CLIMATE CHANGE AND THE WATER RESOURCES SECTOR: IS INTEGRATED WATER RESOURCES MANAGEMENT THE ANSWER?

Roland Schulze

School of Bioresources Engineering & Environmental Hydrology
University of KwaZulu-Natal
Pietermaritzburg, SouthAfrica

UNIVERSITY OF KWAZULU-NATAL


Portugal
Spain
Italy
Turkey
Madeira
Str. of Gibralter
Greece
Canary Islands
(Spain)
Morocco
Tunisia
Mediterranean Sea
Algeria
Libya
Egypt
Western Sahara
Saudi Arabia
Cape Verde
Mauritania
Red Sea
Mali
Niger
Chad
Sudan
Senegal
Eritrea
Yemen
Gambia
Gulf of Aden
Guinea-Bissau
Burkina
Djibouti
Guinea
Benin
Somalia
Nigeria
Sierra Leone
Ghana
Ethiopia
Liberia
Central African
Republic
Ivory Coast
Togo
Cameroon
Equatorial Guinea
Uganda
Kenya
Indian Ocean
Gabon
Democratic
Republic
of the Congo
(ex Zaire)
Sao Tome and Principe
Rwanda
Congo
Burundi
Tanzania
Seychelles
Comoros
Angola
Zambia
Malawi
Atlantic Ocean
Mauritius
Zimbabwe
Madagascar
Namibia
Botswana
Mozambique
Reunion (France)
Swaziland
Lesotho
South Africa


ZIMBABWE
Messina
KALAHARI DESERT
MOZAMBIQUE
Louis Trichardt
BOTSWANA
Seshego
Phalaborwa
Kruger N.P.
Limpopo
Pietersburg
NAMIBIA
Krokodil
Olifants
WITWATERSRAND
PRETORIA
Kalahari
Gemsbok N.P.
Roodepoort
Boksburg
Nelspruit
Mmabatho
Johannesburg
Germiston
Molopo
Soweto
SWAZILAND
Potchefstroom
Vereeniging
Klerksdorp
Sharpeville
Newcastle
Odendaalsrus
Wilge
ZULULAND
Welkom
Vaal
Ulundi
Virginia
Upington
Champagne Castle
Ladysmith
Richards
Bay
Kimberley
Alexander
Bay
Orange
BLOEMFONTEIN
Tugela
Pietermaritzburg
LESOTHO
Port Nolloth
Durban
Carnarvon
Swartberg
Calvinia
SOUTH AFRICA
DRAKENSBERG MTS.
Umtata
GREAT KAROO
Great
Fish
Kei
South
Atlantic
Ocean
Alice
Bisho
King William's Town
East London
Worcester
LITTLE KAROO
Grahamstown
Paarl
Uitenhage
Sondags
CAPE TOWN
George
Indian Ocean
Port Elizabeth
Stellenbosch
Mosselbaai
Cape of
Good Hope
Cape Agulhas
Algoa Bay


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Hydrology

WHAT DO YOU THINK I.W.R.M. IS?

. . . conceptually

. . . in practice for the water resource manager

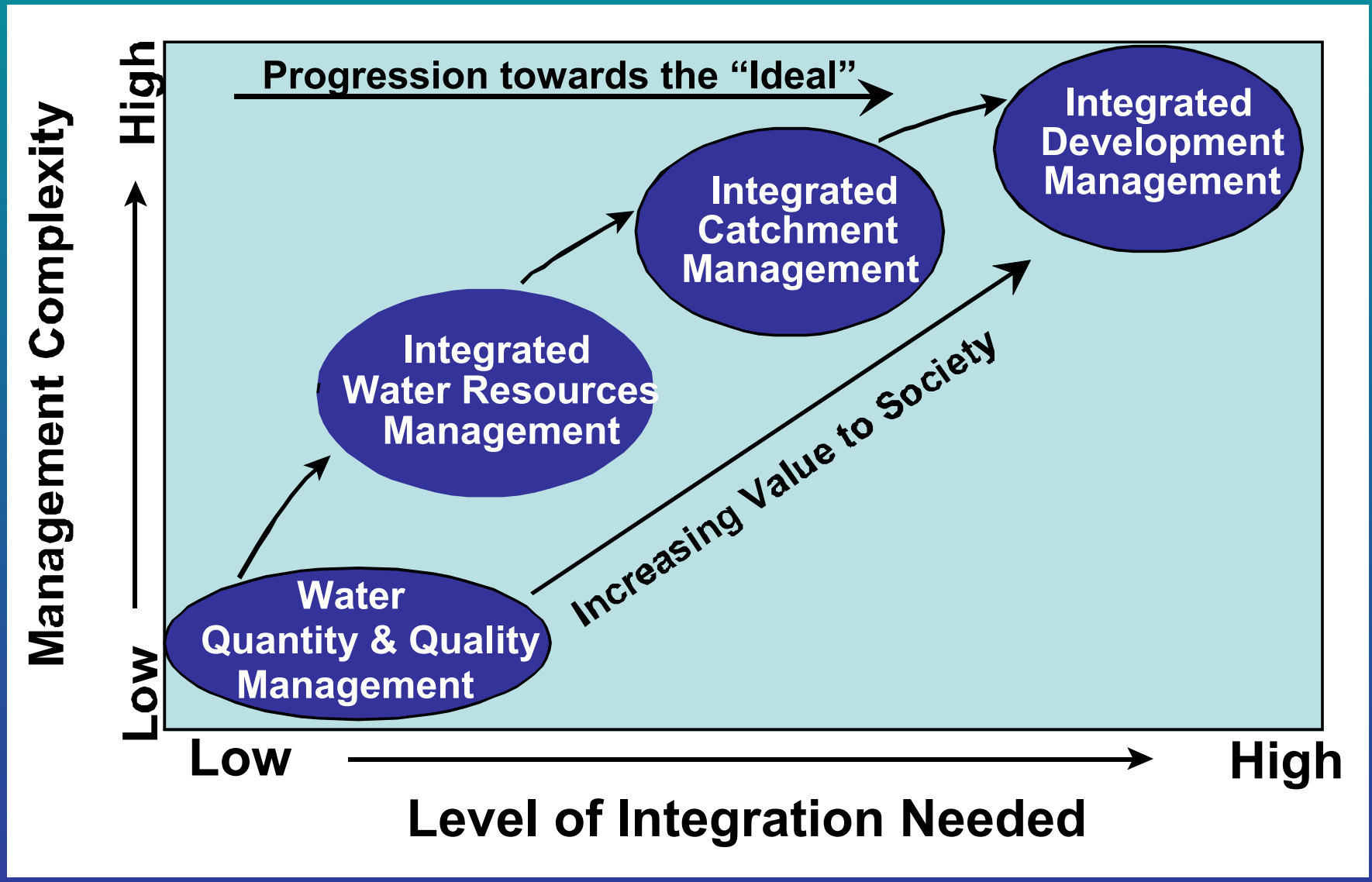
WHAT IS I.W.R.M.?

- . . . a philosophy
  . . . a process
  . . . a management strategy

- to achieve *sustainable use* of resources by all stakeholders at
  . . . catchment
  . . . regional
  . . . national &
  . . . international levels

- while maintaining the characteristics and *integrity* of water resources at the catchment scale within *agreed upon limits*

(DWAF, 1998)


Progression towards the "Ideal"
Integrated Development Management
Integrated Catchment Management
Integrated Water Resources Management
Water Quantity & Quality Management
Increasing Value to Society
Management Complexity
High
Low
Low
High
Level of Integration Needed


SYSTEMS APPROACH
INTEGRATED APPROACH
IWRM
Strategies
and
Goals
SUSTAINABLE APPROACH
MANAGEMENT APPROACH
PARTNERSHIP APPROACH
STAKEHOLDER APPROACH

