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Provisional Modelling of Climate Change Impacts on Floods, Droughts, Sedimentation and Sea Level Rise Impacts and Adaptation Options for Disaster Risk Reduction and Management Sector In South Africa

Long Term Adaptation Strategy (LTAS) Workshop

22nd January 2014

James Cullis (James.Cullis@aurecongroup.com)

STUDY OBJECTIVES

The PRIMARY OBJECTIVES:

- **Provisional modelling of potential impacts of the different LTAS climate scenarios for the different regions of the country on**
  - Droughts
  - Flooding
  - Sedimentation
  - Sea level rise.
- **to inform consideration of potential adaptation options and a qualitative assessment of potential adaptation options.**
- **to highlight particular areas of concerns (i.e. hot spots)**
- **to lay the foundation for more detailed modelling and impacts assessment in key locations or potential case study areas (LTAS III).**

General Points to Consider for Modelling CC Impacts

- **SA already has a highly variable climate**
- **SA is already relatively well adapted to this variable climate**
- **SA currently suffers from a "development deficit" that needs to be addressed before/along with any "adaptation deficit".**
- **SA is better off than many other developing (and some developed) nations due to a legacy of forward planning, infrastructure investment, social welfare and a diversity of economic sectors.**
- **CC is only one of many future uncertainties.**
- **CC is only one of many modelling uncertainties.**
- **SA is full of innovative and adaptable individuals and organizations.**

Increasing temperature and variability in rainfall due to climate change are likely to result in increased risk of droughts in South Africa….but drought is a relative phenomenon that has a spatially and temporal component.

Important Note: Within the time frame available detailed catchment modelling, flood hazard mapping, and sea level rise modelling is NOT possible.

There is more than one type of drought!

Drivers	Drought Types	Consequences	Impacts
Variations in: • Precipitation • Temp Natural Variability Human Impacts	 Meteorological Hydrological Agricultural Socio-economic	 Crop/Livestock Failure Water Supply Failure Ecosystem Failure	Individual Local Regional National Livelihoods Impacts Economic Impacts

Meteorological drought: reduction in **rainfal**l over an extended period compared to the long term average expected conditions.

Hydrological drought: substantial reduction in **streamflow** in a specific area when compared to the long term expected conditions.

Agricultural drought: reduction in water availability (e.g. **soil moisture**) necessary to support agricultural activities in a specific region relative to the expected conditions.

Socio-economic: failure to **supply water** at a given level of assurance. Results from a combination of both changes in supply and demand.

Provisional Modelling of Drought Impacts

Inputs:

- Time series of daily temperature and precipitation values generated for each quinary catchment for selected LTAS CC models from 1950 to 2100.
- Derived time series of daily streamflow using ACRU model.
- Time series of monthly catchment runoff using ACUR or Pitman model.

Meteorological Drought:

- Comparison of the number of drought years (i.e. annual rainfall below the median value) under present and future climate scenarios.

Hydrological Drought:

- Comparison of the number of drought years (i.e. annual streamflow below the median value) under present and future climate scenarios.

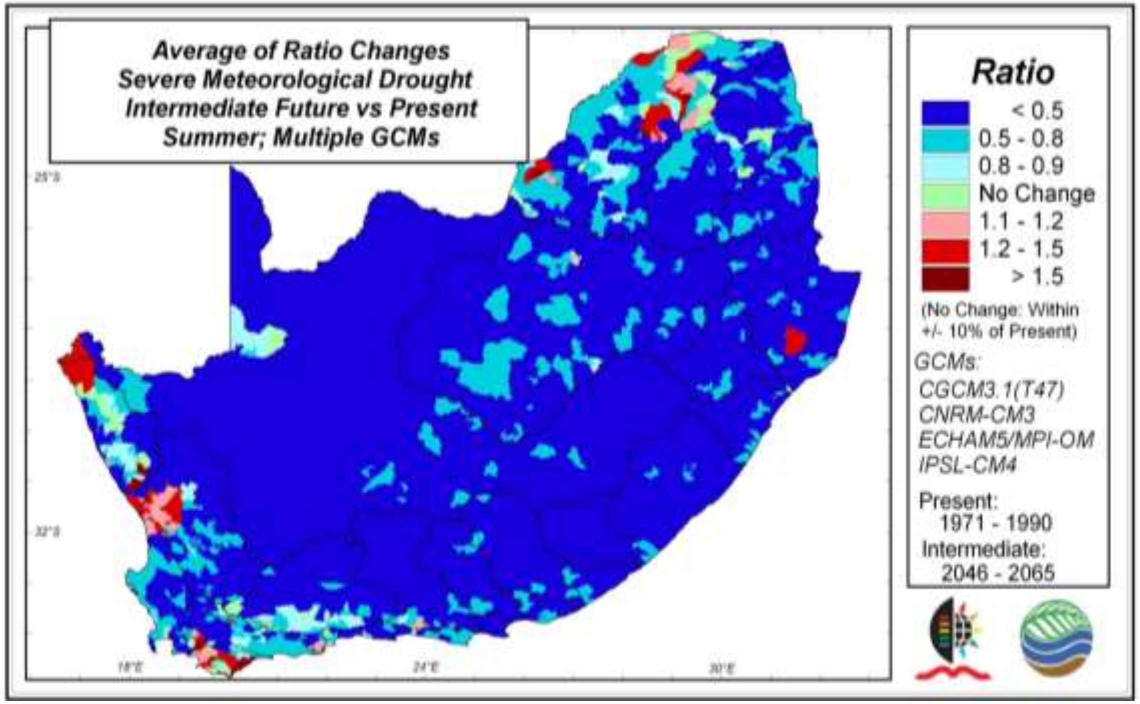
Agricultural Drought:

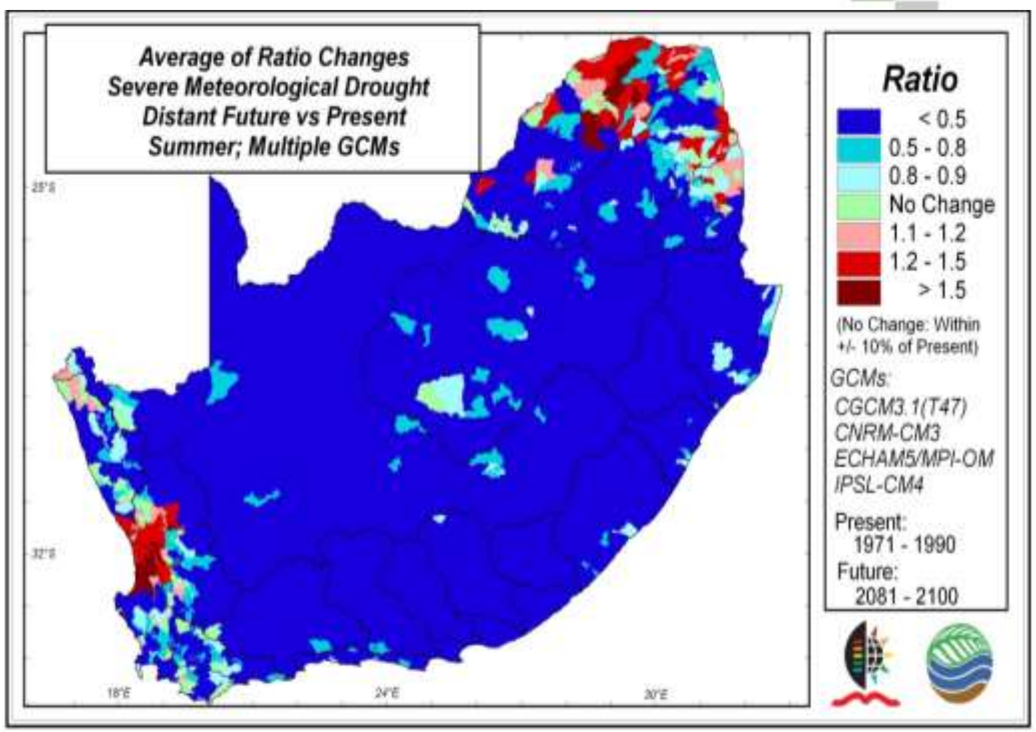
- Impacts on the average annual dry land crop yields for selected crops based on a simple empirical relationship based on annual rainfall.

Socio-economic Drought:

- Changes in the average annual ability to supply water to different user groups (irrigation, urban, mining and industry) using a national WRYM.

Potential Impacts on Meteorological Drought



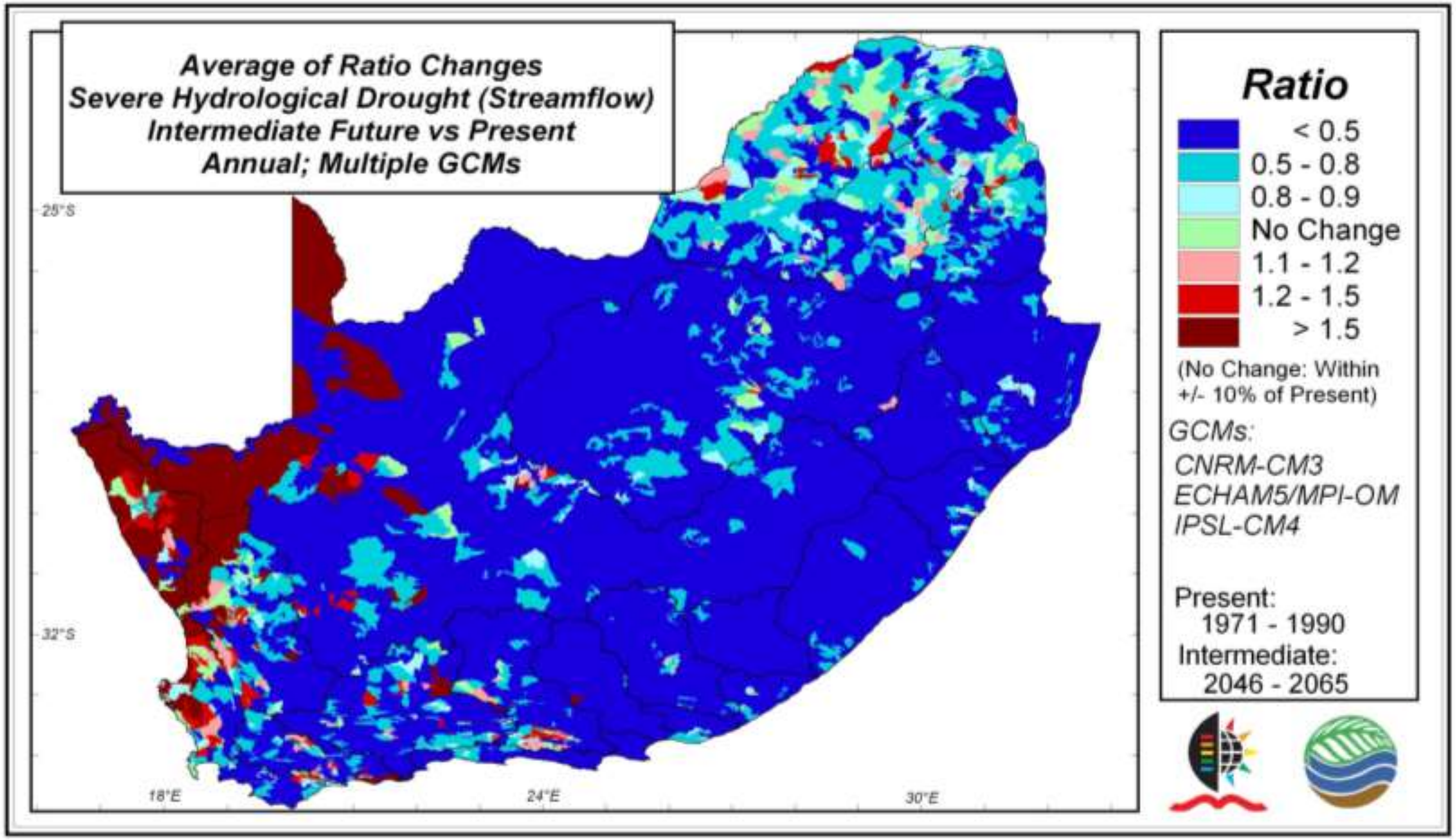


Ratio of the change in the average number of sever drought years (summer months) (I.e. < 10th percentile average precipitation) between the intermediate future and the present (left) and the distant future and present (Right)

(Source: Schulze, 2012)

We expect this to increase under the latest LTAS climate scenarios.

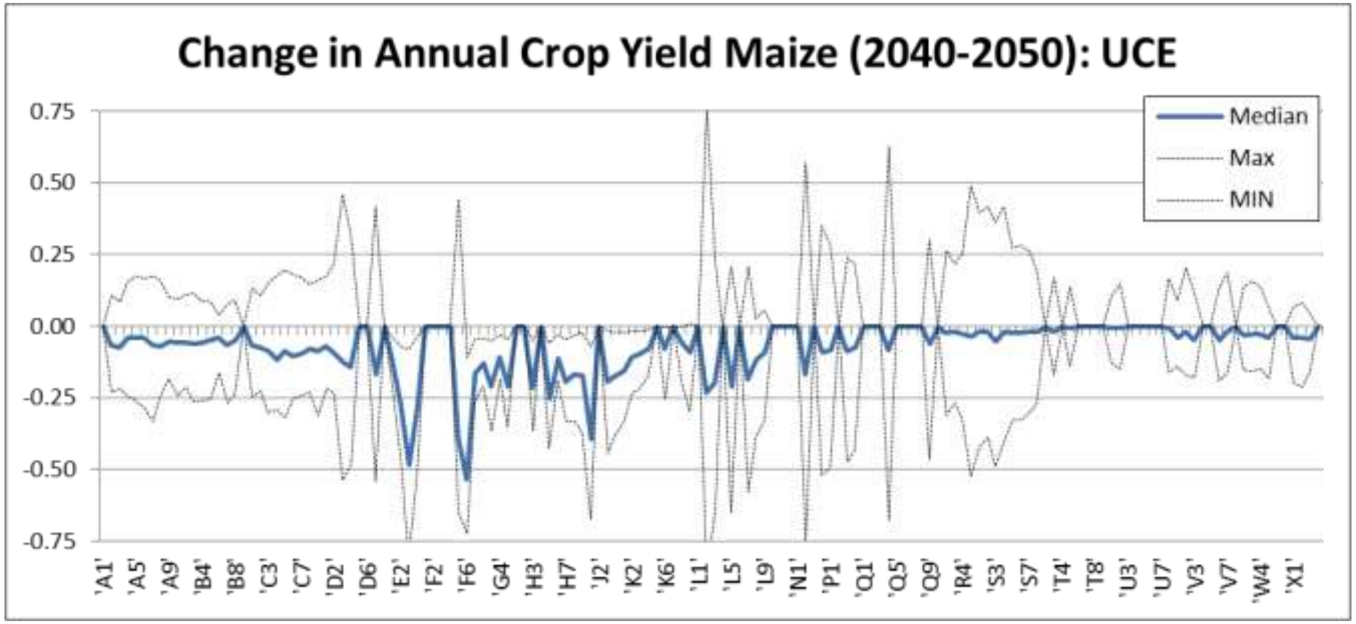
Potential Impacts on Hydrological Drought

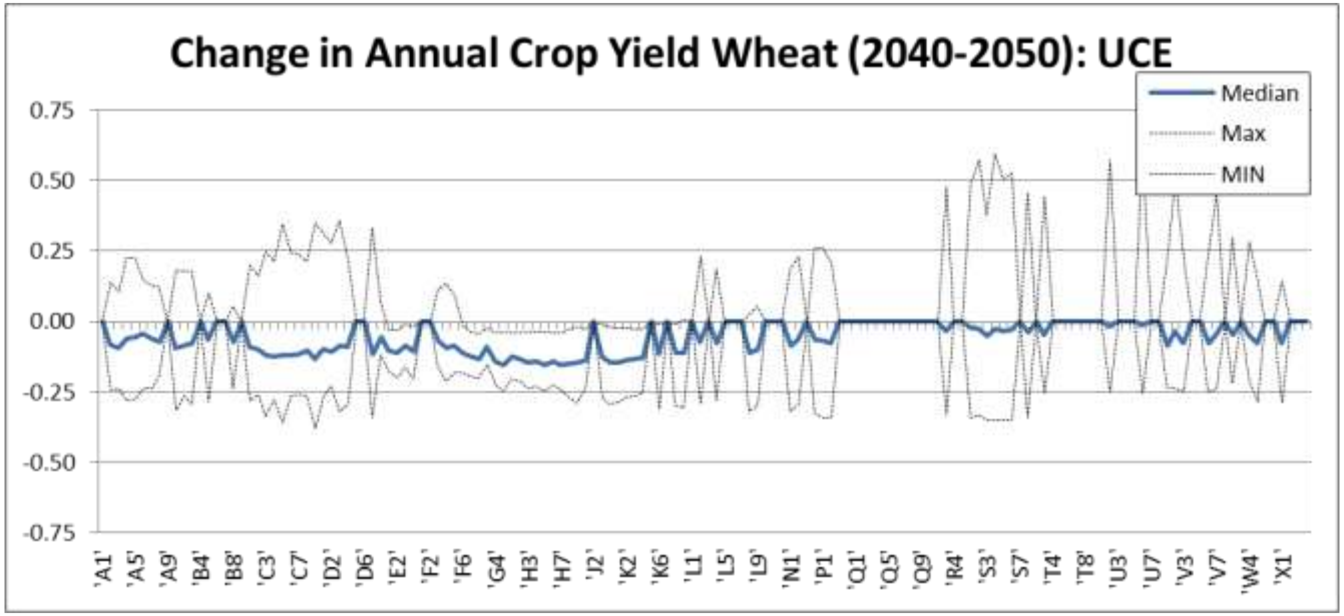


Change in the average number of severe (< 10th percentile) annual hydrological drought years between the intermediate future (2050) and the present.

