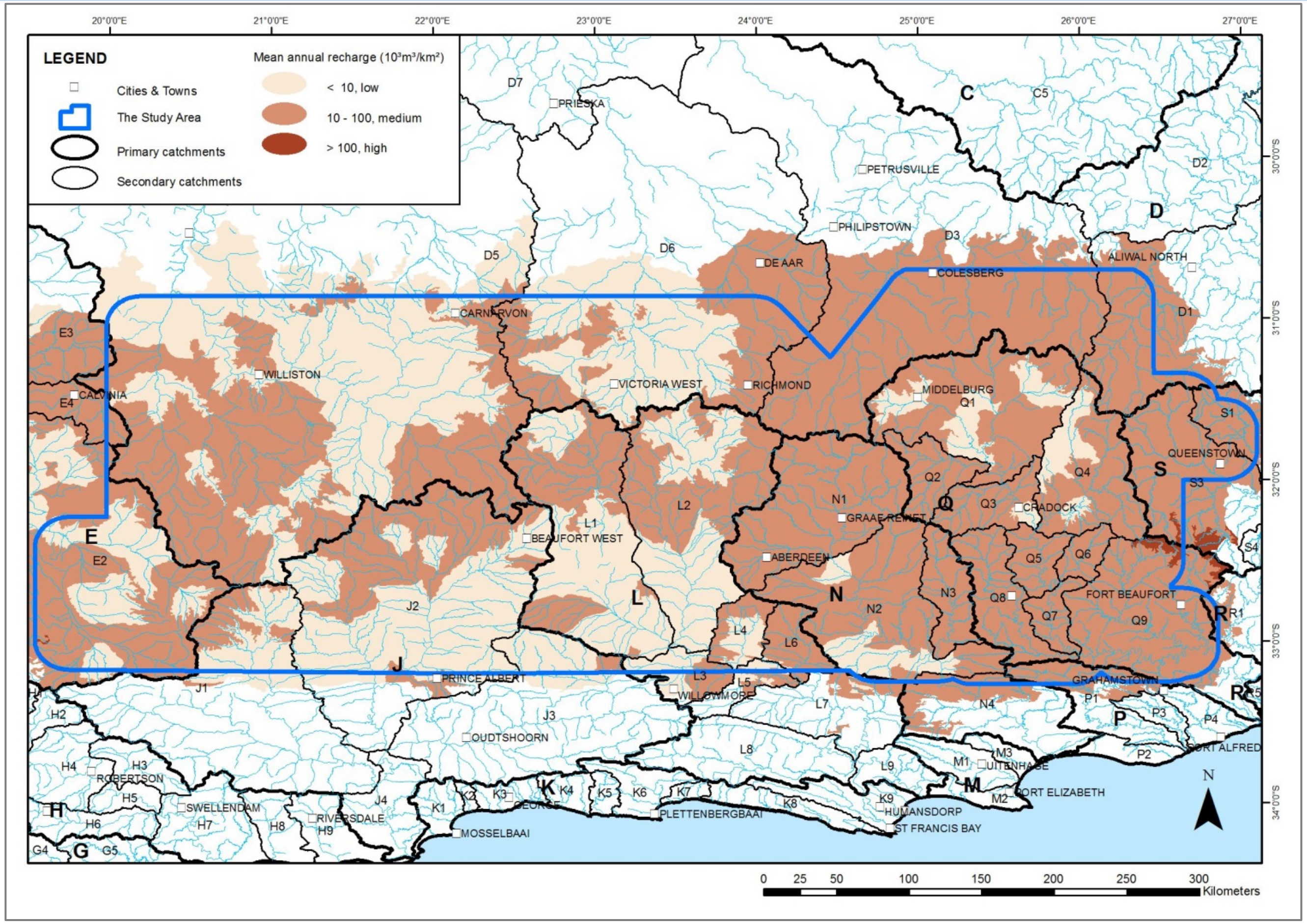


Figure 5A1.10:*Mean Annual Recharge (10^{3}m^3/km^2) Through the Soil Profile*

Recharge generated by the ACRU model takes place once both the topsoil and the subsoil are saturated with soil water and drainage then takes place out of the subsoil (with the rate dependent on soil properties) into an intermediate groundwater store where it is no longer available to plants. Since ACRU is a daily time-step model, this recharge is physically based and takes place as discrete events highly dependent on days with high rainfalls, or consecutive days with sustained rainfalls, or rain falling on an already wet soil. Recharge here is expressed volumetrically as m^3/km^2 and the map shows clearly areas of low and medium mean annual recharge. Original Data Source: Schulze (2012).

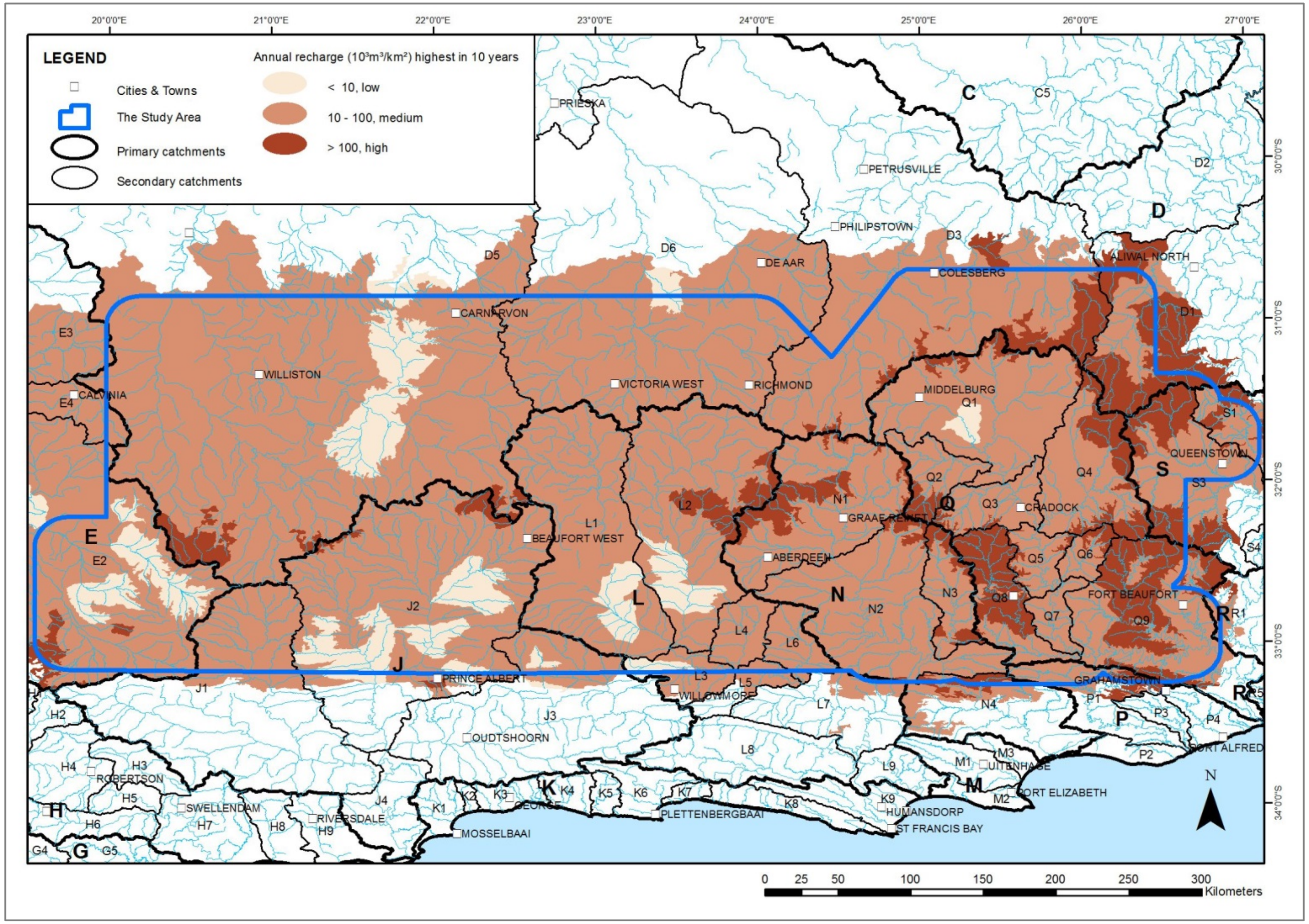


Figure 5A1.11:*Highest Annual Recharge ($10^3 m^3/km^2$) through the Soil Profile – highest in 10 Years*
In wet years recharge is non-linearly and exponentially higher than under average conditions as the thresholds for recharge to occur are exceeded more frequently and with higher magnitudes. Original Data Source: Schulze (2012).

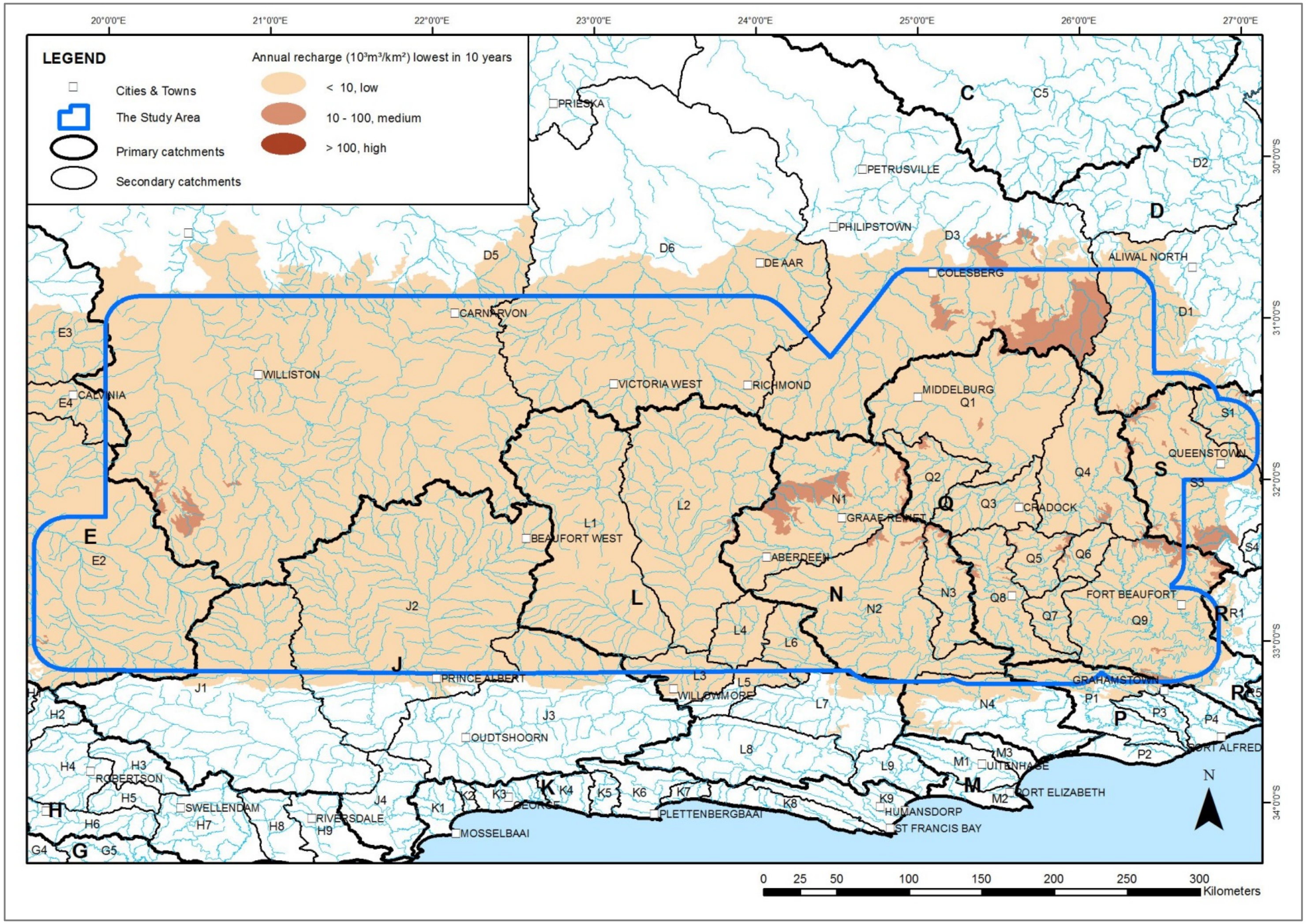


Figure 5A1.12:*Lowest Annual Recharge ($10^3m^3/km^2$) Through the Soil Profile in 10 Years*

By the same token as in Figure 5A1.11, in dry years recharge is non-linearly and exponentially lower than under average conditions as the thresholds for recharge to occur are exceeded less frequently and with lower magnitudes. Most of the study area now experiences recharge on average 10 times lower than in wet years, indicative of very high inter-annual variability of recharge. Original Data Source: Schulze (2012).

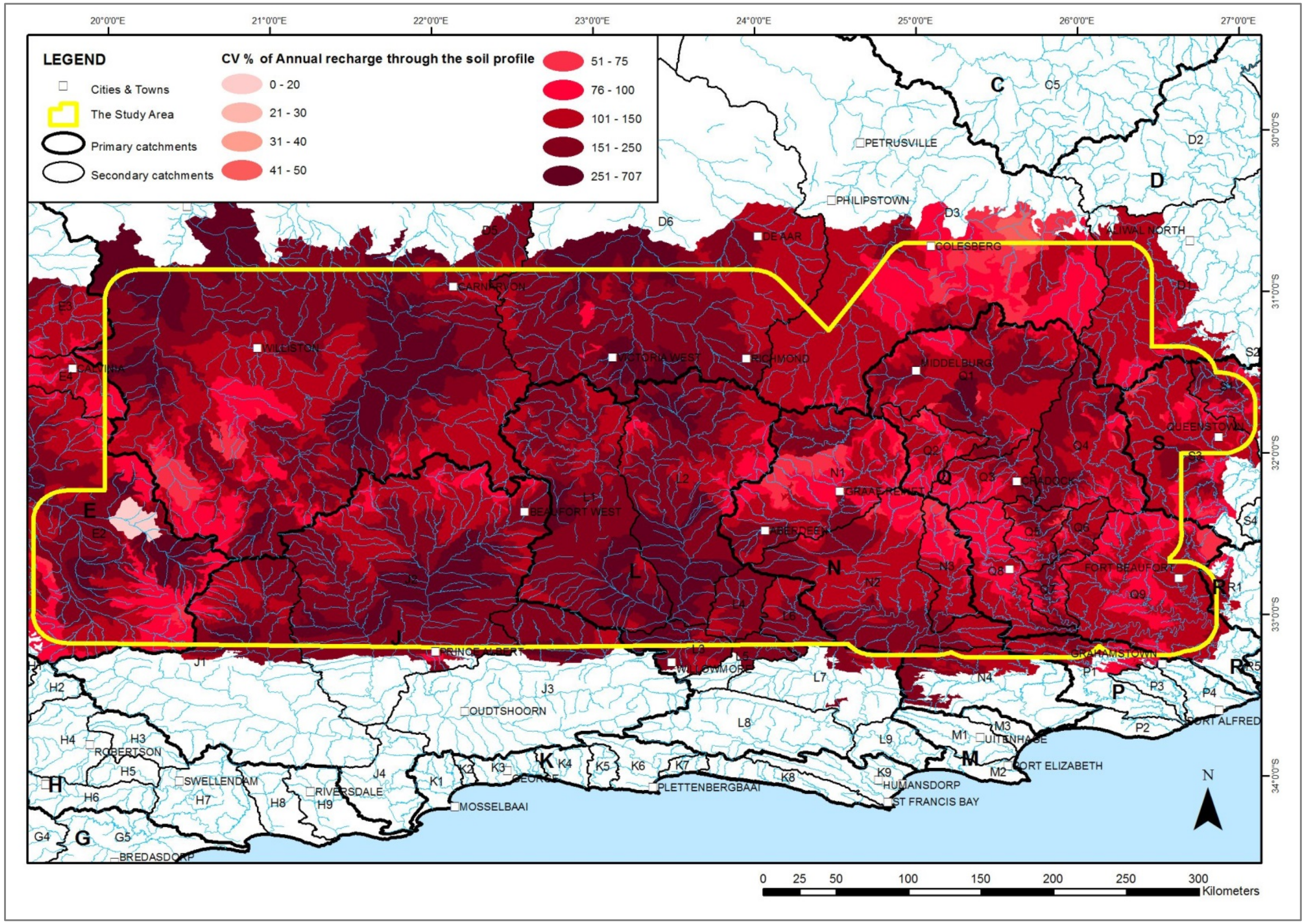


Figure 5A1.13:*Coefficient of Variation (%) of Annual Recharge through the Soil Profile*

As already indicated from the information above, the CV of recharge through the soil profile is exceptionally high in the study area, mostly in the range of 100-250%, rendering this area highly vulnerable to the over-exploitation of shallow groundwater reserves. Note that the CV of annual recharge is considerably higher than that of annual streamflow which, in turn, is considerably higher than that of annual rainfall, reinforcing again the notion of the non-linearity of the hydrological system. Original Data Source: Schulze (2012).