Linkages

human ↔ natural

water ↔ land

local ↔ national

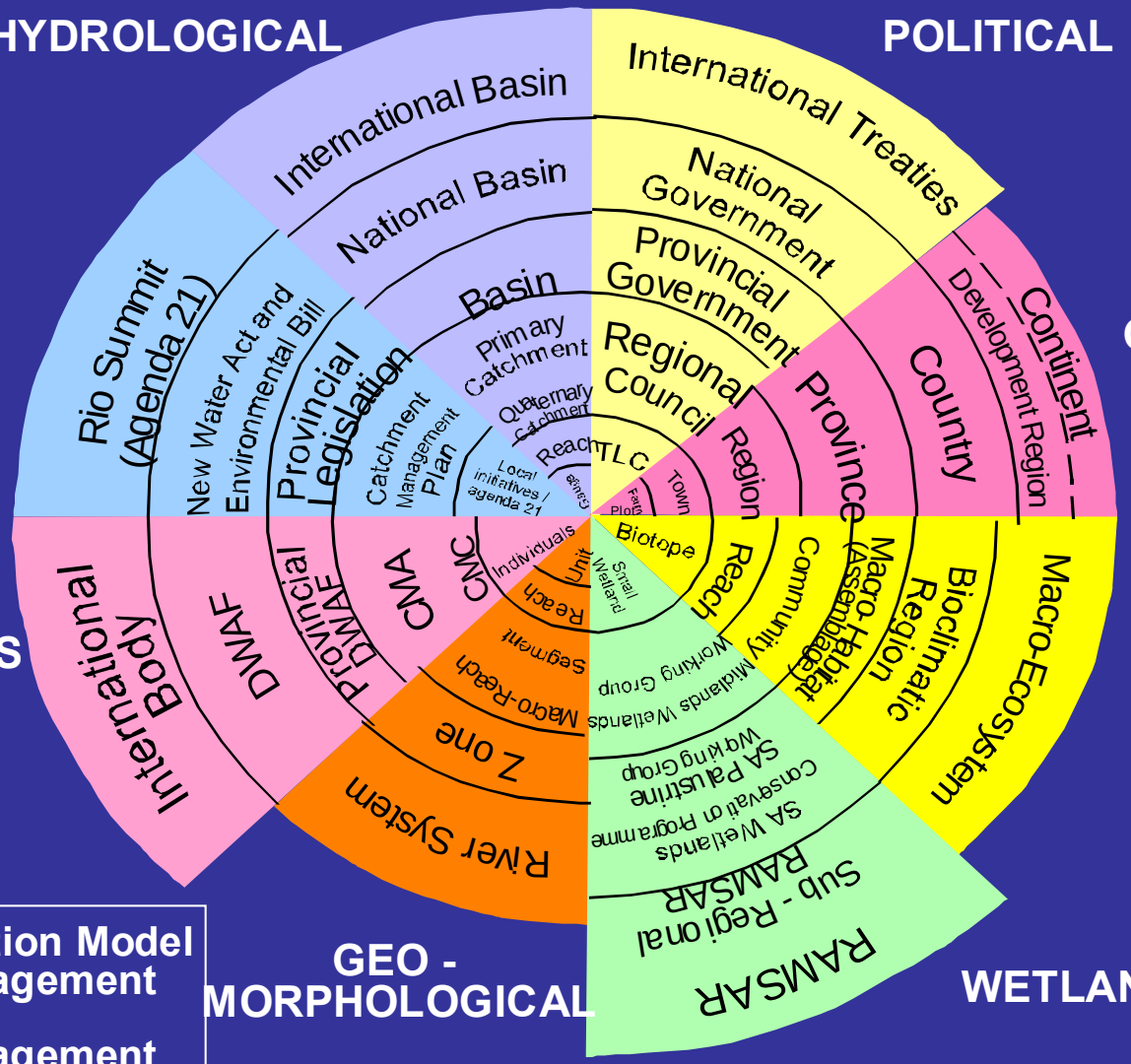
soft tools ↔ hard tools

causes ↔ symptoms

Co-ordinated Development & Management

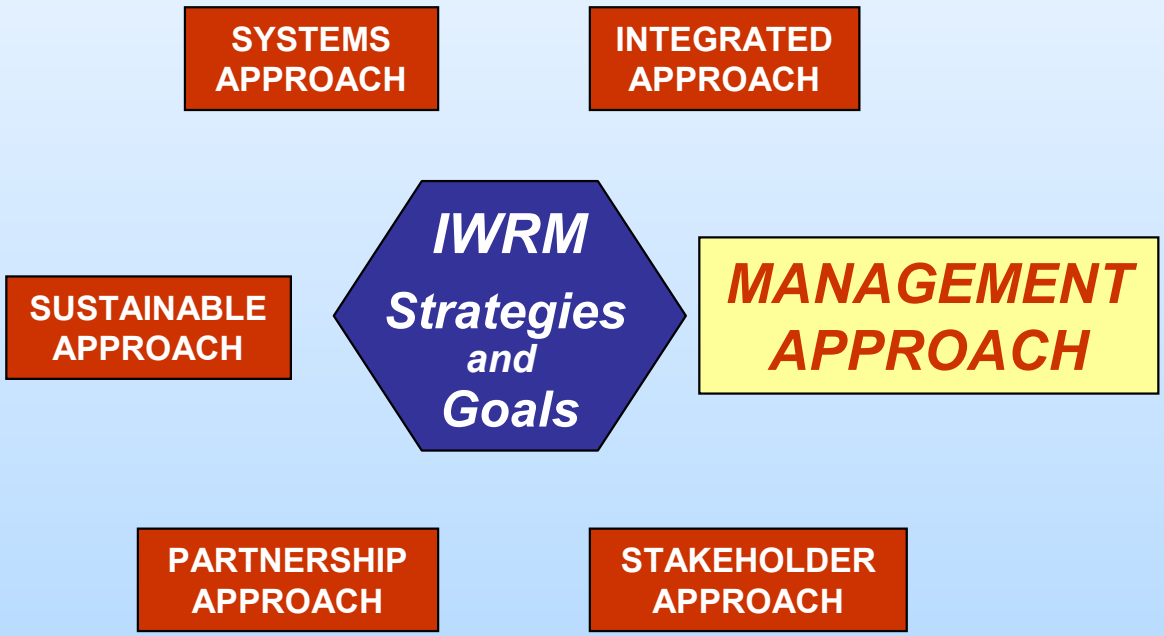
Catchment & coast
Surface & groundwater
Upstream & downstream
Engineered & aquatic systems
Legal & institutional
Equitability & development

Vertical and Horizontal Integration in IWRM



GCM - General Circulation Model
CMA - Catchment Management Agency
CMC - Catchment Management Committee
TLC - Transitional Local Council

Jewitt, 1998



Implications

- *Maximising resources*
- *Minimising impacts*
- *Reversing consequences*
- *Seeking equitable solutions*
- *Enhancing quality of life*
- *Top-down to bottom-up*
- *Supply to demand management*
- *Water as an economic good vs water as a right*

Implications

From government to individual

Participatory decisions

Implications

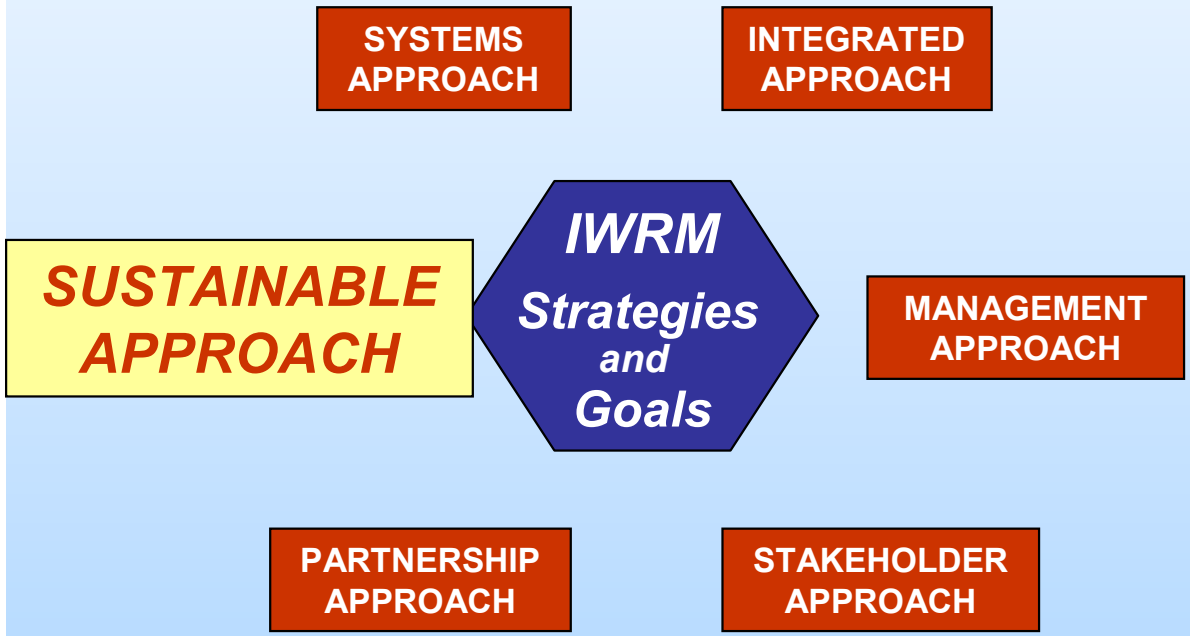
Common objectives

Collective - rules

- *responsibilities*
- *accountability*

Commitment to principle of stewardship

Implications



Equitable access

Protection of resource integrity

Compromise between development and protection

SPATIAL SCALE CONSIDERATIONS IN I.W.R.M.