(Source: Schulze, 2012)

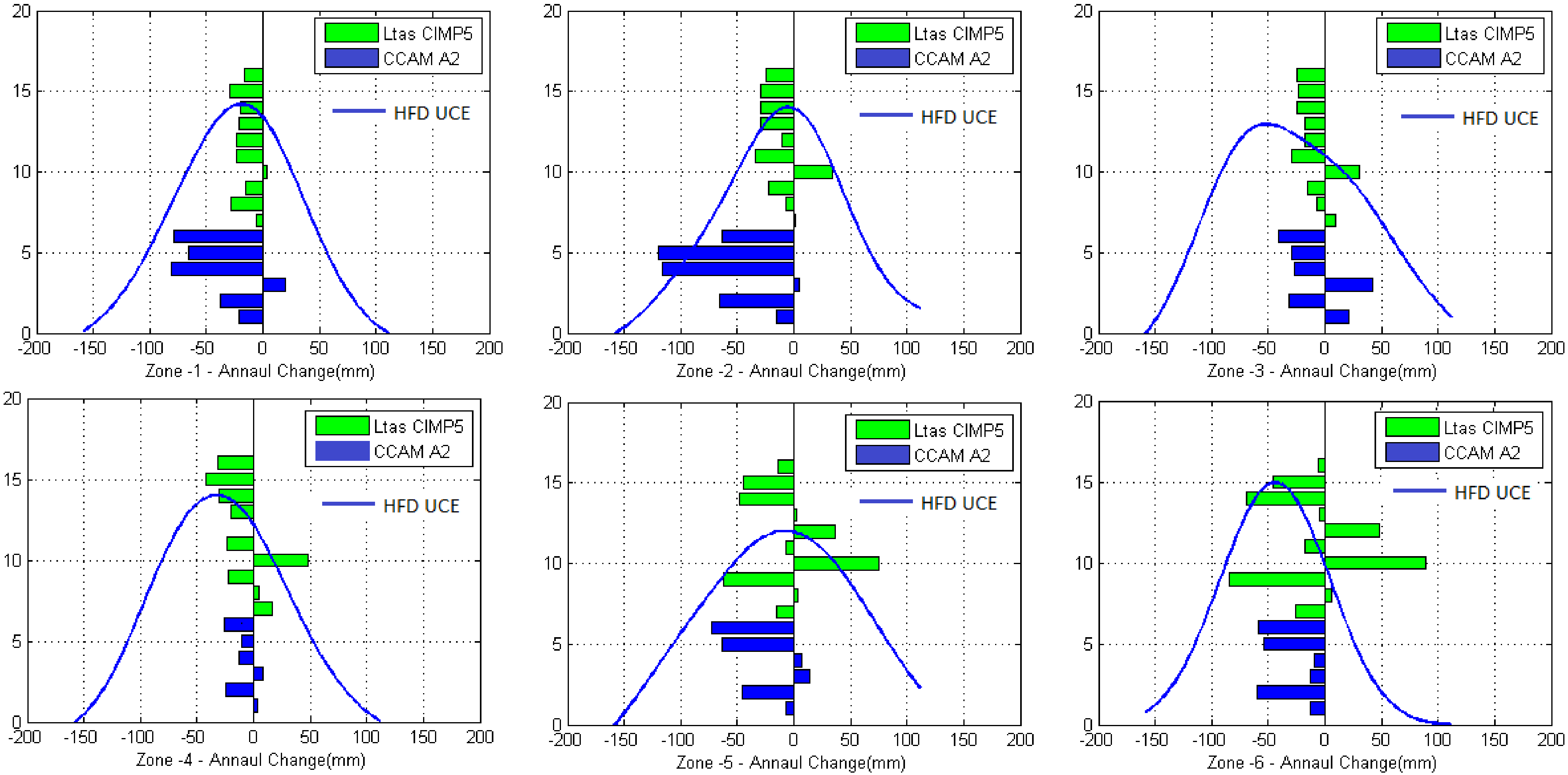
Potential Impacts on Agricultural Drought (DUCC, 2013)





(Cullis et al, unpublished)

Biophysical modelling in support of climate resilient economic development in South Africa (Aurecon/AECOM/MIT,, UNUWIDER 2013) - Development Under Climate Change (DUCC) – NT/NPC/DEA



aurecon AECOM UNITED NATIONS UNIVERSITY UNU-WIDER World Institute for Development Economic Research INSTITUTE OF CLIMATE & CIVIL SYSTEMS MIT JOINT PROGRAM GLOBAL CHANGE

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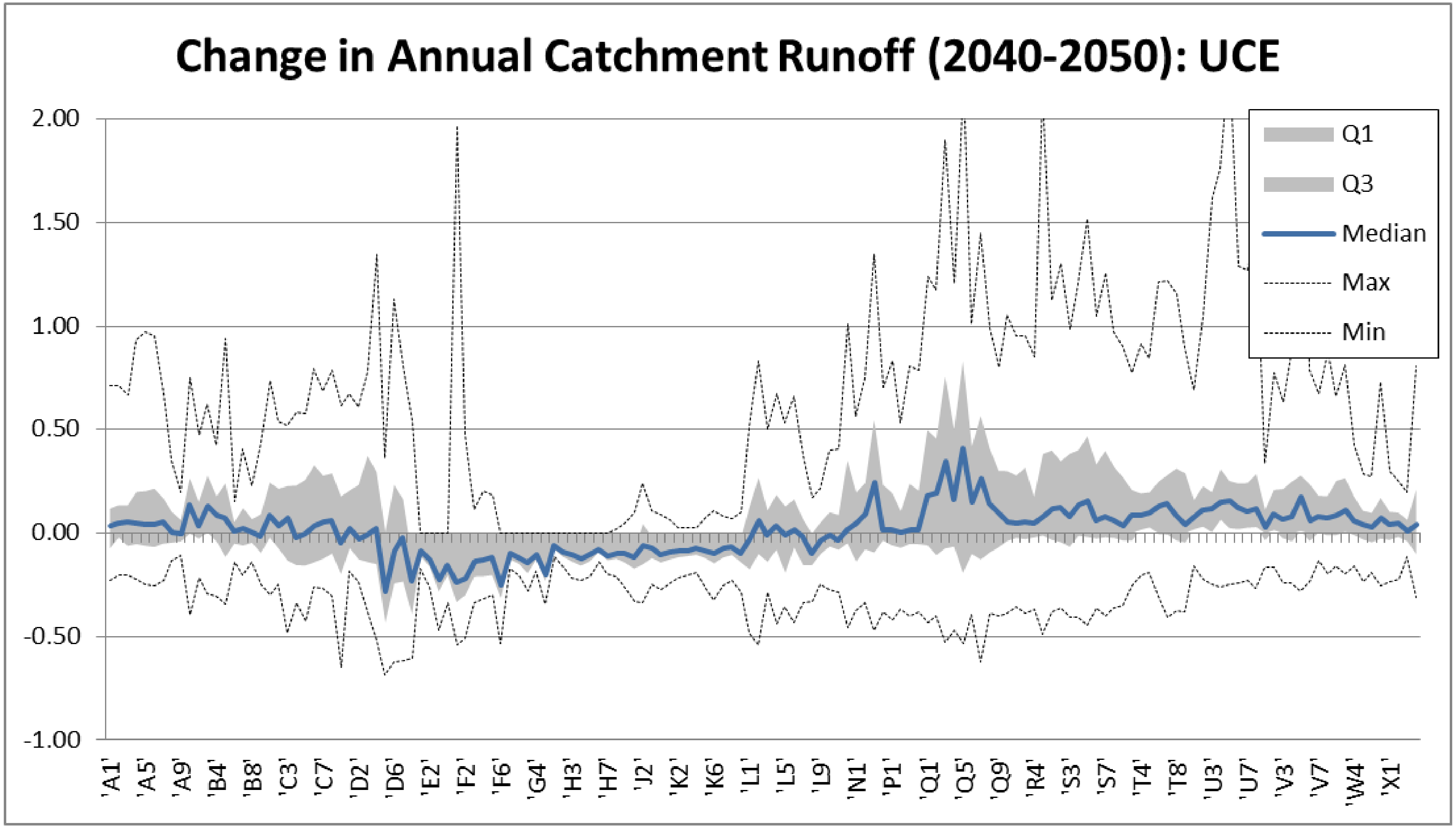


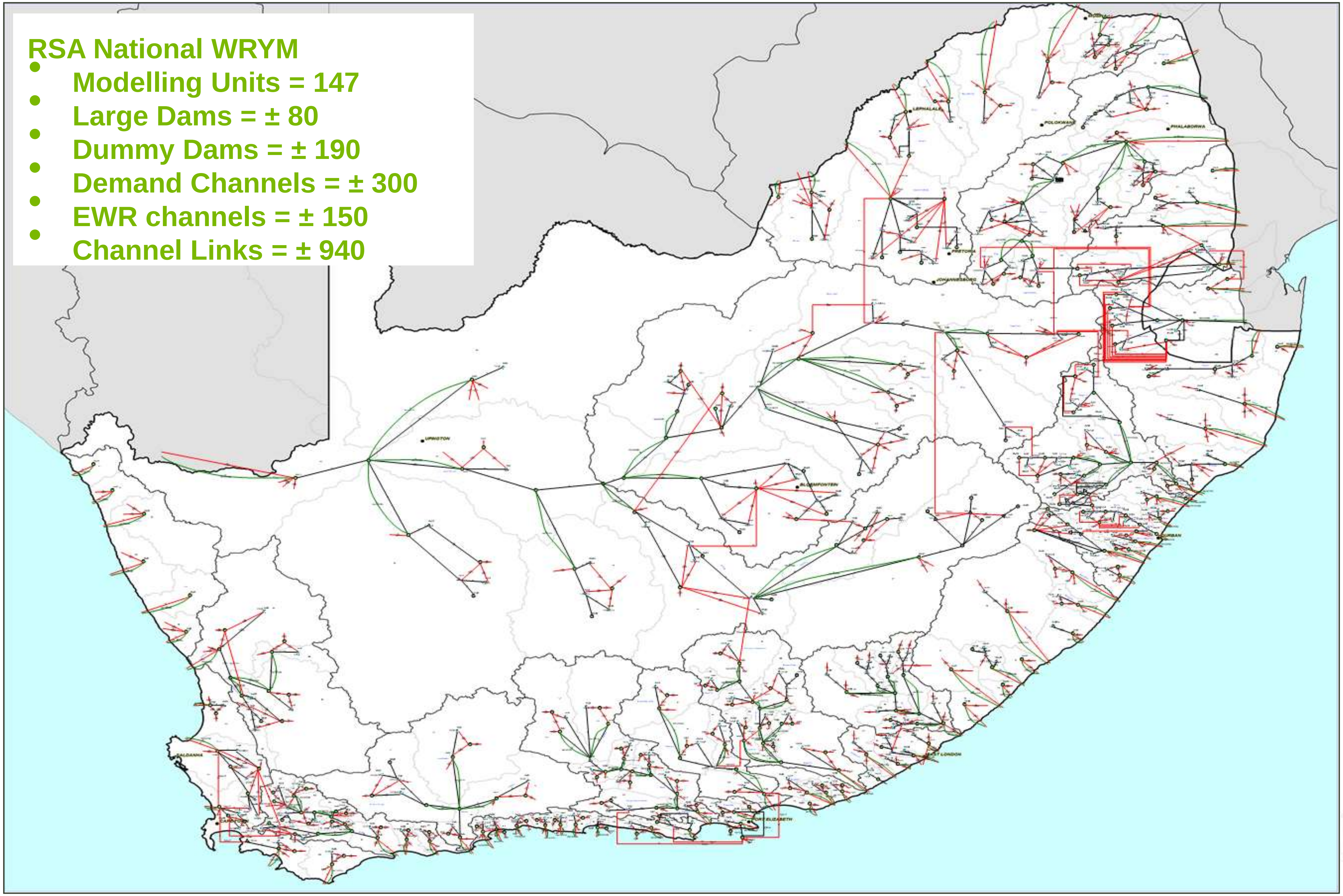
Potential impacts on of climate change on average annual catchment runoff.

Cullis et al (unpublished)

Assess the potential impacts of LTAS scenarios on socio-economic drought in terms of the ability to supply water using a national WRYM for SA

RSA National WRYM

- **Modelling Units = 147**
- **Large Dams = ± 80**
- **Dummy Dams = ± 190**
- **Demand Channels = ± 300**
- **EWR channels = ± 150**
- **Channel Links = ± 940**



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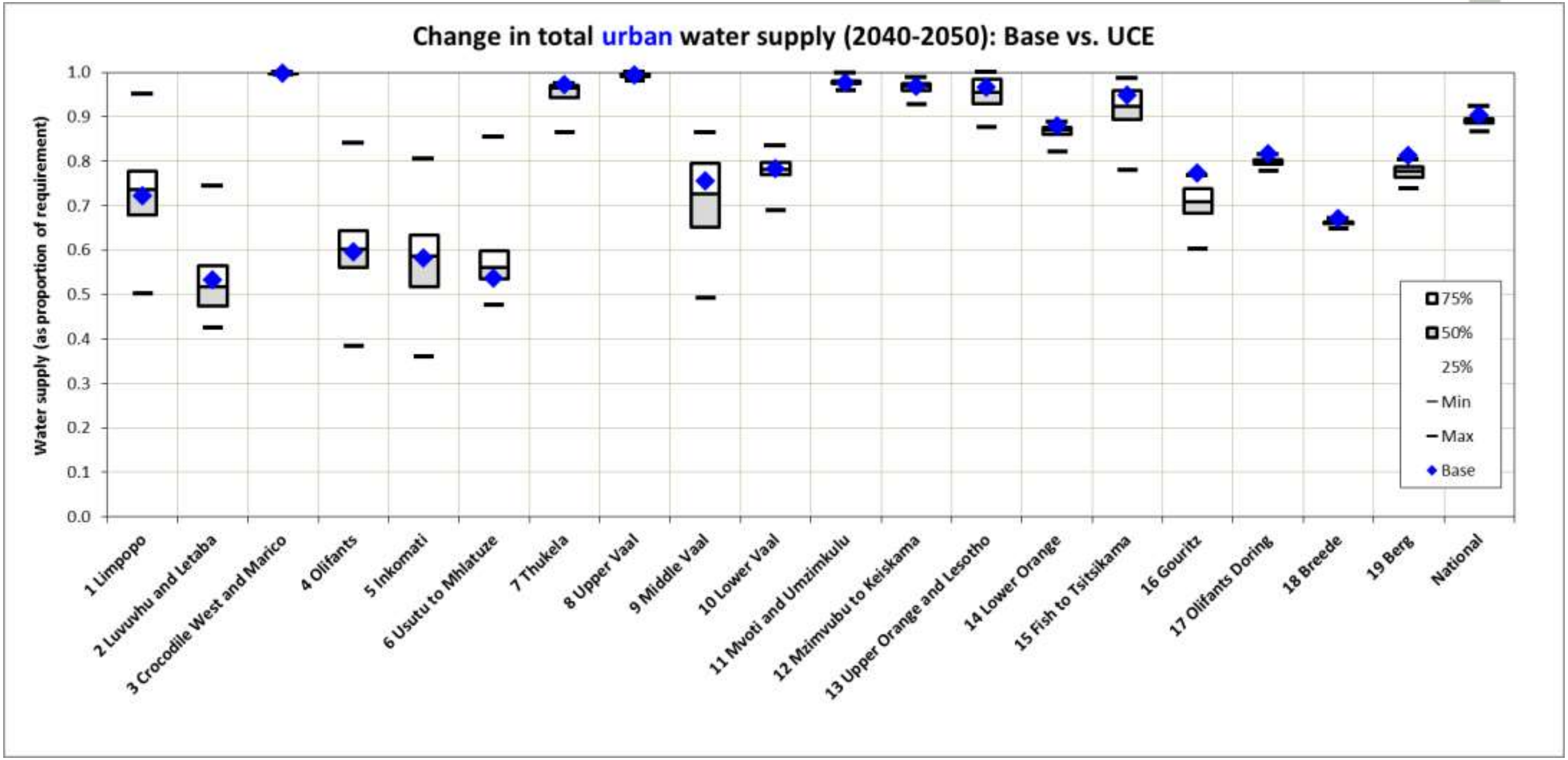

Potential impacts on of climate change on average annual water supply by 2050.

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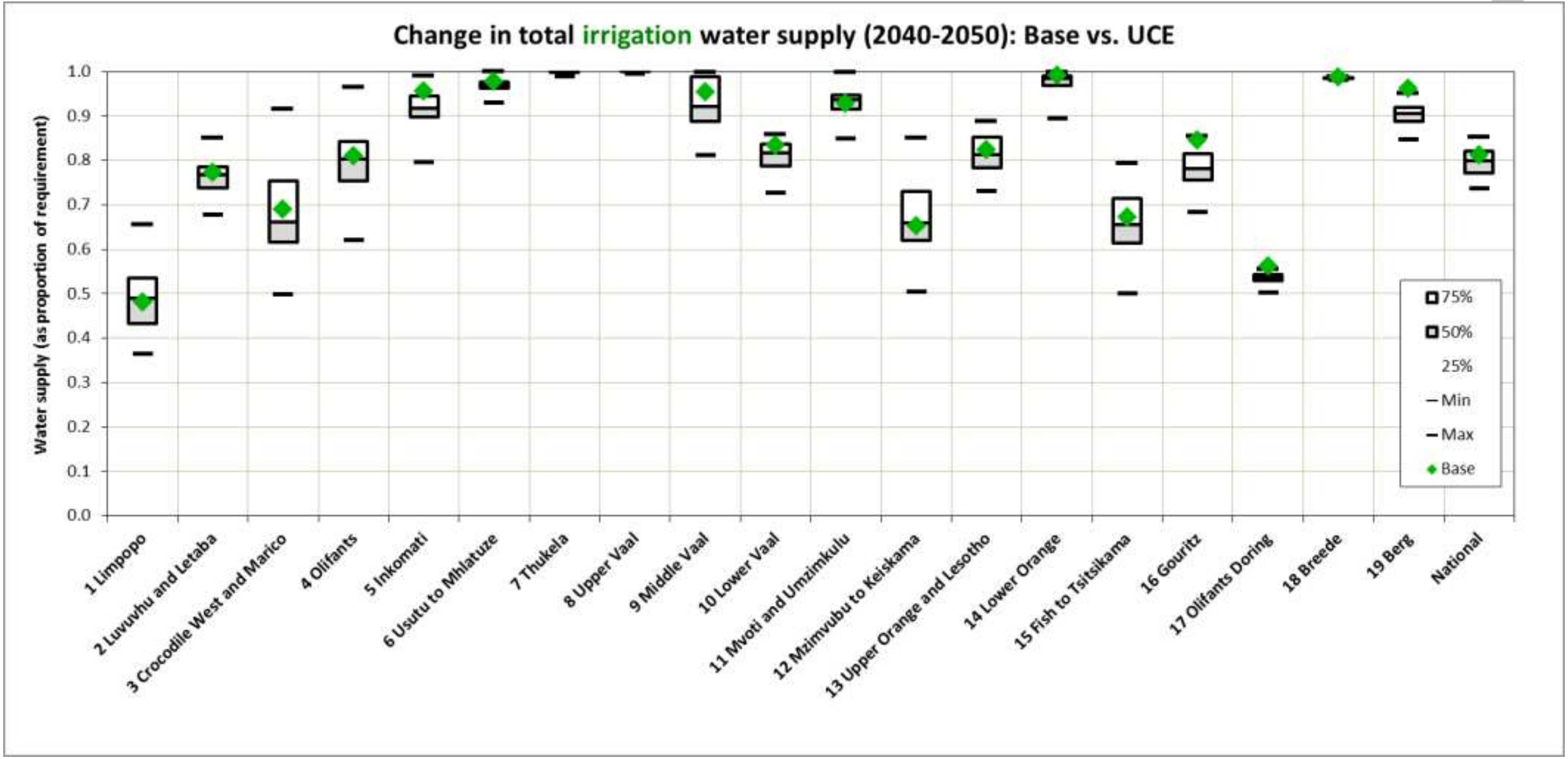

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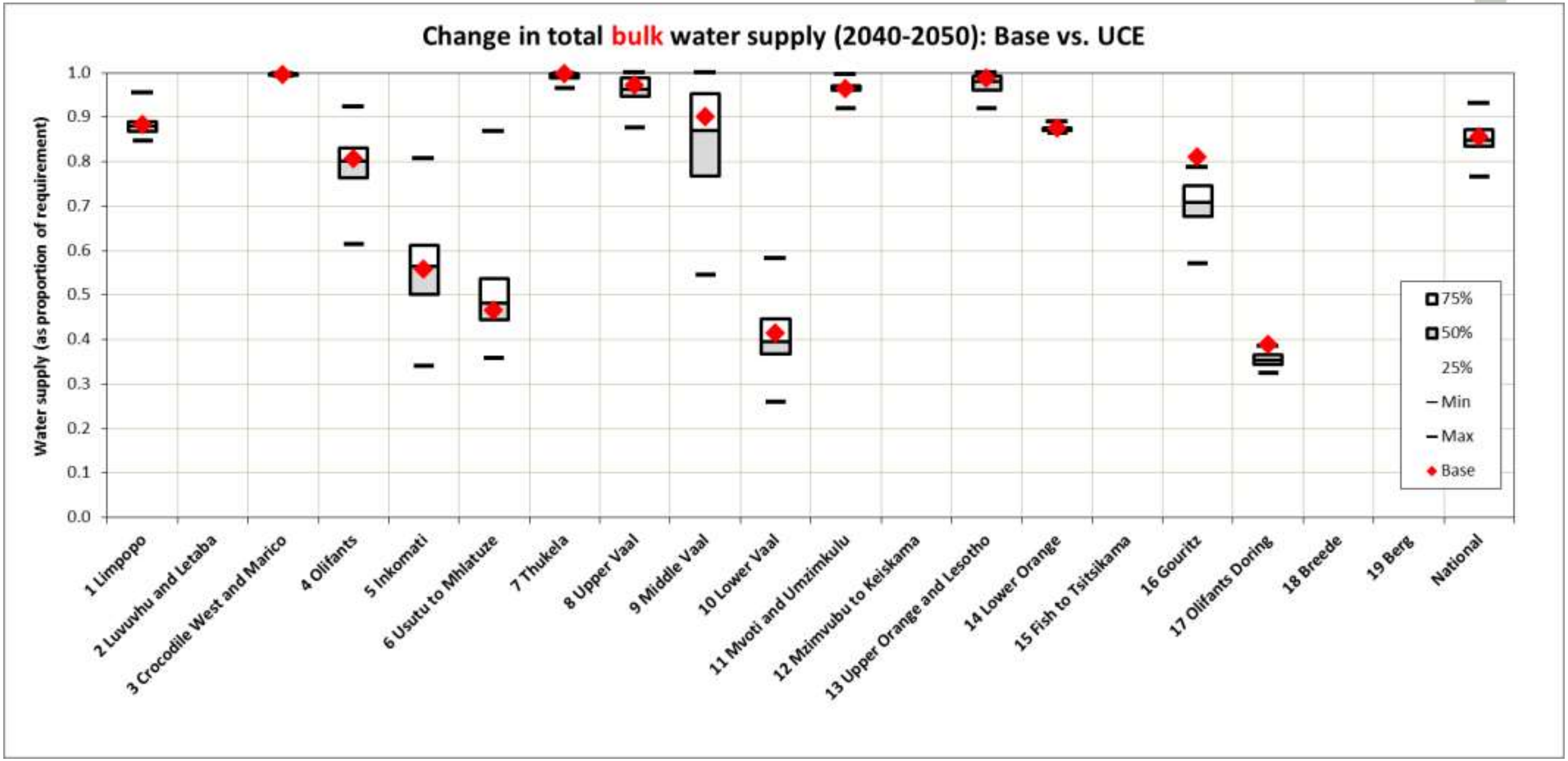

Potential impacts on of climate change on average annual water supply by 2050.