DROUGHT

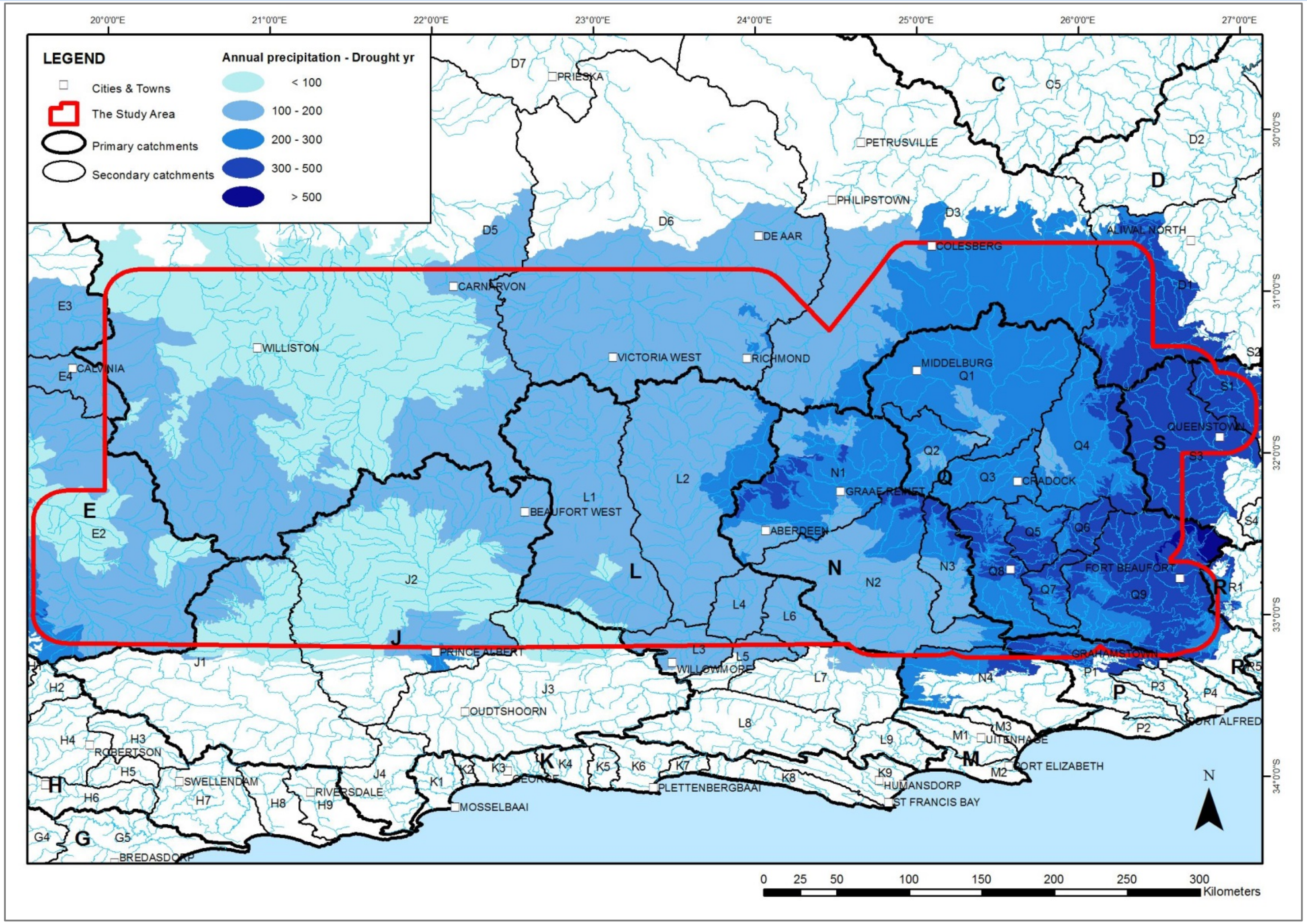


Figure 5A1.14:*Annual Precipitation in a Year with Drought*

A year with drought is defined here as rainfall one standard deviation below the mean annual precipitation. The map shows a decreasing rainfall gradient from east to west from around 500 mm to below 100 mm per year. Source: Newly derived, based on Original Data Generated for Schulze (2012).

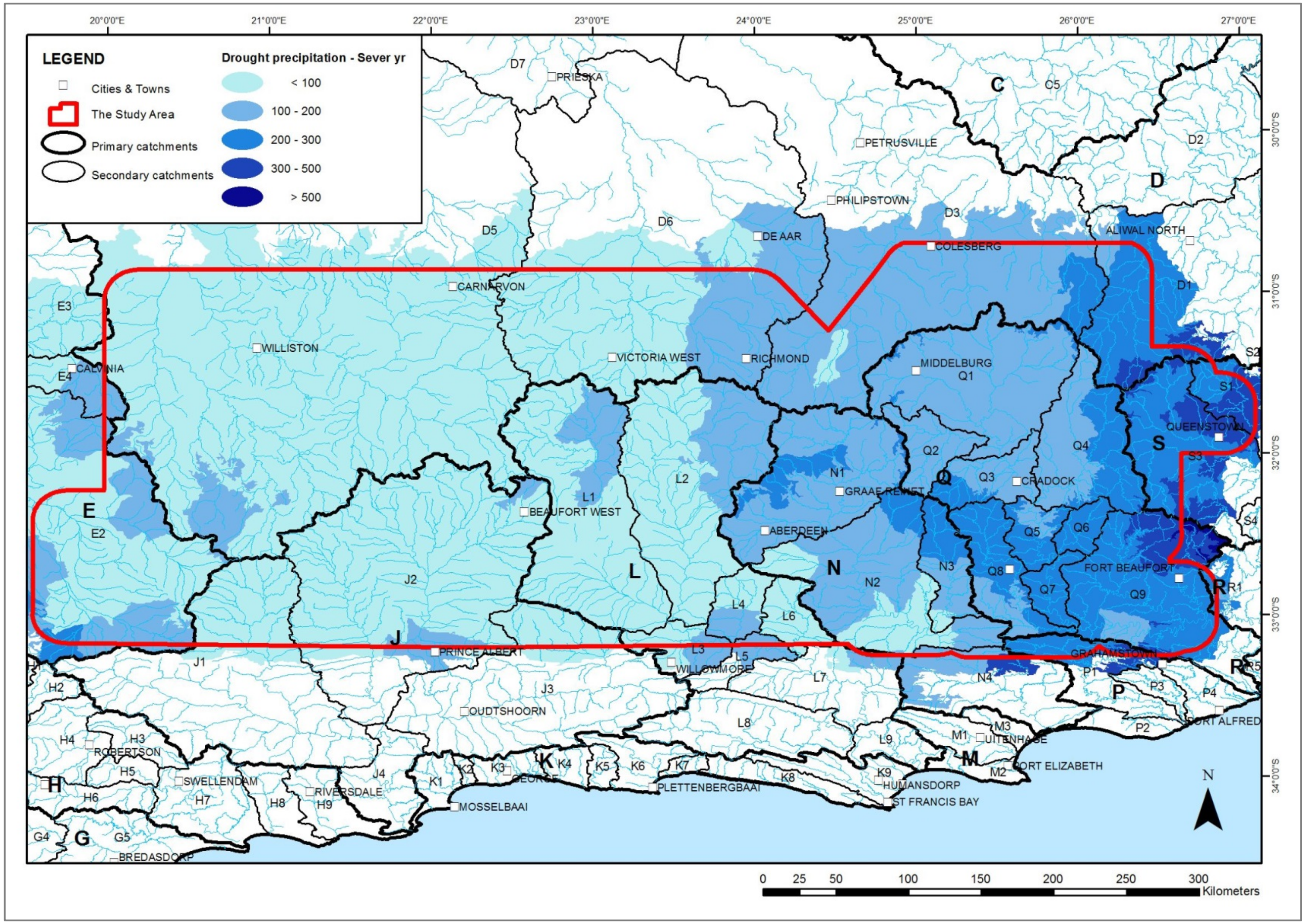


Figure 5A1.15:*Annual Precipitation in a Year with Severe Drought*
A severe meteorological drought is defined here as rainfall 1.5 standard deviations below the mean annual rainfall, and the map shows around 60% of the study area receiving less than 100 mm in such a year – indicative of the harsh climatic conditions existing in this region.
Source: Newly derived, based on Original Data Generated for Schulze (2012).

Figures showing extreme rainfall and streamflow

Extreme rainfall and streamflow events are those that occur, statistically, for example, once every 10 years or once every 50 years, and such extreme events can, for example, be of one days' duration or of a number of consecutive days' duration such as a three day event, resulting in damaging floods.

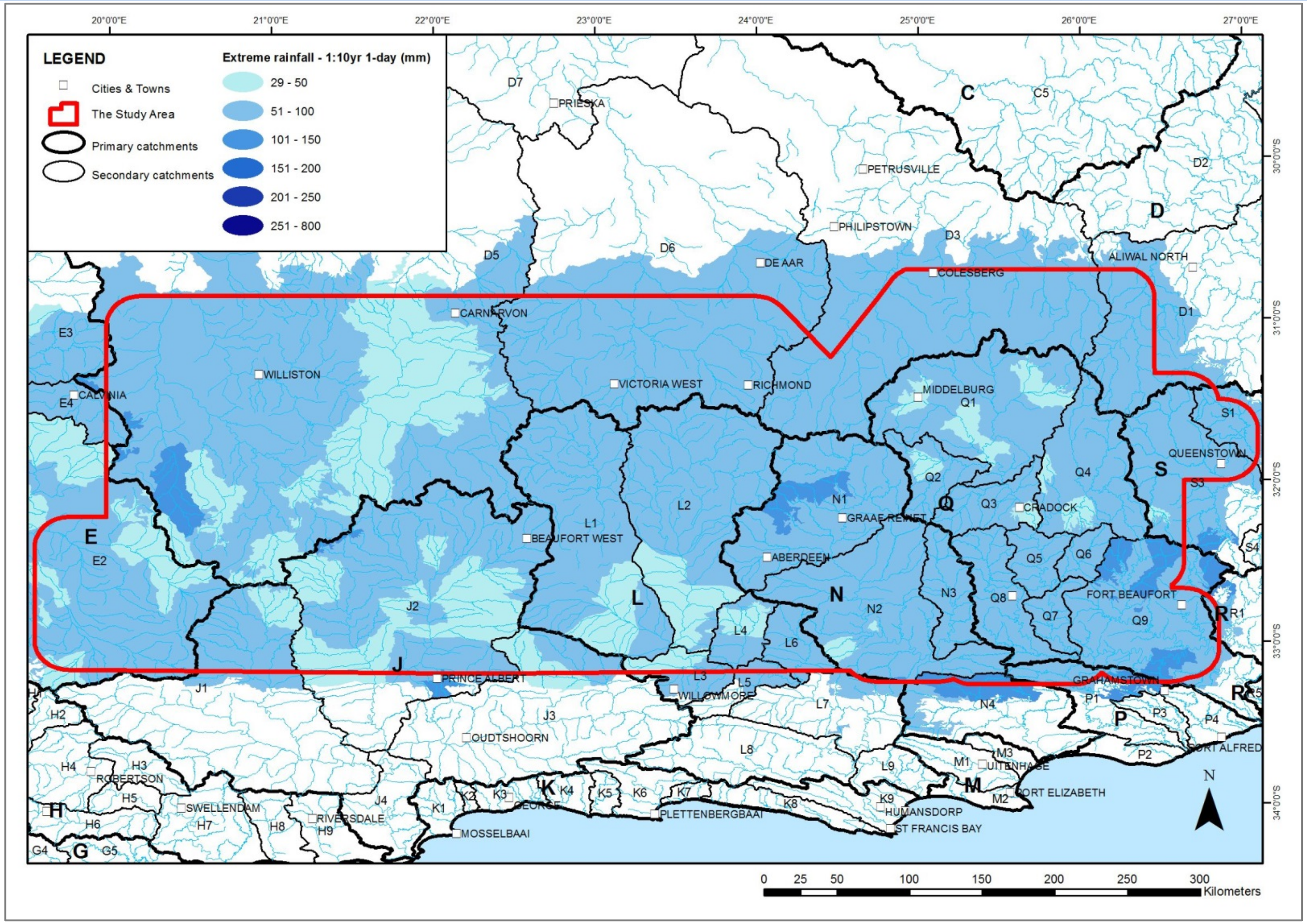


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Figure 5A1.16:*1 in 10 Year 1-Day Rainfall (mm)*
Values are generally in the range of 50-100 mm on a given day. Original Data Source: Schulze (2012).

