# Incorporating Regional Variability in Water Supply Costs into Decision Making for Future Energy Options

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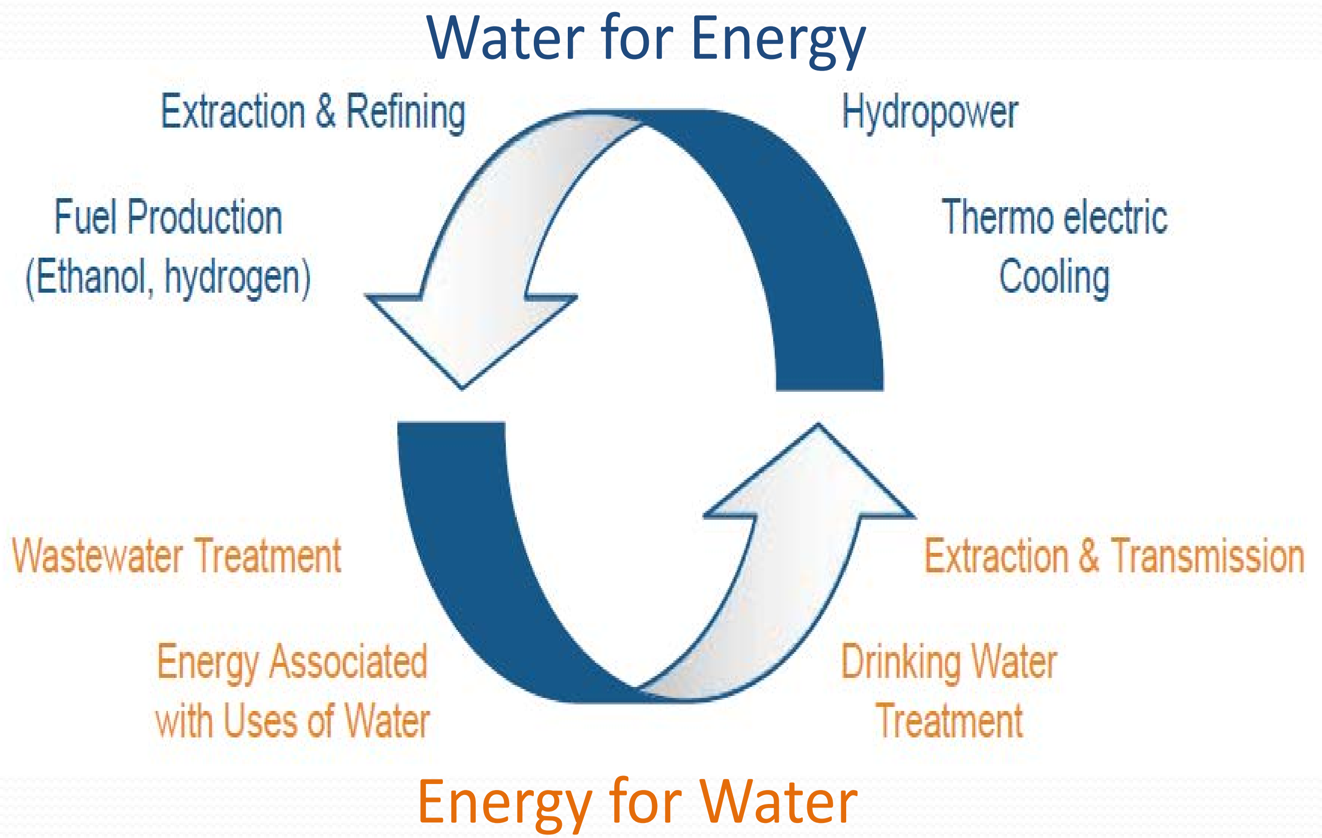
# Modelling the Water-Energy Nexus: Should regional variability in water availability and cost impact the decision making for future energy supply options?

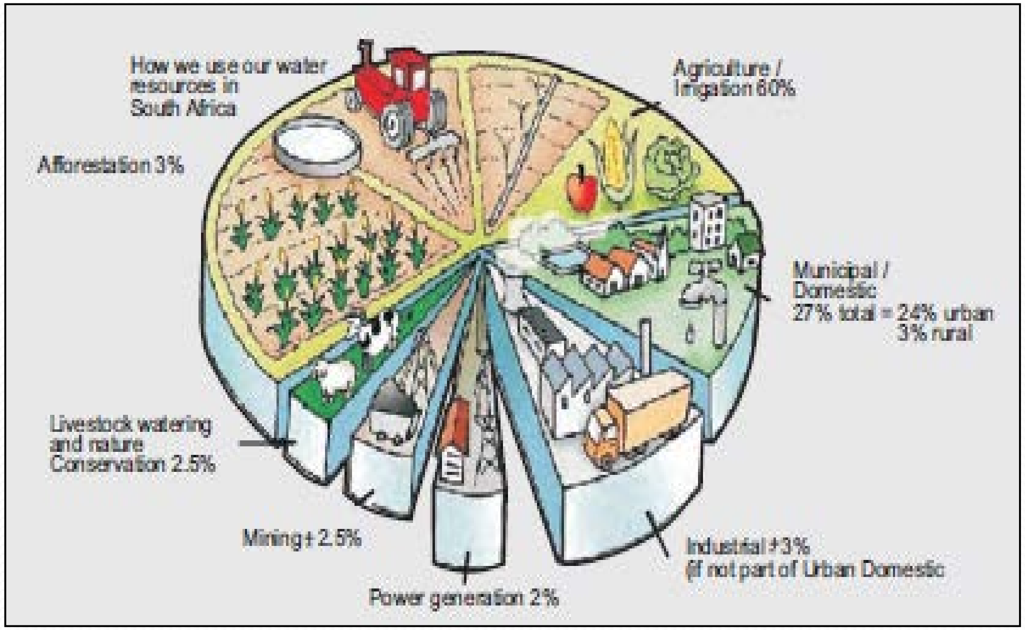
- Task 1: Develop marginal water supply cost schedules
  a) Define the water management areas of interest
  b) Develop marginal water supply cost curves for different technologies
  c) Assess potential climate change impacts for areas of interest
  d) Update marginal water supply cost curves for CC impact
- Task 2: Develop the "water smart" SATIM model
- Task 3: SATIM Energy-Water Nexus (Phase 1) Model simulations
- Task 4: Report on Integrated Energy-Water Modelling and Analysis for the South Africa case study
- PHASE II: Additional water-energy nexus model development . (e.g. linked economic model, incl. externality costs, etc.)

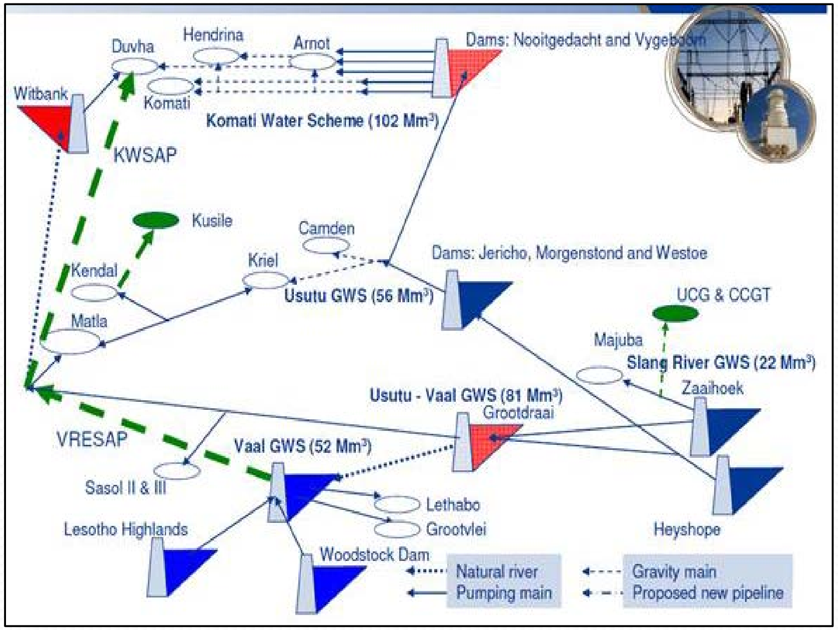
# The Water-Energy Nexus




- Focused on Water for Energy, but has implications for Energy for Water.