Impact of CC on selected water supply systems in support of a Climate Change strategy for DWA (Aurecon/Pegasys/DWA, 2012)

Method

- Precipitation, evaporation and ACRU runoff from UKZN at quinary catchment scale from **five CSAG statistically downscaled GCMs**.
- **Average monthly deltas** applied to long term historical streamflows.
- Model impacts on **Western Cape, Inkomati, Umzimvubu** and **de Aar** systems based on existing model configuration and current demands.

Outcomes:

- How CC affect system yields is not clear in **complex multi-basin** systems such as the Western Cape with potential differences between catchments.
- WCWSS more **sensitive** to a drier than a wetter future scenario.
- **CC could alleviate** some existing catchment stresses such as supply shortages to irrigation or for international obligations (Inkomati).
- A hotter, wetter climate will tend to benefit a system with a **single large dam** more than a distributed system of **many small dams** (Mzimvubu)

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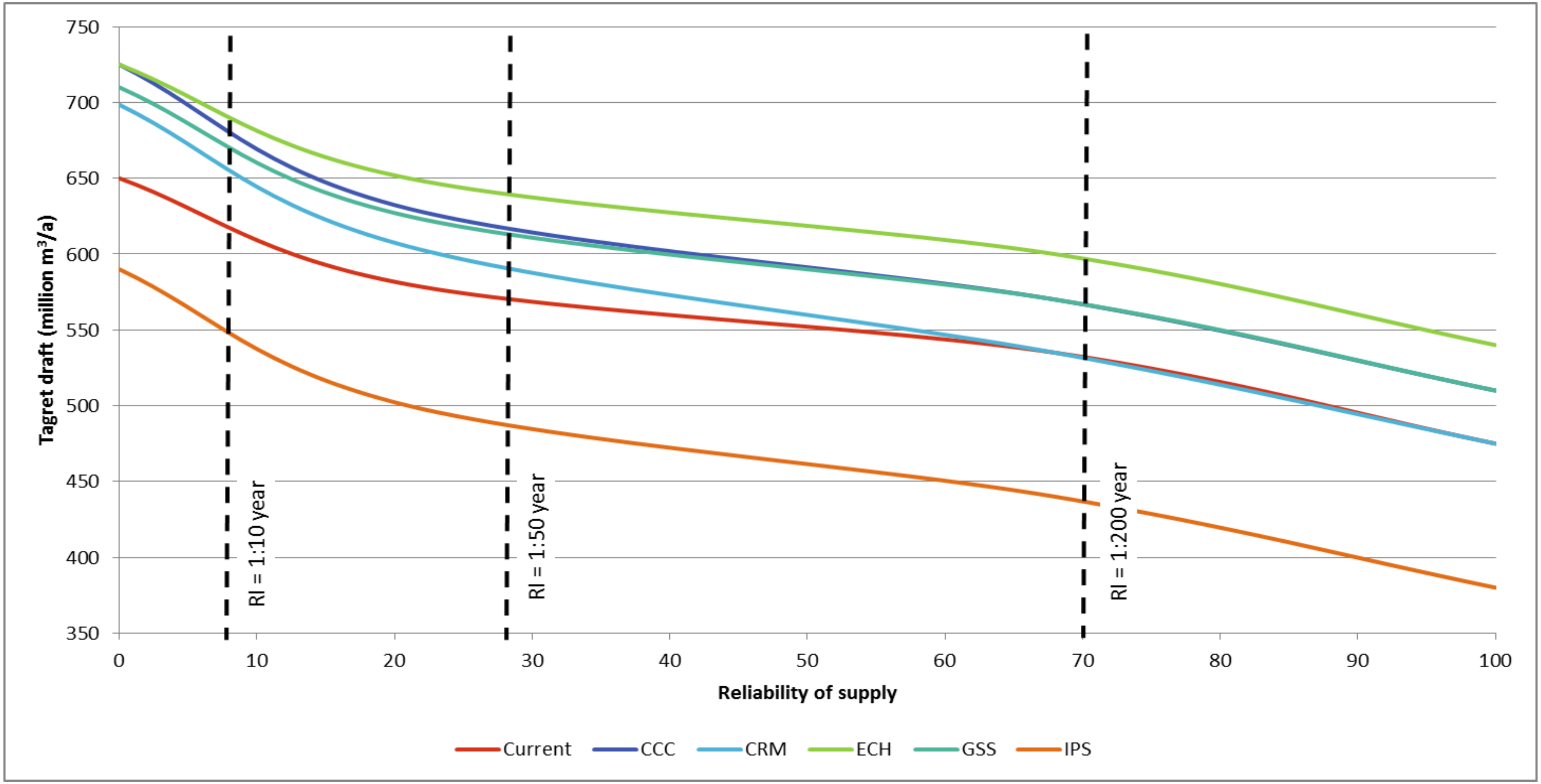

Yield-reliability characteristics for the WCWSS for climate change scenarios

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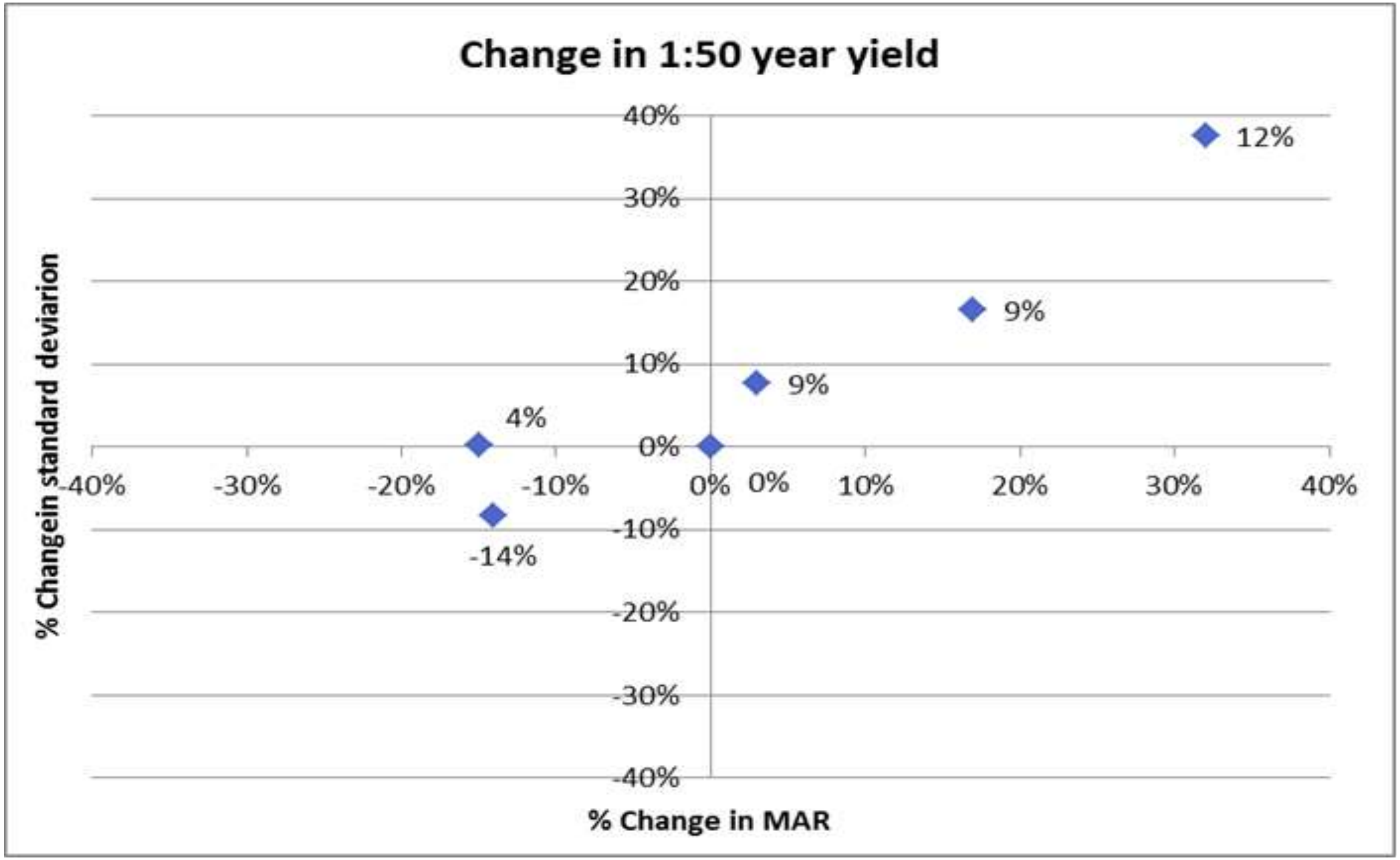


Change in 1:50 year WCWSS yield for different climate change scenarios

Potential Drought Adaptation Options

Physical / Infrastructure

- Increased storage capacity
- Increased use of groundwater
- Alternative water sources (e.g. desalination and re-use)
- Catchment management
- Improved water use efficiency
- New/improved crop types

Social / Institutional

- Social and economic development to reduce vulnerability and to improve climate resilience.
- Increased monitoring
- Continuous forward planning
- Insurance and support services
- Water trading
- Regional agricultural markets

Provisional Modelling of Flooding Impacts

The "Hydrologist" Approach

1. **Comparison of the changes in the annual daily maximum flow for all quinary catchments in SA by mid (2050) and late (2100) century.**

The "Engineers" Approach

1. **Assessment of the potential changes in design flood risks for the main bridges (SANRAL database) and dams (DWA) across SA.**
   a) Small catchments (<200 km^2) –Standard Design Flood (SDF) method
   b) Large catchments (>200 km^2) - Joint Peak Volume (JPV) method
   c) Or based on results from ACRU daily streamflow modelling
2. **Consider changes in design floods across the country using 30 year moving window up to the mid (2050) to late (2100) century).**
3. **Hydraulic calculations to determine bridge or dam freeboard are not possible so we will instead look at the potential change in risk.**
4. **Detailed mapping of changes in flood hazard not possible at this stage, but would be possible on a selected case study basis in LTAS III.**

Typical design flood requirements:

- Bridges and Major Culverts = depends on Road Class (1:5 to 1:100 year RI)
- Dams (spillway design flood) = depends on Category (1:50 to 1:200 year RI)
- Human settlements = 1:100 year flood lines (not modelled)

BACKGROUND PREPARATION FOR APPLICATIONS OF NEW CLIMATE CHANGE SCENARIOS FOR AGRICULTURAL, HYDROLOGICAL AND OTHER IMPACT STUDIES

Richard Kunz, Nicholas Davis, Trevor Lumsden, Roland Schulze

Centre for Water Resources Research
University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa

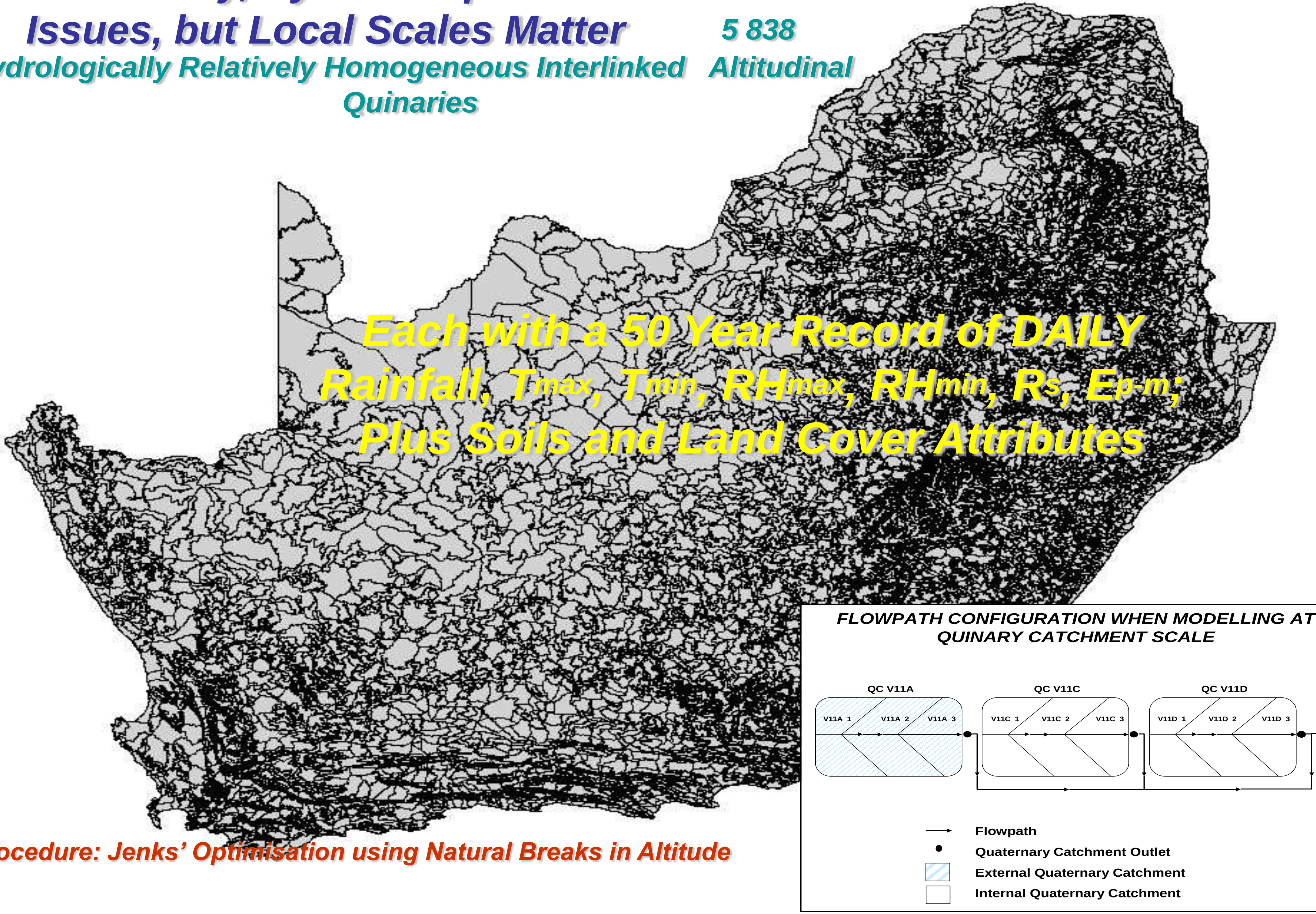
**** Why so much time spent on background preparation?***

Food Security, Hydro Responses are National Issues, but Local Scales Matter

Hydrologically Relatively Homogeneous Interlinked Altitudinal Quinaries

5 838

Each with a 50 Year Record of DAILY Rainfall, T_{max}, T_{min}, RH_{max}, RH_{min}, R_s, E_{p-m}; Plus Soils and Land Cover Attributes