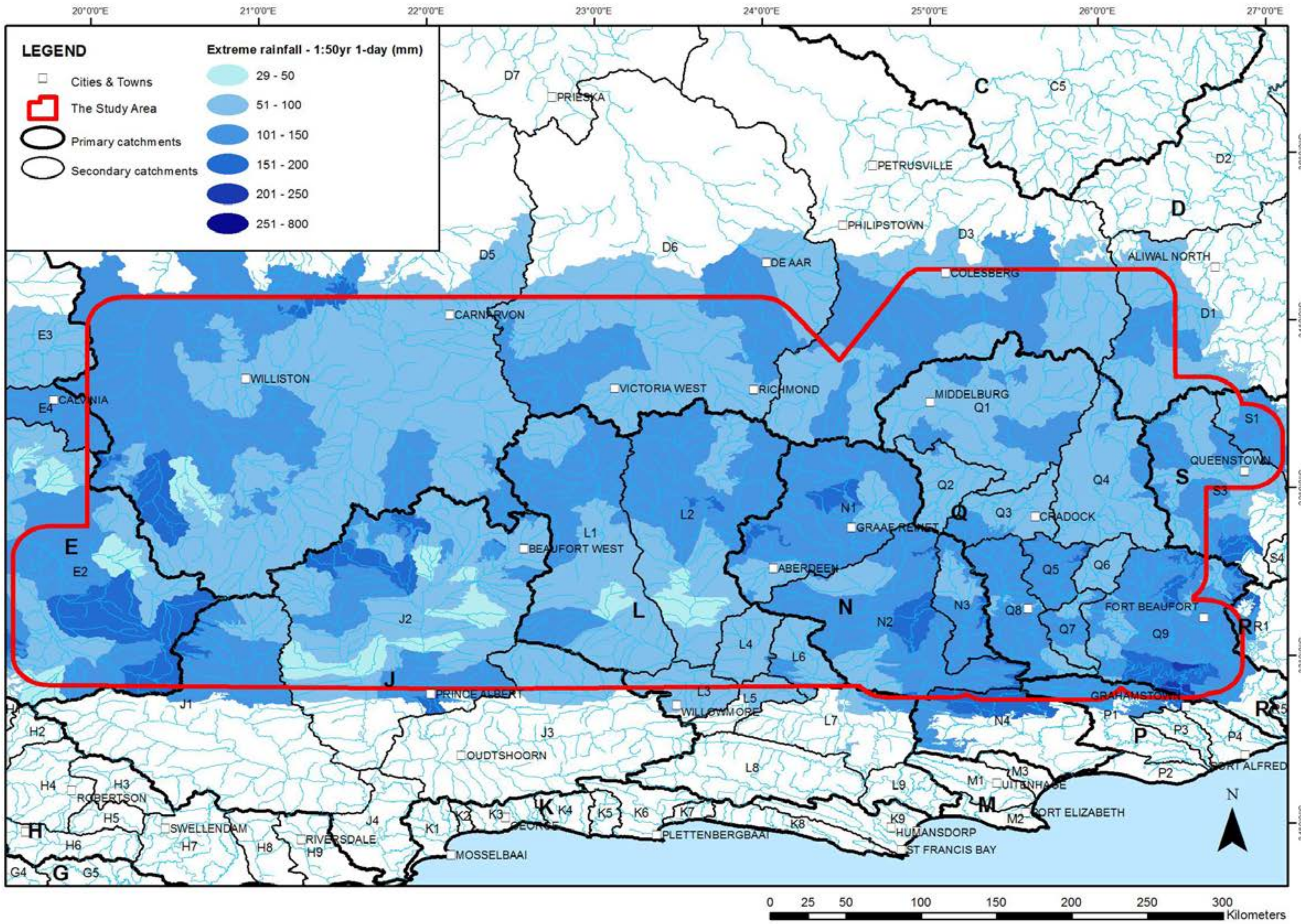

Figure 5A1.17:*1 in 50 Year 1-Day Rainfall (mm)*
Statistically, twice per century this region can expect a daily rainfall between 50 and 150 mm. Original Data Source: Schulze (2012).

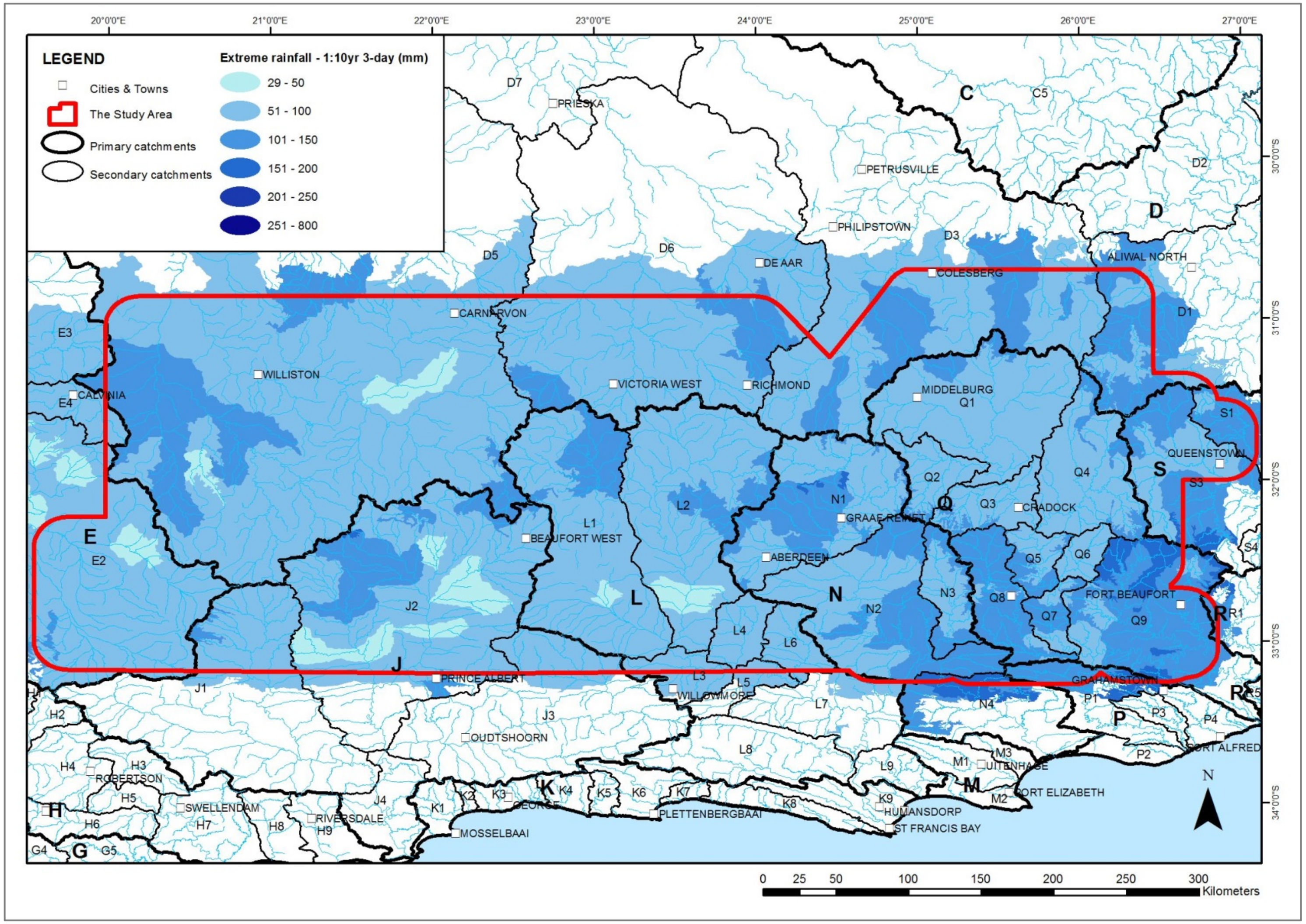

Figure 5A1.18:*1 in 10 Year 3-Day Rainfall (mm)*
For three consecutive days, rainfall values once in 10 years are generally in the range of 50-150 mm. Original Data Source: Schulze (2012).

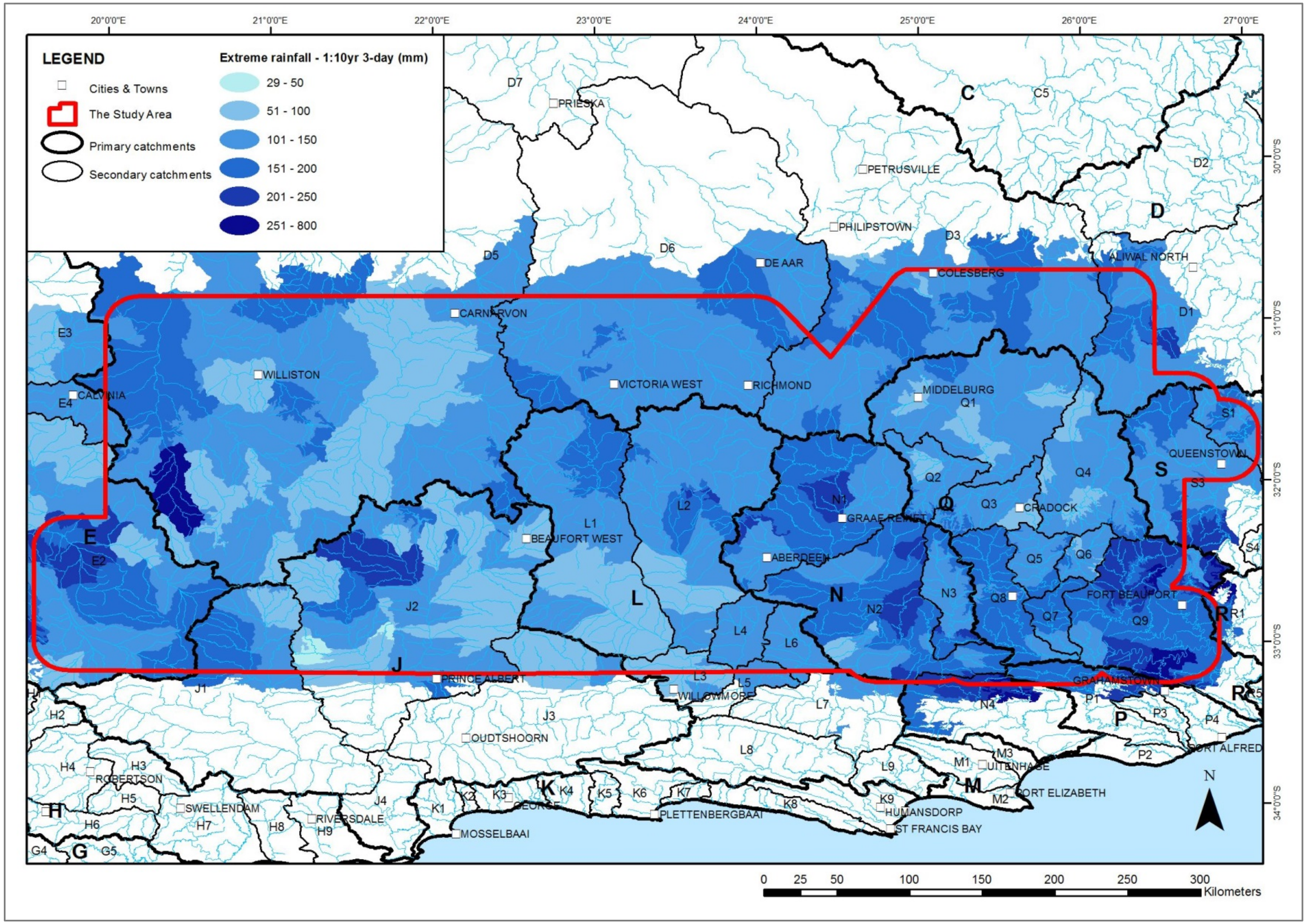

Figure 5A1.19:*1 in 50 Year 3-Day Rainfall (mm)*

For three consecutive days, rainfall values once in 50 years are generally much higher and in the range of 100-200 mm, with the potential to create major disruptions and damage. Original Data Source: Schulze (2012).

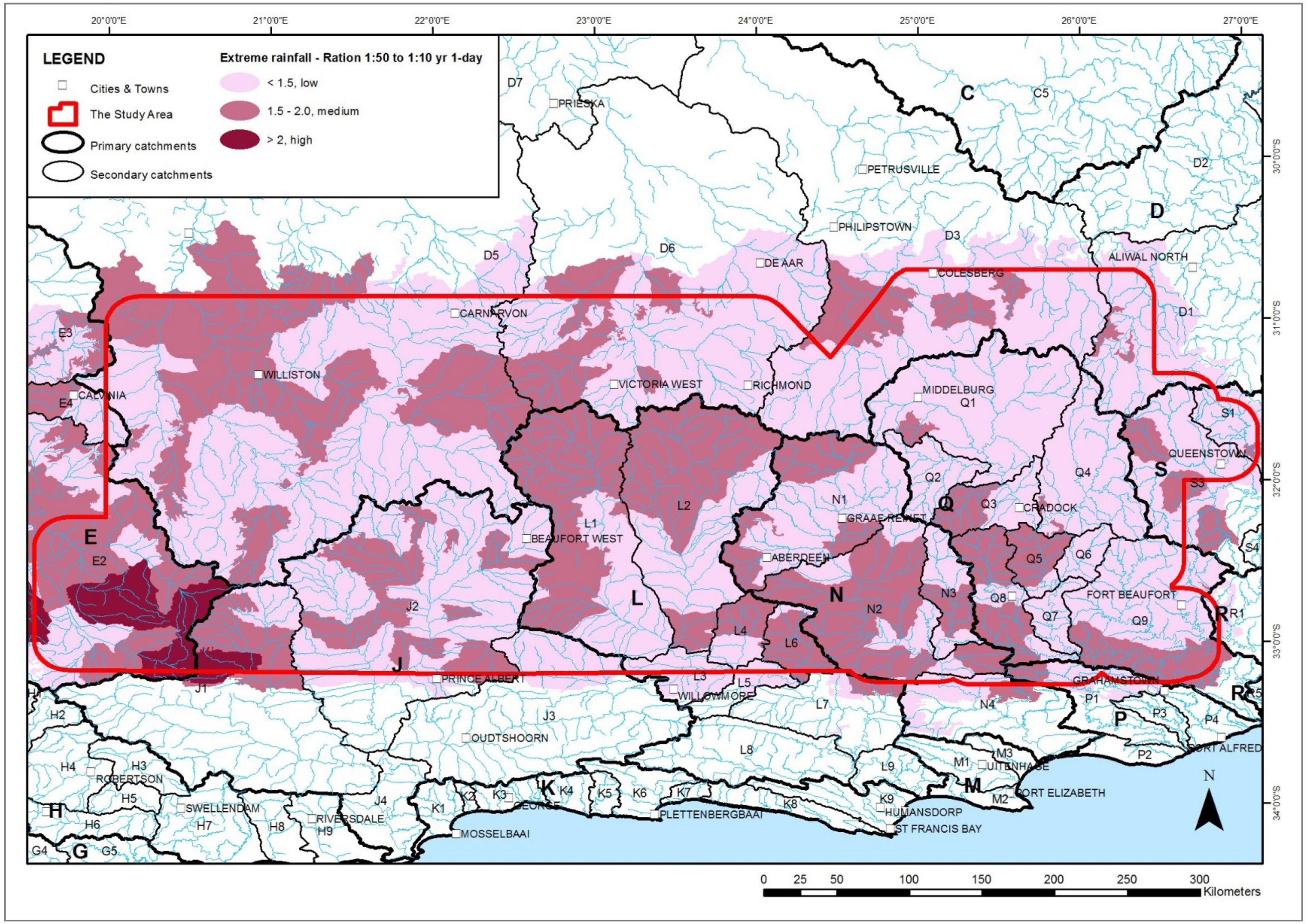

Figure 5A1.20:*Ratio of the 1:50 to 1:10 Year Extreme 1 Day Rainfall*

This ratio identifies particularly vulnerable areas, with a high ratio of the very rare event (1:50 year) to the less rare (1:10 year) event indicating very rare events being "shock" events. The highest ratios are in the south-west. Original Data Source: Schulze (2012).