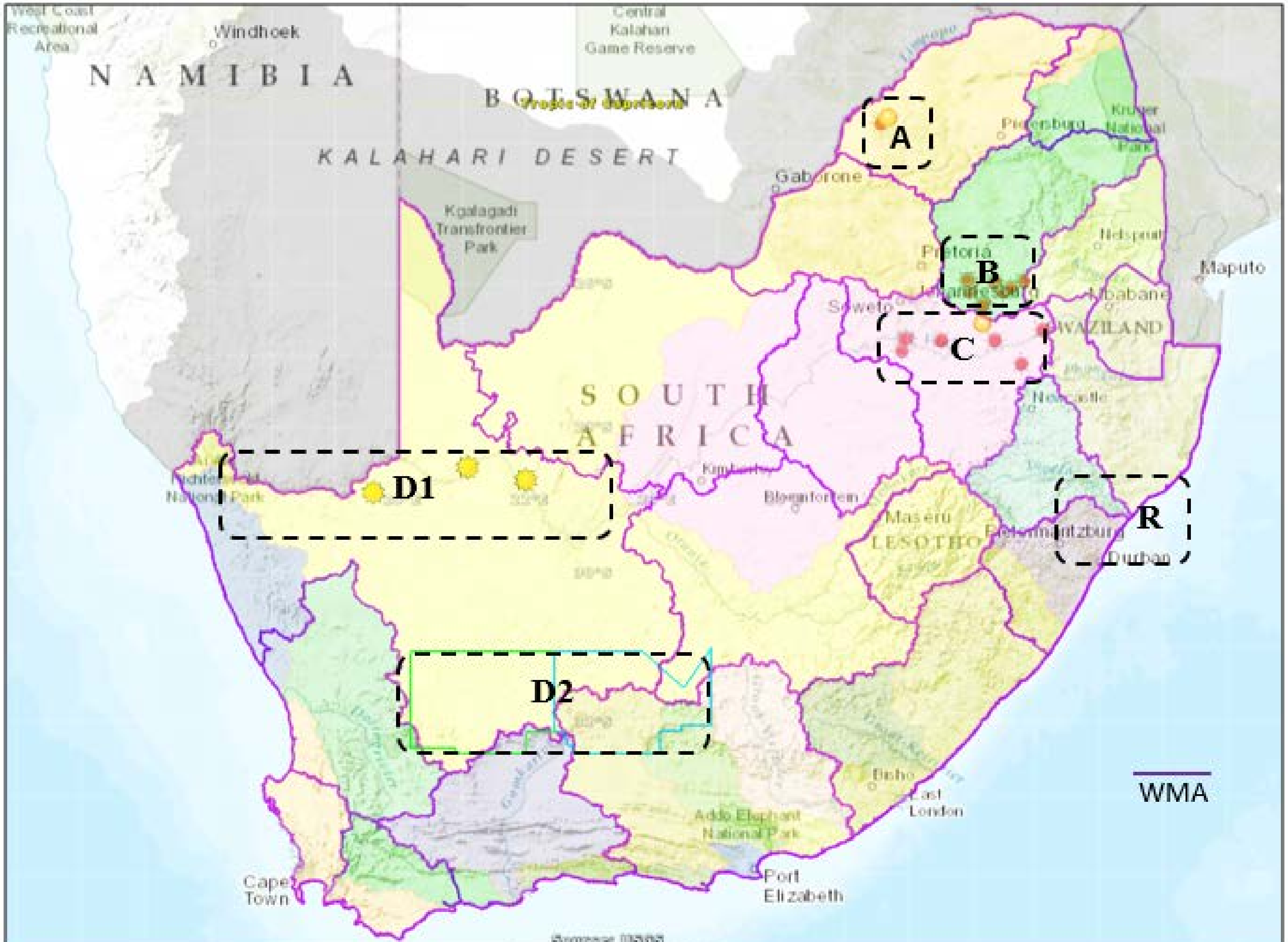
# Water for Energy in SA



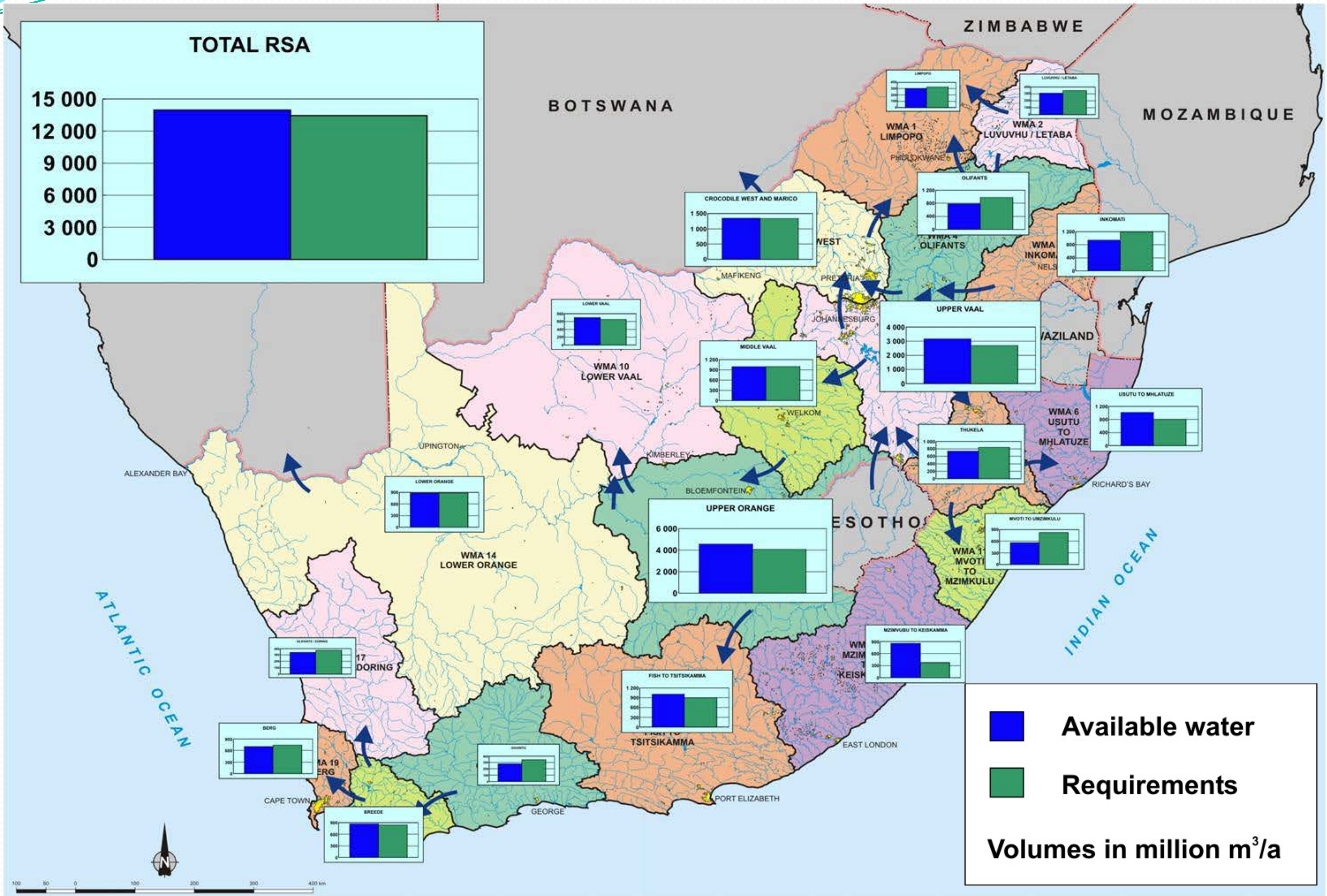




- Direct use for power generation is small (2%) at national level.
- Requires a high level of assurance (99.5%, i.e. 1:200 years) and is significant at a regional level (e.g. 37%. in the Upper Olifants).
- Water for power supported by major inter-basin transfers.
- The transfer and treatment of water is very sensitive to energy costs.

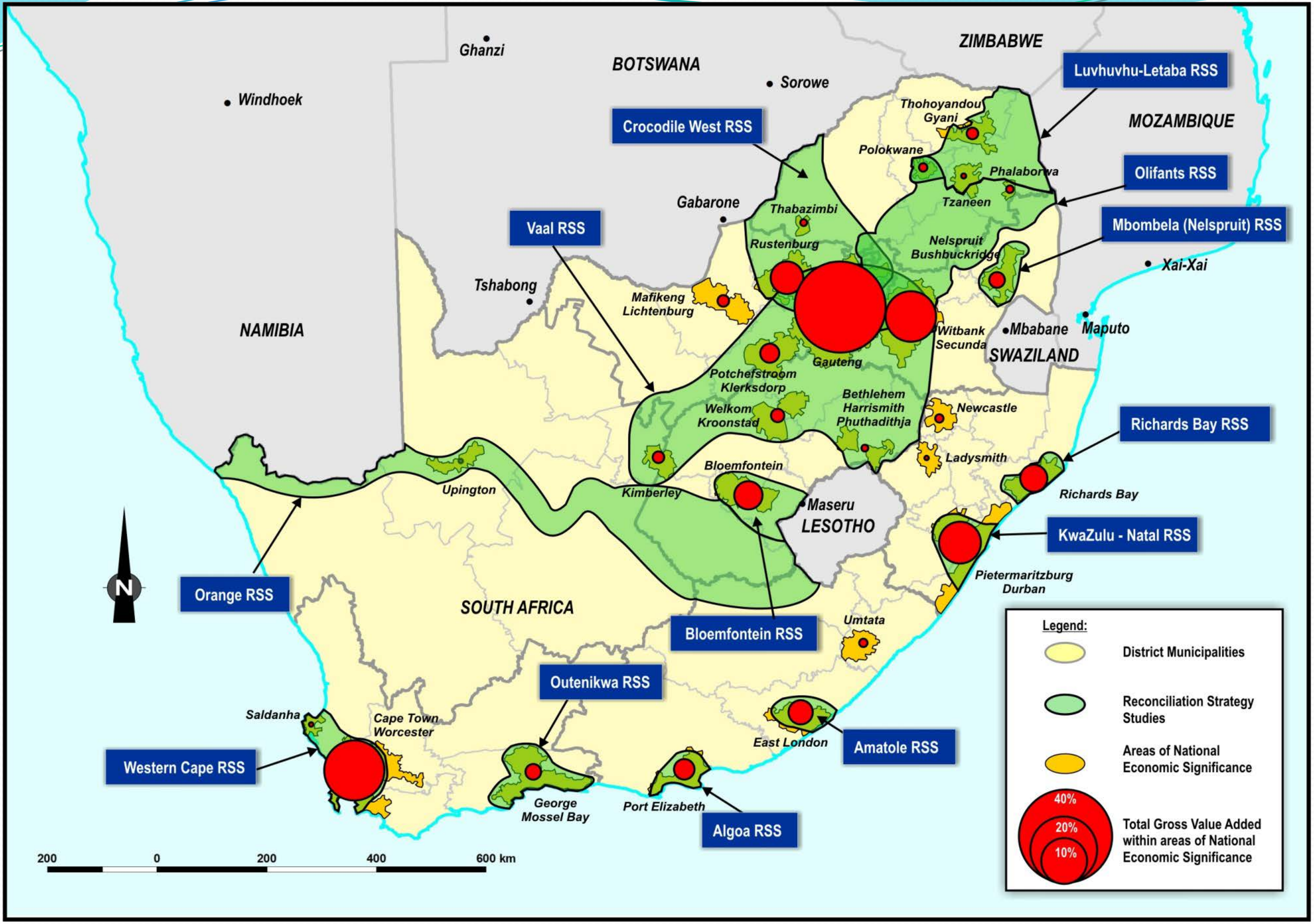
# Matching energy producing regions with water resource areas (WMAs) in SA