Procedure: Jenks' Optimisation using Natural Breaks in Altitude

The Raster : Catchment Downscaling Problem

* For GCMs downscaled to ~ 50 km (1/2 degree), 499 raster points cover SA * But, there are 5 838 Quinaries covering SA
* i.e. on average 11.6 Quinaries per raster point
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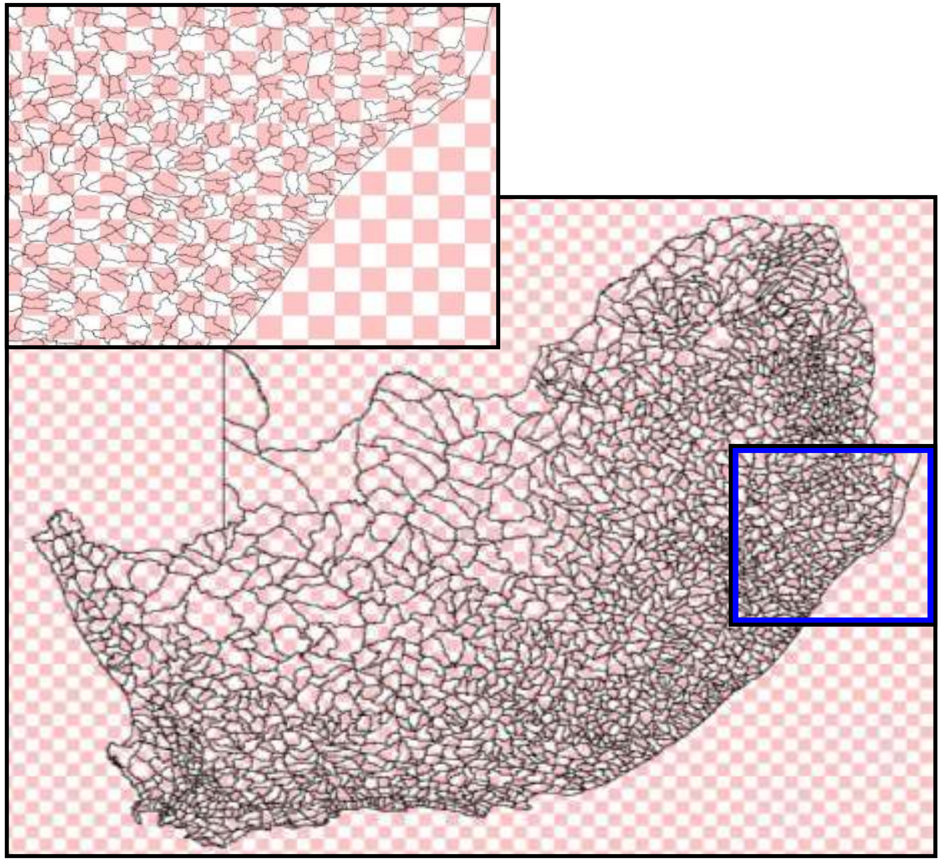
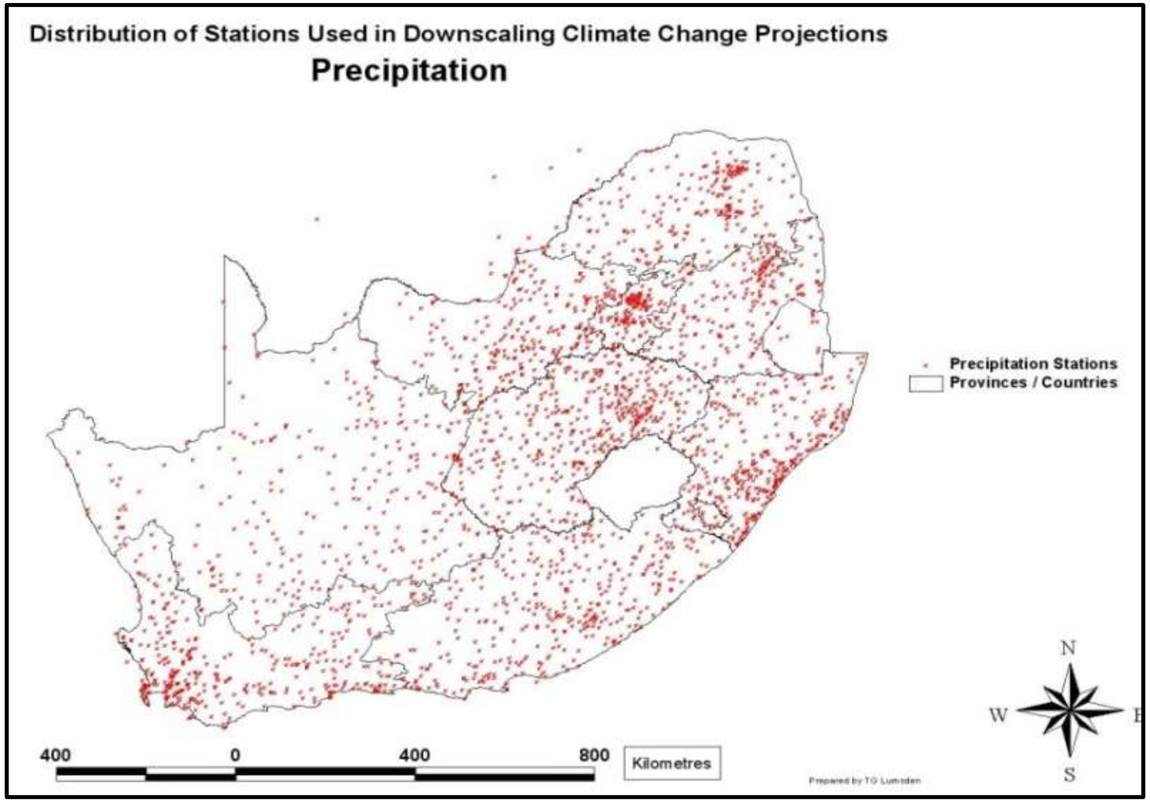
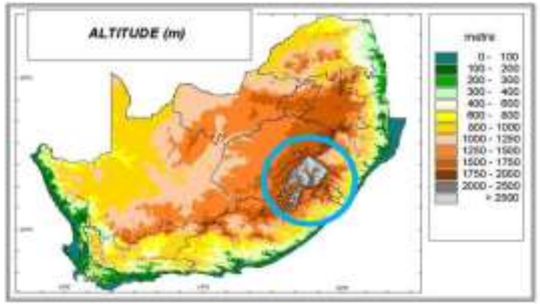
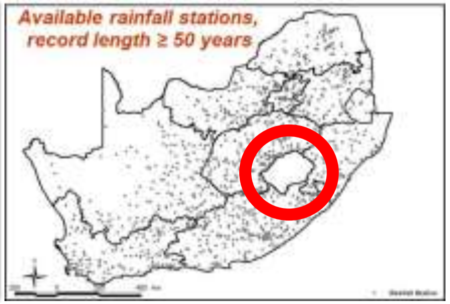
* How do you reconcile, adjust, correct, especially in mountainous, runoff producing regions?

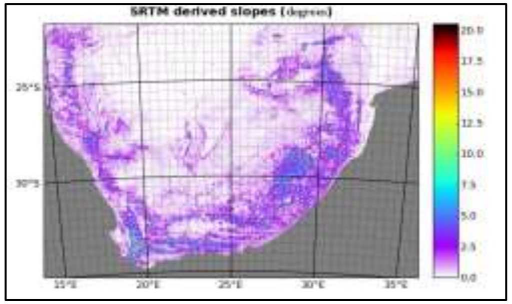


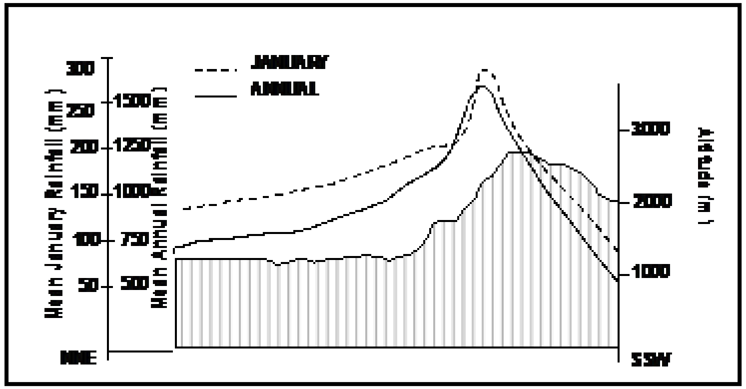


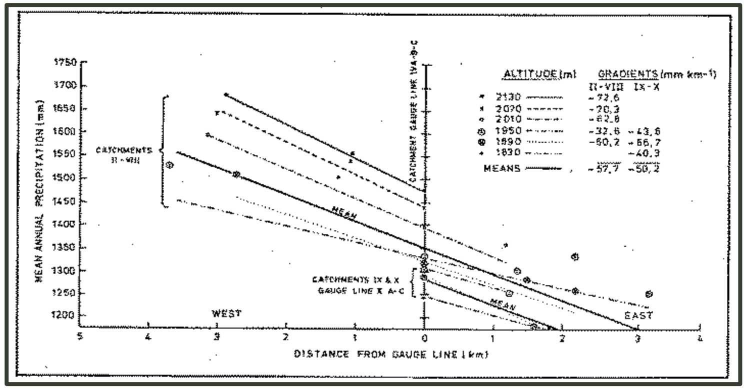
The Challenge of Mountainous, Runoff Producing Areas

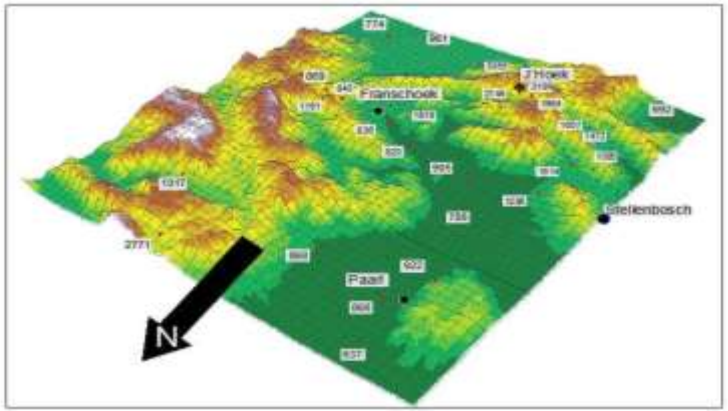


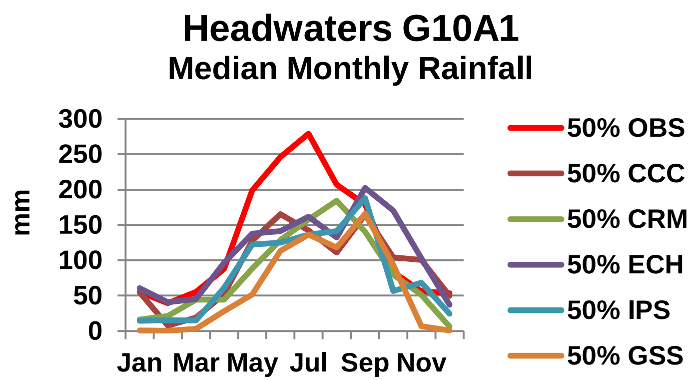




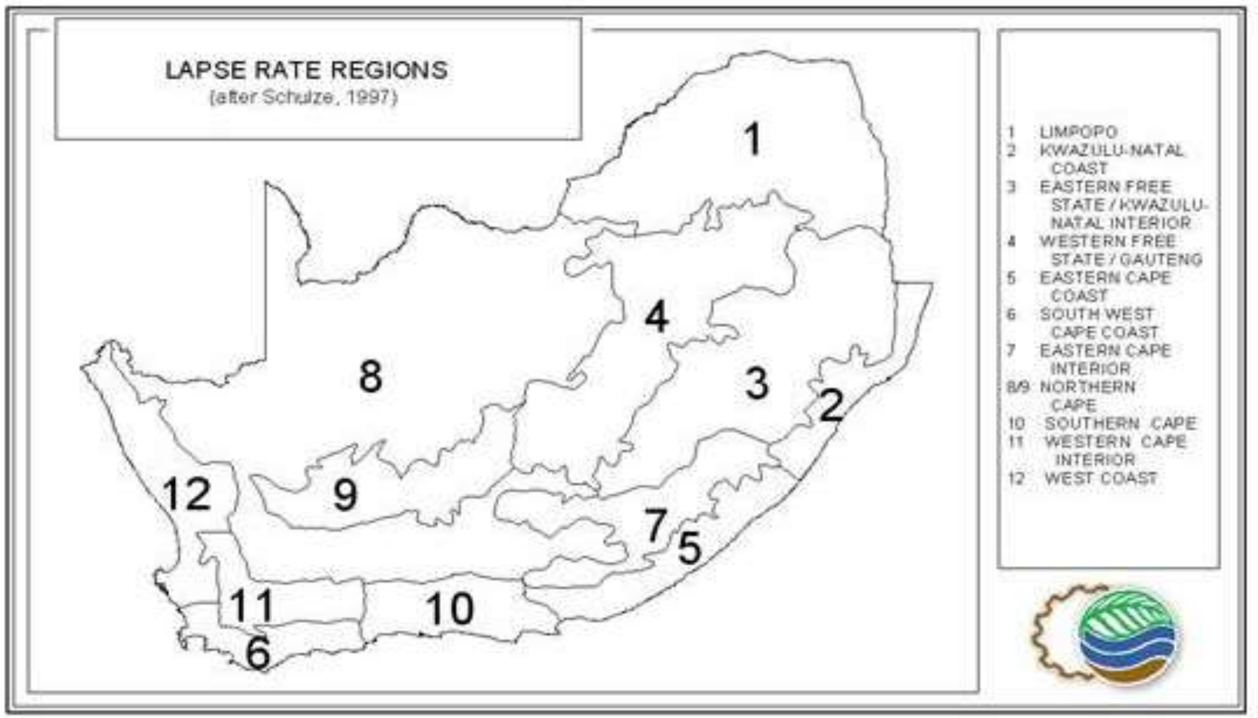


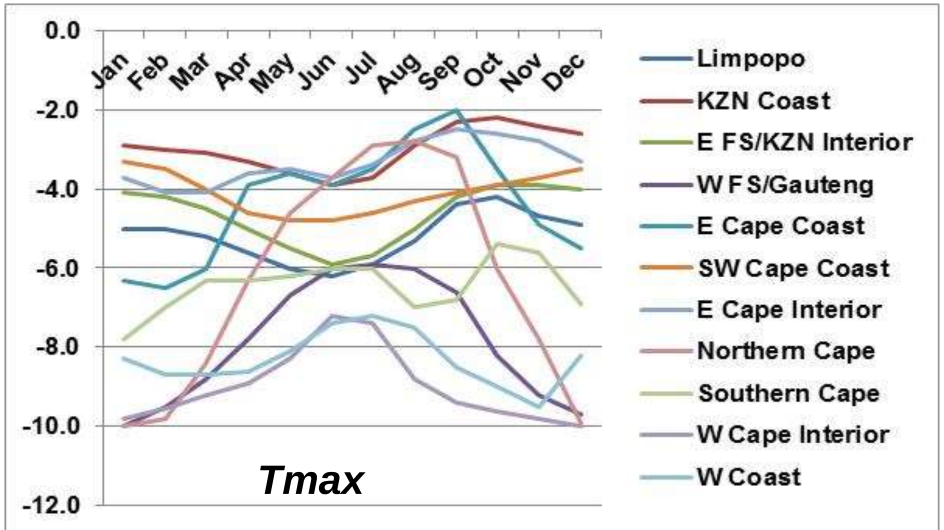


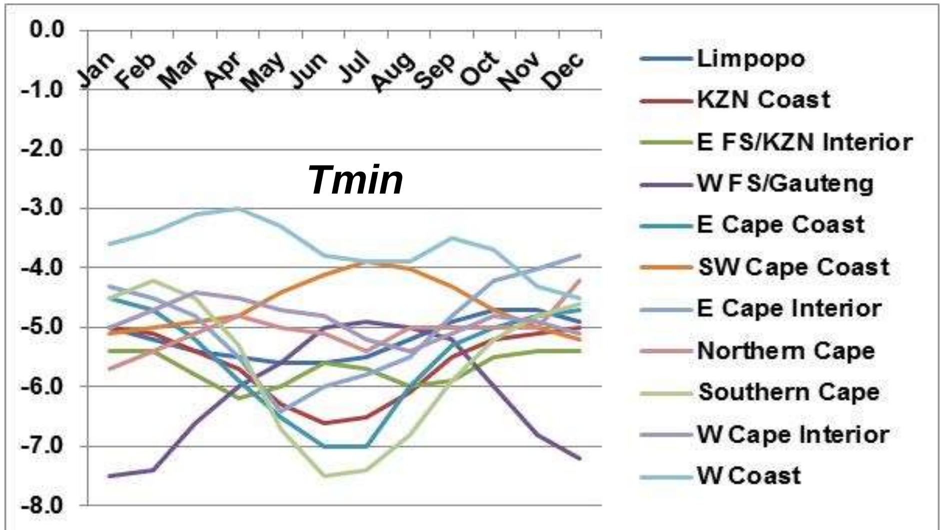


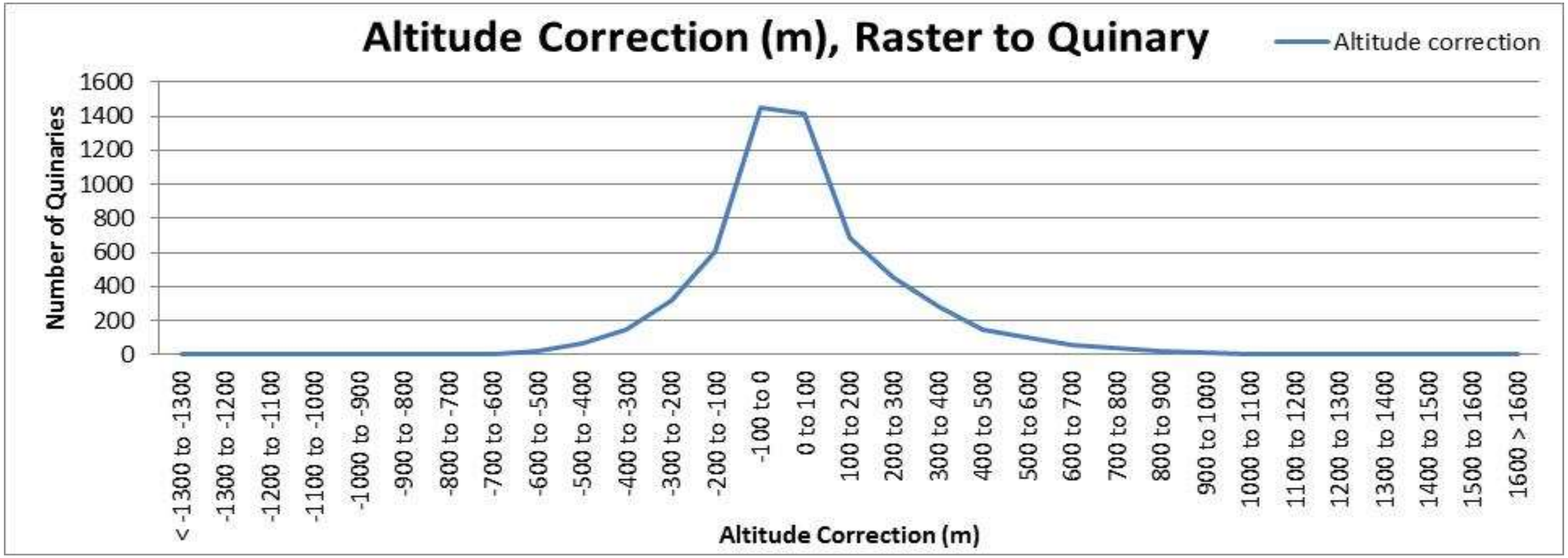


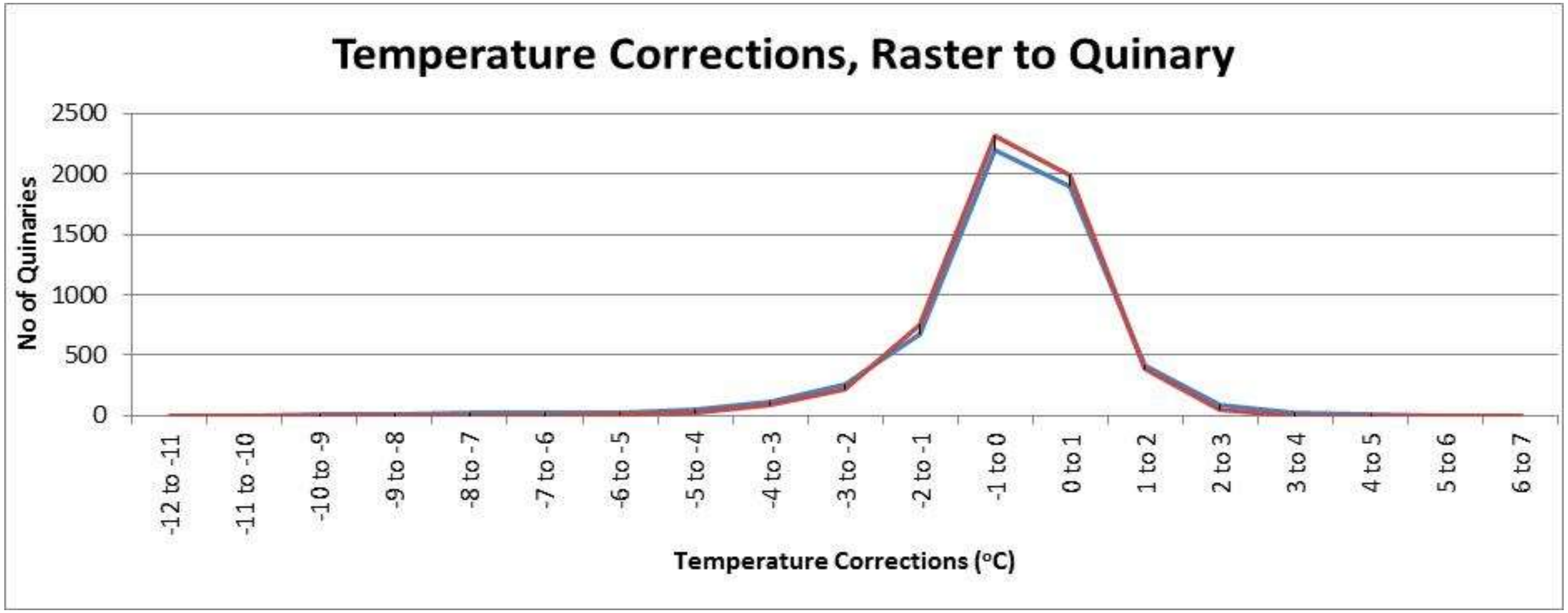
But, for Different Regions in SA the Temperature : Altitude Relationships Differ, Also by Month and by Max vs Min Temperatures