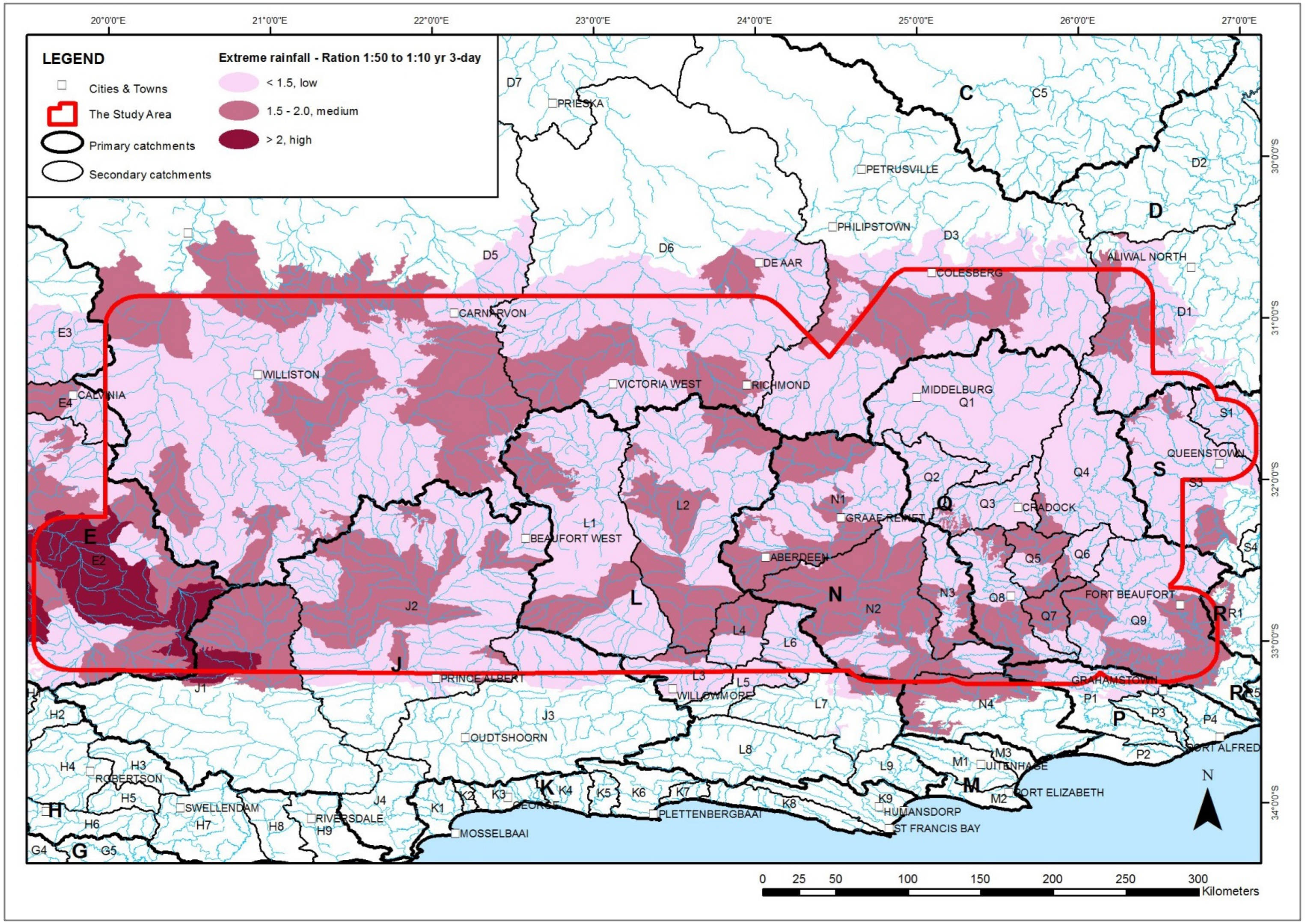

Figure 5A1.21:*Ratio of the 1:50 to 1:10 Year Extreme 3 Day Rainfall*
For longer duration rainfalls the spatial distributions of these ratios are similar to those of the one day events. Original Data Source: Schulze (2012).

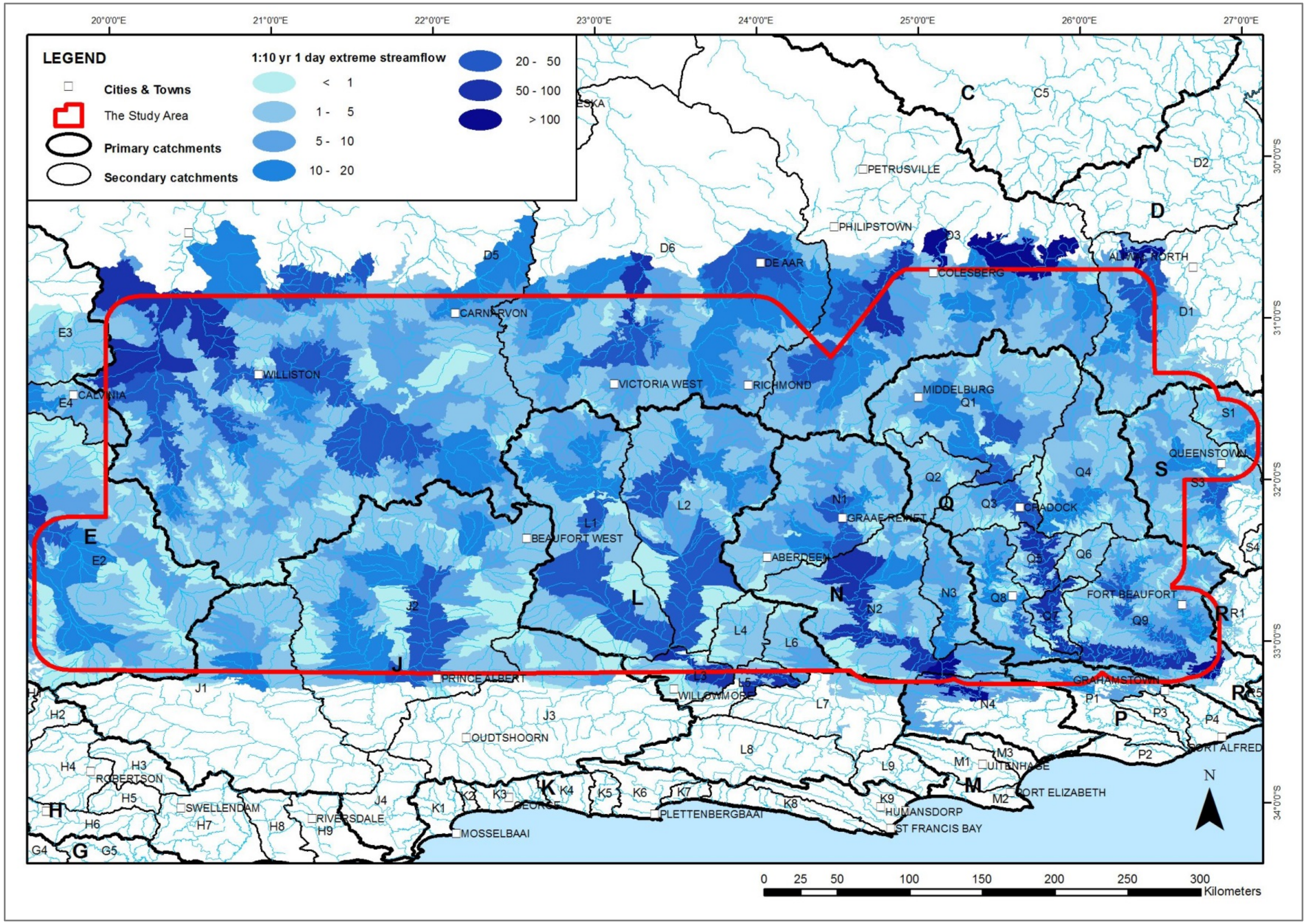

Figure 5A1.22:*1 in 10 Year 1-Day Streamflow ($10^6 m^3$)*

Values range very widely as streamflows are accumulated and presented in cubic metres of water. Clearly visible are the larger rivers with their higher accumulated values of extreme events as one moves downstream and flood waters from tributaries are added. Original Data Source: Schulze (2012).

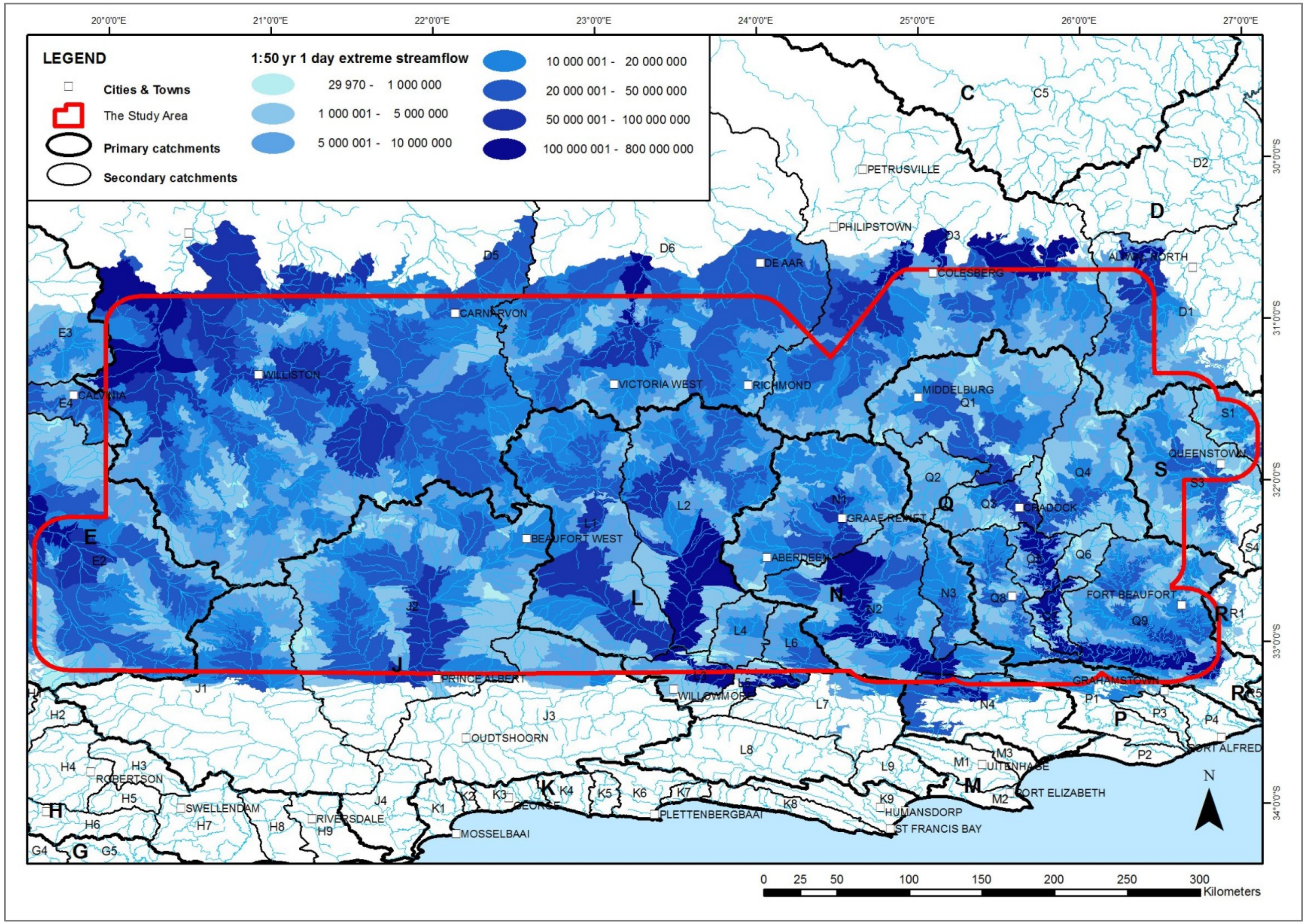

Figure 5A1.23:*1 in 50 Year 1-Day Streamflow ($10^6 m^3$)*
These very rare events display considerably higher flooding than the 1: 10 year equivalents, illustrating again the non-linearity of the hydrological system. Original Data Source: Schulze (2012).

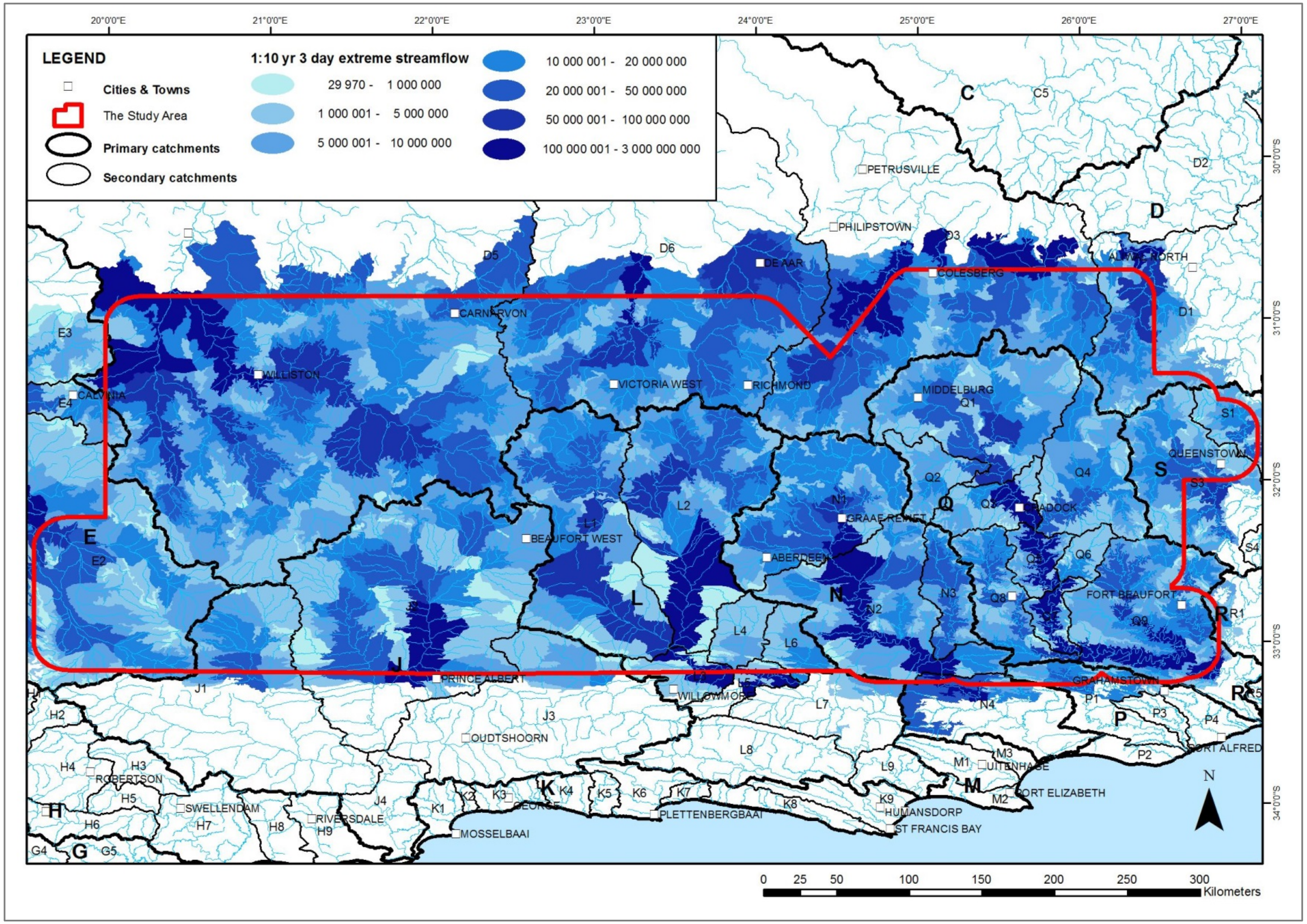

Figure 5A1.24:*1 in 10 Year 3-Day Streamflow ($10^6 m^3$)*
In terms of high flows, the 1:10 year three day flood is more or less equivalent to the 1: 50 year one day flood. Original Data Source: Schulze (2012).