# Balancing Supply and Demand (year 2000)

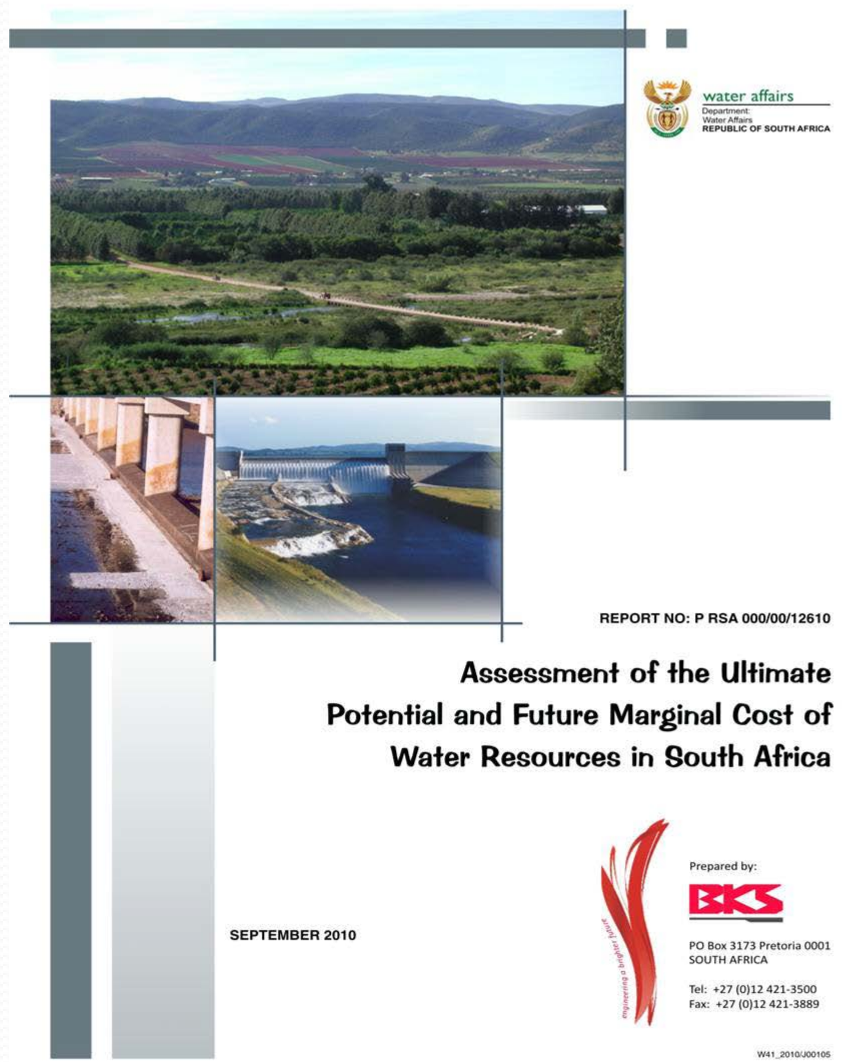


# Reconciliation Studies for Bulk Water Supply Systems

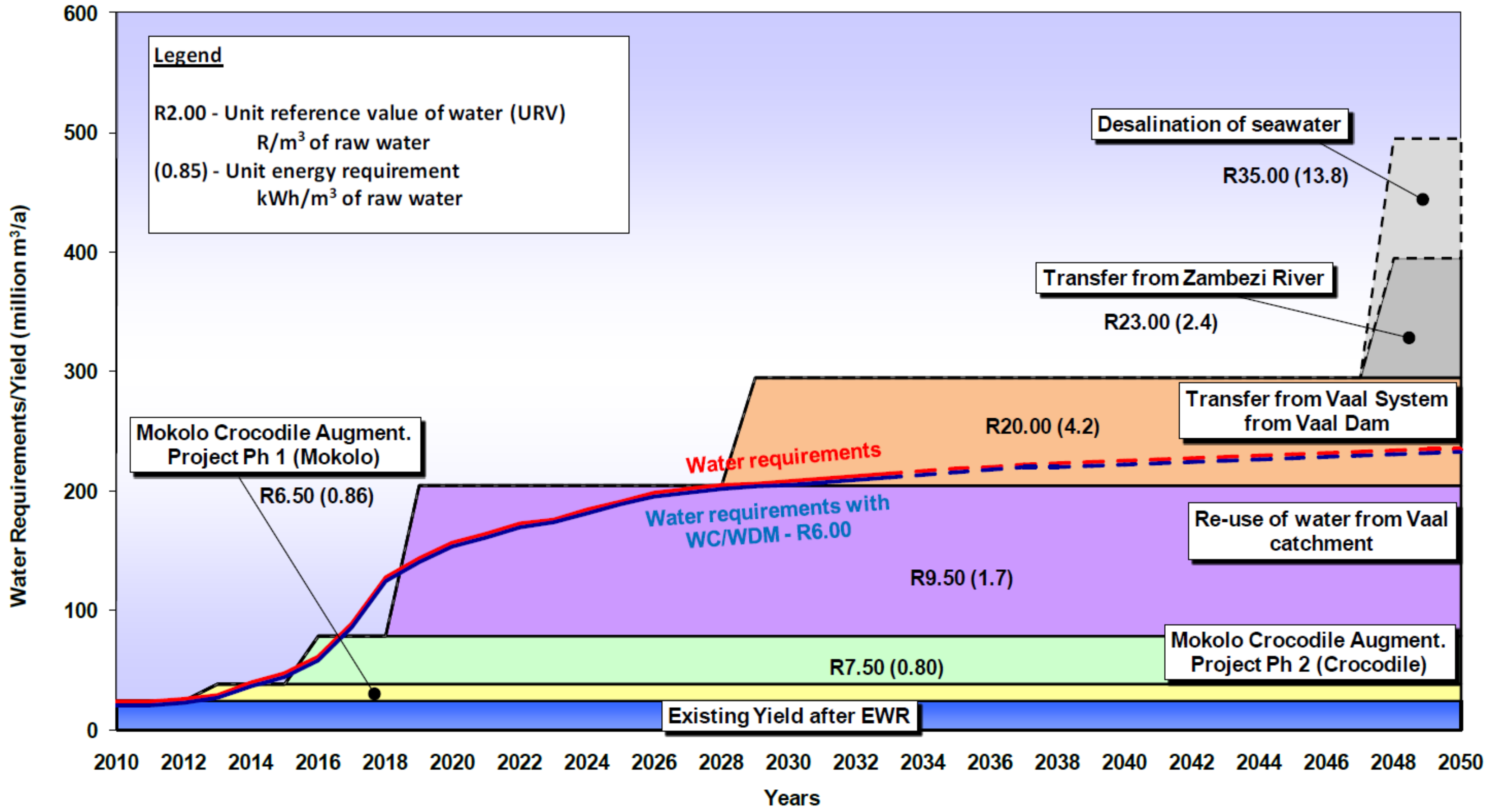


# Determining the Regional Costs of Water for Energy

- Primary source of information is the Ultimate Marginal Cost study undertaken by DWA in 2010 with costs escalated to 2014.
- Study compares the ultimate marginal cost of water supply to different regions using a common set of assumptions.
- Includes desalination as the ultimate water supply option.
- Provides information on future regional water demands to 2050.
- Regional demands and some supply option costs updated with more recent information from reconciliation studies.

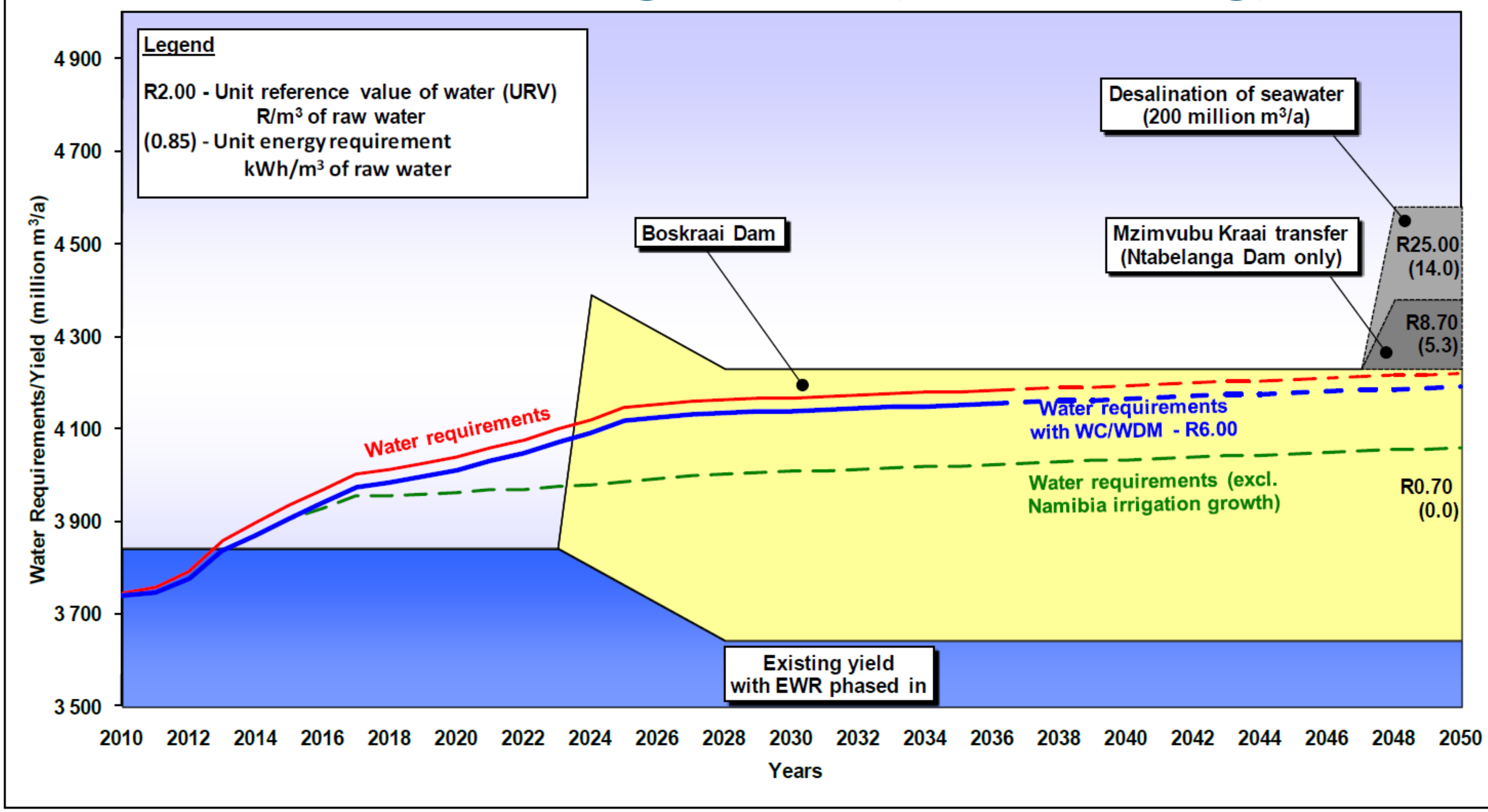


# Lephalale System (Limpopo WMA) - Coal




- Mokolo Crocodile Ph2: R7.50/m³, 0.80 kWh/m³ (2015-2020)
- Re-use from Vaal: R9.50/m³ , 1.7 kWh/m³ (2020-2030)
- Transfer from Vaal: R20/m³ , 4.2 kWh/m³ (2030-2050)
- Transfer from Zambezi: R23/m³, 2.4 kWh/m³ (>2050)

# Lower Orange – CSP (and fracking)




- Boskraai Dam: R0.70/m³, 0 kWh (2020-2030)
- Mzimvubu Transfer: R5.30/m³, 5.3 kWh (2040-2050)
- Desalination (PE): R13/m³, 7.6 kWh (>2050)

# Marginal Cost Curves for Water for Power

- Based on recommendations in DWS water pricing strategy.
- MWSC = Marginal Water Supply Cost (R/m³)
- Where MWSC = $WRMC + WSSIC + WDMC + WSDC + WSEC + PWTC + SWTC + WUOC$ .
  - WRMC = Water Resource Management Charge
  - WSSIC = Water Supply Scheme Infrastructure Costs
  - WDMC = Waste Discharge Mitigation Charges
  - WSDC = Water supply delivery costs
  - WSEC = Water supply energy costs
  - PWTC = Primary water treatment costs
  - SWTC = Primary water treatment costs
- WSSIC includes the annual Unit Water Cost (UWC) for both bulk water supply scheme and delivery option (CUC + ADC).
- Schemes also compared on Unit Reference Value (URV)