Global

International

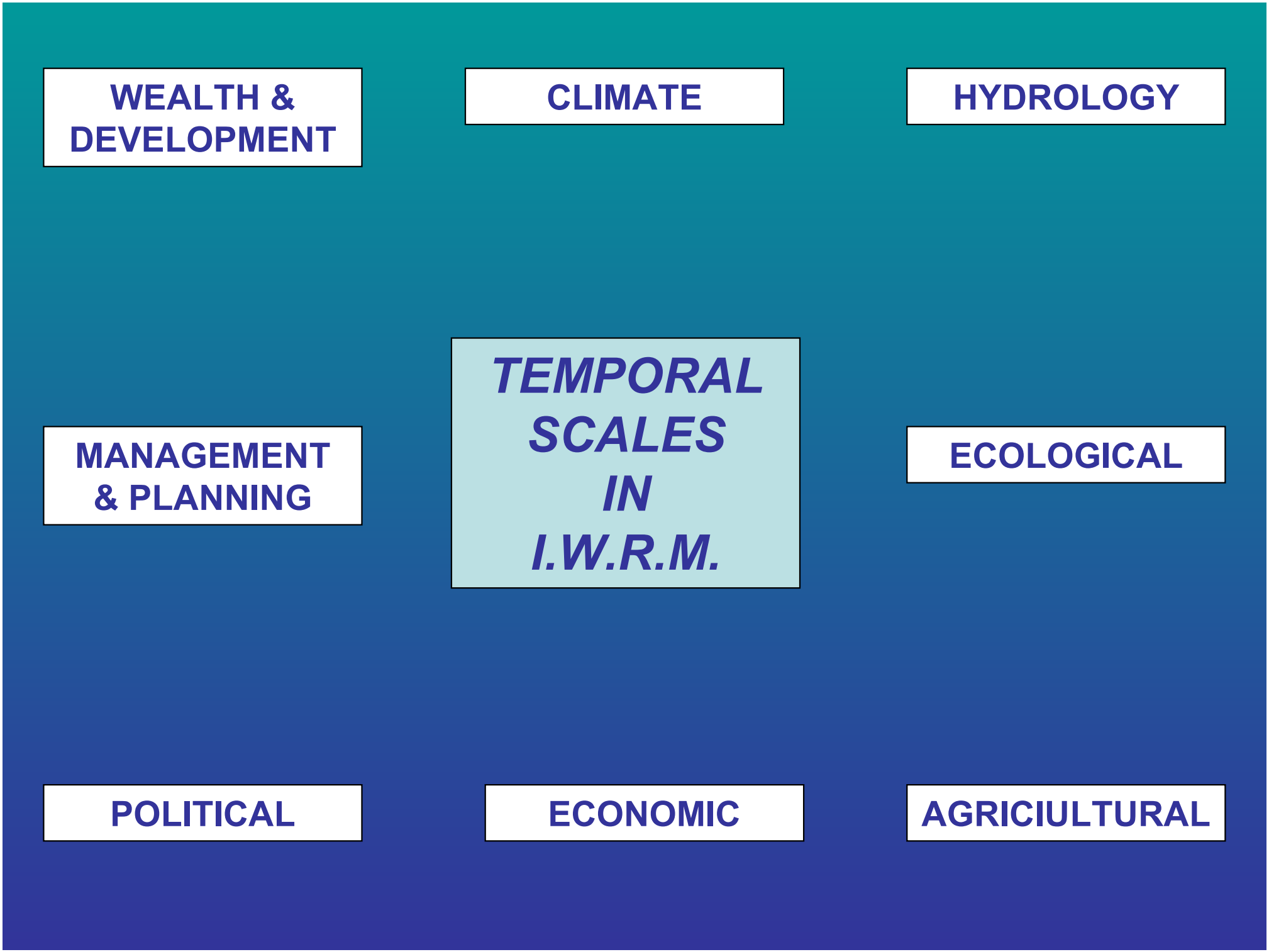
National

Catchment

Local Government

Community

Household


WEALTH & DEVELOPMENT
CLIMATE
HYDROLOGY
TEMPORAL SCALES IN I.W.R.M.
MANAGEMENT & PLANNING
ECOLOGICAL
POLITICAL
ECONOMIC
AGRICIULTURAL

WEALTH & DEVELOPMENT

- Long → short
- "North" → "South"

CLIMATE

- Intra-Seasonal
- Inter-Seasonal
- Decadal

HYDROLOGY

- ENSO → intra-seasonal
- Extremes/Forcasting
- Perennial → ephemeral

MANAGEMENT & PLANNING

- Growing season
- Annual
- 5 years
- 10 - 20 years

TEMPORAL SCALES IN I.W.R.M.

ECOLOGICAL

- Biological Triggers
  - magnitudes
  - variabilities
  - frequencies
  - durations