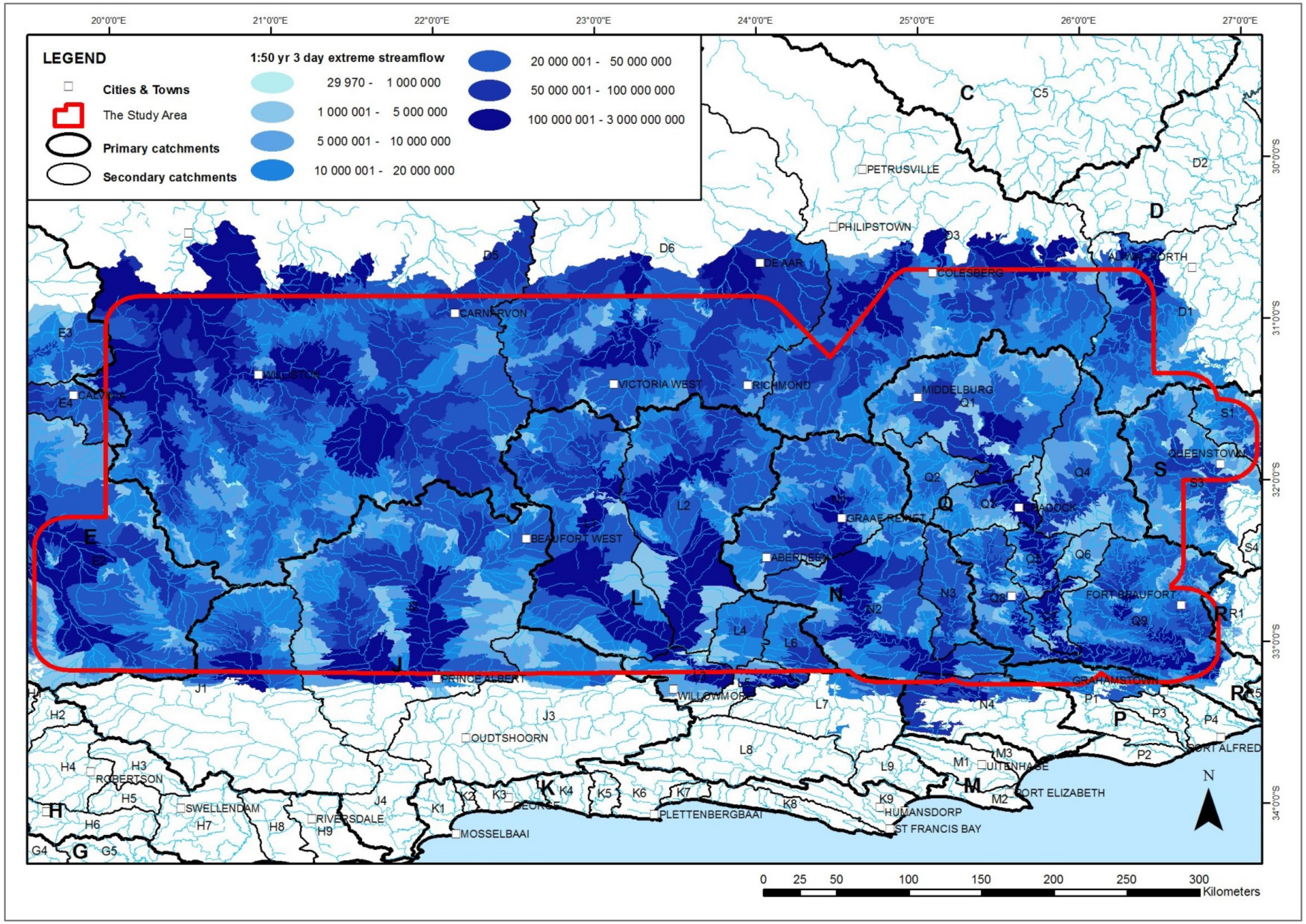

Figure 5A1.25:*1 in 50 Year 3-Day Streamflow ($10^6 m^3$)*

The three day very rare 1: 50 flood is considerably higher and more damaging than the 3 consecutive day less rare 1 : 10 year flood, showing again the amplification of the hydrological system. Original Data Source: Schulze (2012).

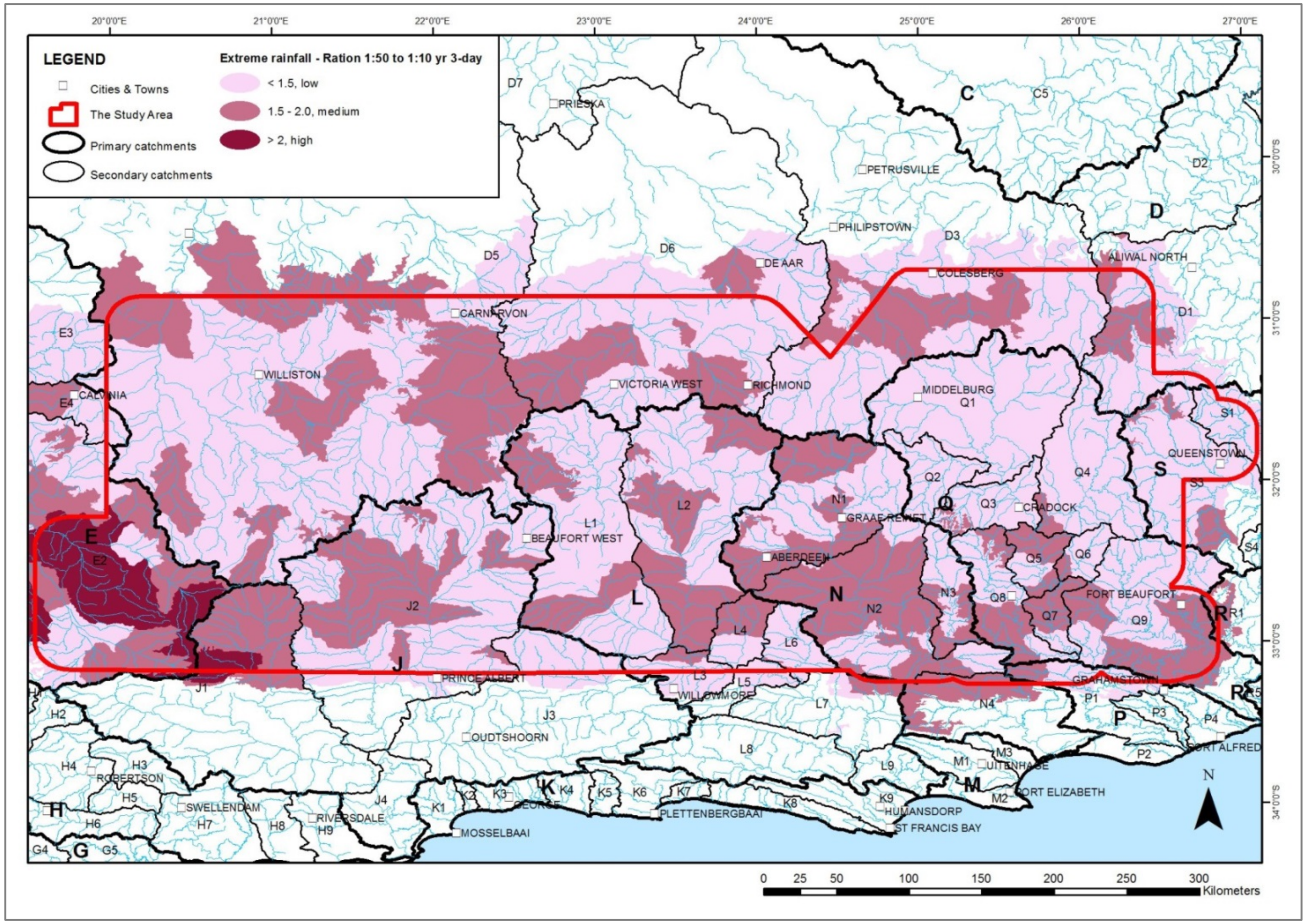

Figure 5A1.26:*Ratio of the 1:50 to 1:10 Year Extreme 3 Day Streamflow*

When this streamflow ratio is compared to its equivalent for rainfall, the high ratios, indicating highly vulnerable areas, cover considerably more of the study area than in the case of rainfall. Once again, this illustrates the rainfall to streamflow amplification that exists in the hydrological system, particularly for higher order statistics such as variability and extremes. Original Data Source: Schulze (2012).

Landuse: Sediment Yield

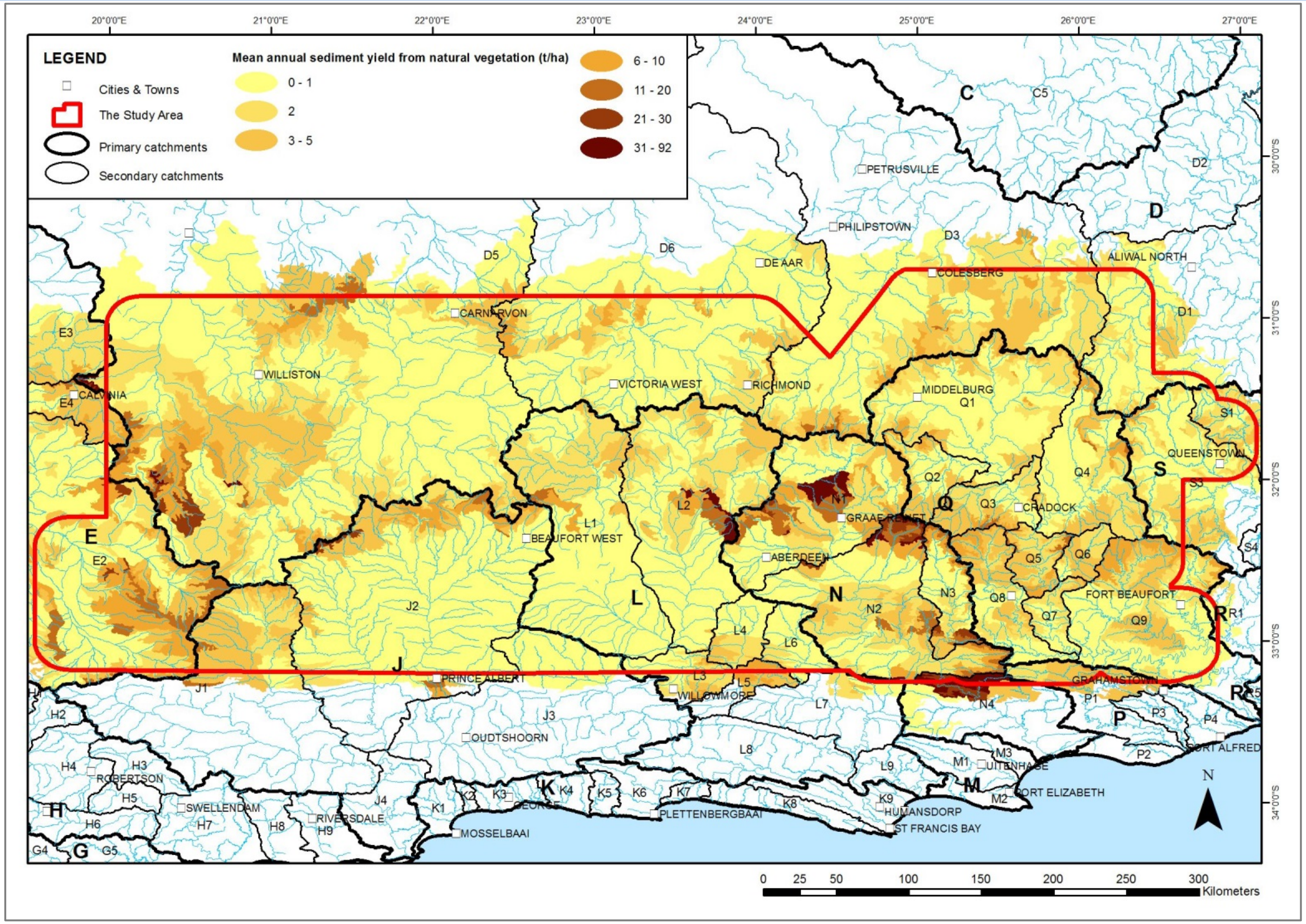

Figure 5A1.27:*Mean Annual Sediment Yield (t/ha)*

Sediment yield has been computed for a natural vegetation land cover with the Modified Universal Soil Loss Equation(MUSLE) on a daily event-by-event basis considering, inter alia, daily stormflow(when it occurs; as a variable to capture the transport of sediment), daily peak discharge on a day with stormflow (as a variable to capture the dislodging of soil), the intrinsic erodibility of the local soil, slope gradient and slope length, as well as intra-annual above-ground and ground level land cover information for natural vegetation.

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Schulze, R.E., Horan, M.J.C., Kunz, R.P., Lumsden, T.G. and Knoesen, D.M. 2010. Methods 2: Development of the Southern African Quinary Catchments Database. In: Schulze, R.E., Hewitson, B.C., Barichievy, K.R., Tadross, M.A., Kunz, R.P., Horan, M.J.C. and Lumsden, T.G. 2010a. Methodological Approaches to Assessing Eco-Hydrological Responses to Climate Change in South Africa. Water Research Commission, Pretoria, RSA, WRC Report 1562/1/10. Chapter 7, 63-74.

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ADDENDUM 5B SECTIONS 88 AND 122 OF THE MINERAL AND PETROLEUM RESOURCES DEVELOPMENT ACT, 2002 (ACT NO. 28 OF 2002)

88. Water resource monitoring

(1) An applicant or holder must appoint an independent specialist to conduct a hydrocensus fulfilling the standard requirements of the department responsible for water affairs which indicates potentially affected water resources, on at least, a 3 kilometres radius from the furthest point of potential horizontal drilling, as well as identify priority water source areas and domestic groundwater supplies indicated on relevant geohydrological maps.

(2) An applicant or holder must prepare and submit, together with the water use licence application, to the department responsible for water affairs, a proposed water resource monitoring plan, for approval. The plan must at least identify-

(a) the sampling methodology;
(b) the monitoring points;
(c) the monitoring parameters;
(d) the monitoring frequency; and
(e) the reporting frequency.

(3) The monitoring plan contemplated in sub-regulation (2) must be submitted to the competent authority for consideration, as part of the application for Environmental Authorisation.

(4) Water samples collected as part of the monitoring plan contemplated in sub-regulation (2) must be analysed by an accredited laboratory and the holder must submit the results and their interpretation to the designated agency and the department responsible for water affairs within 7 days after receipt thereof.

(5) The results must at least include a detailed description of the sampling and testing conducted, including duplicate samples, the chain of custody of the samples and quality control of the testing.

(6) A full water monitoring report must be included in the EMPr required in terms of the Environmental Impact Assessment Regulations, 2014.

(7) A holder must, after conducting a baseline water quality assessment, continue with monitoring in accordance with the approved plan and must-

(a) have the water resources subjected to sampling, analysis and interpretation of water quality and changes in water levels by an independent specialist approved by the designated agency in accordance with the approved plan contemplated in sub-regulation (2);
(b) submit the results of the analysis and interpretation to the designated agency and the department responsible for water affairs within 7 days of receipt of the analysis and interpretation; and
(c) submit the monitoring assessment reports in accordance with the approved monitoring plan contemplated in sub-regulation (2).

(8) (a) The designated agency, Council for Geoscience, Council for Scientific and Industrial Research, designated local authorities or the department responsible for water affairs, may collect samples of fluids encountered in the exploration or production area (water or hydrocarbons, at depth or at the surface) for their own analysis and interpretation.

(b) The holder must allow site access to the authorities mentioned in paragraph (a) for the purpose of collecting the samples.

(9) Data collected as contemplated in this regulation must be published except where it may be shown to directly relate to the availability of petroleum and commercial value of the holder's acreage.

(10) Groundwater aspects must be recorded and reported according to the department responsible for water affairs' Standard Descriptors for Geosites.

(11) The holder must capture the water resource data generated into the relevant department responsible for water affairs' databases.

122. Protection of water resources

(1) A holder must, prior to and during all the phases of drilling and hydraulic fracturing operations, ensure that the operation does not pollute a water resource or reduce such a resource and where such an incident occurs, a holder must implement the necessary remedial measures;

(a) the operation does not cause adverse impact to water quality in the catchment area; and

(b) the rights of existing water users are protected.

(2) A well site where hydraulic fracturing operations are proposed or planned, must not be located-

(a) within 5 kilometres, measured horizontally, from the surface location of an existing municipal water well field and identified future well fields and sources and directional drilling may not be within 2.5 kilometres of municipals well field;

(b) within 500 metres, measured horizontally, from the surface location of an existing water borehole and directional drilling may not be within 500 metres of the borehole; and

(c) within 500 metres, measured horizontally, from the edge of a riparian area or within 1:100 year flood -line of a watercourse.