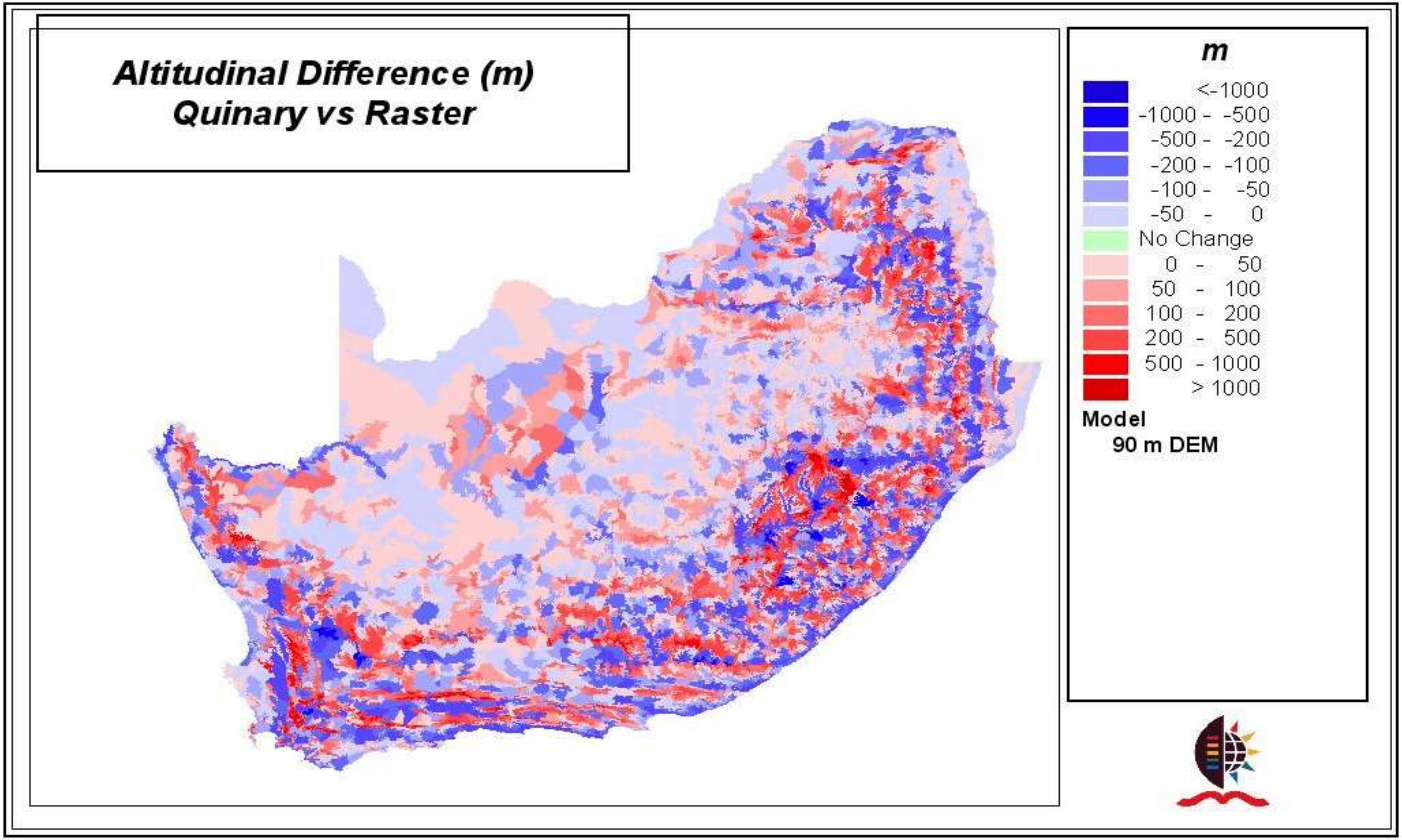






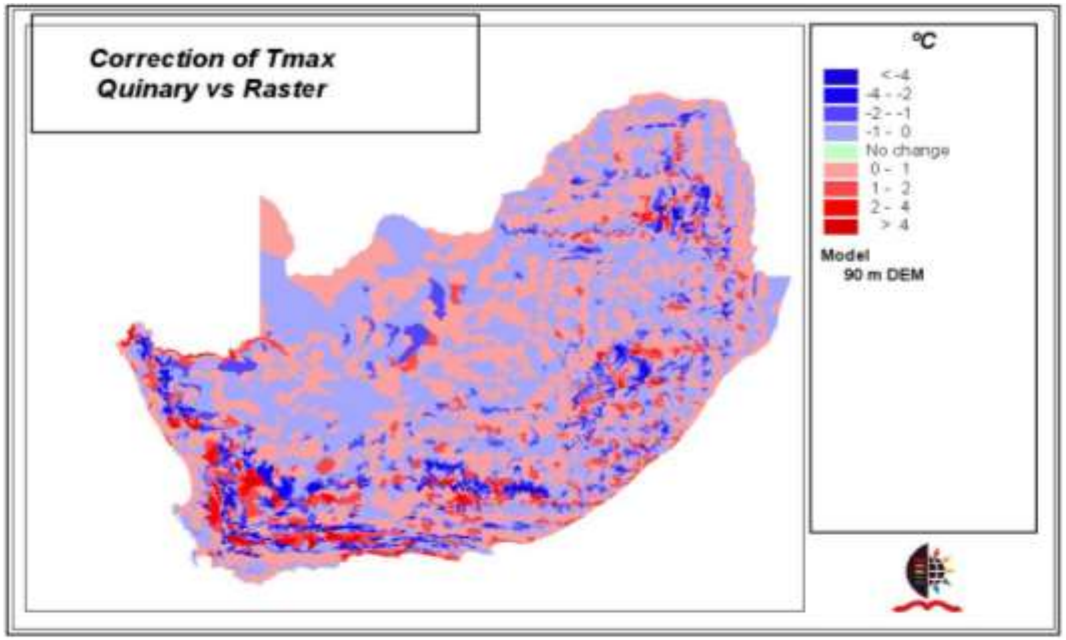

Altitude Correction (m), Raster to Quinary
Altitude correction
Number of Quinaries
1600
1400
1200
1000
800
600
400
200
0
< -1300 to -1300
-1300 to -1200
-1200 to -1100
-1100 to -1000
-1000 to -900
-900 to -800
-800 to -700
-700 to -600
-600 to -500
-500 to -400
-400 to -300
-300 to -200
-200 to -100
-100 to 0
0 to 100
100 to 200
200 to 300
300 to 400
400 to 500
500 to 600
600 to 700
700 to 800
800 to 900
900 to 1000
1000 to 1100
1100 to 1200
1200 to 1300
1300 to 1400
1400 to 1500
1500 to 1600
1600 > 1600
Altitude Correction (m)

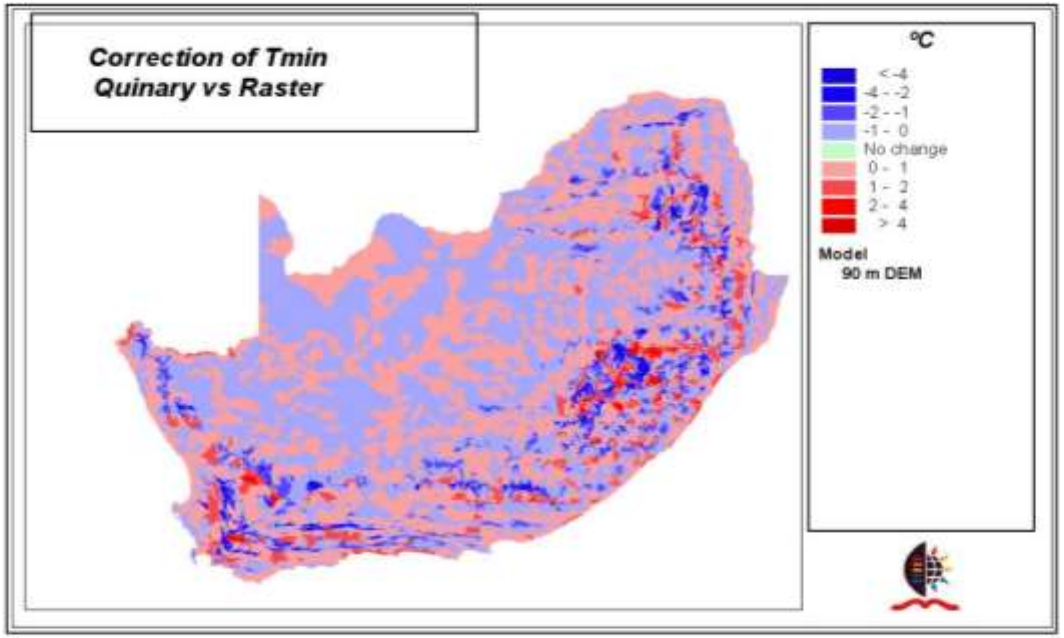

Temperature Corrections, Raster to Quinary
No of Quinaries
2500
2000
1500
1000
500
0
-12 to -11
-11 to -10
-10 to -9
-9 to -8
-8 to -7
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 0
0 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
Temperature Corrections (°C)



Altitudinal Difference (m)
Quinary vs Raster
m
<-1000
-1000 - -500
-500 - -200
-200 - -100
-100 - -50
-50 - 0
No Change
0 - 50
50 - 100
100 - 200
200 - 500
500 - 1000
> 1000
Model
90 m DEM

Maximum & Minimum Temperature Corrections: Quinary to Raster





Example of Rainfall / Runoff File: Quinary Catchment # 853, i.e. C11A Upper Quinary

DATE	RAINFALL	SUB-CAT R/OFF	ACC STRMFL ……
13/01/1961	7.584000587	0.001170044	0.001170044
14/01/1961	12.244999886	0.002349590	0.002349590
15/01/1961	9.795999527	0.001995726	0.001995726
16/01/1961	11.218000412	0.003515125	0.003515125
17/01/1961	3.950000048	0.002870157	0.002870157
18/01/1961	0.158000007	0.003040630	0.003040630
19/01/1961	0.000000000	0.003068754	0.003068754
20/01/1961	0.000000000	0.002971481	

* Each Quinary daily file for each GCM from 1961 – 2100 is 51 135 lines long
* There are 5 838 Quinaries covering SA
* This for each GCM
* Total datafile per GCM ~ 84 Gigabytes

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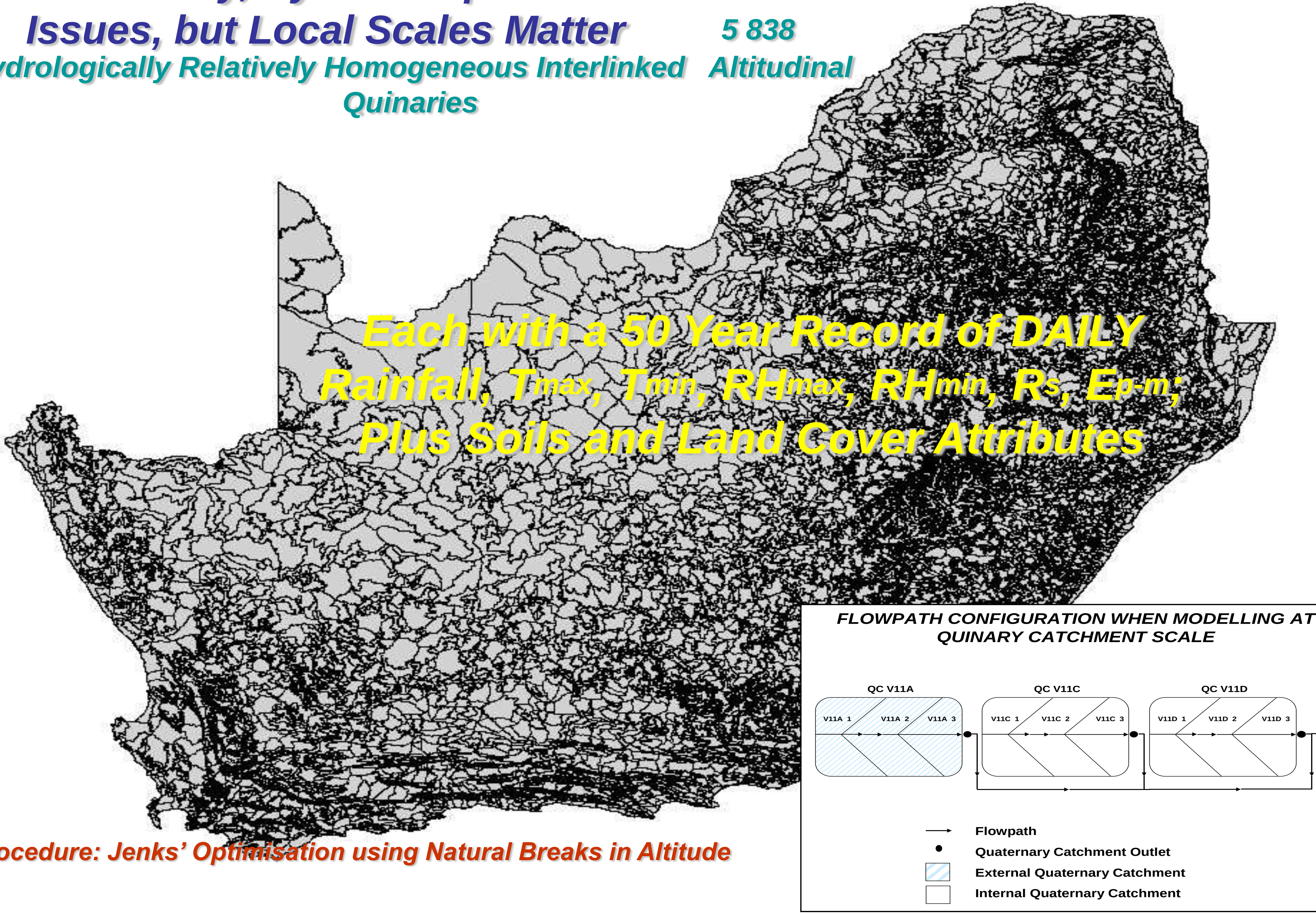

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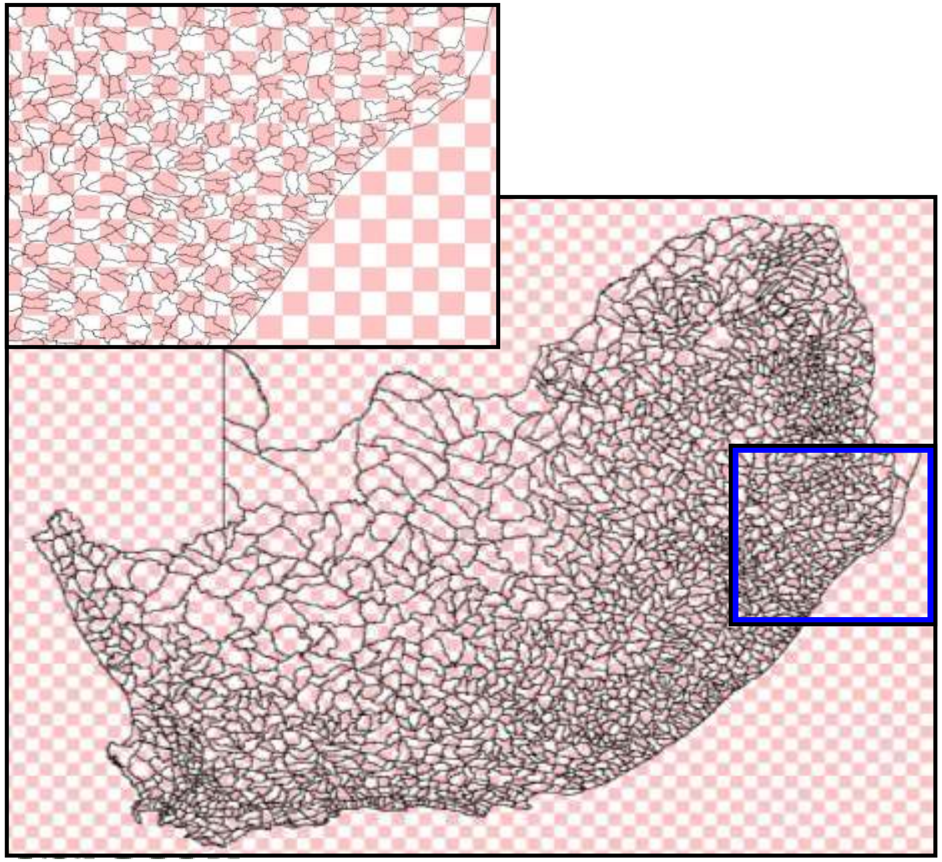