# Unit Water Costs (UWC) for Bulk Water Supply Schemes

| Water Supply Region | Scheme Description | ID | Scheme Yield ($M.m^3/a$) | Energy Requirement ($kWh/m^3$) | Capital Cost ($R \times 10^6$) | Annual O&M Cost ($R \times 10^6$) | CUC* ($R \times 10^6$) | ADC[$] ($R \times 10^6$) | OMC ($R \times 10^6$) | EC[#] ($R \times 10^6$) | UWC ($R/m^3/a$) | Net UWC (R/m3/a) | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lephalale (Limpopo)** | Mokolo Croc Phase 1 | A1 | 28 | 0.85 | 2078 | 12 | 265 | 16 | 12 | 21 | 11.20 | 11.20 | |
| | Mokolo Croc Phase 2 | A2 | 169 | 0.8 | 10280 | 49 | 1311 | 77 | 49 | 122 | 9.22 | 9.22 | |
| | Reuse and transfer from Vaal | A3 | 126 | 0.87 | 1437 | 44 | 183 | 11 | 44 | 99 | 2.67 | 11.89 | 1 |
| | Transfer from Vaal | A4 | 90 | 1 | 3027 | 18 | 386 | 23 | 18 | 81 | 5.64 | 14.86 | 1 |
| | Transfer from Zambezi | A5 | 100 | 2.44 | 17097 | 88 | 2180 | 128 | 88 | 220 | 26.16 | 31.16 | 2 |
| | Desalination of seawater | A6 | 100 | 13.82 | 24691 | 438 | 3148 | 185 | 438 | 1244 | 50.15 | 48.15 | 3 |
| **Upper Olifants** | Olifants Dam | B1 | 55 | 0 | 1466 | 4 | 187 | 11 | 4 | 0 | 3.67 | 3.67 | |
| | Use of acid mine drainage | B2 | 31 | 2.2 | 1934 | 54 | 247 | 15 | 54 | 61 | 12.16 | 10.16 | 3 |
| | Transfer from Vaal River | B3 | 190 | 1.07 | 5058 | 32 | 645 | 38 | 32 | 183 | 4.73 | 9.15 | 4 |
| | Transfer from Zambezi River | B4 | 95 | 3.6 | 21922 | 117 | 2795 | 164 | 117 | 308 | 35.62 | 40.62 | 2 |
| | Desalination of seawater | B5 | 100 | 13.82 | 16791 | 401 | 2141 | 126 | 401 | 1244 | 39.12 | 37.12 | 3 |
| **Vaal** | LHWP II (Polihali DAm) | C1 | 437 | 0.00 | 14117 | 27 | 1800 | 106 | 27 | 0 | 4.42 | 4.42 | 5 |
| | Use of AMD | C2 | 38 | 2.51 | 2150 | 136 | 274 | 16 | 136 | 86 | 13.48 | 11.48 | 3 |
| | Thukela-Vaal Transfer | C3 | 522 | 3.35 | 25967 | 80 | 3311 | 195 | 80 | 1574 | 9.88 | 9.88 | |
| | Orange-Vaal transfer | C4 | 517 | 1.99 | 21998 | 84 | 2805 | 165 | 84 | 926 | 7.70 | 7.70 | |
| | Mzimvubu transfer scheme | C5 | 631 | 4.38 | 49117 | 227 | 6262 | 368 | 227 | 2487 | 14.81 | 14.81 | |
| | Transfer from Zambezi | C6 | 650 | 4.21 | 61744 | 333 | 7872 | 463 | 333 | 2463 | 17.12 | 22.12 | 2 |
| | Desalination of seawater | C7 | 100 | 13.6 | 9253 | 270 | 1180 | 69 | 270 | 1224 | 27.43 | 25.43 | 3 |
| **Lower Orange** | Boskraai Dam | D1 | 227 | 0 | 1188 | 3 | 152 | 9 | 3 | 0 | 0.72 | 0.72 | |
| | Mzimvubu kraai Transfer | D2 | 165 | 5.26 | 5164 | 48 | 658 | 39 | 48 | 781 | 9.25 | 9.25 | |
| | Desalination of seawater | D3 | 100 | 14.1 | 13204 | 373 | 1683 | 99 | 373 | 1269 | 34.24 | 34.24 | |

Notes:
* Annual capital loan repayment over a period of 25 years at 12% interest
[$] Assumes 30% depreciation portion and an average lifetime of 40 years
[#] Based on R0.90 /kWh electricity cost.
1 Requires additional cost of transfer to Lephalale
2 R5/$m^3$ royalties for transfer from Zambezi
3 Excludes R2/$m^3$ water treatment cost
4 Additional cost of water from LHWPII
5 Excludes cost for hydropower station

# Unit Water Costs (UWC) for Delivery Options

| Region | Description of Final Delivery from Bulk water scheme to power plant | ID | Annual Supply (M.m$^3$) | Capital Cost (R x $10^6$) | O & M Cost (R x $10^6$/a) | Energy Requirement (kWh/m$^3$) | Fuel Cost (R x $10^6$) | CUC* (R x $10^6$) | ADC$ (R x $10^6$) | OMC (R x $10^6$) | EC# (R x $10^6$) | UWC (R/m$^3$/a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lephalale (Limpopo)** | Gravity pipeline from Lephalale | A1 | 30 | 87 | 0.1 | 0 | | 11 | 1 | 0 | 0 | 0.39 |
| **Upper Olifants** | Pipeline from Olifants Dam | B1 | 30 | 3139 | 9.1 | 0.41 | | 400 | 24 | 9 | 11 | 14.80 |
| | Import Vaal Dam - pipeline from dam in Upper Olifants | B2 | 30 | 479.5 | 1.7 | 0.41 | | 61 | 4 | 2 | 11 | 2.58 |
| | Reuse AMD - pipeline from dam in Upper Olifants | B3 | 30 | 479.5 | 1.7 | 0.41 | | 61 | 4 | 2 | 11 | 2.58 |
| | Zambezi water - pipeline from Mokopane | B4 | 30 | 3740 | 11 | 1.38 | | 477 | 28 | 11 | 37 | 18.44 |
| **Lower Orange** | CSP - Pipeline pumping directly from Orange River | D1 | 0.27 | 6.64 | 0.26 | 0.32 | | 1 | 0 | 0 | 0 | 4.57 |
| | Hydraulic fracturing – road transport | D2 | 0.015 | 1.5 | 0 | | 0.91 | 0 | 0 | 0 | 1 | 74.17 |
| | Hydraulic fracturing – pipeline | D3 | 3 | 2678 | 6.7 | 1.30 | | 341 | 20 | 7 | 4 | 123.91 |
| | Hydraulic fracturing – groundwater | D4 | 0.1 | 3.1 | 0.008 | 4.01 | | 0 | 0 | 0 | 0 | 7.87 |

*Annual capital loan repayment over a period of 25 years at 12% interest

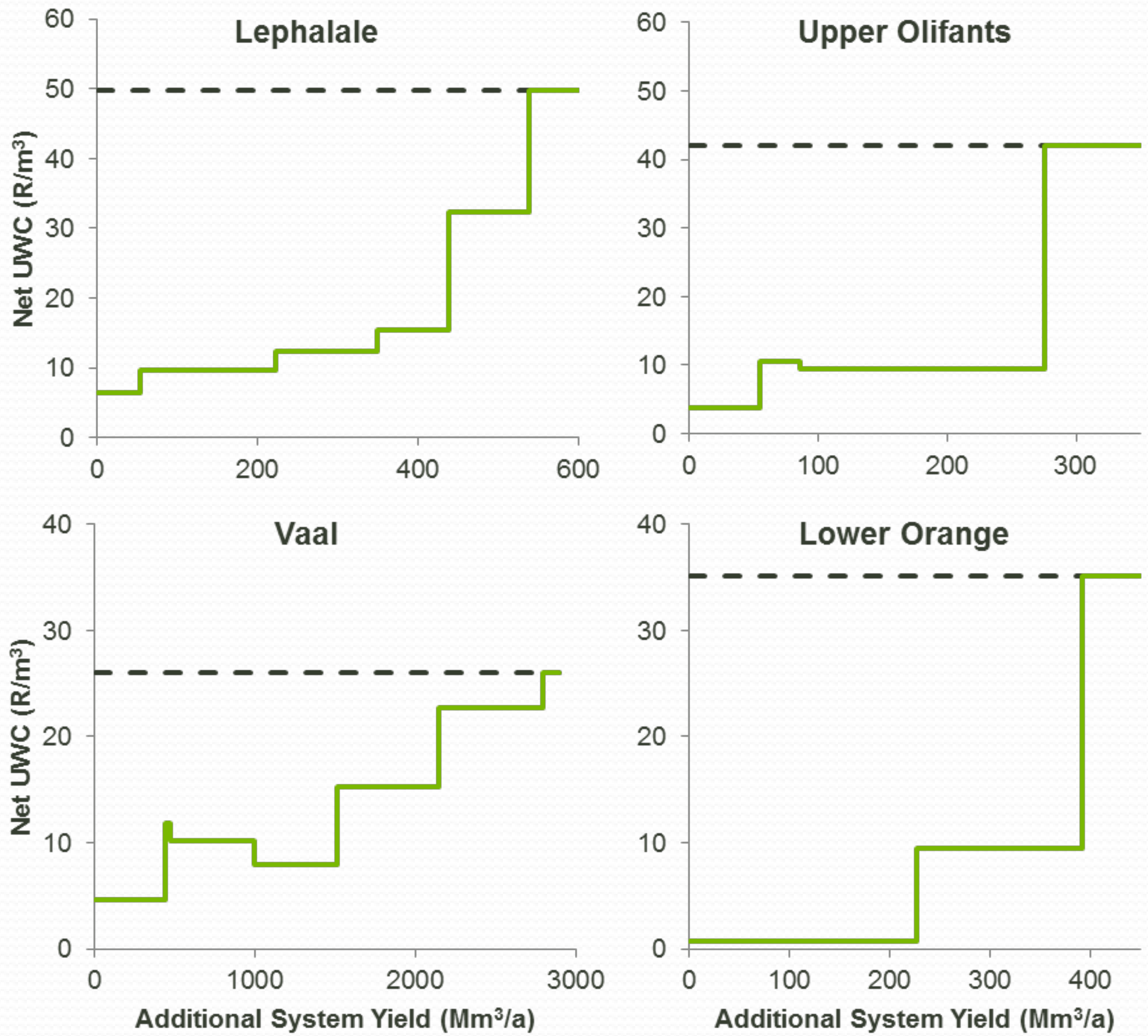
$Assumes 30% depreciation portion and an average lifetime of 40 years

#Using R0.90 /kWh electricity cost.