(3) A well may not be drilled within 1 kilometre of a wetland.

(4) A holder must undertake regular water quality testing as determined by the department responsible for water affairs.

ADDENDUM 5C SUBSTANCES THAT HAVE BEEN DETECTED IN FLOWBACK WATER BUT NOT IN DRILLING OR FRACKING FLUIDS, AND THEREFORE ASSUMED TO BE DERIVED FROM UNDERLYING SUBSTRATES

Compound	Source	Toxicity	Comments
Brines	Deep formations	Renders water undrinkable; Hazardous to surface and groundwater ecosystems	Potentially a problem in parts of the Karoo
Metals (e.g. barium, strontium)	Desorbed from deep clays	Barium itself extremely toxic; some salts (e.g. barium sulfate, used in “barium meals” not toxic but some (e.g. barium carbonate) extremely toxic when swallowed because stomach acid releases barium ions)	Barium is also sometimes used in the fracking process
Volatile organic compounds (e.g. toluene, benzene, xylene)	Found in surface waters near some fracking operations but said not to be used in the process	Extremely toxic: effects particularly on the central nervous system	Not clear if these substances used in fracking and not declared, or they are displaced from underground by the fracking process
Radioactivity	Deep rocks	Dose-dependent	Needs to be monitored in all flowback fluids

ADDENDUM 5D DEFINITION OF BUFFER/SETBACK ZONES FOR DYKES AND THERMAL SPRINGS (ADAPTED FROM WOODFORD (2012))

Definition of buffer/setback zones

The objective of this assessment is to provide a preliminary guideline for establishment of Buffer/Setback Zones around dolerite dykes and thermal springs in the Karoo Basin. The current understanding is that these exploration holes will be drilled vertical and that hydraulic fracturing tests will be conducted in the vertical holes (i.e. that no horizontal holes will be drilled). It is likely that some of the exploration holes will be realigned at the targets depths (1 500 to 4 500 m) to develop single, horizontal holes extending up to 1 500 m from the drill pad for assessment of the ‘fracking’ conditions and gas flows.

Dolerite dykes

Dolerite dykes are vertical to sub-vertical discontinuities that, in general, represent thin, linear zones of relatively higher hydraulic conductivity which act as conduits for groundwater flow within Karoo fractured-rock aquifers. However, they may also act as semi- to impermeable barriers to the movement of groundwater.

The common characteristics of Karoo dolerite dykes in the Main Karoo Basin (Woodford and Chevallier, 2002b) are:

- The majority of the dolerite dykes are stratabound and concentrated in the Upper Ecca and Beaufort stratigraphic units, which means that certain dykes may have propagated laterally along strike.
- Dolerite dykes typically range in width from 3 to 15 m. Enslin (1951) noted that dolerite dykes are seldom wider than 20 m. Dykes with widths of less than 3 m usually represent short, shallow-seated intrusions, whilst the more extensive, regional dykes are typically significantly thicker (i.e. an E-W ‘shear’ dyke north of Victoria West is c.65 m wide, the width of the ‘Gap’ dykes in the Eastern Karoo Basin often exceed 100 m) and can extend over lengths in excess of 300 km.
- Kruger and Kok (1976) evaluated the drilling results for 177 boreholes drilled on dykes in the north-eastern Free State and found a relationship between the dyke width (assessed range 4.5 to 14m) and borehole airlift yield (assess range 2 – 5 L/s), and concluded that the highest yields were obtained on dykes ranging in width between 7 and 11 m. Vandoolaeghe (1980) found that in the Queenstown area (Eastern Karoo) higher yields are generally obtained alongside dykes that are wider than 5 m.
- The dip of dykes generally range from 80º to vertical. Shallower dipping intrusions correspond more to inclined sheets and ring-feeder dykes.
- Extensive, regional dykes often exhibit en-échelon segmentation, where the segments are co-planar to the main strike of the intrusions (with angles of less than 10º).
- Typically, groundwater is intersected in a relatively narrow fracture zone developed along the dyke contacts. The width of this zone of jointing, thermal metamorphism (‘baking’) and weathering alongside dykes remains fairly constant, averaging ~5 m, and is largely independent of dyke width.
- Sub-horizontal ‘open’ fractures do occasionally transgress some dykes and they may extend up to tens of metres away from the dyke contact into the country rock. These transgressive fractures are thought to be related to thermal cooling, hydrothermal activity and/or erosional

unloading following intrusion. They are therefore expected to be confined to the near surface (i.e. upper 200 m).

- Thermal joints or cooling cracks develop perpendicular to the cooling surface of the dyke and their strike is therefore sub-horizontal. They affect the sediments in the host rock over relative short distances of only a few metres.
- Many dykes show signs of later tectonic reactivation (possibly associated with hydrothermal events). Such dykes are typically well fractured and display a brittle and brecciated aspect. The sediment is also affected over a distance of 5 to 10 m from the contact. In the western and central Karoo, tectonic reactivation seems to be a common feature of NNW trending dykes.
- On a regional scale there is a close correlation between the extensive NNW trending dykes and ‘corridors’ of fracturing, these are thought to be associated with the prolongation of mega-joints in the Cape Fold Belt. Systematic NNW (N150º to N170º) joints are very conspicuous in the western and central Karoo Basin.
- The regional E-W orientated dykes of the western and central Karoo Basin, as well as the associated N110º, N150º and N70º fracture systems, display a pattern in accordance with a typical right lateral shear zone. During emplacement of these dykes the maximum compressive stress was vertical, and therefore all fracture orientations could potentially be ‘open’.
- Dyke contact aquifers are typically semi-confined and immediate borehole yields in the order of 2 to 5 L/s are relatively common.
- There is considerable debate concerning to what distance away from a dyke the host rock is metamorphosed and jointed - thereby affecting the yield of boreholes drilled into this zone. Campbell (1975) referred to a ‘rule-of-thumb’ width of less than 3 m. Enslin (1951) found that the highest borehole yields are obtained within 1 m of the dyke contact. It must be noted that because in the field the distance from the dyke is measured at the surface, the dip of the dyke must also be considered.

GIS methodology for defining buffer/setback zones

The following GIS-based methodology is proposed for defining Buffer/Setback Zones around dolerite dykes and is based on the general assumption that the length of the dyke is related to its vertical extent with depth (i.e. the longer the dyke, the greater its depth of origin):

- It is assumed that the mapped 1:250 000 scale dolerite dyke dataset will initially be used to establish the Buffer/Setback Zones. Unfortunately, the dykes are often not mapped as continuous features as they are often ‘masked’ by overburden, exhibit small scale offsets etc. Therefore, it is necessary to review each dyke passing through an area of interest and, if necessary, to manually ‘join’ all co-linear dyke segments to form a single contiguous dyke feature (i.e. a single poly-line) and thereby obtain an estimate of the ‘actual’ length of the dyke (or dyke ‘corridor’ in the case an en-échelon dyke systems). Satellite and/or aerial photograph (Google Earth) imagery, or geophysical data (i.e. the CGS aeromagnetic ‘fabric’ map) could be used to assist with this process. Importantly, in order to obtain the best estimate of dyke length, it will be necessary to ‘trace’ the dyke beyond the boundary of the AoI. The GIS is then used to assign a length (D_L, m) to each ‘re-mapped’ dyke (it is recommended that ArcGIS’s COGO routine be used to estimate dyke length, as it will also calculates other useful parameters such a dyke ‘curvature’ and orientation). It should be noted that the 1:250 000 dyke dataset includes some complex, curvi-linear features that are not dykes but rather inclined sheets or narrow, sub-horizontal sill outcrops mapped in steep sided valleys (particularly in the Ecca Group) that should be excluded from the dataset.
- It is assumed that the mapped dyke is linear in outcrop and therefore the its dip is only likely to vary between 85º and 89º, and then the following power functions are then applied to each dyke

to estimate the width of its Buffer/Setback Zone (i.e. width by which to buffer the dyke):

- $EZ_{85^\circ} = \left(0.186 \times D_L^{0.65}\right) + \frac{D_W}{2}$ .... Equation 1
- $EZ_{89^\circ} = \left(0.046 \times D_L^{0.65}\right) + \frac{D_W}{2}$ .... Equation 2

Where EZ - width of Buffer (metres)
D_L - Length of Dyke (metres)
D_W- Dyke Width

The dyke width can either be measured directly in the field, estimated from high-resolution aerial photography or aeromagnetic imagery, or by using of the following equation:

$D_W = 0.1 \times D_L^{0.54}$ .... Equation 3

- If the estimated width of the calculated dyke EZ is <50 m, then it should be set to 50 m (i.e. the minimum EZ is 50 m). This minimum EZ value is prescribed to account for spatial accuracies in location of the dyke (i.e. 1:250 000 scale dyke GIS dataset) and uncertainties related to the subsurface geometry and fracturing of the dyke.

- It must be note that the relationship between dyke length and dyke vertical extent used in developing Equations 1 and 2 is based on the assumption that such a relationship exists in reality and using 'values' based purely on the authors experience ("gut feel"). It is recommended that following GIS assessment be conducted to provide a 'reality check' before they are implemented:
  - The process described above for defining 'true' dyke (corridor) lengths (D_L) be applied to various length and orientation dykes within the western and central Karoo Basin, especially selecting those that trangress topographic features and lithostratigraphic units (i.e. the E-W 'shear' dyke just south of Calvina extends through the Karoo sequence, down the Van Rhynsdorp Pass, and into to underlying Nama Group, the NNW Middelburg ('Dublane') dyke etc.).
  - These dykes (polylines) should be buffered (by c.50 m) and converted to ArcGIS GRIDS, which are then intersected with the SRTM90 Digital Terrain Model (DTM) and lithological units. This will produce an output GRIDs (or 'Fishnet' polygons) wherein each dyke has a unique ID and can be interrogated for length, minimum and maximum elevation and lithostratigraphic units intersected.
  - The relationship between dyke length and 'minimum' vertical thickness (maximum – minimum elevation along dyke length) can be assessed, as well as the relative density of dykes within the various lithostratigraphic units (particularly the 'target' Ecca Units).
- Similarly, Equation 3 was developed based purely on the authors experience and the values used to define the relationship between dyke length and dyke width have not been verified using actual values from mapped dykes.

At this stage two '*EZ*' functions are provided with the idea that some testing of the method needs to be conducted within selected AoIs' and that the ArcGIS COGO 'curvature' value (as a rough guide to dyke dip) will be assessed and used to define which function to apply (i.e. low 'curvature' use Equation 2 and moderate 'curvature' use Equation 1). Based on the results of the proposed test work, it may be possible to incorporate the actual COGO 'curvature' value directly into a single equation that accounts for variations in dip.

The two power functions (Equations 1 and 2) defining a Buffer Zone' width envelope for various lengths of dyke are presented in **Figure 1**.

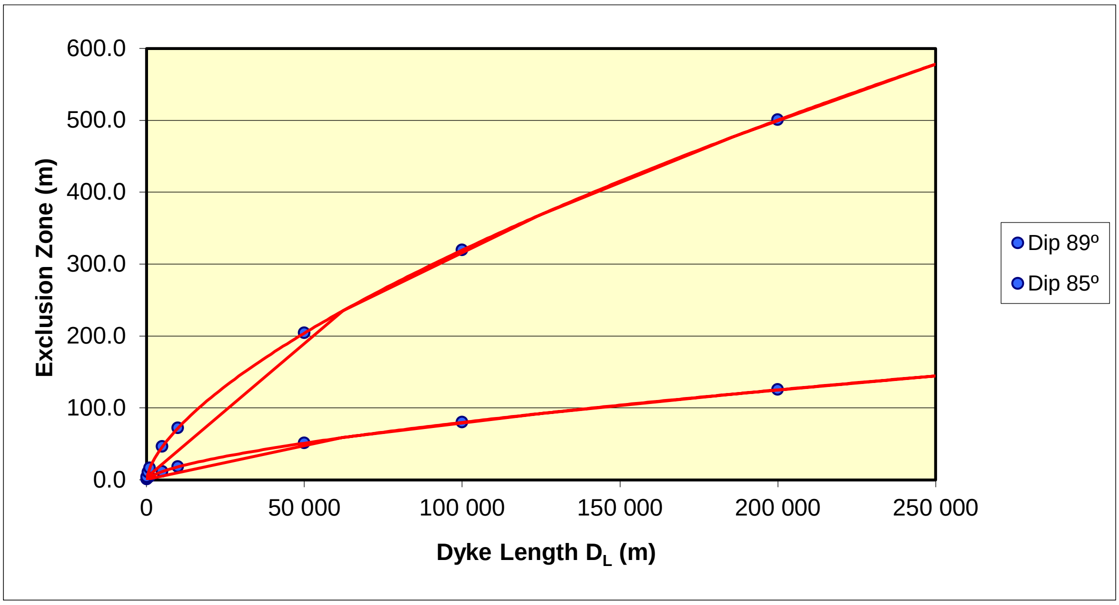
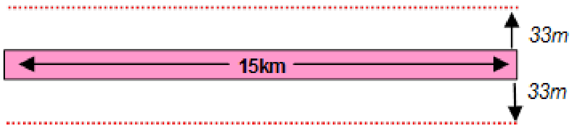


Figure 1: Width of Buffer Zone versus Length of Dyke

Example: if a near linear (in outcrop) dyke is 15 km long, then it is assumed that it is almost vertical and Equation 2 is used to estimate a Buffer Zone width of 33 m (See schematic below). If however, the dyke is curvi-linear in outcrop (less steeply dipping), then Equation 1 is used and the estimated EZ is then 105m. Note, in the case of Equation 2 being applicable, the *EZ* would be adjusted from 24 m to the recommended minimum of 50 m.



Thermal spring

Groundwater temperatures may be used as an indicator of the depth of groundwater circulation and therefore the relative scale of flow within the aquifer system. In reality, the depth may be greater because cooling typically takes places during upward flow along fractures to the surface.

Jones (1992) found that the geothermal gradients in South Africa vary from as low as 8°C/km to as much as 40°C/km, whilst a value of 30°C/km is more typical for Karoo rocks.

In order to define a Buffer Zone about the 'eye' of a thermal spring (EZ_{SP}), it is proposed that the minimum source depth of the spring be used to calculate a circular zone (i.e. assumes not significant regional hydraulic gradient) about the 'spring, as follows:

$$EZ_{SP} = \frac{T_{GW} - T_{MA}}{G_T} \times \arctan(\phi) \quad \text{....... Equation 4}$$

Where

EZ_{SP} - Radius of the circular Buffer Zone at the surface.

T_{GW} - Temperature (ºC) of thermal spring.

T_{MA} - Mean Annual Air (ºC) (possibly use Schulze's climatological dataset).

Possibly use the average temperature of the shallow (5-10 m below water table) groundwater.

G_T - Geothermal Gradient (ºC/m) for Karoo Basin (assumed 0.03ºC/m)

Ø - Angle (See **Figure 2**), currently assumed to be 30º, to take account potential dip / width of fracture system (tortuous preferential flow path) from source to surface.