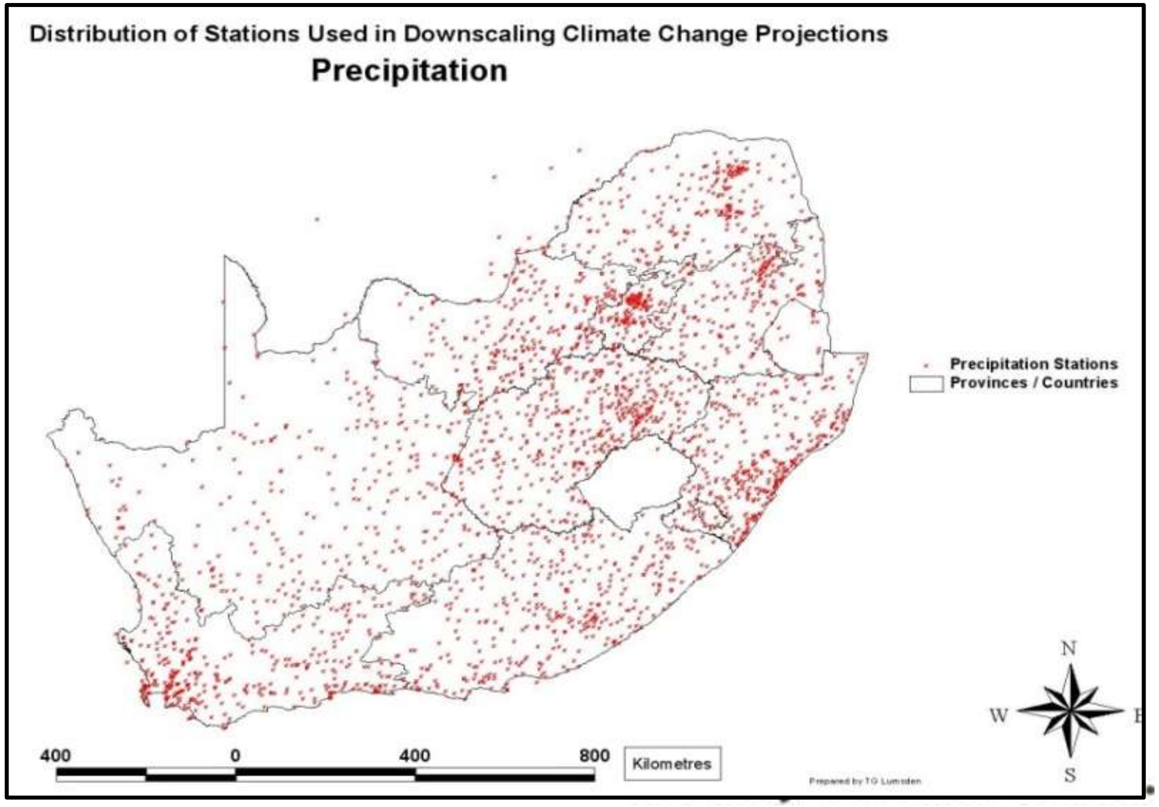

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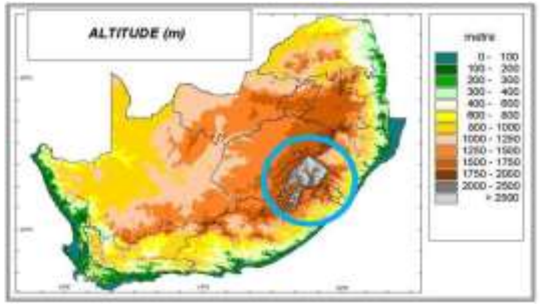
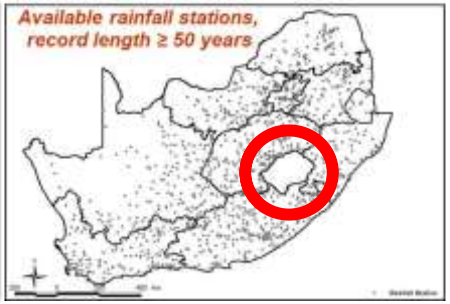
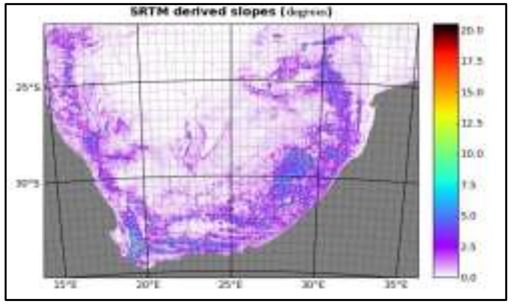
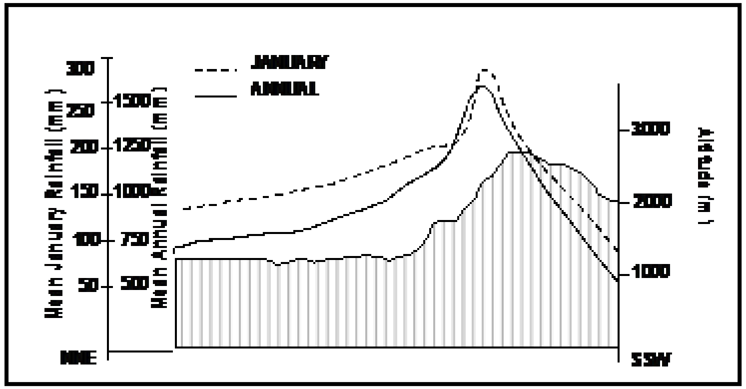
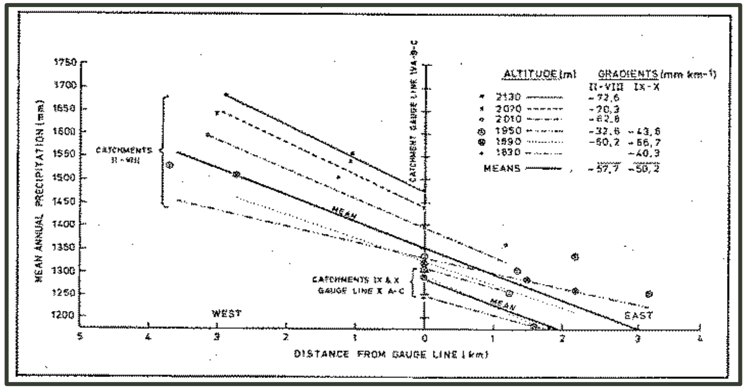
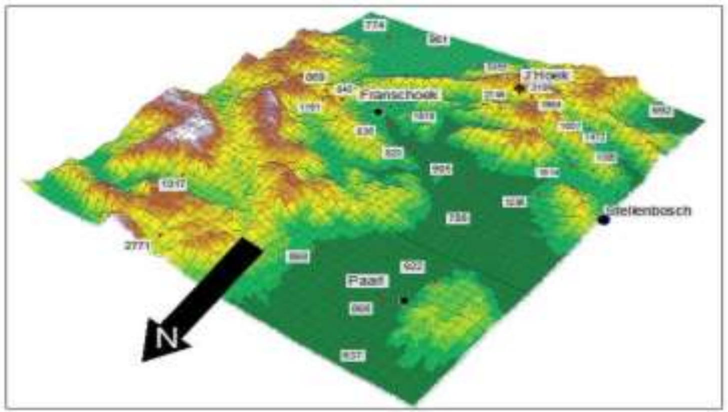




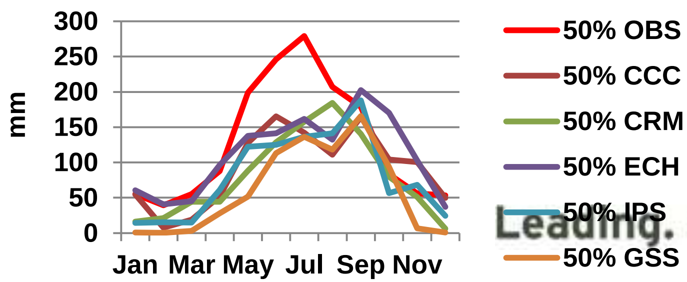




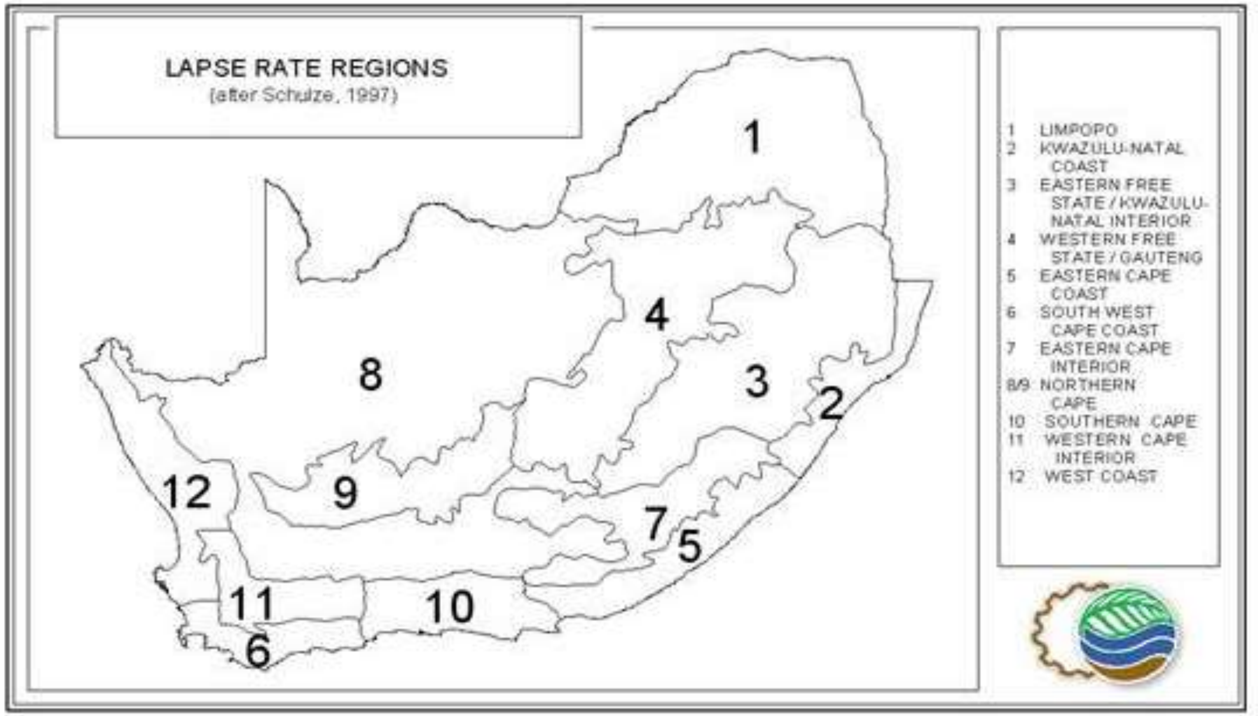


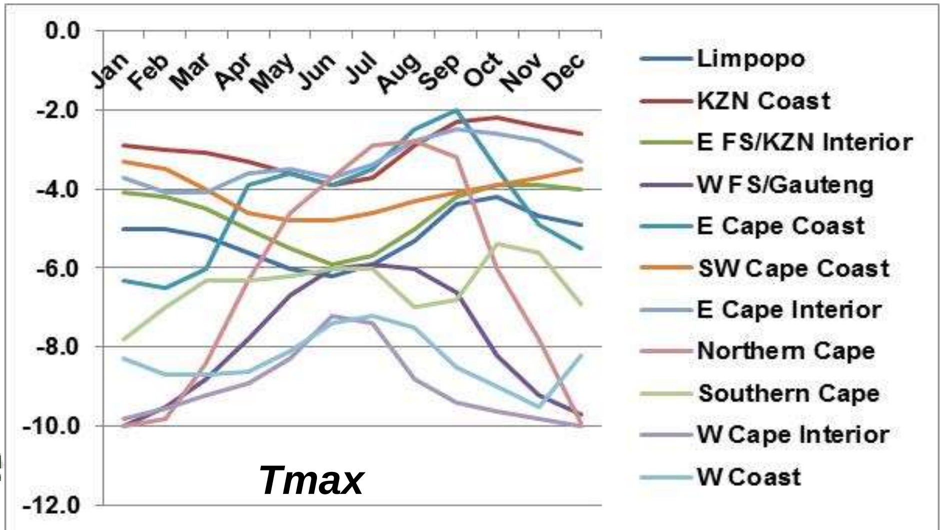


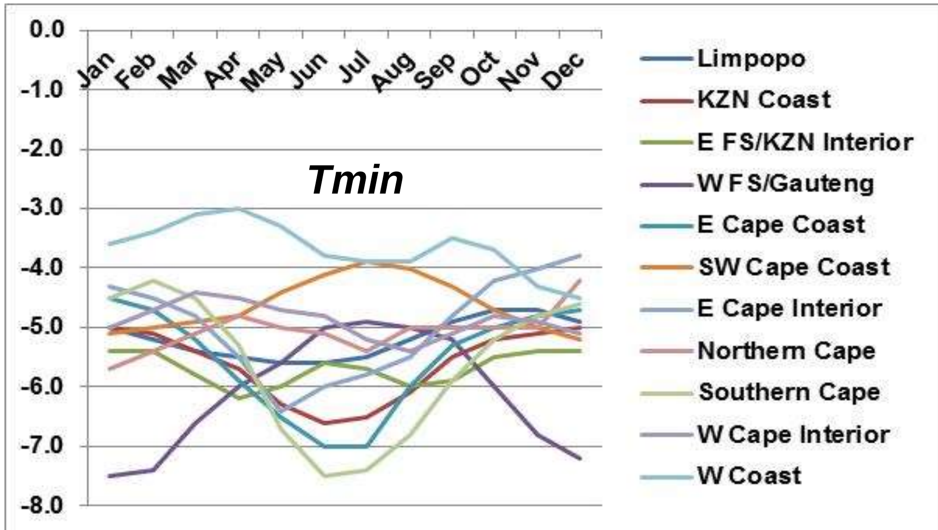
Headwaters G10A1
Median Monthly Rainfall



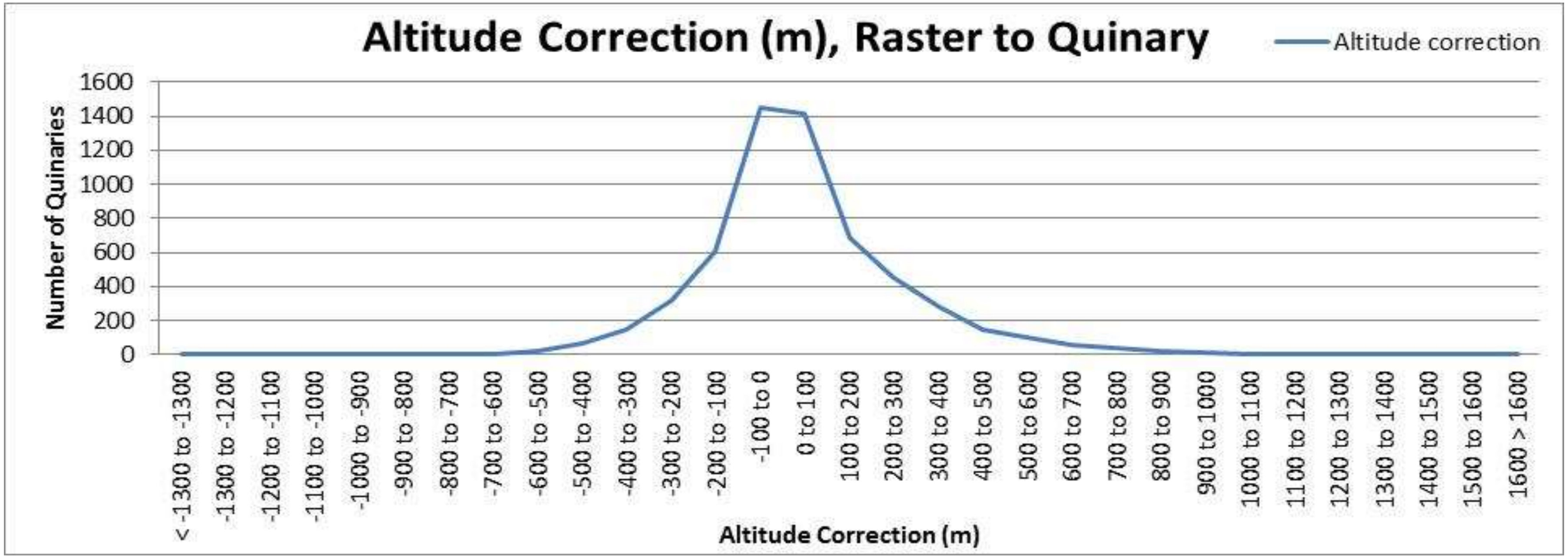
But, for Different Regions in SA the Temperature : Altitude Relationships Differ, Also by Month and by Max vs Min Temperatures

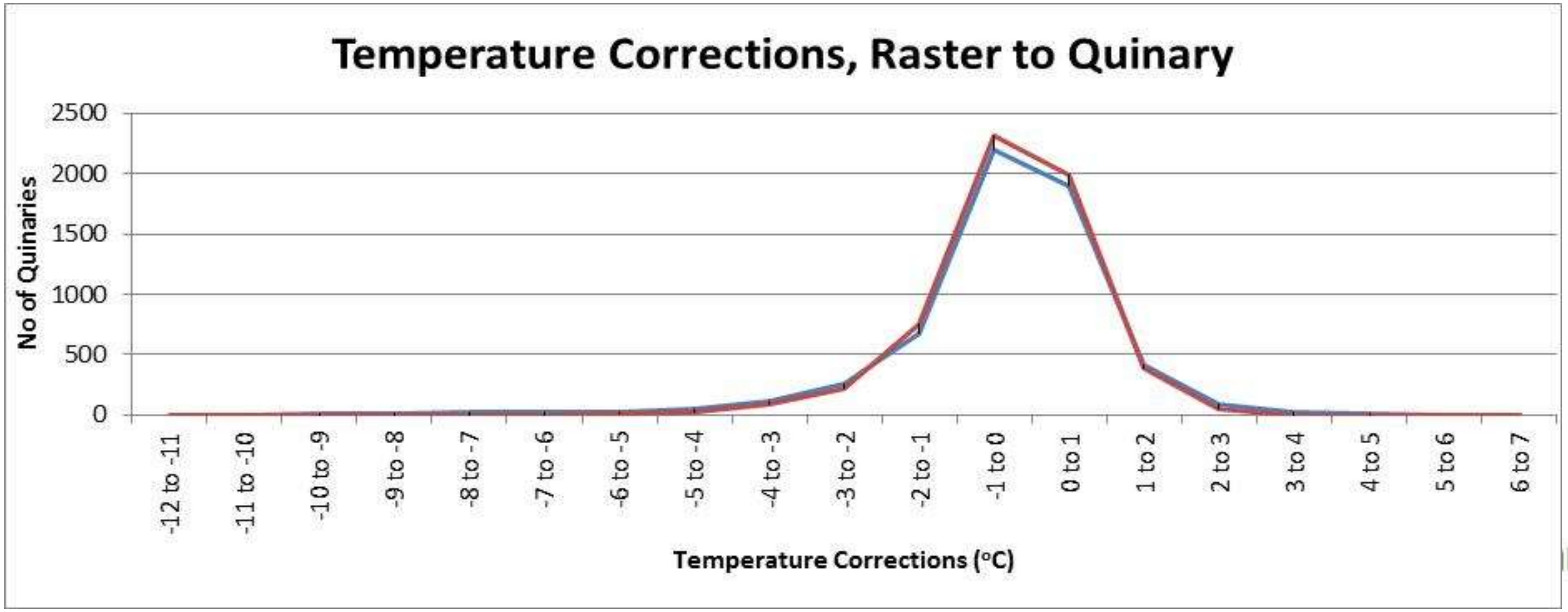


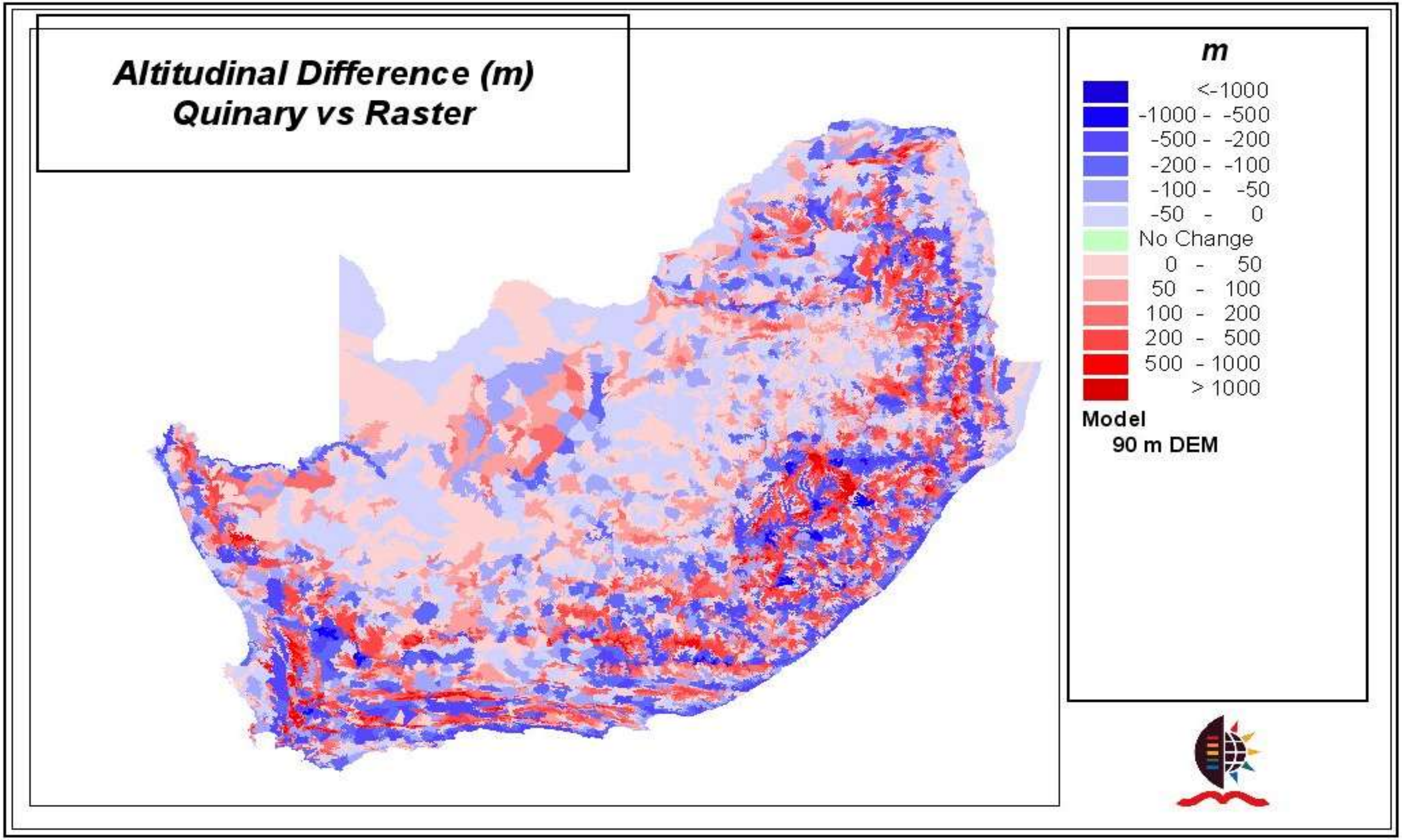




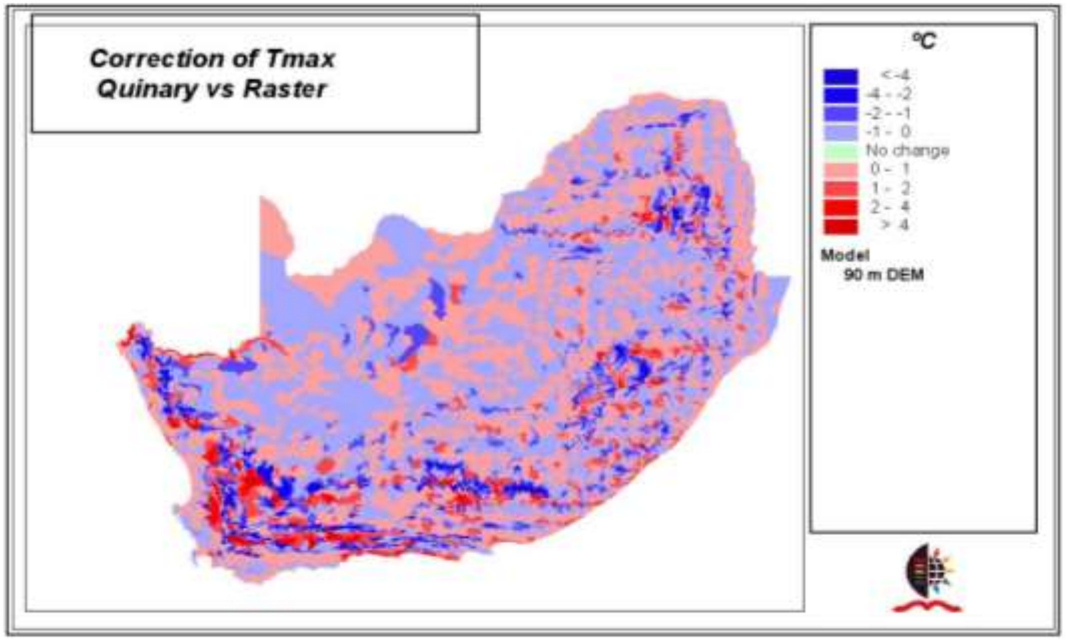
aure bal.