# Regional Marginal Cost Curves for Water Supply

Region A
(New Coal)

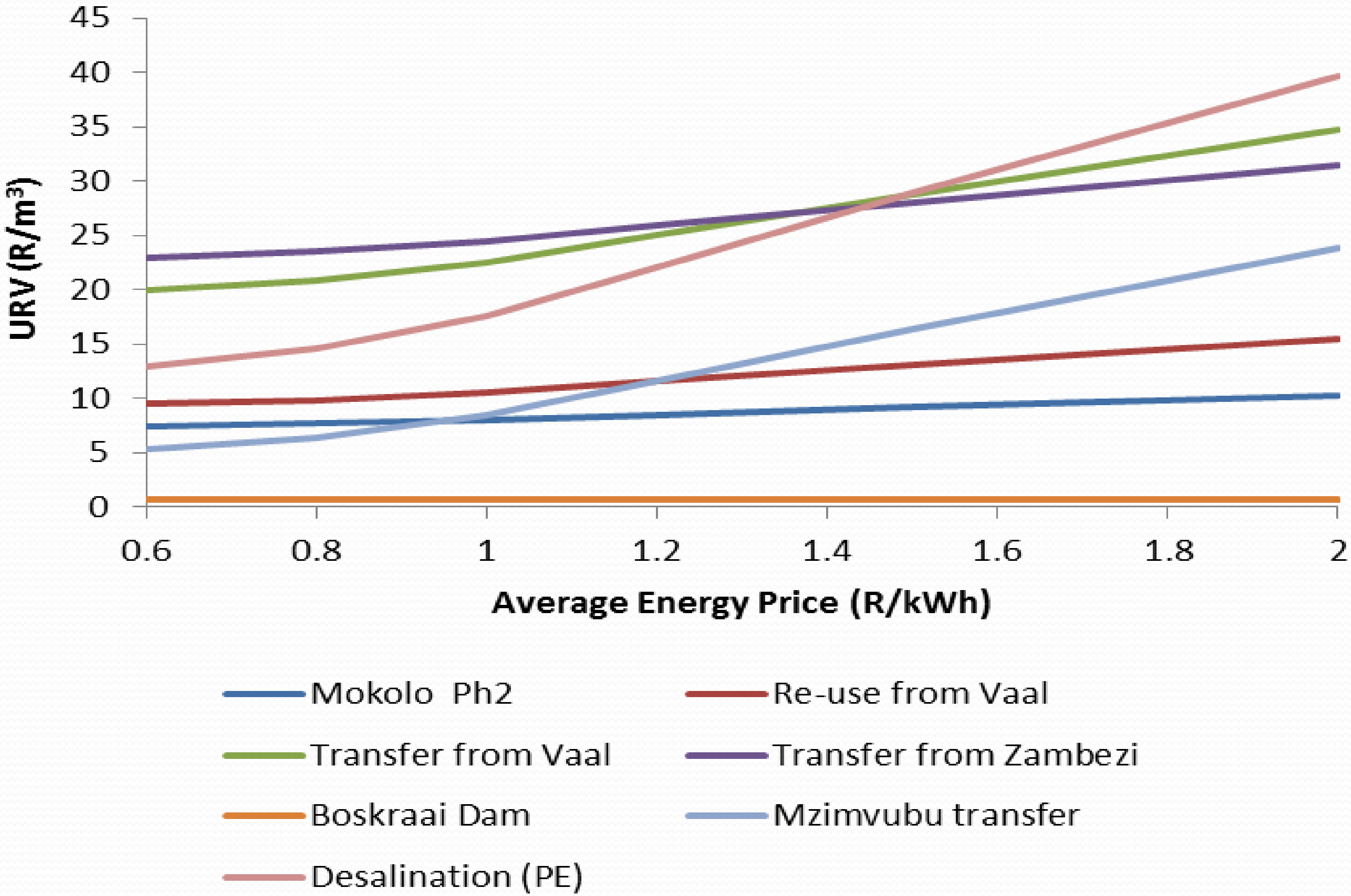
Region B
(Old Coal)




Region C
(Old Coal)

Region D
(CSP & PV)

# Sensitivity of Costs to Changes in Electricity Prices



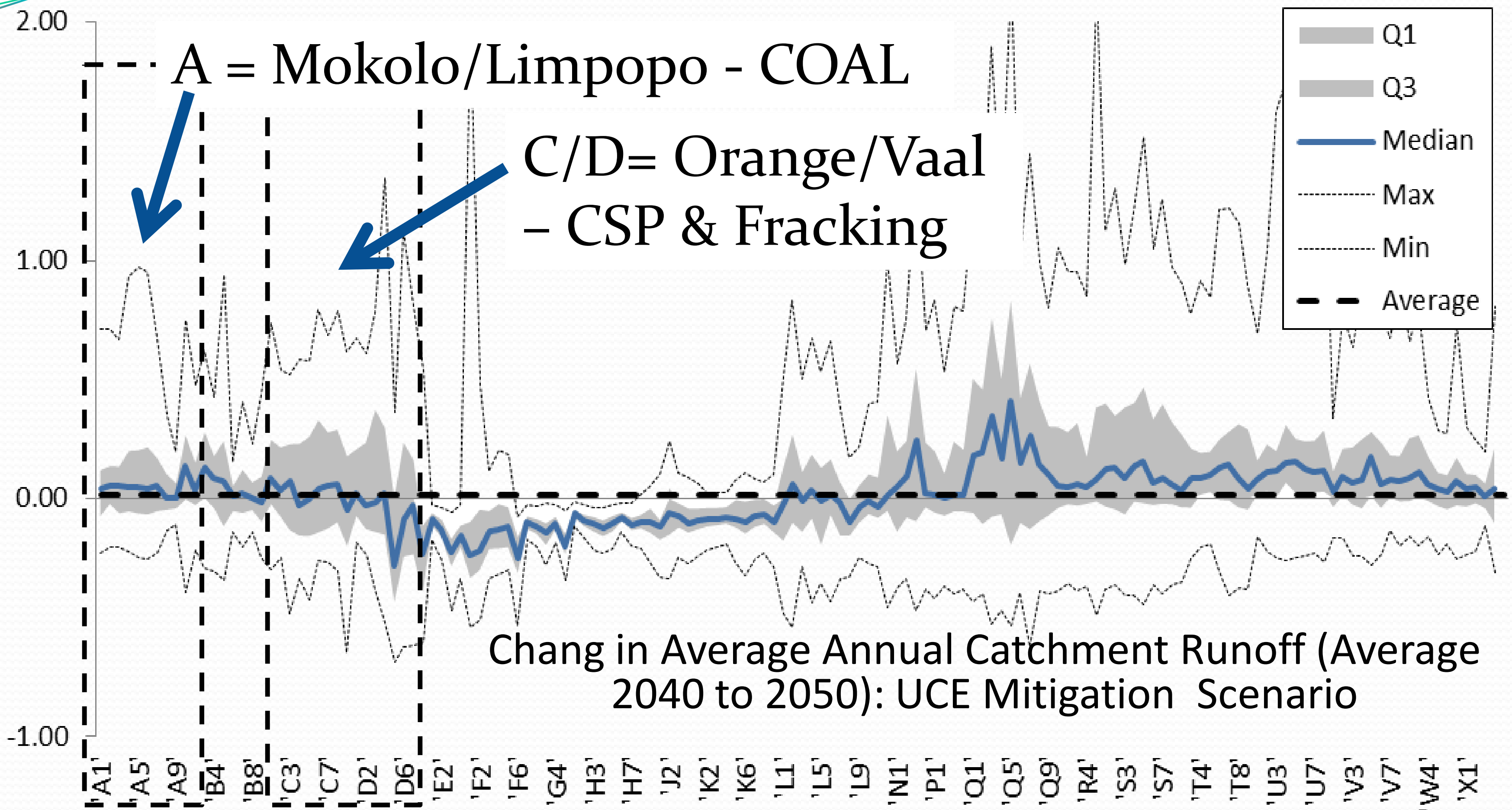
# Initial Comparison of the Impact of using the Marginal Costs for Water for Power (Case study: New Coal vs CSP)

| | Year | | ≈ 2020 | | ≈ 2030 | | ≈ 2040 | |
|---|---|---|---|---|---|---|---|---|
| | Technology | | Coal (Dry) | CSP | Coal (Dry) | CSP | Coal (Dry) | CSP |
| | Region | | Lephalale | Orange | Lephalale | Orange | Lephalale | Orange |
| | Demand | ($Mm^3/a$) | 150 | 4000 | 200 | 4100 | 225 | 4150 |
| **BULK WATER SUPPLY COSTS (BW)** | | | | | | | | |
| Water Resource Management Charge | WMA ID | | 1 | 14 | 1 | 14 | 1 | 14 |
| (Refer to Table 12) | WRMC | ($c/m^3$) | 2.4 | 1.28 | 2.4 | 1.28 | 2.4 | 1.28 |
| Bulk Water Supply Scheme | Scheme ID | | A2 | D1 | A3 | D1 | A4 | D2 |
| (Refer to Table 22) | WSSIC | ($R/m^3$) | 9.22 | 0.72 | 11.89 | 0.72 | 14.86 | 9.25 |
| **Regional Supply Opportunity Cost** | | **($R/m^3$)** | | **8.50** | | **11.18** | | **5.61** |
| Water Supply Delivery Scheme | Description | | A1 | D1 | A1 | D1 | A1 | D1 |
| (Refer to Table 23) | WSDC | ($R/m^3$) | 0.39 | 4.57 | 0.39 | 4.57 | 0.39 | 4.57 |
| Primary Treatment Cost | PWTC | ($R/m^3$) | 2 | 2 | 2 | 2 | 2 | 2 |
| Total Regional Marginal Costs | TRMC | ($R/m^3$) | 11.64 | 7.30 | 14.31 | 7.30 | 17.28 | 15.83 |
| **TRMC Opportunity Cost** | | | | **4.34** | | **7.01** | | **1.45** |
| Water Use Efficiency | Fuel Supply | ($m^3/MWh$) | 0.144 | | 0.144 | | 0.144 | |
| (Refer to Table 4) | Production | ($m^3/MWh$) | 0.560 | 0.296 | 0.560 | 0.296 | 0.560 | 0.296 |
| | TOTAL | ($m^3/MWh$) | 0.704 | 0.296 | 0.704 | 0.296 | 0.704 | 0.296 |
| Total Bulk Water Supply Cost | | (R/MWh) | 8.20 | 2.16 | 10.08 | 2.16 | 12.17 | 4.69 |
| **Total Bulk Water Opportunity Cost** | | **(R/MWh)** | | **6.03** | | **7.92** | | **7.48** |