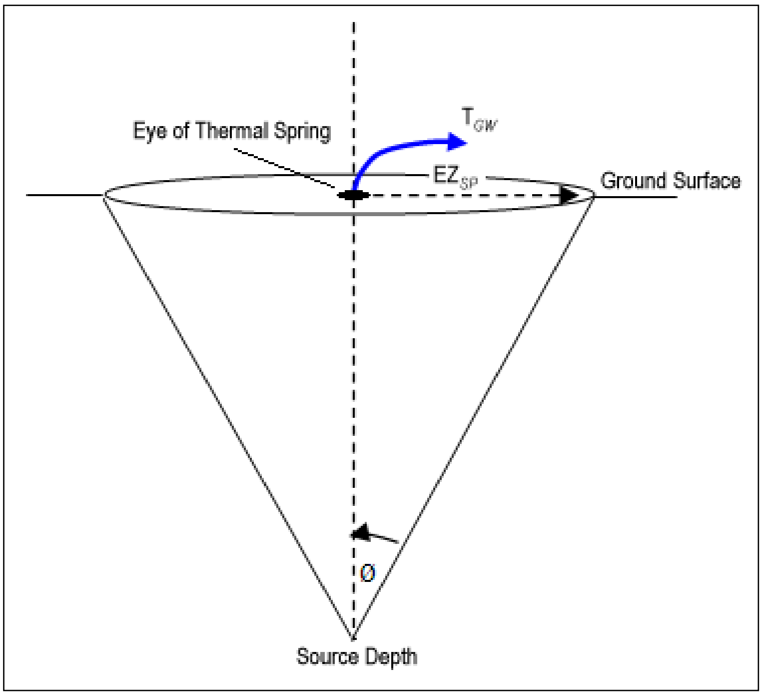


Figure 2: Circular 'Exclusion Zone' around Hydrothermal Spring

Example: Thermal spring with water temperature of 36ºC and mean annual air temperature of 24ºC. The radius of the Buffer Zone (EZ_{SP}) is estimated at c.230 m.

Geothermal Gradient =	25	ºC/km
Mean Annual Temperature =	24	ºC
Groundwater Temperatures =	36	ºC
Minimum Source Depth =	480	m
Angle Theta =	30	º
Radius Exclusion Zone	232	m

References

Ozkaya, S.I. 2009. *Use of Exclusion Zones in Mapping and Modeling Fracture Corridors*, Society of Petroleum Engineers, paper presented at the 'Oil and Gas Show & Conference', Bahrain, 15-18 March 2009, 11p.

Woodford, A.C. & Chevallier, L. 2002a. Regional Characterization and Mapping of Karoo Fractured Aquifer Systems – An integrated Approach using Geographical Information Systems and Digital Image Processing, Water Research Commission, Report No. 653/1/02, 192p.

Woodford, A.C. & Chevallier, L. (eds.). 2002b. *Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs*, Water Research Commission, Report No. TT 179/02, 466p.

Xu, Y. & van Tonder, G.J. 2002. Capture Zone simulation for boreholes located in Fractured Dykes using the Linesink Concept, *Water SA*, *28*(2), 5p.

ADDENDUM 5E FIGURES SHOWING APPLICATION OF SETBACKS TO PROTECT SURFACE- AND GROUNDWATER RESOURCES

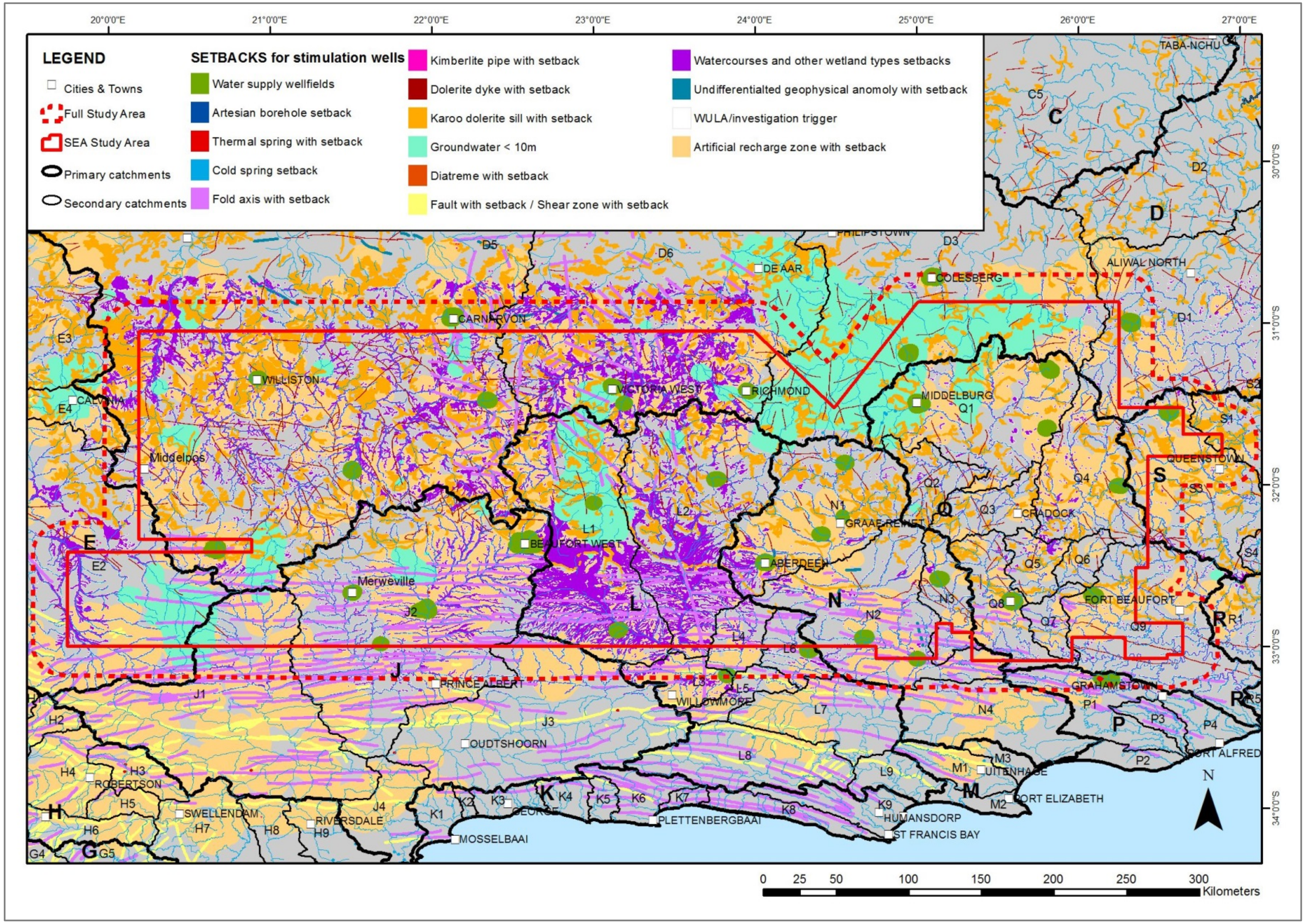


Figure 5A5.1: Recommended setbacks for stimulation well activities – differentiating between different setback or exclusion zones /areas.

Map showing remaining areas (grey) in which well stimulation (fracking) activities might take place without impacting significantly on known surface and/or groundwater resources. Shaded (non grey) areas variously comprise those areas in which some risk to water resources is potentially possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard to those of mapping scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). In addition, dolerite dykes have been accorded a minimum setback of 250 m which might not always apply – these features must be mapped and buffered with better levels of resolution in any SGD planning. Setbacks shown here illustrate the setback distances recommended in Table 5.8. Note: Not all features in this table are represented in this figure, only features for which spatial data was available at the time of compilation of this chapter, are shown.

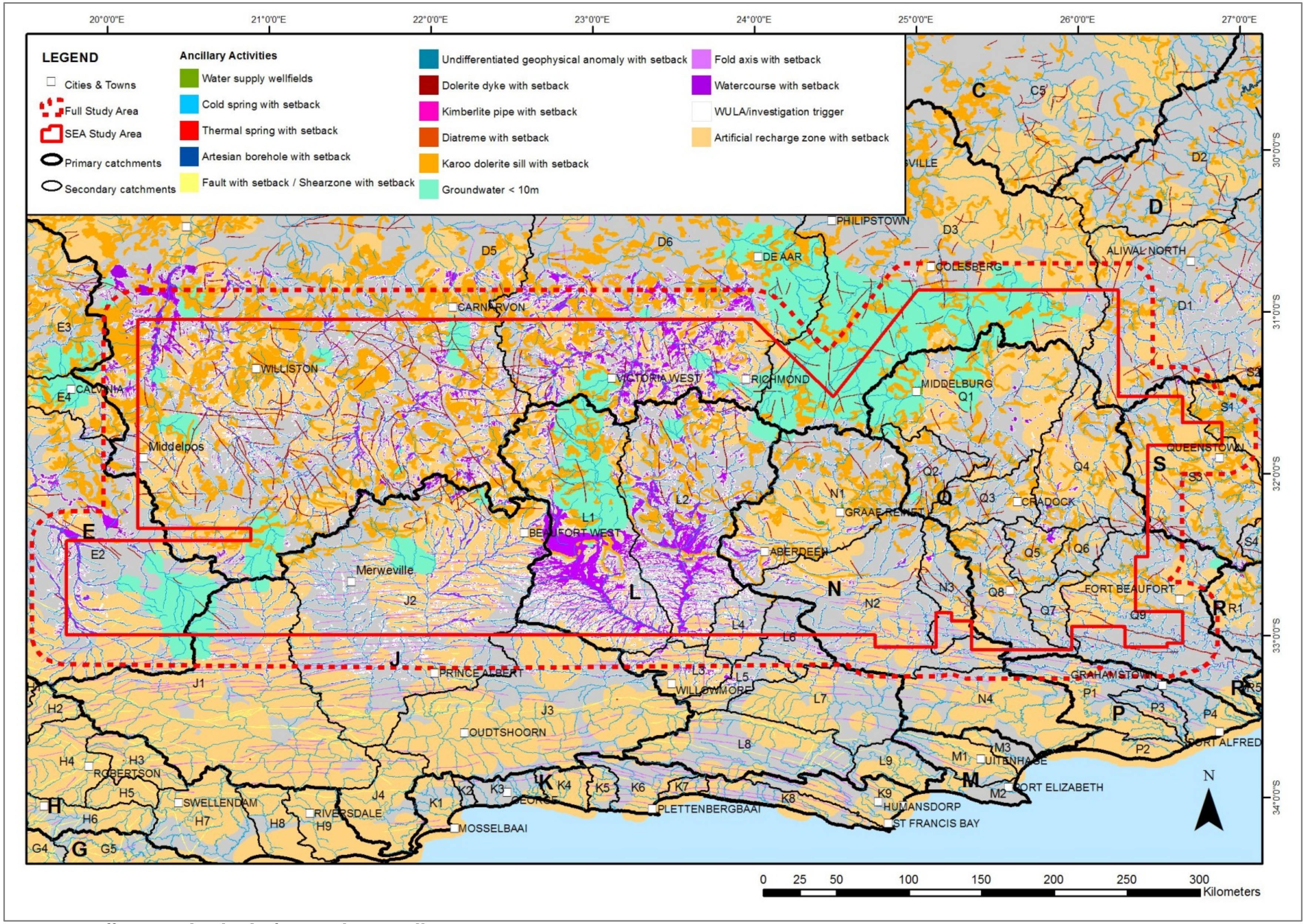


Figure 5A5.2: Differentiated setbacks for stimulation well activities.

Map showing remaining areas (grey) in which well stimulation (fracking) activities might take place without impacting significantly on known surface and/or groundwater resources. Other highlighted areas comprise those areas in which some risk to water resources is potentially possible, and if so, might have highly negative consequences. The figure must be interpreted in the light of known mapping constraints, with particular regard to those of mapping scale (some features mapped at a very small scale, while setbacks defined at a very fine scale). Setbacks shown here illustrate the setback distances recommended in Table 5.10. Note: Not all features in this table are represented in this figure, only features for which spatial data were available at the time of compilation of this chapter, are shown.

ADDENDUM 5F MONITORING FRAMEWORKS

5F(i) Monitoring Framework for Surface Water (from Esterhuyse et al., 2014)

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that needs to be monitored (WHY?)	• No possible impacts were identified during the pre-exploration phase. • It is, however, important to gather appropriate baseline information during this phase.	**Quality** • Increased runoff of contaminants such as diesel or constituents from fracking fluid. [1] • Water abstraction could lead to deterioration of water quality[2] in isolated pools. • Water quality deterioration due to sewage effluent from human settlements at exploration sites entering streams. **Quantity** • Removal of sand/sediment from rivers for proppant use would influence alluvial aquifers. • Water abstraction in conflict with current users. • Reduction of stream flow in perennial rivers.	**Quality** • Various sources of pollutants may contaminate surface water or have an impact on aquatic biota[3-7]. • Flowback water can contain high levels of TDS, waste water treatment works do not have the capacity to remove high levels of TDS, which could impact on receiving waterbodies. • Sewage effluent from drill pads could contaminate surface water systems. • Toxic or carcinogenic chemicals in fracturing fluid cocktail could contaminate surface water. • Increase in sediment could lead to high turbidity and associated impact on biota and water quality. **Quantity** • Water needed for hydraulic fracturing may impact on the natural hydrology of the resources. • Possible sand removal would impact on available surface water, especially during drought periods, in small tributaries and in non-perennial rivers.	**Quality** • Long term impacts of chemical pollutants on surface water uncertain, it may impact negatively on aquatic biota and fish. • Reduced fitness and health of fishes[9]. • Fish kills[9, 10]. • Reduction in the availability of food sources for fish, e.g. invertebrates. • Bioaccumulation of toxic substances in fish tissue[8, 11, 12], could also have an effect on food web.

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that needs to be monitored (WHY?) continued.	• No possible impacts have been identified during the pre-exploration phase. • It is, however, important to gather appropriate baseline information during this phase.	**Habitat** • Vibrations from seismic surveys may have an impact on invertebrate and fish abundance. • Increased sediment delivery to rivers would alter available habitat for biota. • Flash floods due to increased overland flow to rivers would increase disturbance to aquatic biota. • Fragmentation of aquatic habitat due to road crossings may disrupt fish migrations for feeding and breeding. • Loss of critical refuge habitat for biota during dry periods[8]. • Loss of biota diversity due to the combined effect of increased sedimentation, turbidity and fragmentation[8]. • Reduction in the fitness and health of aquatic biota due to increased predation, intra- and interspecific competition and crowdedness in isolated pools.	**Habitat** • Destruction of pans results in genetic isolation of invertebrates. • Improper construction of pipelines could cause erosion, increasing sediment transport to surface water bodies and impacts on habitat available for biota. • Change in land use could isolate rivers and pans, resulting in genetic isolation, a reduction in number of refugia, and a disruption of migrating routes of birds, amphibians, invertebrates and other biota [11]. • Flash floods due to increased overland flow to rivers would increase disturbance to aquatic biota [8]. • Loss of critical refuge habitat during dry periods [8]. • Loss of critical passage habitat, e.g. riffles and runs that connect pools. Lead to, e.g. loss of mobility, reduced availability of food, fragmentation and isolation of fish assemblages.	**Habitat** • Reduced habitat quality due to exposure to toxic substances.
Aspects that need to be monitored (WHAT?)	**Quality** • Baseline data for water quality (T, conductivity, TDS, oxygen, turbidity, barium, strontium, chloride). Include chemicals present in fracking fluids to be used in exploration and extraction process. • Baseline Present Ecological State (PES) of relevant indices in rivers, wetlands and pans as prescribed by the DWS. • Baseline data on *E. coli* and total coliform levels in surface water systems need to be determined.	**Quality** • Parameters to be monitored include T, conductivity, pH, Dissolved oxygen, turbidity, TDS and possibly chloride, strontium and barium (if elevated TDS is found). Barium (Ba) and Strontium (Sr) may point to oil and gas extraction activities, as these metals could be mobilized by the fracking operation. If conductivity/TDS are high, test for Ba and Sr. If those are also very high it can be assumed that the source is flowback water [17]. • Specific chemicals used in fracking fluid need to be monitored if contamination is suspected. • If sewage effluent from human settlements at exploration site enters a stream/wetland or pan then *E. coli* and total coliforms concentrations need to be monitored.	**Quality** • Parameters to be monitored are T, conductivity, pH, dissolved oxygen (DO), and turbidity, which would indicate a spill especially of saline waste water, in particular. • Need to monitor for TDS, strontium and barium levels in flowback water to be released into surface water. Receiving water also needs to be tested regularly to detect any increase from natural trends. • Ecostatus using HAI, PAI, MIRAI, FRAI, GAI, VEGRAI methods where possible or else an adjusted PES method as prescribed by the DWS especially in episodic rivers. • If sewage effluent from human settlements at exploration site enters a stream/wetland or pan then *E. coli* and total coliforms concentrations need to be monitored.	**Quality** • Parameters to be measured include T, conductivity, pH, DO, turbidity, TDS, and if needed strontium and barium. • Specific chemicals from fracking fluid need to be monitored if contamination of surface water is suspected.