POLITICAL

- Stable vs Less Stable structures
- Inter-election time scales

ECONOMIC

- Long → Short
- International → national → local → household

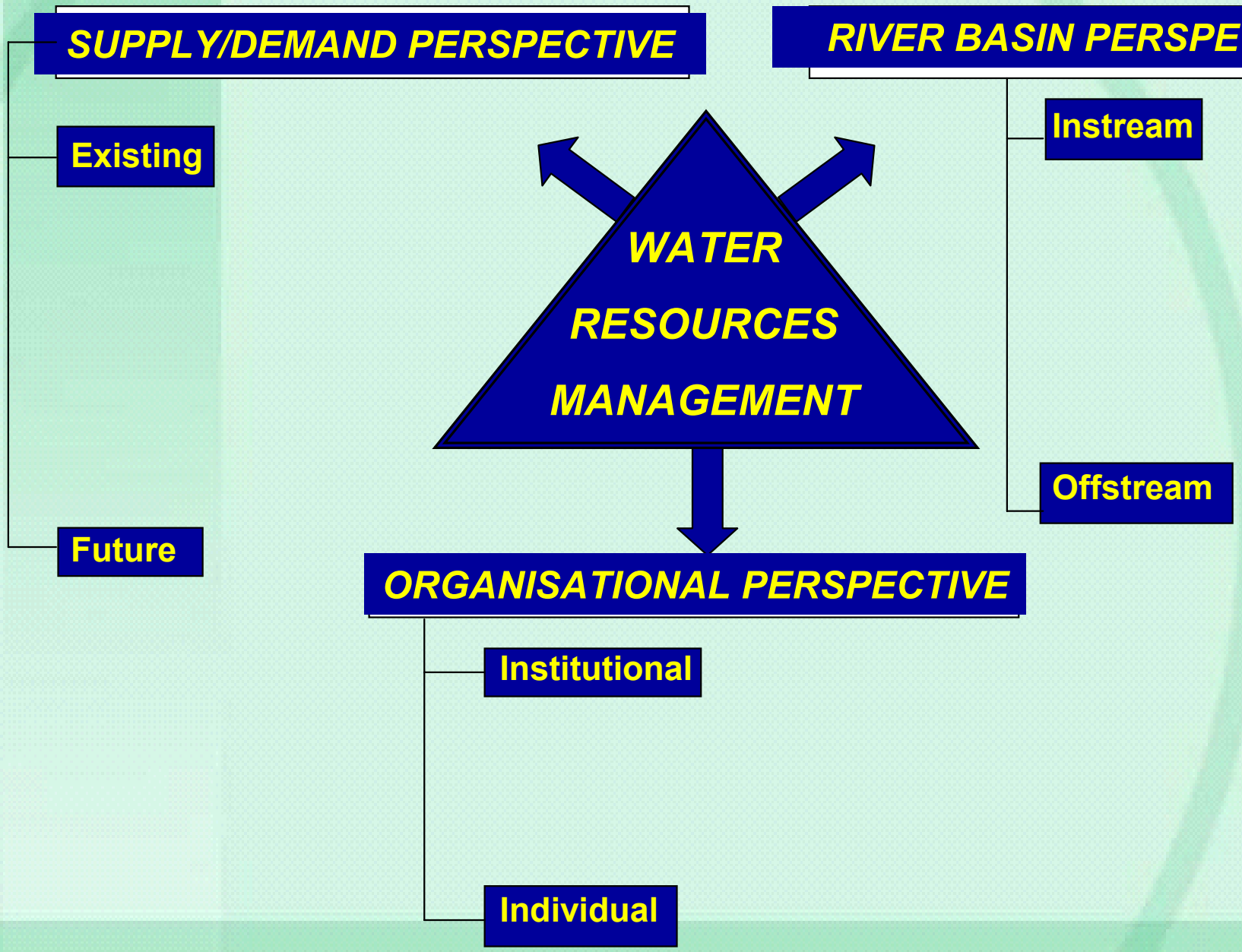
AGRICIULTURAL

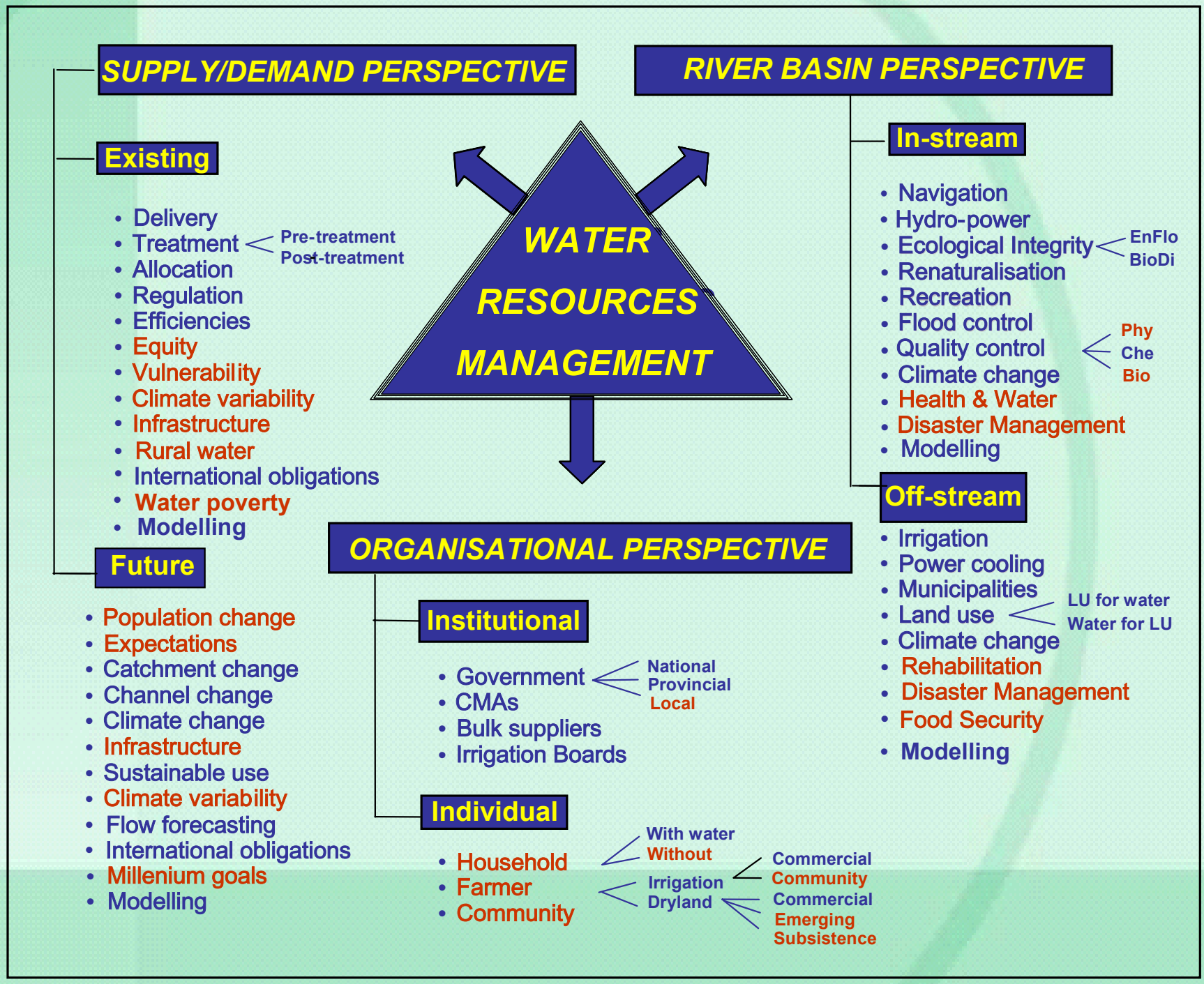
- Crops
  - intra/inter-seasonal
- Forestry
  - decadal

SUPPLY/DEMAND PERSPECTIVE

RIVER BASIN PERSPECTIVE

ORGANISATIONAL PERSPECTIVE


SUPPLY/DEMAND PERSPECTIVE
Existing
Future
RIVER BASIN PERSPECTIVE
Instream
Offstream
WATER RESOURCES MANAGEMENT
ORGANISATIONAL PERSPECTIVE
Institutional
Individual


SUPPLY/DEMAND PERSPECTIVE
RIVER BASIN PERSPECTIVE
WATER RESOURCES MANAGEMENT
Existing
• Delivery
• Treatment
Pre-treatment
Post-treatment
• Allocation
• Regulation
• Efficiencies
• Equity
• Vulnerability
• Climate variability
• Infrastructure
• Rural water
• International obligations
• Water poverty
• Modelling
Future
• Population change
• Expectations
• Catchment change
• Channel change
• Climate change
• Infrastructure
• Sustainable use
• Climate variability
• Flow forecasting
• International obligations
• Millenium goals
• Modelling
In-stream
• Navigation
• Hydro-power
• Ecological Integrity
EnFlo
BioDi
• Renaturalisation
• Recreation
• Flood control
• Quality control
Phy
Che
Bio
• Climate change
• Health & Water
• Disaster Management
• Modelling
Off-stream
• Irrigation
• Power cooling
• Municipalities
• Land use
LU for water
Water for LU
• Climate change
• Rehabilitation
• Disaster Management
• Food Security
• Modelling
ORGANISATIONAL PERSPECTIVE
Institutional
• Government
National
Provincial
Local
• CMAs
• Bulk suppliers
• Irrigation Boards
Individual
• Household
With water
Without
• Farmer
Irrigation
Commercial
Community
Dryland
Commercial
Emerging
Subsistence
• Community

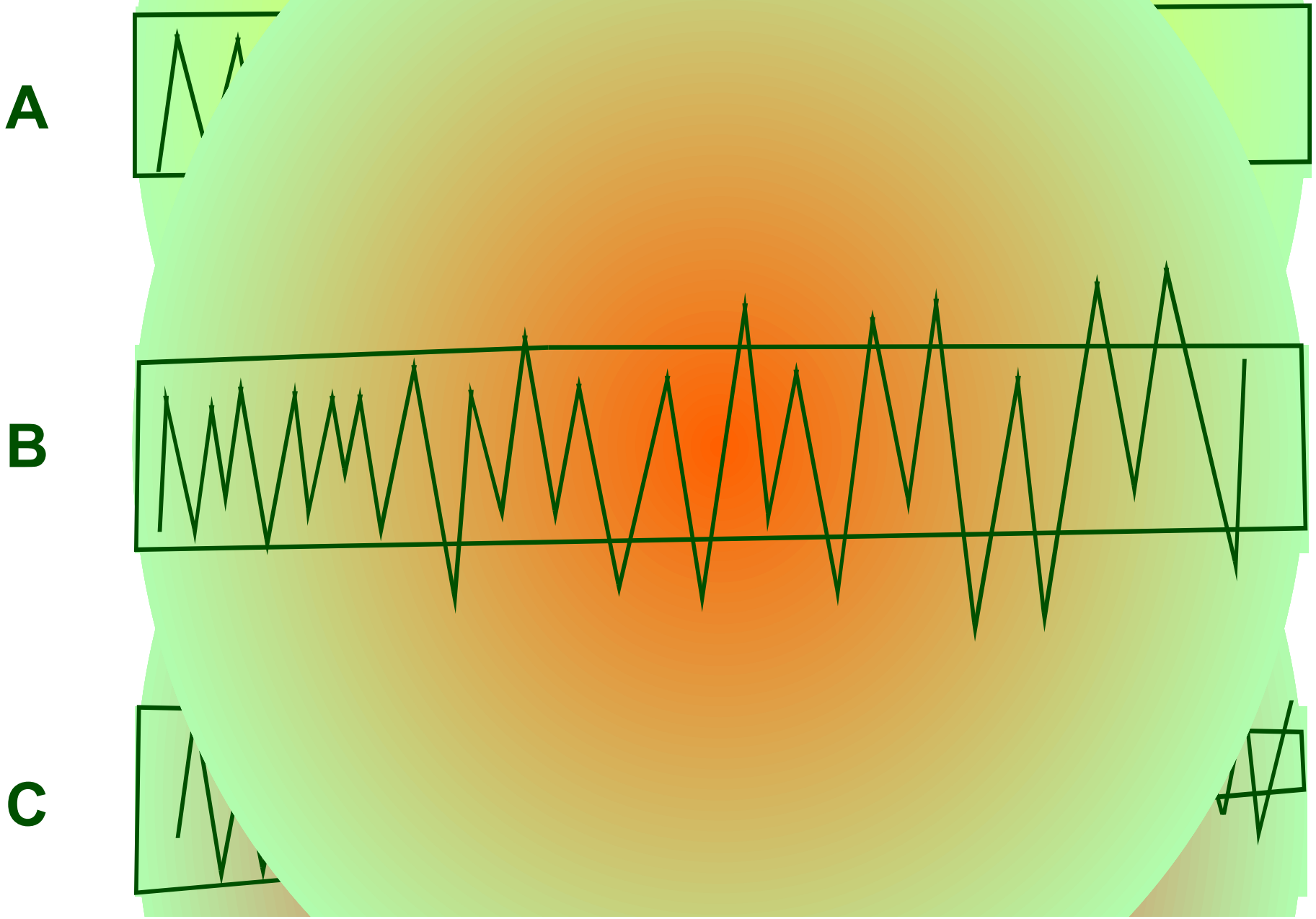
WHAT DO WE HAVE TO CONSIDER IN THE WATER RESOURCES SECTOR IN REGARD TO CLIMATE CHANGE?