***Putting this into context …***

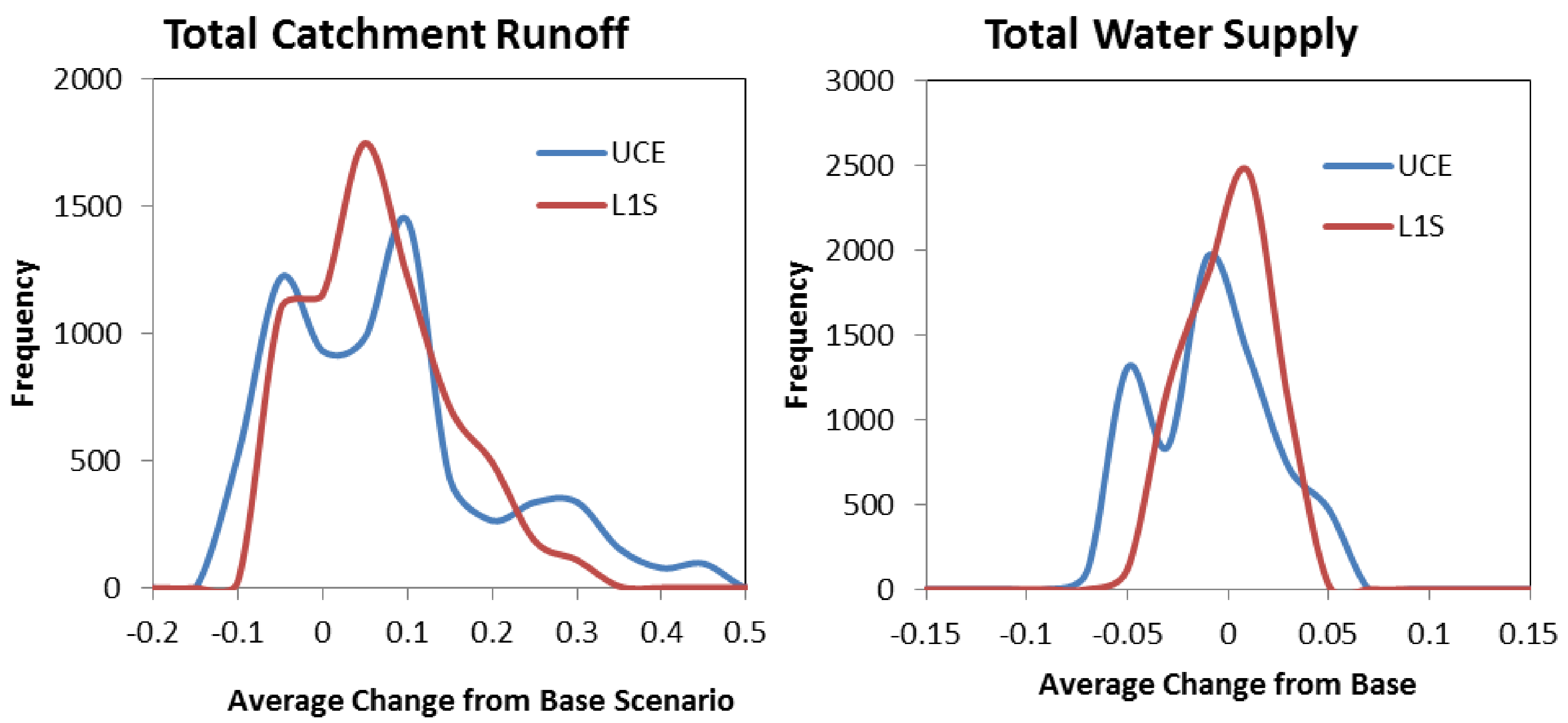
***The current cost of electricity = R 0.90 /kWh = R 900 /MWh!***

# Climate Change Impacts on Water Availability



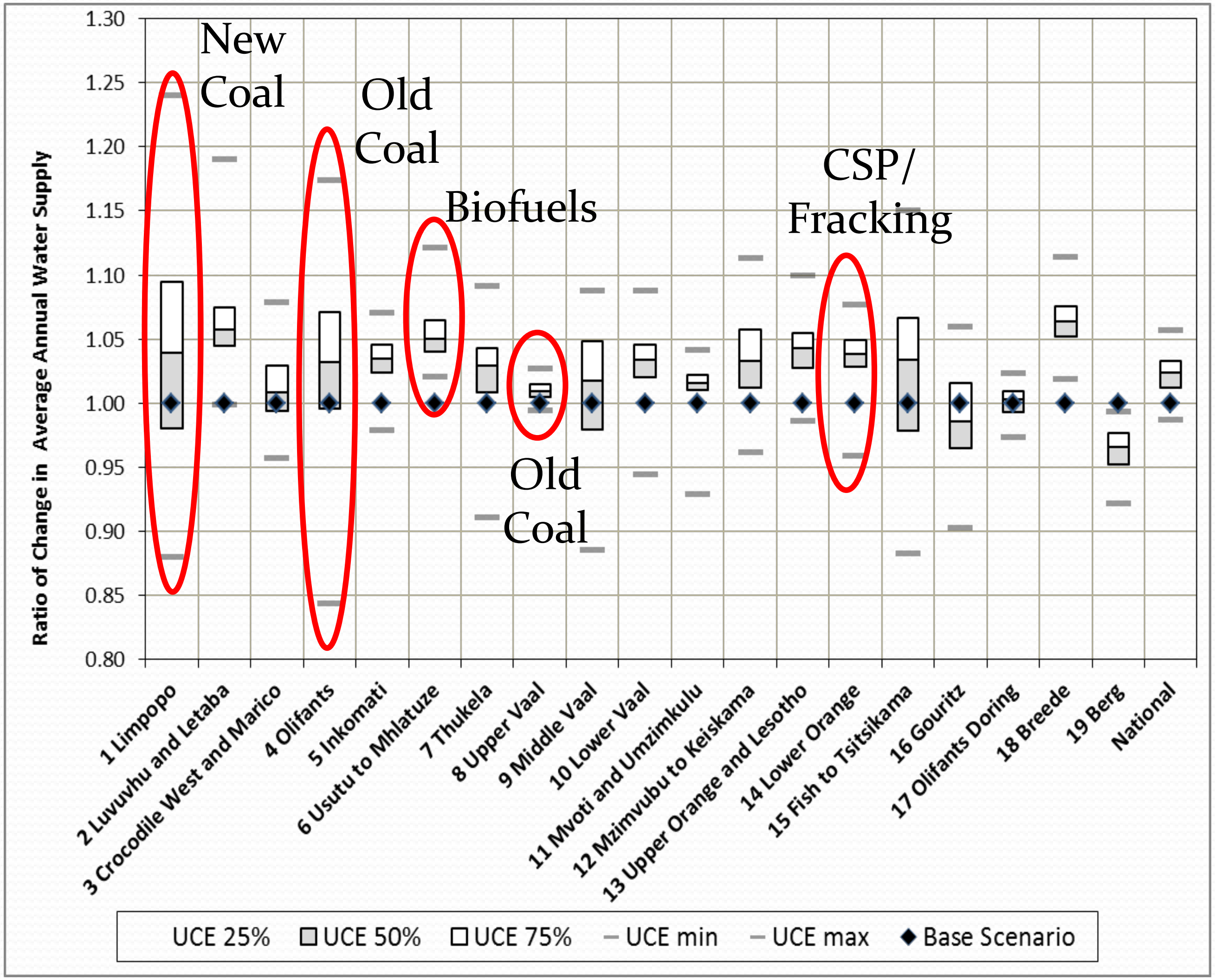

Range of potential impacts on the change in the average annual catchment surface water runoff for the period 2040 to 2050 in each secondary catchment based on a Hybrid Frequency Distribution (HFD) analysis of multiple GCM outputs from the MTI IGSM Model for an unconstrained emissions scenario (UCE). (Cullis et al, 2015)

# SA's integrated water supply system provides resilience to potential Climate Change impacts




Comparison of the potential impacts of climate change under the UCE and L1S scenarios in terms of total catchment runoff for the country and the change in the ability to meet the total national water supply demands for the period 2040 to 2050 (Cullis et al, 2015)

# Potential Climate Change impacts on the average annual bulk water supply by 2050




**Range of potential impacts of climate change on the average annual bulk water supply to each WMA for the period 2040 to 2050 due to the UCE scenario relative to the base scenario (Cullis et al, 2015)**

# Summary of Potential Climate Change Impacts

| Percentage Change From Base (CC Scenario/Base -1) | Avg. Annual Irrigation Demand | | | | | Avg. Annual Total Water Supply | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Min | 25% | 50% | 75% | Max | Min | 25% | 50% | 75% | Max |
| 1 Limpopo | -1.5% | 2.8% | 4.8% | 8.9% | 15.1% | -12.0% | -2.0% | 3.9% | 9.5% | 24.0% |
| 2 Luvuvhu and Letaba | 0.0% | 4.7% | 7.4% | 10.3% | 18.1% | -0.2% | 4.5% | 5.7% | 7.4% | 19.0% |
| 3 Crocodile West/Marico | -6.3% | 5.2% | 7.4% | 10.9% | 16.4% | -4.2% | -0.6% | 0.8% | 2.9% | 7.9% |
| 4 Olifants | -5.4% | 4.4% | 7.5% | 11.4% | 22.0% | -15.7% | -0.5% | 3.2% | 7.1% | 17.4% |
| 5 Inkomati | -5.0% | 4.8% | 8.8% | 11.3% | 22.5% | -2.1% | 2.3% | 3.5% | 4.5% | 7.1% |
| 6 Usutu to Mhlatuze | -12.1% | 3.3% | 6.0% | 8.8% | 17.4% | 2.0% | 4.0% | 5.0% | 6.4% | 12.2% |
| 7 Thukela | -18.1% | 2.2% | 7.0% | 9.9% | 23.3% | -8.9% | 0.9% | 3.0% | 4.3% | 9.1% |
| 8 Upper Vaal | -9.3% | 4.5% | 7.4% | 13.0% | 19.6% | -0.6% | 0.4% | 0.9% | 1.5% | 2.7% |
| 9 Middle Vaal | -5.3% | 1.2% | 7.7% | 12.6% | 21.0% | -11.5% | -2.0% | 1.7% | 4.9% | 8.8% |
| 10 Lower Vaal | -1.0% | 3.0% | 5.9% | 9.2% | 14.8% | -5.5% | 2.0% | 3.3% | 4.5% | 8.8% |
| 11 Mvoti and Umzimkulu | -35.3% | 0.4% | 4.3% | 8.8% | 27.1% | -7.1% | 1.0% | 1.6% | 2.2% | 4.2% |
| 12 Mzimvubu to Keiskama | -10.7% | -0.8% | 5.2% | 10.0% | 24.6% | -3.8% | 1.2% | 3.3% | 5.8% | 11.3% |
| 13 Upper Orange | -1.9% | 1.8% | 6.2% | 9.7% | 16.0% | -1.4% | 2.7% | 4.3% | 5.5% | 10.0% |
| 14 Lower Orange | 1.3% | 3.8% | 4.9% | 6.7% | 10.4% | -4.1% | 2.8% | 3.8% | 4.9% | 7.7% |
| 15 Fish to Tsitsikama | -3.7% | 2.0% | 5.2% | 9.0% | 19.6% | -11.8% | -2.2% | 3.3% | 6.7% | 15.1% |
| 16 Gouritz | 2.2% | 6.6% | 8.1% | 10.0% | 16.0% | -9.7% | -3.5% | -1.5% | 1.5% | 5.9% |
| 17 Olifants Doring | 2.1% | 4.2% | 5.0% | 5.9% | 8.8% | -2.6% | -0.7% | 0.3% | 0.9% | 2.3% |
| 18 Breede | 2.2% | 5.9% | 7.3% | 8.7% | 13.2% | 1.9% | 5.2% | 6.3% | 7.6% | 11.4% |
| 19 Berg | 2.2% | 5.0% | 5.9% | 7.0% | 11.0% | -7.8% | -4.7% | -3.4% | -2.3% | -0.7% |
| **National** | **-0.8%** | **4.5%** | **6.3%** | **8.8%** | **11.8%** | **-1.3%** | **1.2%** | **2.3%** | **3.3%** | **5.7%** |