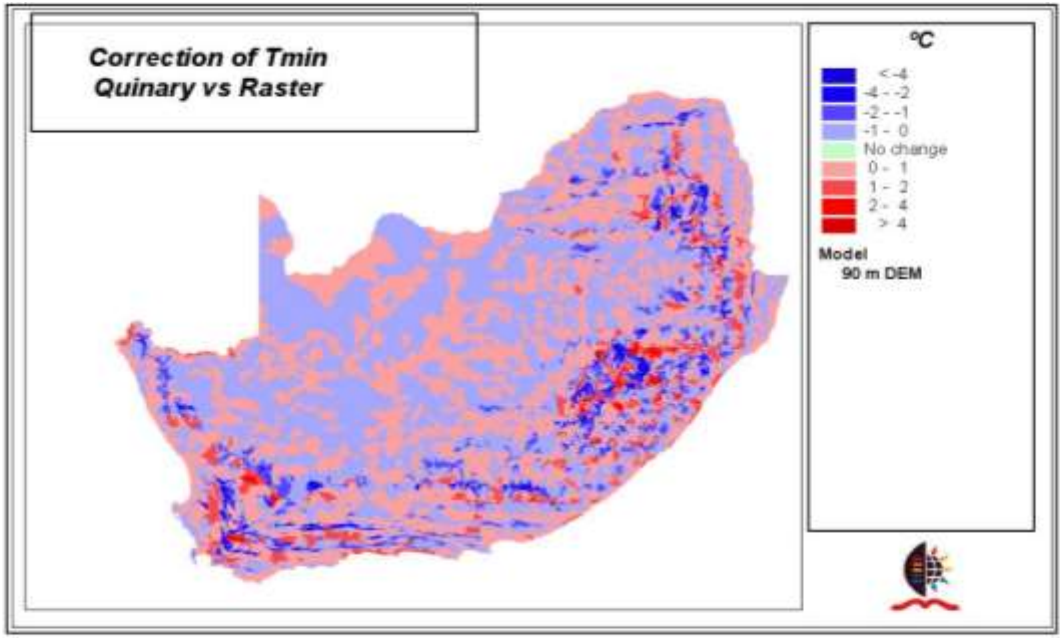

Altitude Correction (m), Raster to Quinary
Altitude correction
Number of Quinaries
1600
1400
1200
1000
800
600
400
200
0
< -1300 to -1300
-1300 to -1200
-1200 to -1100
-1100 to -1000
-1000 to -900
-900 to -800
-800 to -700
-700 to -600
-600 to -500
-500 to -400
-400 to -300
-300 to -200
-200 to -100
-100 to 0
0 to 100
100 to 200
200 to 300
300 to 400
400 to 500
500 to 600
600 to 700
700 to 800
800 to 900
900 to 1000
1000 to 1100
1100 to 1200
1200 to 1300
1300 to 1400
1400 to 1500
1500 to 1600
1600 > 1600
Altitude Correction (m)


Temperature Corrections, Raster to Quinary
No of Quinaries
2500
2000
1500
1000
500
0
-12 to -11
-11 to -10
-10 to -9
-9 to -8
-8 to -7
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 0
0 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
Temperature Corrections (°C)


Altitudinal Difference (m)
Quinary vs Raster
m
<-1000
-1000 - -500
-500 - -200
-200 - -100
-100 - -50
-50 - 0
No Change
0 - 50
50 - 100
100 - 200
200 - 500
500 - 1000
> 1000
Model
90 m DEM

Maximum & Minimum Temperature Corrections: Quinary to Raster





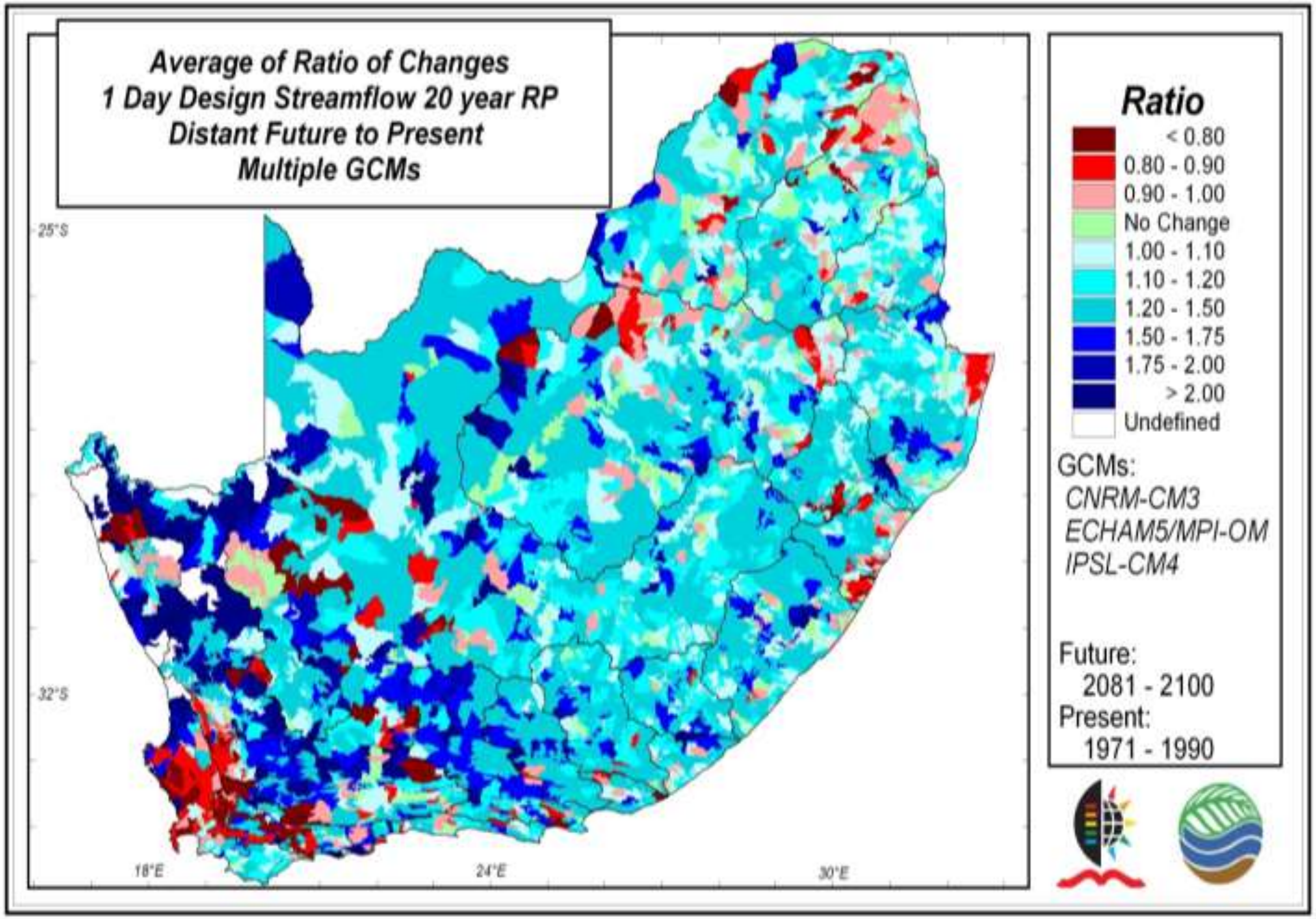
Example of Rainfall / Runoff File: Quinary Catchment # 853, i.e. C11A Upper Quinary

DATE RAINFALL SUB-CAT R/OFF ACC STRMFL ……

13/01/1961 7.584000587 0.001170044 0.001170044
14/01/1961 12.244999886 0.002349590 0.002349590
15/01/1961 9.795999527 0.001995726 0.001995726
16/01/1961 11.218000412 0.003515125 0.003515125
17/01/1961 3.950000048 0.002870157 0.002870157
18/01/1961 0.158000007 0.003040630 0.003040630
19/01/1961 0.000000000 0.003068754 0.003068754
20/01/1961 0.000000000 0.002971481

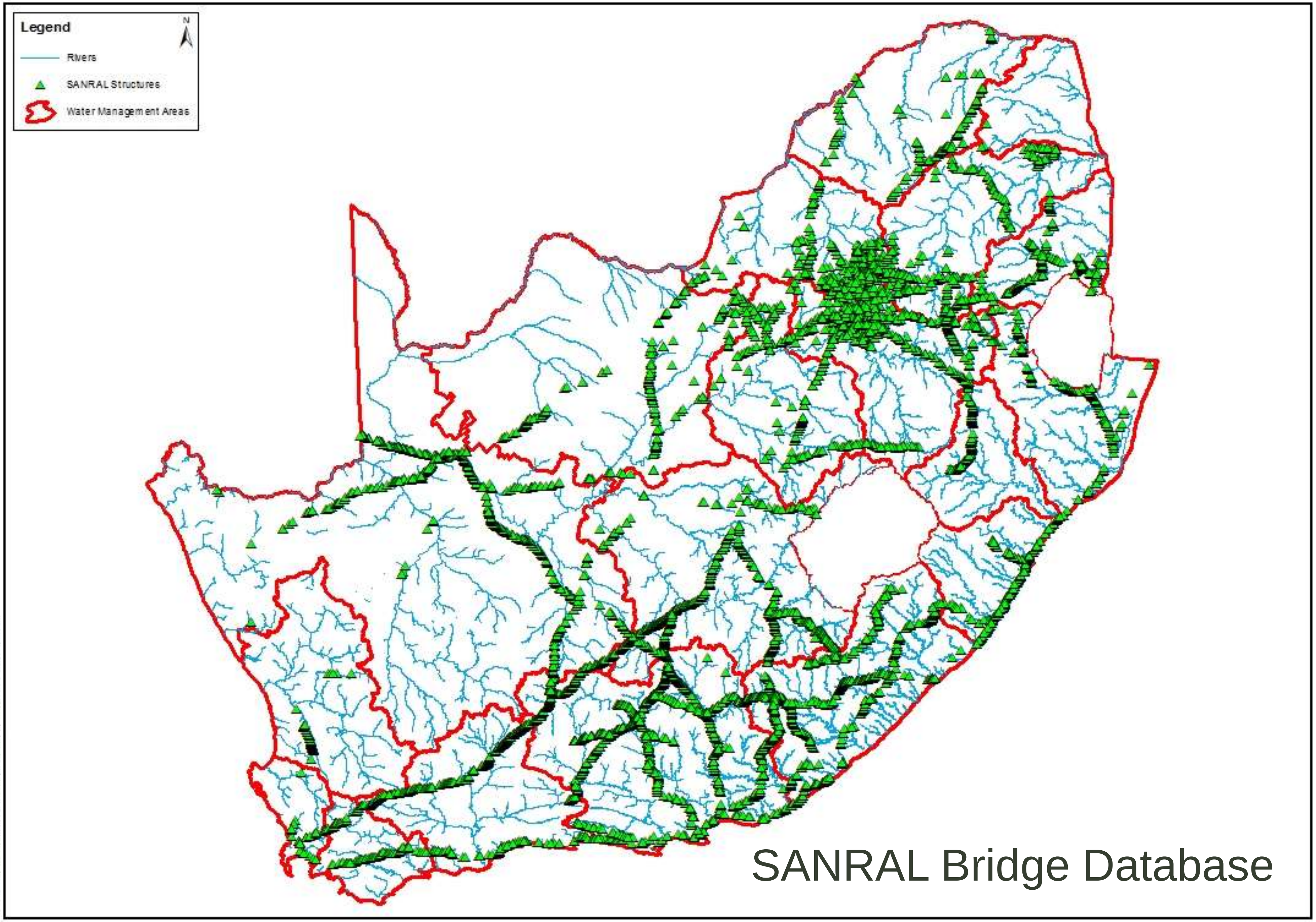
* Each Quinary daily file for each GCM from 1961 – 2100 is 51 135 lines long
* There are 5 838 Quinaries covering SA
* This for each GCM
* Total datafile per GCM ~ 84 Gigabytes

Provisional ACRU Modelling Results



Change in the 10 year RP one day design streamflow between the distant future (2050) and the present.

(Source: Schulze, 2012)



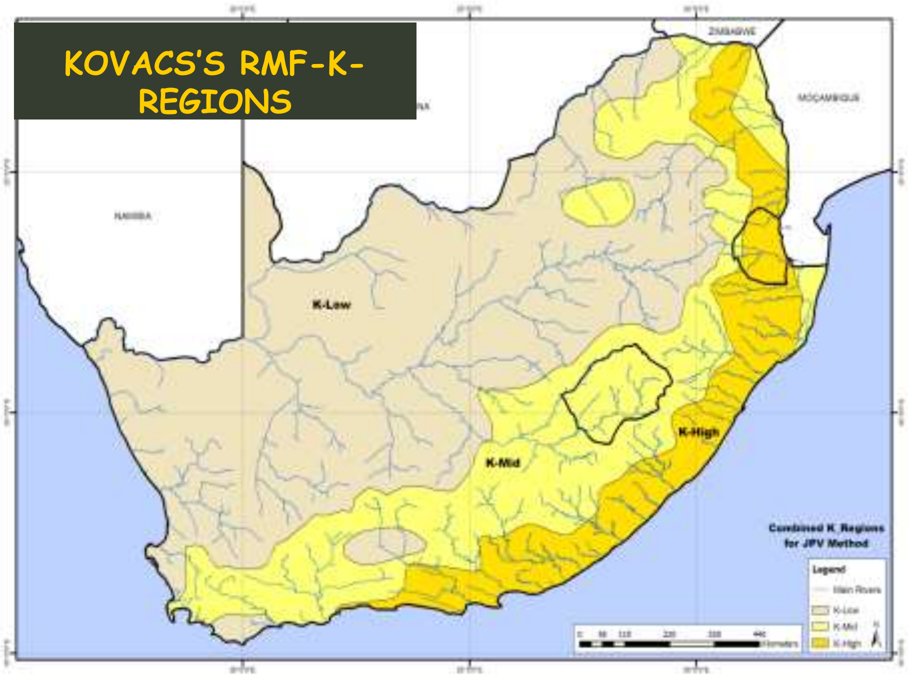
U:\H109009_PH2\mxd\Dams_Classification.mxd

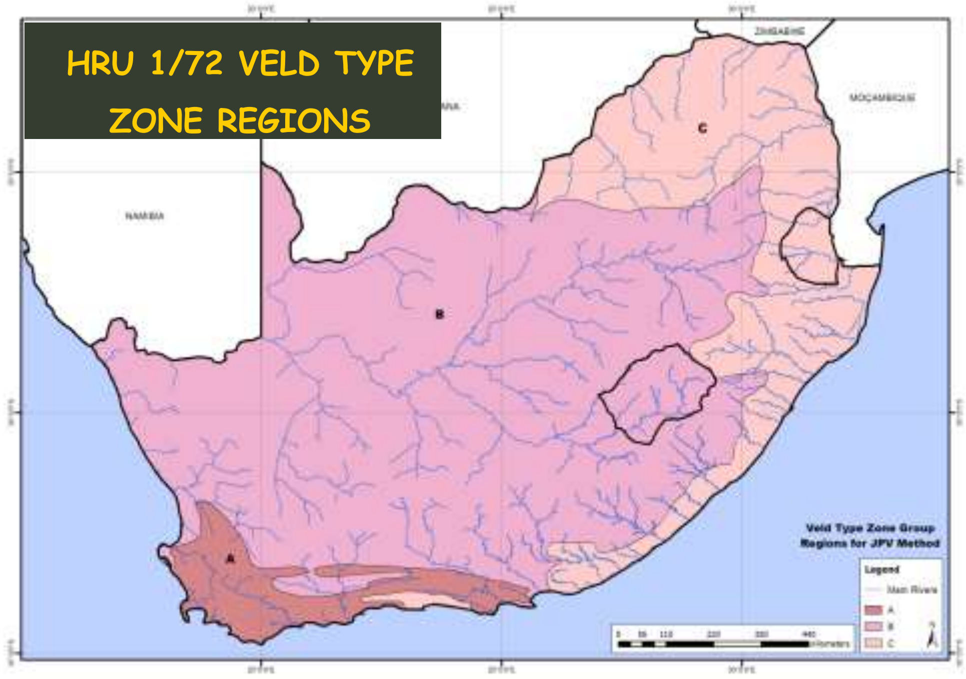
SANRAL Bridge Database

Standard Design Flood (SDF) (< 200 km^2) (Alexander, 2002)

- **Recommended method in the SANRAL Road Drainage Manual**
- **Based in the Rational Method: $Q_T = C_T I_T A / 3.6$.**
- **Uses calibrated run-off coefficients (Ct) for 29 “basins” in SA.**
- **Identifies a single “driver” SAWS station in each basin.**
- **Generally provides a simple and conservative estimate of design flood peaks, (except in the dolomite area and the SW Cape rivers)**
- **Assess CC impacts in terms of change in 1 day maximum precipitation (I_T)**

Joint Peak Volume (JPV) Method (> 200 km^2) (Görgens, 2007)





- **Regionally pool design flood estimate for ungauged basins in SA**
- **Empirically derived estimate of flood peak $Q_T = \mu_Q + K_{g,T}\,\sigma_Q$**
  - μ_Q = mean annual max flood peak – function of Area, MAR, slope, region.
  - $K_{g,T}$= frequency factor for give return period (T) and skewness (g)
  - σ_Q = standard deviation of the annual flood peak – pooled values for region
- **Pooled by existing K-regions and HRU veld type zones**
- **Assess climate change impacts in terms of ΔMAR**

Adaptation Options for Increased Flooding Risk

Physical / Infrastructure

Catchment management

Green urban design

Maintenance of buffer strips, wetlands and ponds

Flood control dams (or changed dam operating rules)

River training works and dykes

Maintenance and cleaning (e.g. prevent blockages at bridges, and maintenance of dam flood gates)

Social / Institutional

New development zoning

Resettlement out of flood plain

Flood early warning systems

Insurance and other support and disaster risk preparedness

There is currently a "**development deficit**" in SA, particularly for flooding. Climate Change will add an "**adaptation deficit**" in addition..