(a) Scenarios, appropriately downscaled

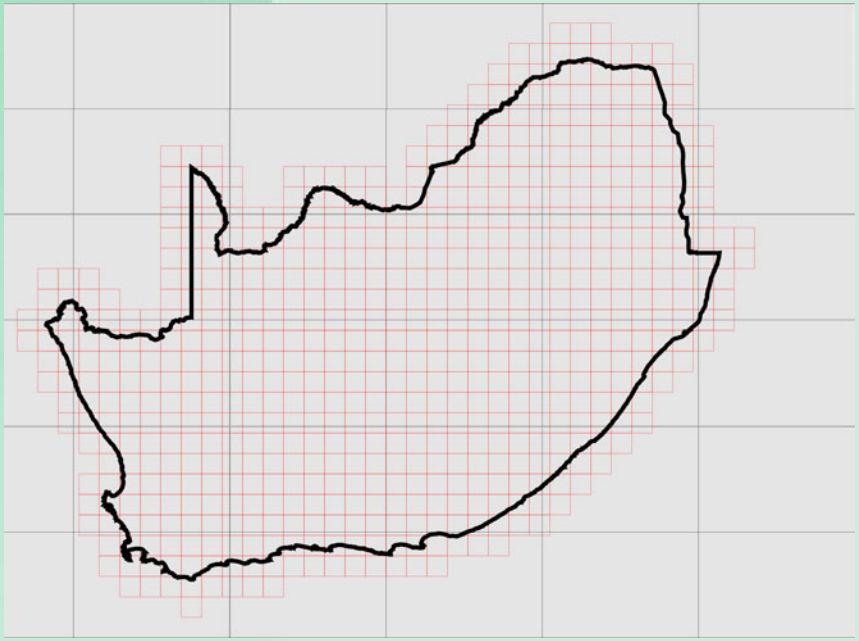
"MR. NOAH, DON'T YOU THINK THE PROPHESIES OF A GLOBAL CLIMATE CHANGE ARE A BIT EXAGGERATED?"