(Source: Cullis et al, 2015)

# The Way Forward

- Incorporate Marginal Cost Curves into SATIM-W (Task 2)
- Analysis of alternative energy supply scenarios (Task 3)
- Considerations for further research and model development:
  - Revising of regional marginal cost curves with updated Recon Studies
  - Incorporating externalities (social, environmental and opportunity)
  - Consider opportunity costs for water for power in different regions.
  - Review future water demands and develop a linked water-energy-economic model to investigate the potential impact of alternative economic scenarios in terms of future water and energy demands.
  - Evaluate the economic impact of water allocations to power sector
  - Undertake more detailed study on potential climate change impacts on water supply and production efficiency for individual power stations.
  - Incorporate additional climate change risks such as flooding.

# Additional Slides

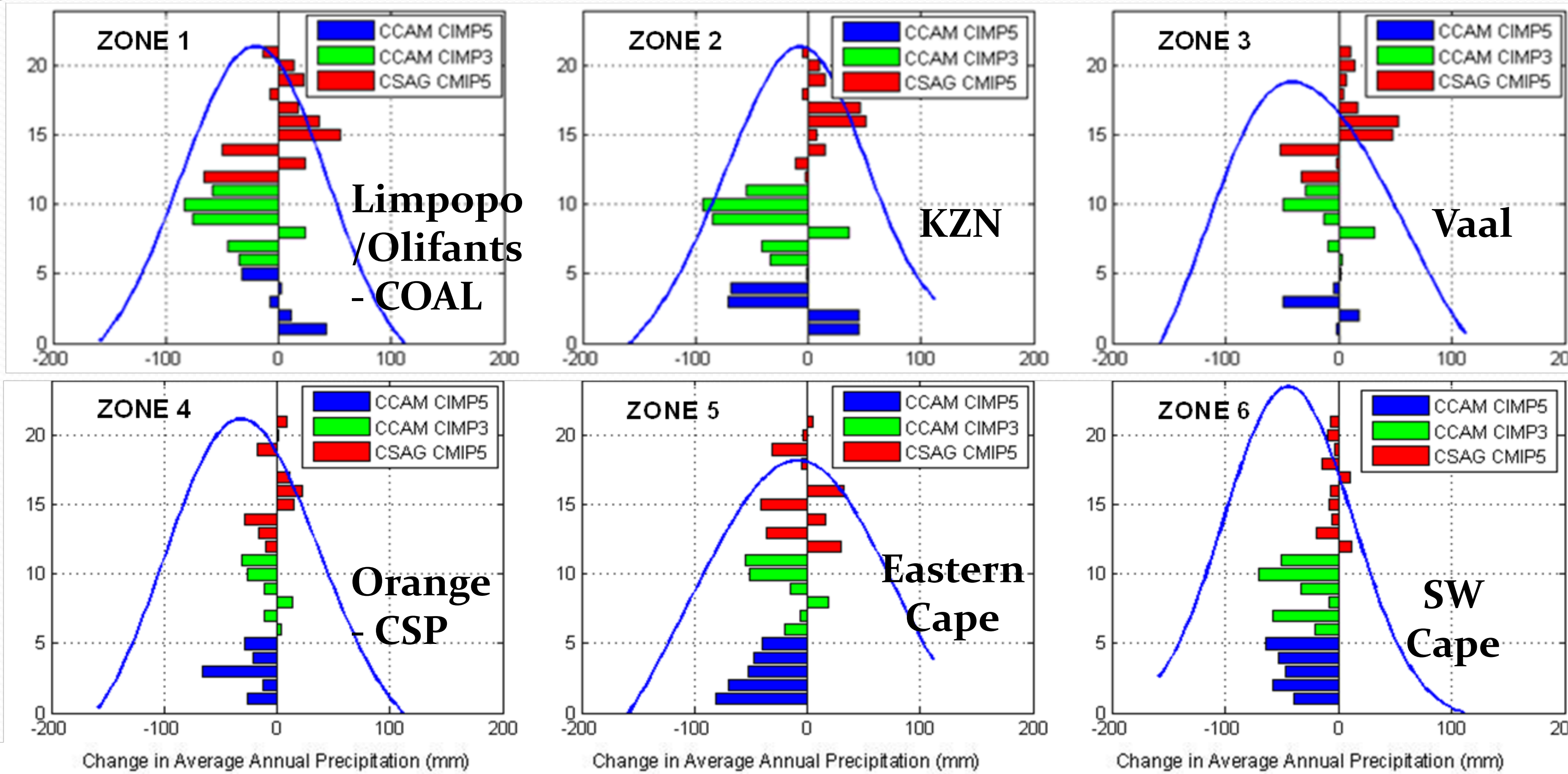
# The "True" cost of water for Power

- "The **water tariff**, neither reflects scarcity nor the socio-economic cost of erroneous allocation of water to suboptimal applications. **The water tariff therefore does not have any signalling power.** To aggravate matters, the water tariff is only in rare cases reflective of the **full cost of delivering the water** – although that is an ideal the government is aspiring to." (Blignaut et al, 2011).
- Incorporating **Marginal Cost Curves for Water Supply** into SATIM-W addresses (in part) the **second of these issues, but not the first**… i.e. the externalities including social and environmental impacts and opportunity costs

| | NMR of water (R/m3) | Difference (R/m3) | Water volume Mm3 | Net Generation Output GWh | Society wide loss or gain R (million) | Opportunity cost R/kWh |
|---|---|---|---|---|---|---|
| Dry-cooled with FGD | 9717 | | 26.17 | 32300 | | |
| Dry-cooled with no FGD | 11149 | -1432 | 16.25 | 32300 | -23277 | -0.72 |
| Conventional coal | 3399 | 6318 | 53.52 | 32300 | 338153 | 10.47 |
| Solar | 14667 | -4950 | 5.41 | 18237 | -26757 | -1.47 |
| Wind | 930736 | -921019 | 0.05 | 12102 | -42357 | -3.50 |
| Biomass | 11210 | -1493 | 14.27 | 31925 | -21309 | -0.67 |

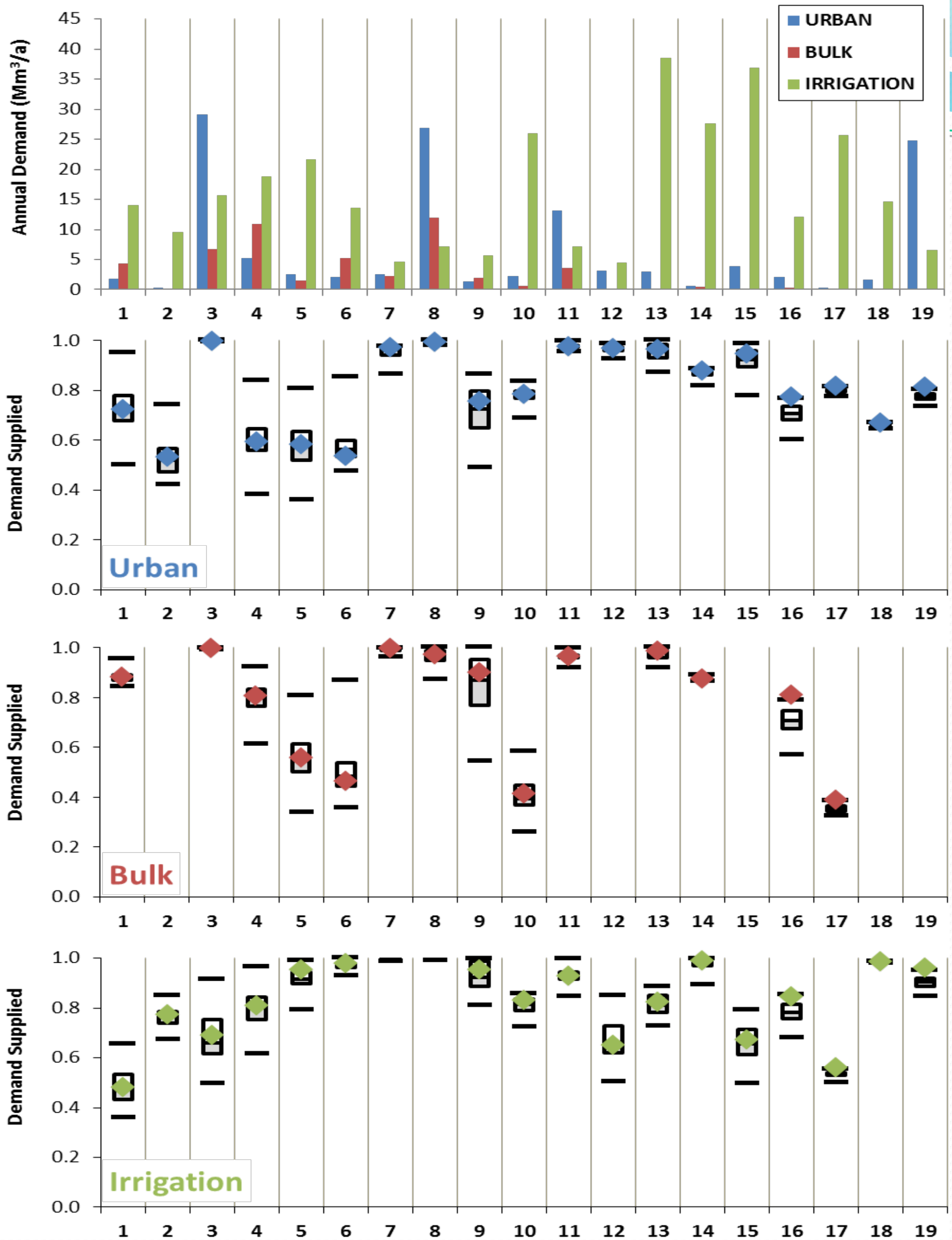
NMR = Net Marginal Rate for water (Blignaut et al, 2011)