BUT … many of the **adaptation options** for addressing the "development deficit" will also address the "adaptation deficit".

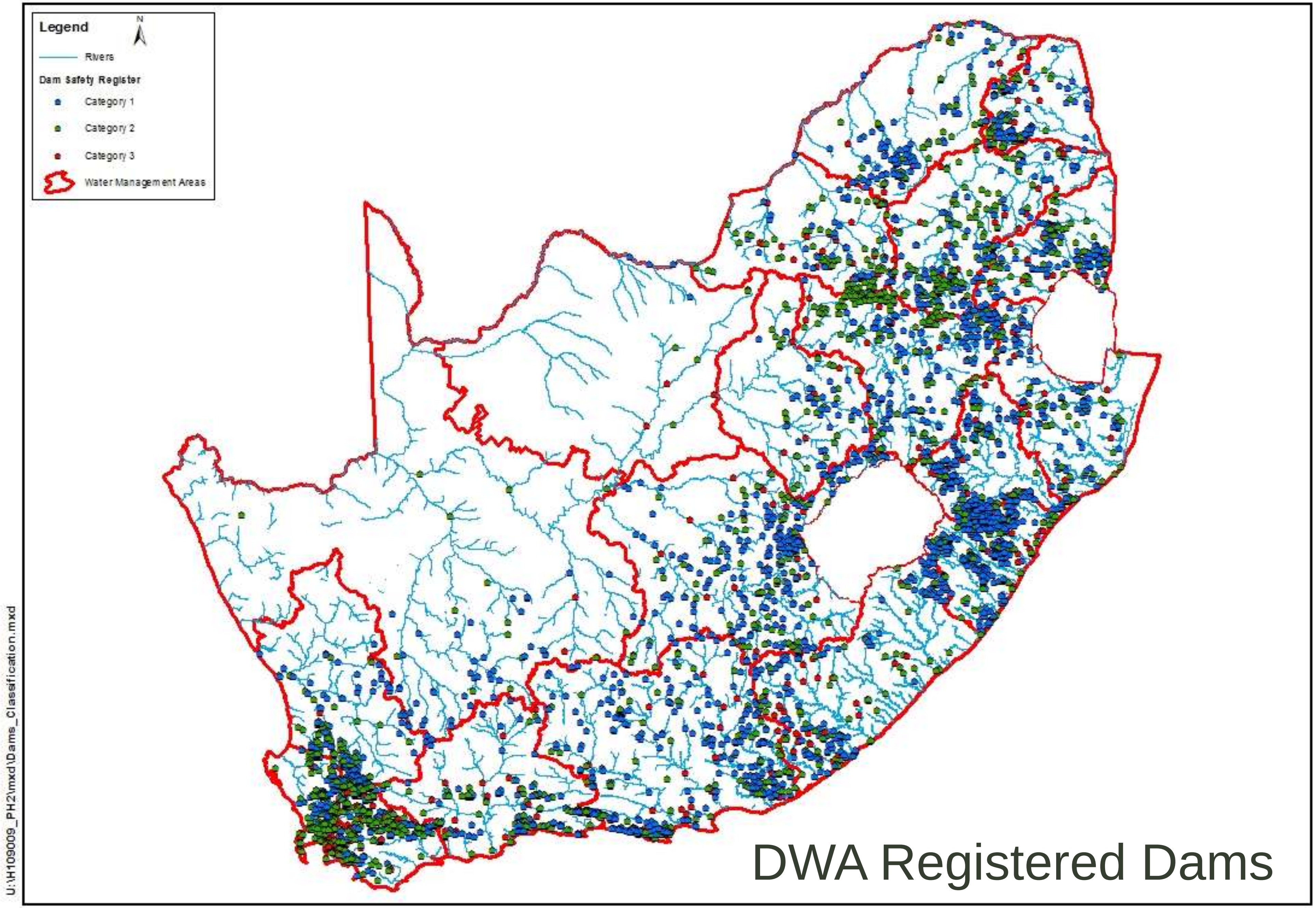
Provisional Modelling of Sedimentation Impacts

The "Hydrologist" Approach

- **Modeling of changes in the daily sediment load using ACRU across SA.**

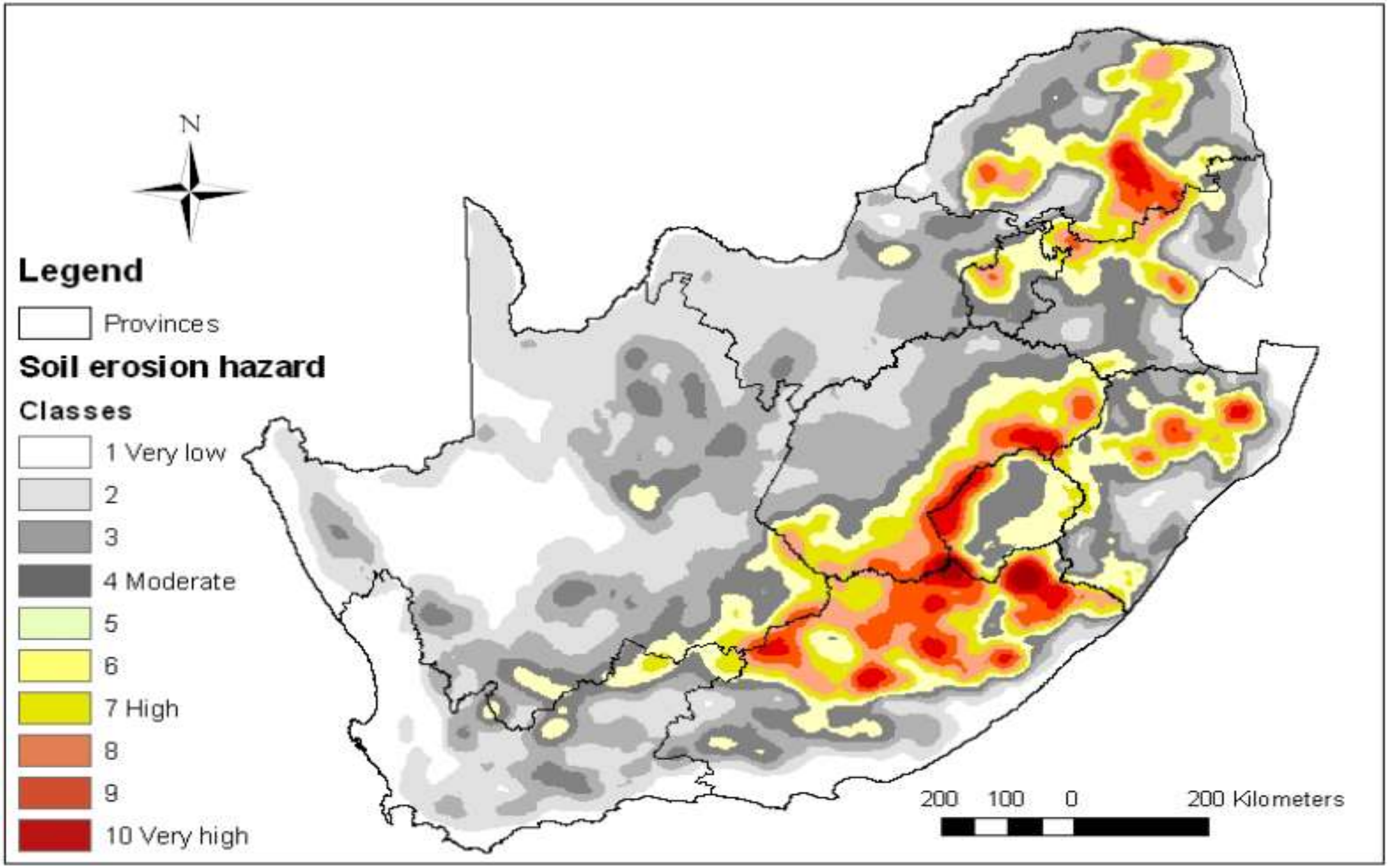
The "Engineers" Approach

- **Model changes in annual sediment load for selected dam locations using the WRC regionalized mean annual sediment load equations**
- $Q_s = f[Q_{10}, S_0, R_{nd}, A_e, EI_w]$
  - Q_s = mean annual sediment load (t/a)
  - Q_{10} = 1:10 year flood peak (m^3/s)
  - S_0 = average river slope (%)
  - R_{nd} = river network density (m/km^2)
  - A_e = Effective catchment area (km^2)
  - E_{iw} = Weighted erosion hazard class
- **Climate change impacts assessed in terms of the change in the Q_{10}.**
- **The impact of changes in sediment yield can be assessed in terms of loss of storage capacity in dams and loss of topsoil from catchments.**
- **Increased sediment loading also has a Water Quality impact**



DWA Registered Dams

Map of Erosion Hazard Classes (WRC, 2012)



Erosion hazard map for South Africa (Roux, 2009 in WRC, 2012)

Adaptation Options for Increased Sedimentation Risk

Physical / Infrastructure

Sediment diversion weirs

Sediment traps

Increased dredging

Soil and slope stabilization

Additional water treatment requirements or shut downs.

Social / Institutional

Improved Land care and catchment management

- Farming practices
- Grazing control
- Forestry practices

Buffer strips and wetlands

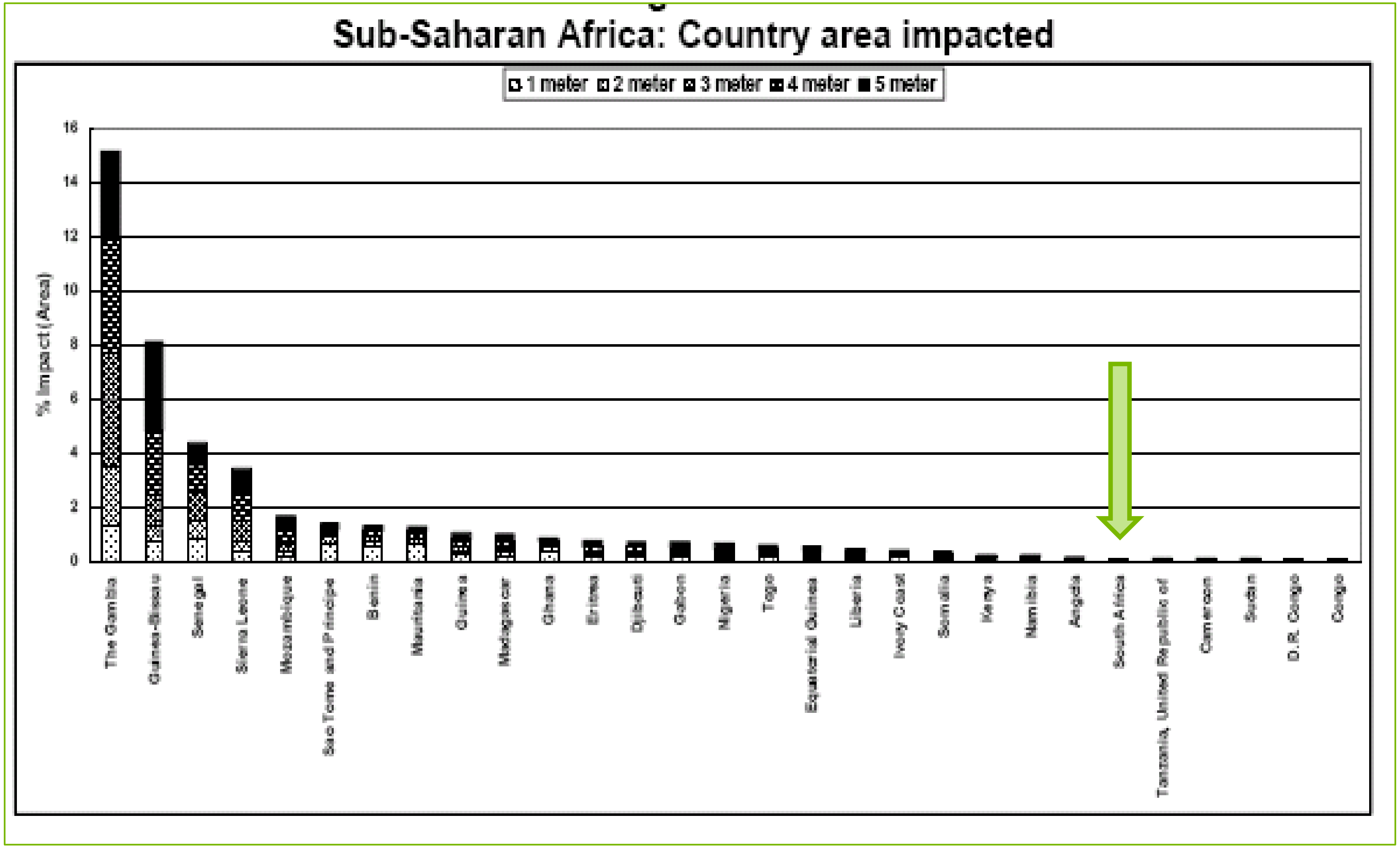
Rehabilitate lands e.g. dongas

Provisional Modelling of Sea Level Rise Impacts

- **Sea is not, is never, level.**
- **IPCC 2007: 18 - 59 cm rise by 2100.**
- **IPCC 2013: 26 – 82 cm rise by 2100.**
- **Rate of change is uncertain, but it is currently increasing and at an accelerating rate.**
- **Potential for much greater impacts.**
- **e.g. Pliocene (2-3°C warmer), SL 25m – 30m higher**
- **In SA gauges show 1.42 mm - 3.55 mm per annum.**
- **Wave impacts on top of elevated platform.**

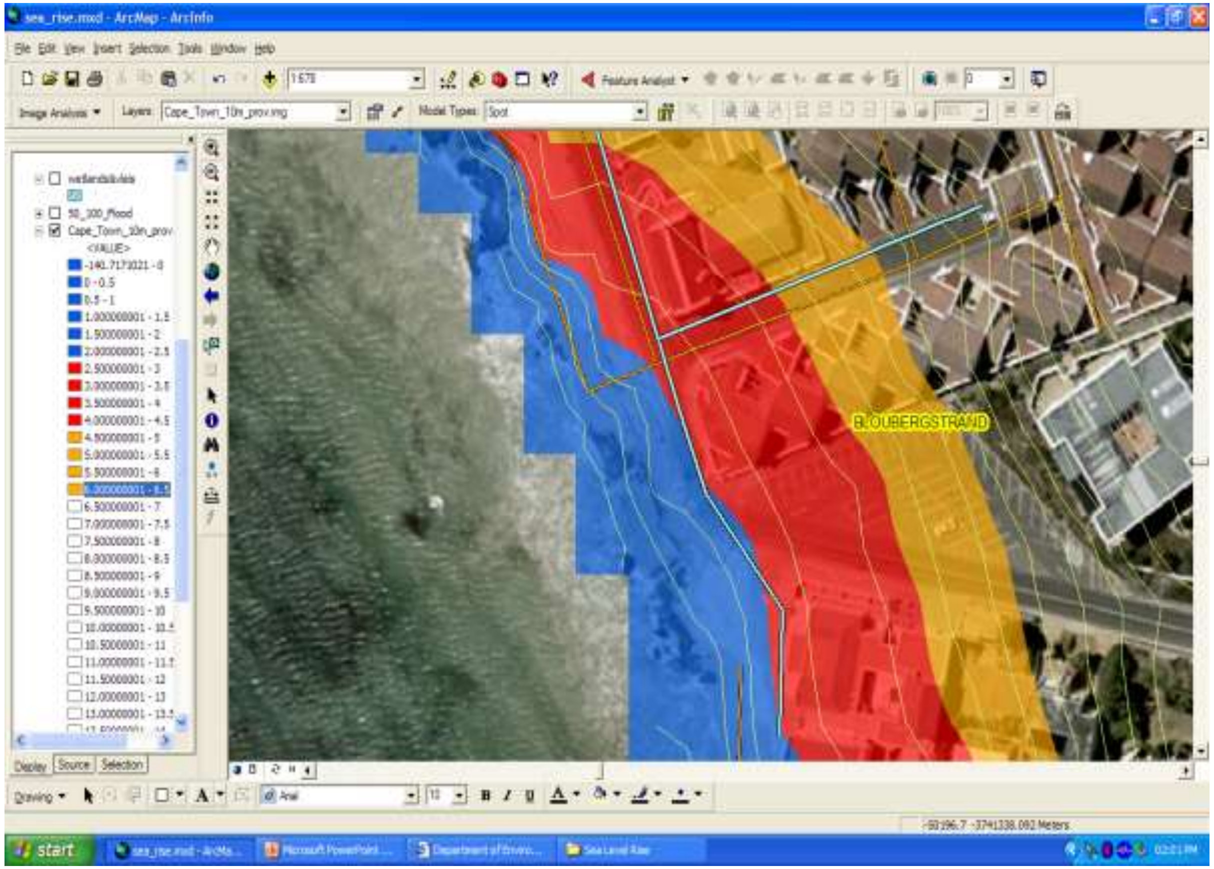
Sea Level Rise has a significant LOCAL/REGIONAL IMPACT, if not significant at a NATIONAL SCALE.

- **South Africa ranks 24th out of 29 sub-Saharan countries in terms of the proportion of the country exposed, which suggested that less than 1% of the total population may risk exposure to a 5 metre increase. (Dasgupta *et al, 2007)***



City of Cape Town Study: Economic Impacts of SLR

- **The cost of sea-level rise risk in Cape Town ranged between R4.9 and R20.2 billion over the ensuing 25 years (Brundrit and Cartwright, 2010*).***
- **The City identified 19 critically exposed “hotspots” for further studies.**
- **Incorporated SLR into the delineation of coastal set back lines in accordance with ICMA**



Provisional Sea Level Rise Modelling Assumptions
(with support from Anton Cartwright of Econologic)

- No scope (time) for detailed wave modelling or modelling of coastal processes.
- Assessment based on existing studies:
  - City of Cape Town (2008)
  - Eden District Municipality (2010)
  - Kwa-zulu Natal – eThekwini Municipality (2012)
  - Overberg Municipality
  - Development Under Climate Change (DUCC) study (2013)
- Assessment based on identification of potential low-lying areas based on existing coastal topography.
- Assumes 0.25 m to 0.50 m eustatic rise (i.e. rise in MSL) and 2.50 m to 4.50 m swash impacts (10% damage)
- Used to identify “hot spots” of concern for further work.
- Provisional economic assessment based on numerous simplifications and assumptions at LM and National Level

Sea Level Rise Adaptation Options

A hierarchy of adaptation options:

1. **Socio-institutional**

   E.g. Early warning, set back lines, insurance industry intervention

2. **Biological**

   E.g. Dune cordons, mangroves, kelp beds, beach replenishment

3. **Hard / Infrastructural**

   E.g. sea-walls, off shore reefs, dolosse.

Other climate change impacts that may affect coastal economies

- Increase wind strengths and high-wind events
- Hurricanes and cyclones
- Fisheries impacts

Thank you!

More to come in tomorrow's session:

- **Provisional modelling of the economic impacts of Climate Change and alternative development and adaptation scenarios.**

ANY QUESTIONS?

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