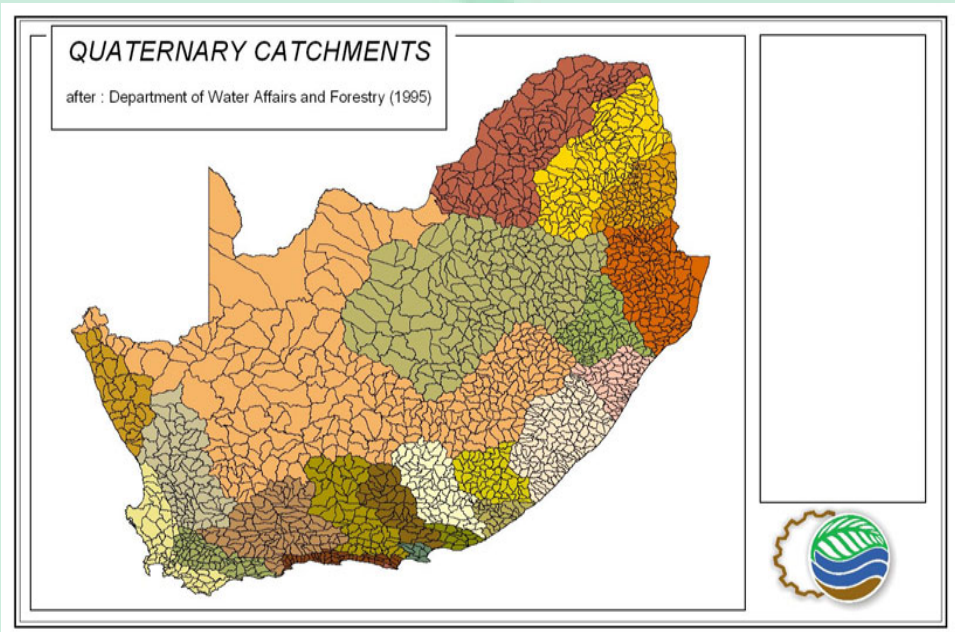
RES8067

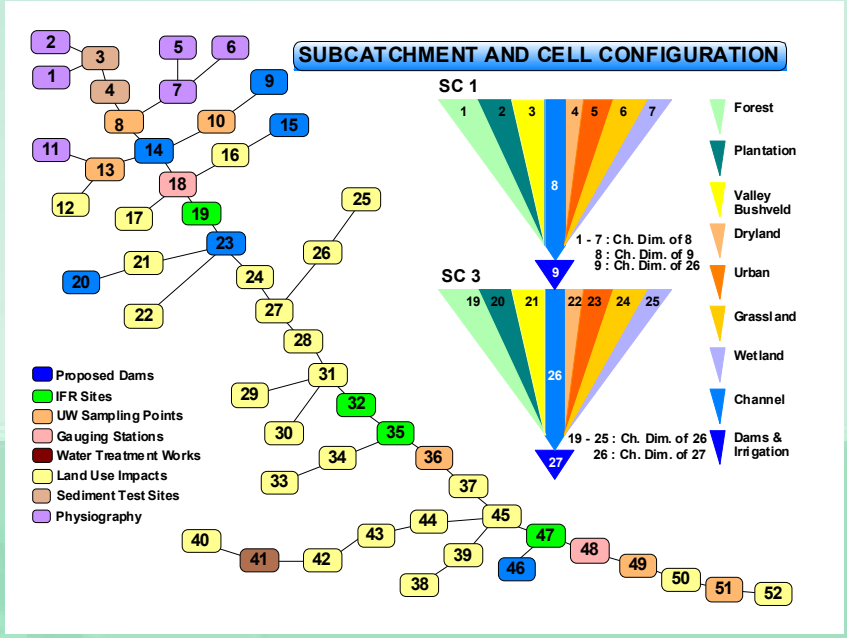
TYPES OF RISK INCREASES OVER TIME

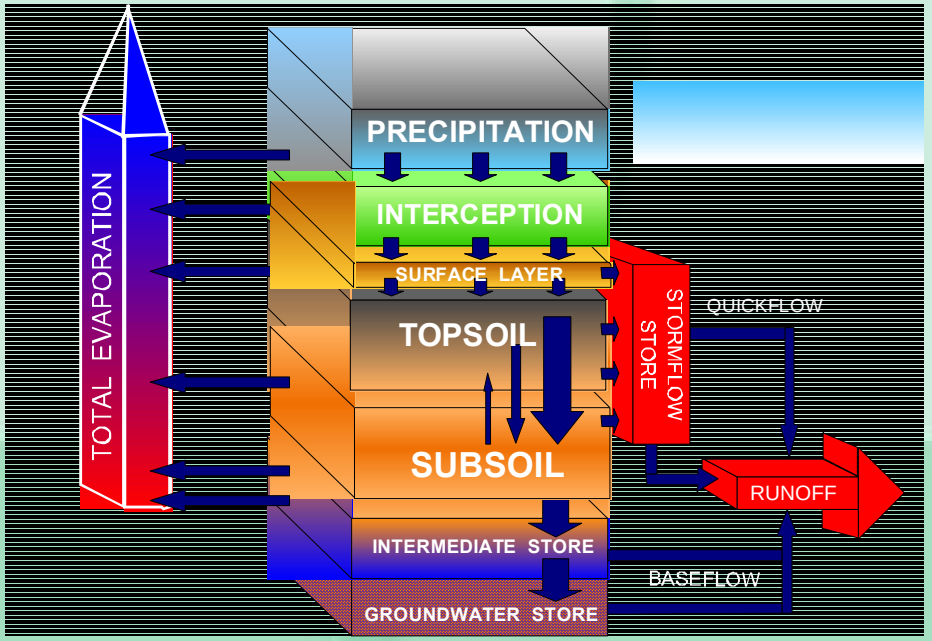


The Challenge: GCM ⇒ RCM ⇒ DHM



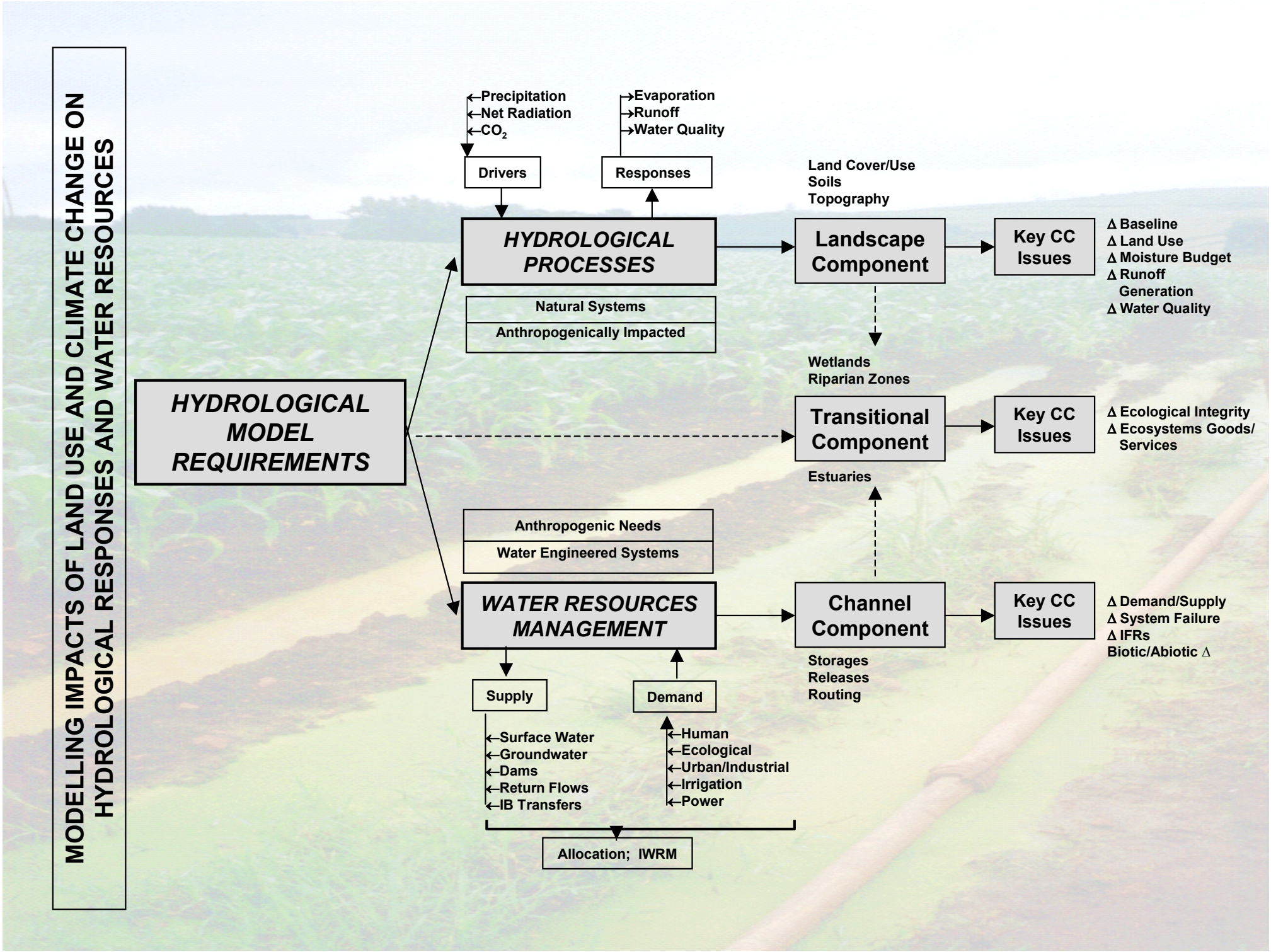


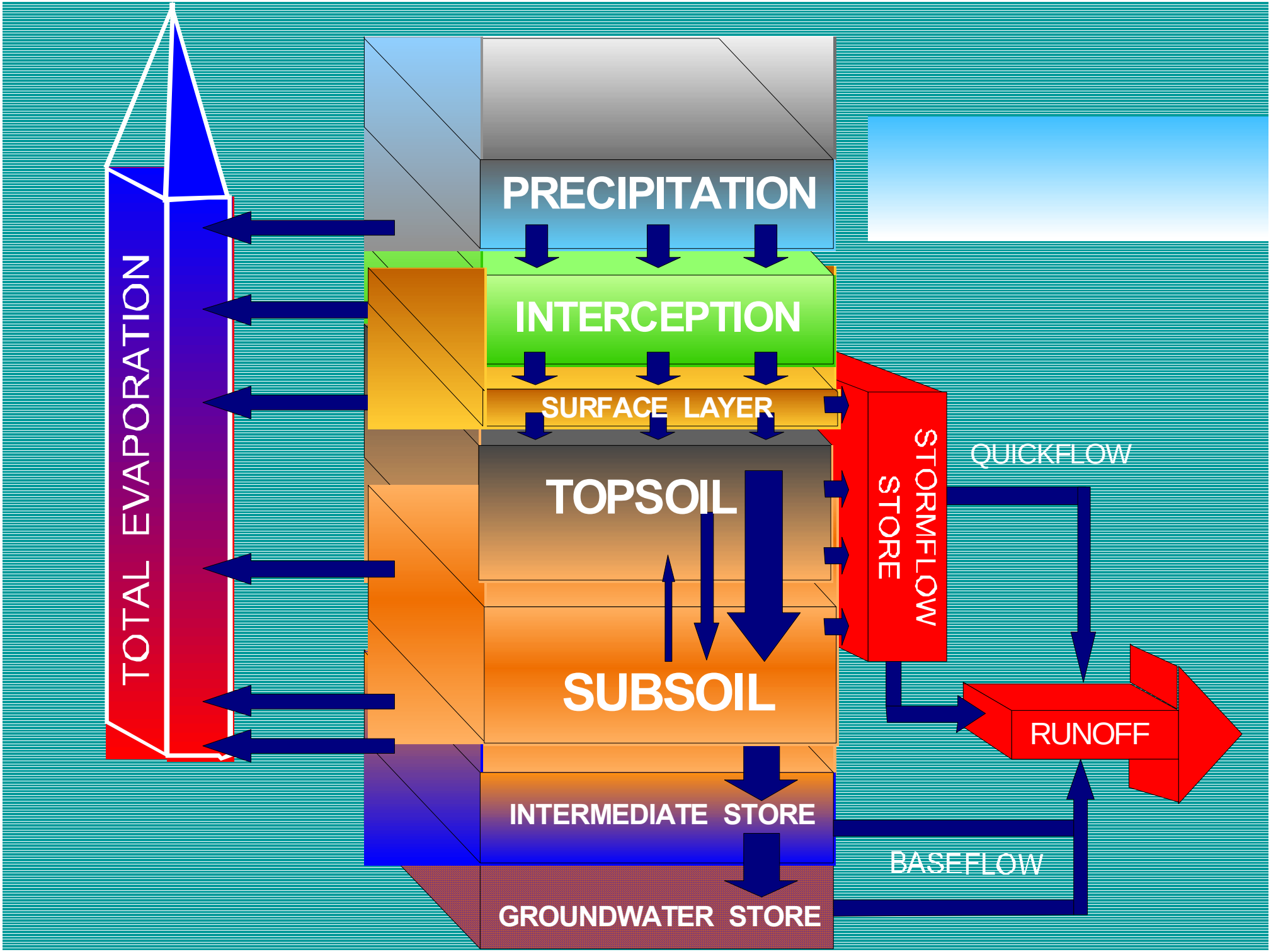


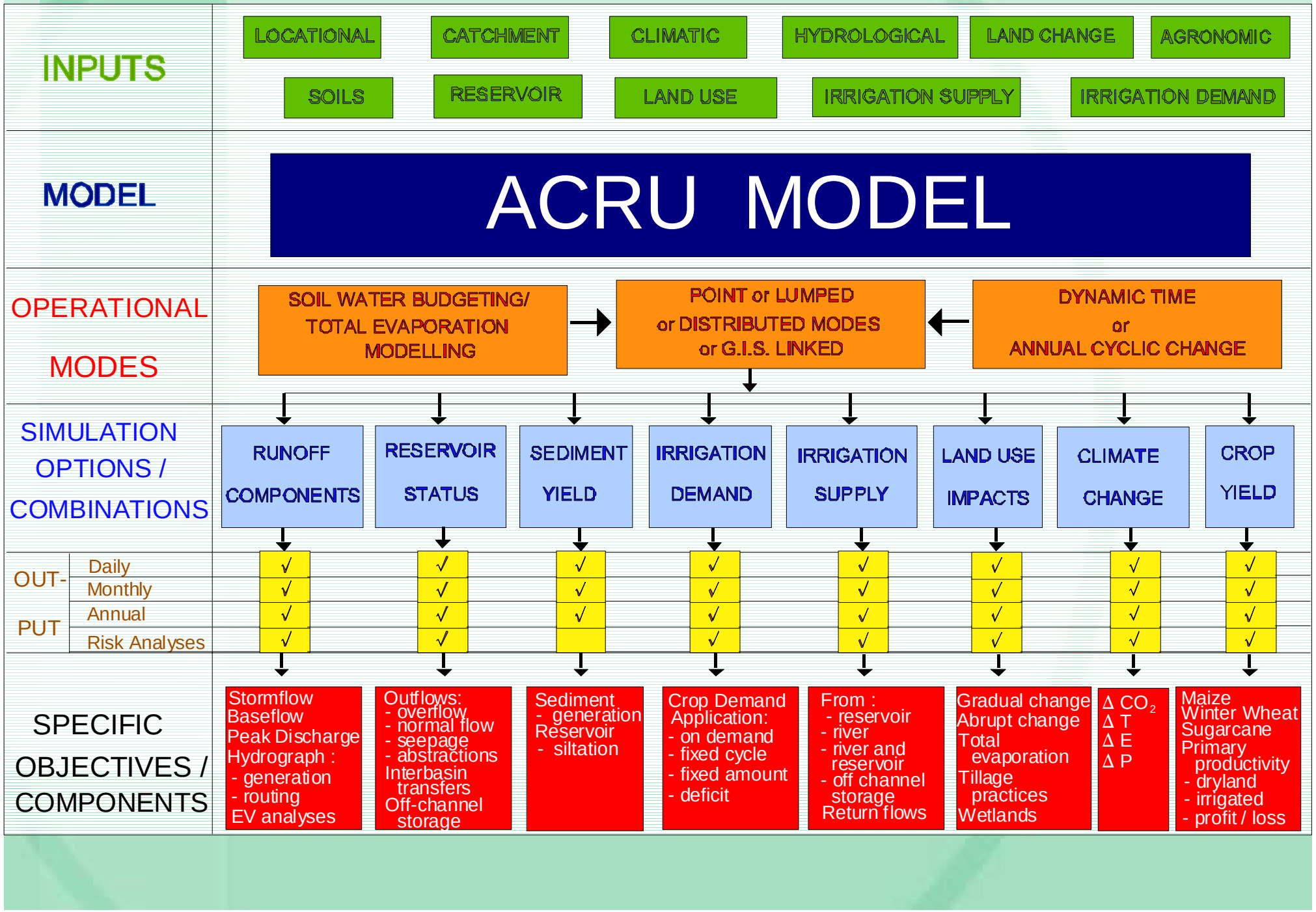


WHAT DO WE HAVE TO CONSIDER IN THE WATER RESOURCES SECTOR IN REGARD TO CLIMATE CHANGE?

(b) An appropriate hydrological model

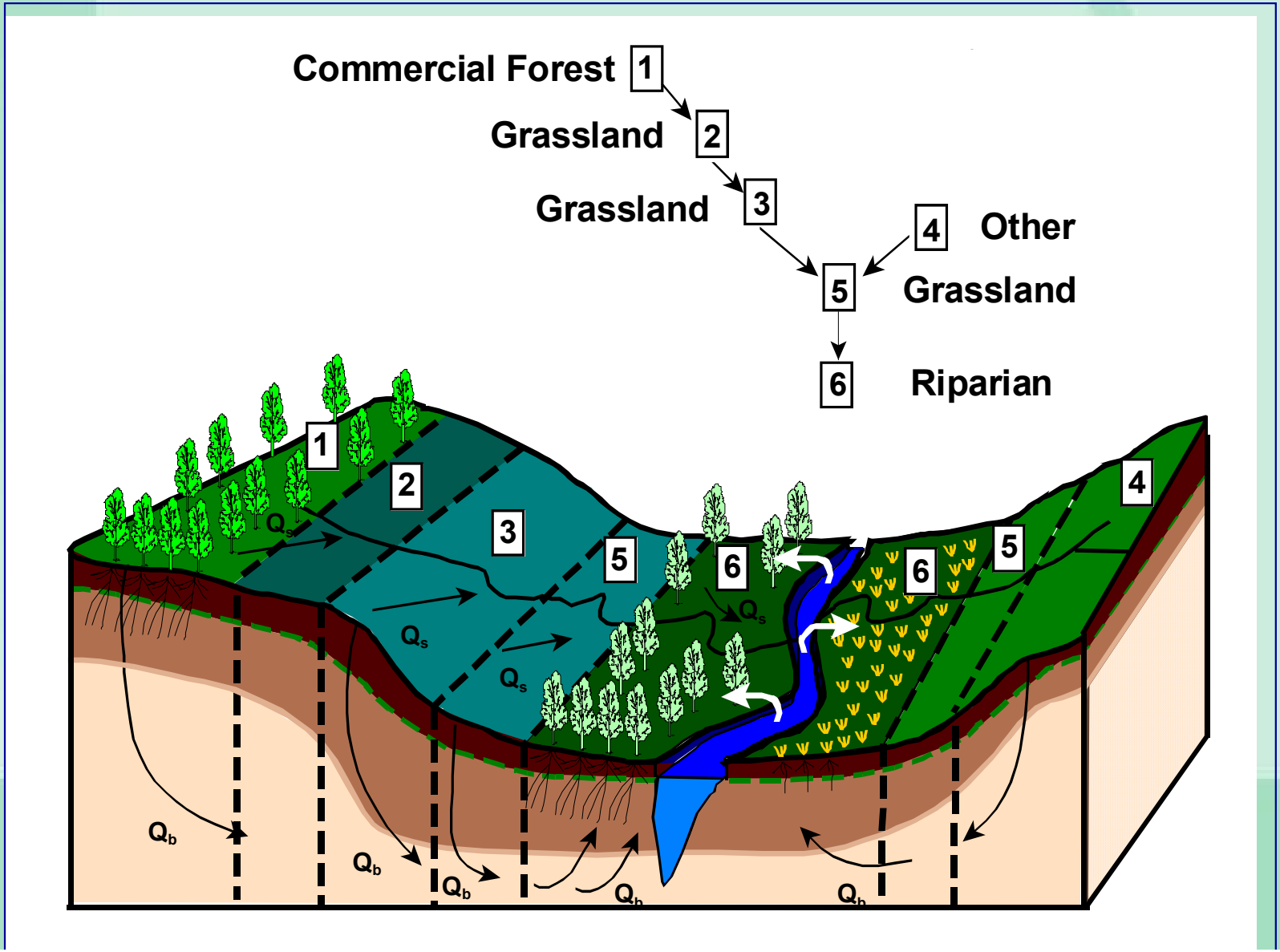

MODELLING IMPACTS OF LAND USE AND CLIMATE CHANGE ON HYDROLOGICAL RESPONSES AND WATER RESOURCES
HYDROLOGICAL MODEL REQUIREMENTS
←Precipitation
←Net Radiation
←CO_2
Drivers
→Evaporation
→Runoff
→Water Quality
Responses
HYDROLOGICAL PROCESSES
Natural Systems
Anthropogenically Impacted
Land Cover/Use
Soils
Topography
Landscape Component
Key CC Issues
Δ Baseline
Δ Land Use
Δ Moisture Budget
Δ Runoff Generation
Δ Water Quality
Wetlands
Riparian Zones
Transitional Component
Key CC Issues
Δ Ecological Integrity
Δ Ecosystems Goods/ Services
Estuaries
Anthropogenic Needs
Water Engineered Systems
WATER RESOURCES MANAGEMENT
Channel Component
Key CC Issues
Δ Demand/Supply
Δ System Failure
Δ IFRs
Biotic/Abiotic Δ
Storages
Releases
Routing
Supply
Demand
←Surface Water
←Groundwater
←Dams
←Return Flows
←IB Transfers
←Human
←Ecological
←Urban/Industrial
←Irrigation
←Power
Allocation; IWRM


PRECIPITATION
INTERCEPTION
SURFACE LAYER
TOPSOIL
SUBSOIL
INTERMEDIATE STORE
GROUNDWATER STORE
TOTAL EVAPORATION
STORMFLOW STORE
QUICKFLOW
RUNOFF
BASEFLOW