# HFD of Potential Climate Change Impacts




Potential increase in average annual precipitation in mm/year for the period 2040-2050 for six general hydro-climatic zones across South Africa. Comparison of the hybrid frequency distribution (HFD) of UCE scenario from the IGSM climate model with outputs from a number of statistically (CSAG) and dynamically (CCAM) downscaled regional climate models for South Africa (Cullis et al, 2015)

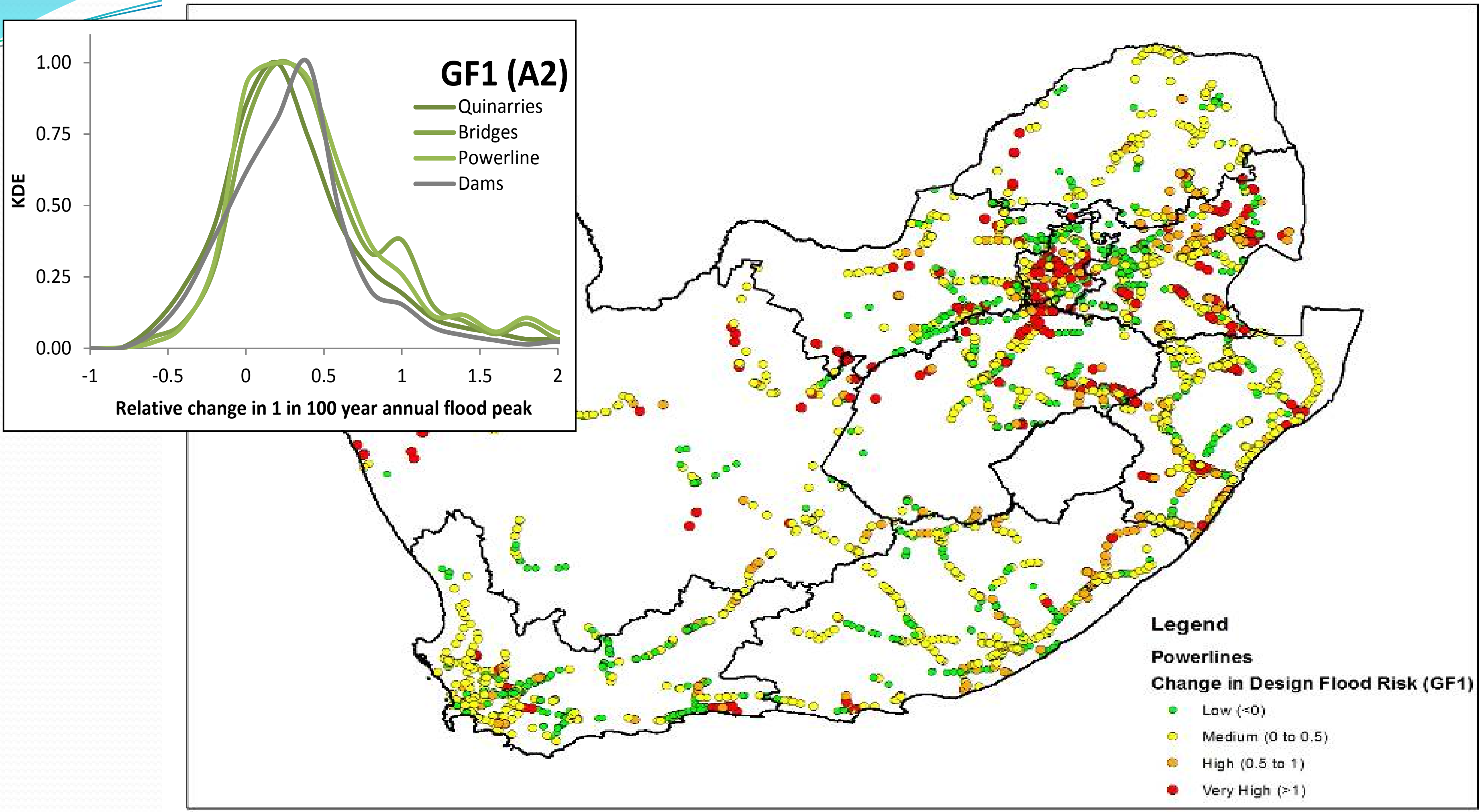
# Range of potential CC impacts on bulk water supply in SA by 2050




| |
|---|
| **1 Limpopo (NEW COAL)** |
| 2 Luvuvhu and Letaba |
| 3 Crocodile West and Marico |
| 4 Olifants |
| 5 Inkomati |
| 6 Usutu to Mhlatuze |
| 7 Thukela |
| 8 Upper Vaal |
| 9 Middle Vaal |
| 10 Lower Vaal |
| 11 Mvoti and Umzimkulu |
| 12 Mzimvubu to Keiskama |
| 13 Upper Orange and Lesotho |
| **14 Lower Orange (CSP)** |
| 15 Fish to Tsitsikama |
| 16 Gouritz |
| 17 Olifants Doring |
| 18 Breede |
| 19 Berg |

(Source: Cullis et al, 2015)

# Other Climate Change Risks for Energy = FLOODING!




Provisional assessment of the risk of climate change impacts on the design flood by 2100. (Analysis based on potential changes in 1:100 year RI flood for the GF1 climate model– no consideration of hydraulic characteristics of individual structures.)  (Cullis et al., 2015)

# Matching energy producing regions with water resource areas (WMAs) in SA

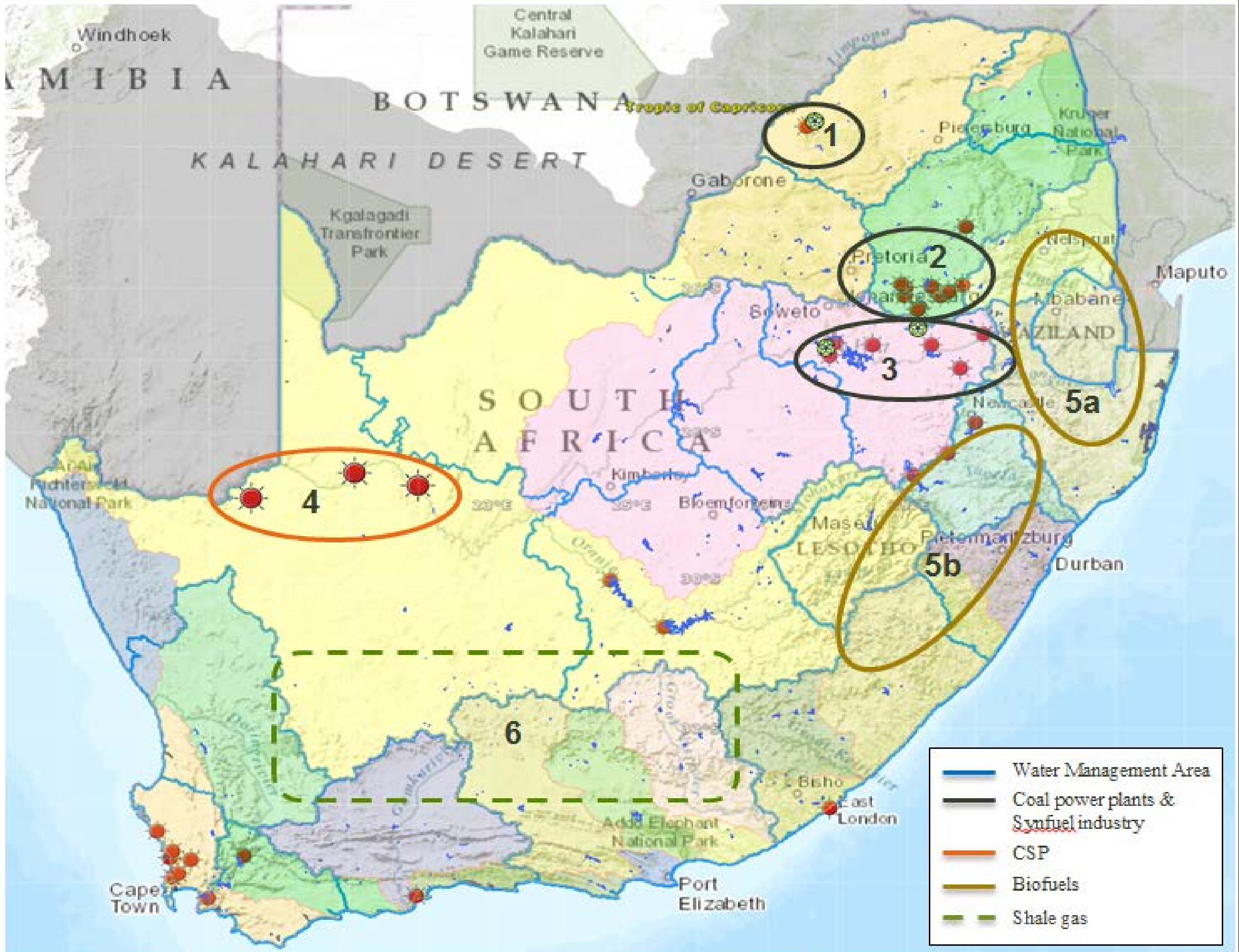



Figure 1 Locations of power generation plants in the country along with the regions of interest for the water-energy dimension of the power sector. Colour-shaded areas depict the country's primary surface water drainage basins or catchments.

# Marginal Cost Curves for Water for Power

- Based on components of DWS bulk water pricing strategy
- Components of the marginal cost of water
  - Water Resources Management Charge (WRMC)
  - Scheme capital cost (function of region, year, other demands)
  - Delivery capital cost (pipeline, pumpstation, trucking, etc.)
  - Treatment cost (to meet required standard)
  - O&M costs and Energy costs (for pumping)
- Based on a unit reference value (URV)
  - Used for standardised comparison of options
  - Includes capital costs for scheme
  - Includes operations and maintenance (O&M)
  - URV (R/m$^3$) = NPV(costs)/NPV(supply = 1:50 year yield)
  - Discounted over a 30 year period using an annual discount rate of 8%.
  - Does not include cost of borrowing (i.e. not the final water tariff)
- Cost of treating effluent (waste discharge charge) is not included as Eskom has a Zero Liquid Effluent Discharge (ZLED) policy.