Phases	Before exploration	During exploration	During extraction	After extraction
Aspects that need to be monitored (WHAT?) continued.	**Quantity** • Baseline for water quantity in rivers, pans and wetlands (parameters: stream flow, discharge, depth and stream width).The collection of daily rainfall and evaporation data is crucial. **Habitat** • Baseline Habitat Integrity study or RHAM to establish a baseline for habitat. **Present ecological state (PES)** • Riparian vegetation, aquatic macroinvertebrates, fish. • Terrestrial insects, mammals associated with water bodies (episodic rivers). • Hydrology, geomorphology, water chemistry. **Regulatory** • Address water availability requirements for oil and gas extraction, before exploration and extraction. • Basic water quality testing before drilling or exploration commences. Analyses at an accredited laboratory, data should be made available to all interested parties.	**Quantity** • Monitor surface flow, water depth and volume in rivers, pans and wetlands. **Habitat** • The IHI or RHAM method can be used as a surrogate for habitat quality and invertebrate and fish health. **Present ecological state (PES)** • Riparian vegetation, aquatic macroinvertebrates, fish. • Terrestrial insects and mammals associated with water bodies (episodic rivers). • Hydrology, geomorphology, water chemistry. **Technical** • Rate and amount of water withdrawal if surface water is used as water source. **Regulatory** • Application for water use licence – unconventional oil and gas extraction has been proposed as a controlled activity and compliance with licence obligations needs to be monitored.	**Quantity**: • Water level to indicate any artificial increase or decrease in flow or depth in streams, pans or wetlands. **Habitat** • RHAM method can be used as surrogate for habitat and biota integrity assessments. **Technical** • Rate and amount of water withdrawal should be monitored if surface water is used as water source. **Regulatory** • Require permission/ licence to withdraw any water for unconventional oil and gas extraction. • Domestic and ecosystem water use must be prioritised especially during drought periods (Water use for oil and gas extraction should not interfere with current local use especially for food production). • Reuse of waste water to be encouraged and prescribed where possible. • The assessment (and enforcement) of compliance with set water quality standards is important[18].	**Habitat** • The RHAM method can be used as a surrogate for habitat, invertebrates and fish. **Regulatory** • Compliance with mine closure specifications need to be monitored.

Phases	Before exploration	During exploration	During extraction	After extraction
How should these aspects be monitored?	**Water quality** • A baseline/reference needs to be determined for each site and for each parameter. This can only be done using long term data or collecting data seasonally and during different hydrological phases (wet/dry). **Water quantity** • Baseline flow, depth and width measurements in rivers, pans and wetlands. Need to establish long term records to identify patterns especially in rivers in arid and semi-arid regions. Rainfall and evaporation data should also be collected. **Habitat** • Use IHI method [13, 14] or HAM method [15, 16] to determine baseline. **Stream biota** • PES of biota and drivers for rivers, wetlands and pans should be monitored using the standard methods prescribed by the DWS. • Fish (FRAI); macroinvertebrates (MIRAI); riparian vegetation (VEGRAI). **Observational and visual monitoring** • Use checklists and fixed point photography to determine a control or baseline.	**Water quality** • TDS must be monitored and if elevated levels are found then barium, strontium and chloride need to be monitored. If elevated levels of Strontium, etc. are found other fracking fluid chemicals also need to be monitored. **Quantity** • Flow, depth and width measurements in rivers, pans and wetlands. Daily rainfall and evaporation data should also be collected. **Habitat** • Use IHI method [13, 14] or RHAM method [15, 16] to determine change in habitat from baseline. **Present ecological state (PES)** • EcoStatus methods where appropriate, otherwise adjusted methods for rivers, wetlands and pans: • Fish (FRAI), macroinvertebrates (MIRAI), riparian vegetation (VEGRAI); • Hydrology (HAI), geomorphology (GAI), water chemistry (PAI). **Observational and visual monitoring** • Use checklists and point photography to determine change from baseline.	**Water quality** • TDS must be monitored and if elevated levels are found then barium, strontium and chloride need to be monitored. If elevated levels of strontium, etc. are found other fracking fluid chemicals also need to be monitored. • PES of biota and drivers for rivers, wetlands and pans should be monitored using the standard methods prescribed by the DWA. **Quantity** • Flow, depth and width measurements in rivers, pans and wetlands. Daily rainfall and evaporation data should also be collected. **Habitat** • IHI method [13, 14] or RHAM method [15, 16] to determine change in habitat from baseline. **Observational and visual monitoring** • Use checklists and point photography to determine change from baseline.	**Water quality** • If any groundwater pollution is suspected then the surface water quality needs to be monitored using firstly the TDS and then if needed levels of strontium, barium and chloride. • The RHAM method can be used as a surrogate for habitat, invertebrates and fish as habitat could be affected if surface water is polluted. . **Observational and visual monitoring** • Use checklists and fixed point photography to determine change from baseline. **Regulatory** • Compliance with mine closure specifications need to be monitored for as long as specified in mine closure regulations.

Phases	Before exploration	During exploration	During extraction	After extraction
Where do these aspects need to be monitored? (on site, regional?)	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites. Flowback and production water should be monitored at source and at point of discharge.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites Flowback and production water should be monitored at source and at point of discharge as well as downstream of discharge.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites. • Sites in at least a 1km radius from closed production site should be monitored if contamination is suspected.
Who must do the monitoring?	• DWS, oil and gas company and/or independent organisation appointed by DWA.	• DWS, oil and gas and/or independent organisation appointed by DWA.	• DWS, oil and gas company and/or independent organisation appointed by DWS.	• DWS, oil and gas company and/or independent organisation appointed by DWA.
Reference s		1: Lechtenböhmer et al., 2011; 2: Zorn et al., 2008; 8: Davis et al., 2006; 13: Kleynhans, 1996; 14: Kleynhans et al., 2008; 15: DWA, 2009a; 16: DWA 2009b; 17: Chapman, 2012	3: Herridge et al., 2012; 4: Rahm and Riha, 2012; 5: Lyons, 2012; 6: Scott et al., 2011; 7: Jackson et al., 2011. 18: DWAF, 2006.	9: Bishop, 2011; 10: Bamberger and Oswald, 2012; 11: Davis, 2008; 12: Lloyd-Smith and Senjen, 2011

Please refer to Esterhuyse et al. (2014) for details of the references cited.

5F(ii) Monitoring Framework for Groundwater (from Esterhuyse et al., 2014)

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that needs to be monitored (WHY?)	None that could be identified.	**Quality** Possible migration of formation fluids to freshwater aquifers during exploration drilling under localised artesian conditions. [12,13,14] Poor management of saline water produced by coalbed methane extraction [4,14] and shale oil and gas extraction may impact on surface water and groundwater quality. Possible contamination of aquifers with fracturing fluids if hydraulic fracturing is allowed during this phase. [4,14,15] **Technical** Poor drilling practices and poor well construction may impact on aquifers. [4,27,28, 29] Shale instability may lead to borehole collapse, aquifer connectivity. [16,17,18,19]	**Quality** Fluid migration and aquifer connectivity due to geological structures. [4,14,15] Surface activities may contaminate aquifers via surface water-groundwater interaction. [25, 26] **Quantity** Sourcing large quantities of water may impact on aquifers [4,15, 23,24] and large scale groundwater extraction may affect aquifer connected streams. [14] **Technical** Poor drilling practices and poor well construction may impact on aquifers. [4,27,28, 29] Shales that pose drilling problems, may lead to contamination. [16,17,18,19] **Regulatory** Poor wastewater treatment and disposal of large volumes of water may put aquifers at risk. [14,15,30]	**Quality** Aquifer pollution from deep shale layers may only surface years after a pollution incident. The extent of possible long-term contamination in freshwater aquifers could not be predicted at this stage. **Technical** South Africa may not be able to rehabilitate contaminated aquifers in complex geology (physically and economically). [31] Oil and gas well casing failure and leakage may pose long term legacy issues and lead to inevitable groundwater contamination. [14,32,33] **Regulatory** Well abandonment and long term monitoring may be problematic. [14,15,34]
Aspects that need to be monitored (WHAT?)	**Quality** Determine regional groundwater quality: Drinking water quality[1], stockwater quality parameters[2], parameters possibly associated with deeper zones [3,4,5,6], radioactivity [7] isotopes [7,8], methane, ethane[7,9], noble gases[10,11] **Quantity** Determine more accurately groundwater quantities used and yields. Determine baseline on type of groundwater use. Get baseline groundwater levels. **Regulatory** Monitor regulatory compliance with baseline monitoring requirements.	**Quality** Drinking water quality[1], stockwater quality parameters [2], parameters possibly associated with deeper zones[3,4,5,6], radioactivity[7], isotopes [7,8], methane, ethane[7,9], noble gases [10,11] **Quantity** Volumes of groundwater and surface water use on a regional scale linked with type of groundwater and surface water use (e.g. transfer schemes), monitor groundwater levels. **Technical** Drilling rate, fluid usage (volumes and type), microseismicity. [20,21,22] **Regulatory** Monitor regulatory compliance with fluid storage, volumes of waste produced per well, reporting frequencies to authorities Monitor compliance with license conditions. Monitor waste treatment methods and efficiency.	**Quality** Drinking water quality[1], stockwater quality parameters [2], parameters possibly associated with deeper zones [3,4,5,6], radioactivity [7] isotopes [7,8] methane, ethane[7,9], noble gases [10,11] **Quantity** Volumes of groundwater and surface water use on a regional scale linked with type of groundwater and surface water use (e.g. transfer schemes); monitor groundwater levels. **Technical** Drilling rate, fluid usage (volumes and type), microseismicity, well integrity during fracking operations. [20,21,22] **Regulatory** Monitor regulatory compliance with fluid storage, volumes of waste produced per well, reporting frequencies to authorities. Monitor compliance with license conditions. Monitor waste treatment methods and efficiency.	**Quality** Long term monitoring of Drinking water quality [1], stockwater quality parameters [2], parameters possibly associated with deeper zones [3,4,5,6], Radioactivity [7] isotopes [7,8], methane, ethane[7,9], noble gases [10,11] at a lower frequency unless pollution suspected. **Quantity** Long term monitoring groundwater levels at lower frequency also recommended together with quality, monitor changes in water use in previous oil and gas extraction areas. **Technical** Monitor well integrity over the long term. [31] **Regulatory** Monitor compliance with long term monitoring requirements. Monitor long term acceptability of waste treatment methods and efficiency.

Phases	Before exploration	During exploration	During extraction	After extraction
How should these aspects be monitored?	**Quality** Monitor identified list of parameters for regional baseline. Do higher resolution sampling in vicinity of expected oil and gas extraction (e.g. one sample per farm) and lower resolution in other areas. **Quantity** Monitor volumes by assessing baseline groundwater use (registration and licensing volumes at DWA) linked with type of groundwater use – fast track registration and licensing verification. Monitor water levels in aquifers.	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Continue high resolution monitoring in vicinity of oil and gas exploration (e.g. one sample per farm and higher resolution at oil and gas exploration wells); lower resolution in other areas. **Quantity** Monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use (especially transfer schemes). Monitor water levels in aquifers. **Technical** Monitor drilling rate, fluid usage (volumes and type), microseismicity at exploration sites. [20,21,22]	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Continue high resolution monitoring in vicinity of oil and gas extraction (e.g. one sample per farm and higher resolution around oil and gas extraction wells); lower resolution in other areas. **Quantity** Continue to monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use (especially transfer schemes). Monitor water levels in aquifers. **Technical** Monitor drilling rate, fluid usage (volumes and type), microseismicity at oil and gas extraction sites. [20,21,22] **Regulatory** Ensure that data dissemination occurs as required per license conditions.	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Monitor in vicinity of oil and gas extraction (e.g. one sample per farm and selected sites around oil and gas extraction wells); lower resolution in other areas. **Quantity** Continue to monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use to identify any linked usage patterns with other changes. Monitor water levels in aquifers. **Technical** Monitor well stability and integrity if wells are not closed [31] **Regulatory** Ensure continuous data dissemination of post extraction monitoring to regulatory authorities.
Where do these aspects need to be monitored? (e.g. on site, regional)	**Quality and quantity** Need to be monitored on a regional scale to determine a baseline. Monitor on a higher resolution in exploration target site areas.	**Quality and quantity** need to be monitored on site (local scale) as well as on a regional scale **Technical** To be monitored at drilling sites.	**Quality and quantity** Need to be monitored on site (local scale) as well as on a regional scale **Technical** To be monitored at oil and gas extraction sites.	**Quality and quantity** Need to be monitored on site (local scale) as well as on a regional scale. Expected timeframes for on-going monitoring will have to be determined based on monitoring observations and analyses. **Technical** To be monitored at closed oil and gas well sites.

Phases	Before exploration	During exploration	During extraction	After extraction
Who must do the monitoring?	**Regional baseline:** DWS/independent entity (new or existing for example academia, consultants, etc.). **Target area baseline:** Oil and gas company with reporting to the DWS, and independent spot check verification by DWS/independent entity (new or existing for example academia, consultants, etc.).	**Regional quality and quantity monitoring:** DWS/independent entity (new or existing for example academia, consultants, etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWS, and independent verification by DWS/independent entity (new or existing for example academia, consultants, etc.) **Site specific technical monitoring:** Oil and gas companies with rigorous reporting structure to government and/or independent monitoring entity.	**Regional quality and quantity monitoring:** DWS/independent entity (new or existing for example academia, consultants, etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWS, and independent verification by DWS/independent entity (new or existing for example academia, consultants, etc.) **Site specific technical monitoring:** Oil and gas companies with rigorous reporting structure to government and/or independent monitoring entity.	**Regional quality and quantity monitoring:** DWS/independent entity (new or existing for example academia, consultants, etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWS, and independent verification by DWS/independent entity (new or existing for example academia, consultants, etc.) **Site specific technical monitoring:** Over short term after closure: Oil and gas companies with verification by independent body, handover to government or independent entity for long term monitoring.
References	1: SANS 241 2: DWA, 1996 3: USDOE, 2004 4: USEPA, 2011a 5: Vidic, 2010 6: Clark and Veil, 2009 7: O'Brien et al., 2013 8: Vengosh et al, 2014 9: Talma and Esterhuyse, 2013 10: Darrah et al., 2013	11: Darrah et al, 2014 12: Steyl et al., 2012 13: Woodford and Chevalier. 2002 14: Williams et al., 2012 15: Broomfield 2012 16:Manohar, 1999 17: Khan et al., 2011 18: Cabot, 2010 19: Khodja et al., 2010 20: UKHC, 2012 21: National Assembly of Wales, 2012	22: GAO, 2012a 23: Broderick et al., 2011 24: Galusky, 2007 25: Seaman et al., 2010 26: Parsons, 2004 27: Kargbo et al., 2010 28: IEA, 2012 29: USEPA, 2011b 30: Lechtenböhmer et al., 2011	31: GAO, 2010 32: Dusseault et al., 2000 33: Jinnai and Morita, 2009 34: Diller, 2011

Please refer to Esterhuyse et al. (2014) for details of the references cited.