INPUTS
LOCATIONAL
CATCHMENT
CLIMATIC
HYDROLOGICAL
LAND CHANGE
AGRONOMIC
SOILS
RESERVOIR
LAND USE
IRRIGATION SUPPLY
IRRIGATION DEMAND
MODEL
ACRU MODEL
OPERATIONAL MODES
SOIL WATER BUDGETING/ TOTAL EVAPORATION MODELLING
POINT or LUMPED or DISTRIBUTED MODES or G.I.S. LINKED
DYNAMIC TIME or ANNUAL CYCLIC CHANGE
SIMULATION OPTIONS / COMBINATIONS
RUNOFF COMPONENTS
RESERVOIR STATUS
SEDIMENT YIELD
IRRIGATION DEMAND
IRRIGATION SUPPLY
LAND USE IMPACTS
CLIMATE CHANGE
CROP YIELD
OUT-PUT
Daily
Monthly
Annual
Risk Analyses
SPECIFIC OBJECTIVES / COMPONENTS
Stormflow
Baseflow
Peak Discharge
Hydrograph :
- generation
- routing
EV analyses
Outflows:
- overflow
- normal flow
- seepage
- abstractions
Interbasin transfers
Off-channel storage
Sediment
- generation
Reservoir
- siltation
Crop Demand
Application:
- on demand
- fixed cycle
- fixed amount
- deficit
From :
- reservoir
- river
- river and reservoir
- off channel storage
Return flows
Gradual change
Abrupt change
Total evaporation
Tillage practices
Wetlands
Δ CO2
Δ T
Δ E
Δ P
Maize
Winter Wheat
Sugarcane
Primary productivity
- dryland
- irrigated
- profit / loss

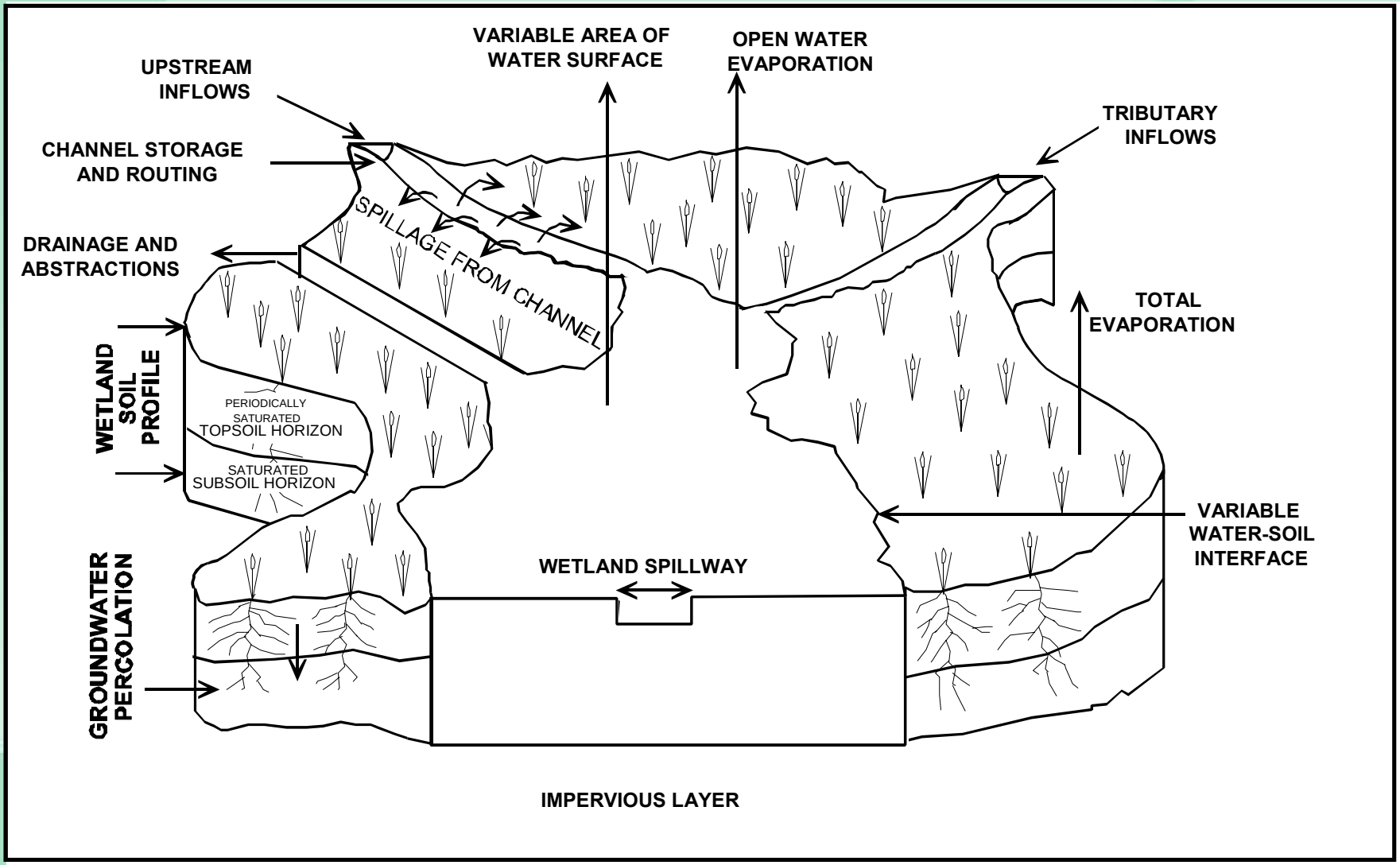
Hillslope and Riparian Zone Processes in ACRU

(after Meier et al., 1997; Schulze, 2000b)



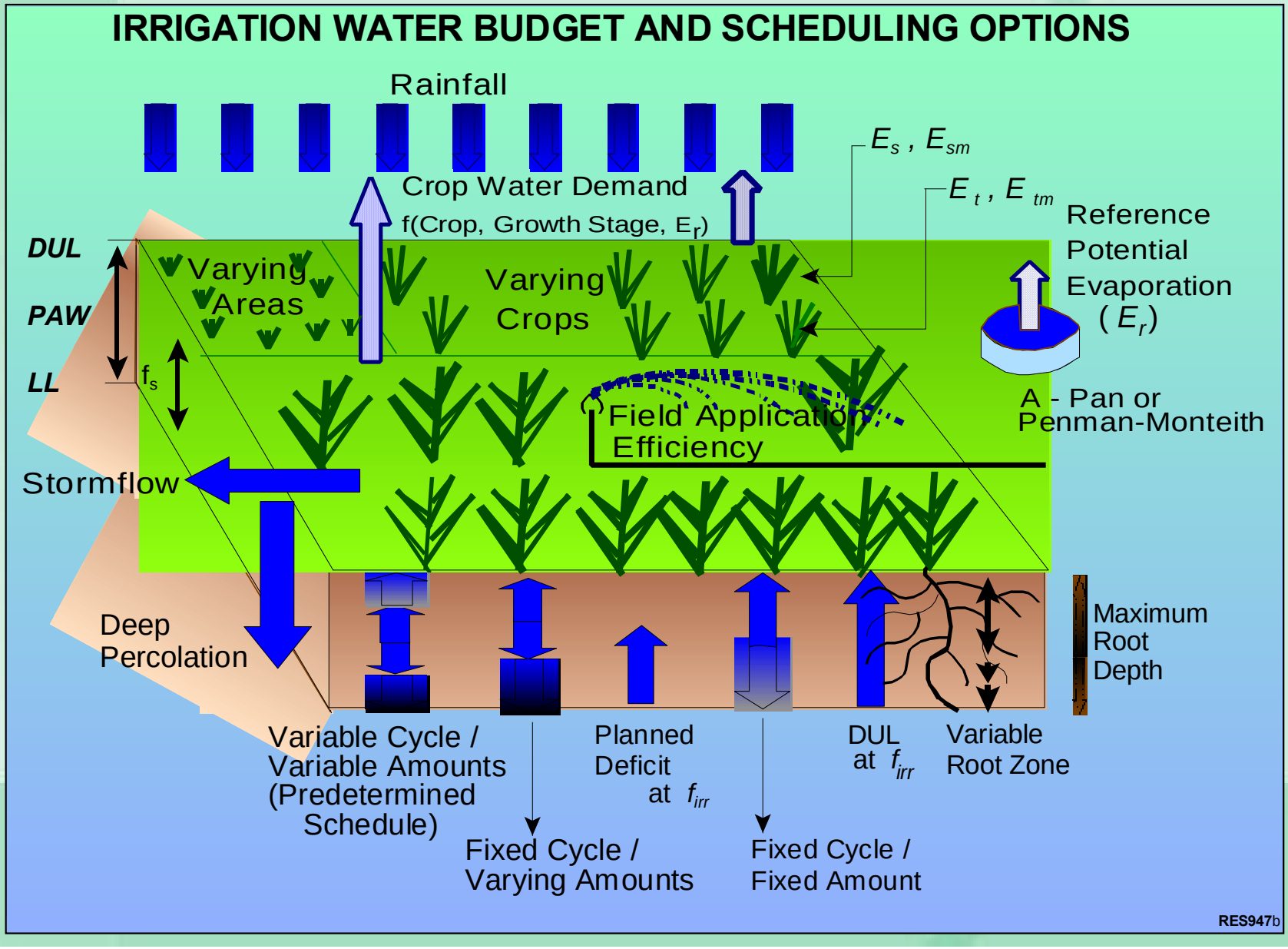
Concepts, Processes and Assumptions in the ACRU Wetlands Module

(after Schulze et al., 1987; with modifications by Schulze, 2001d)

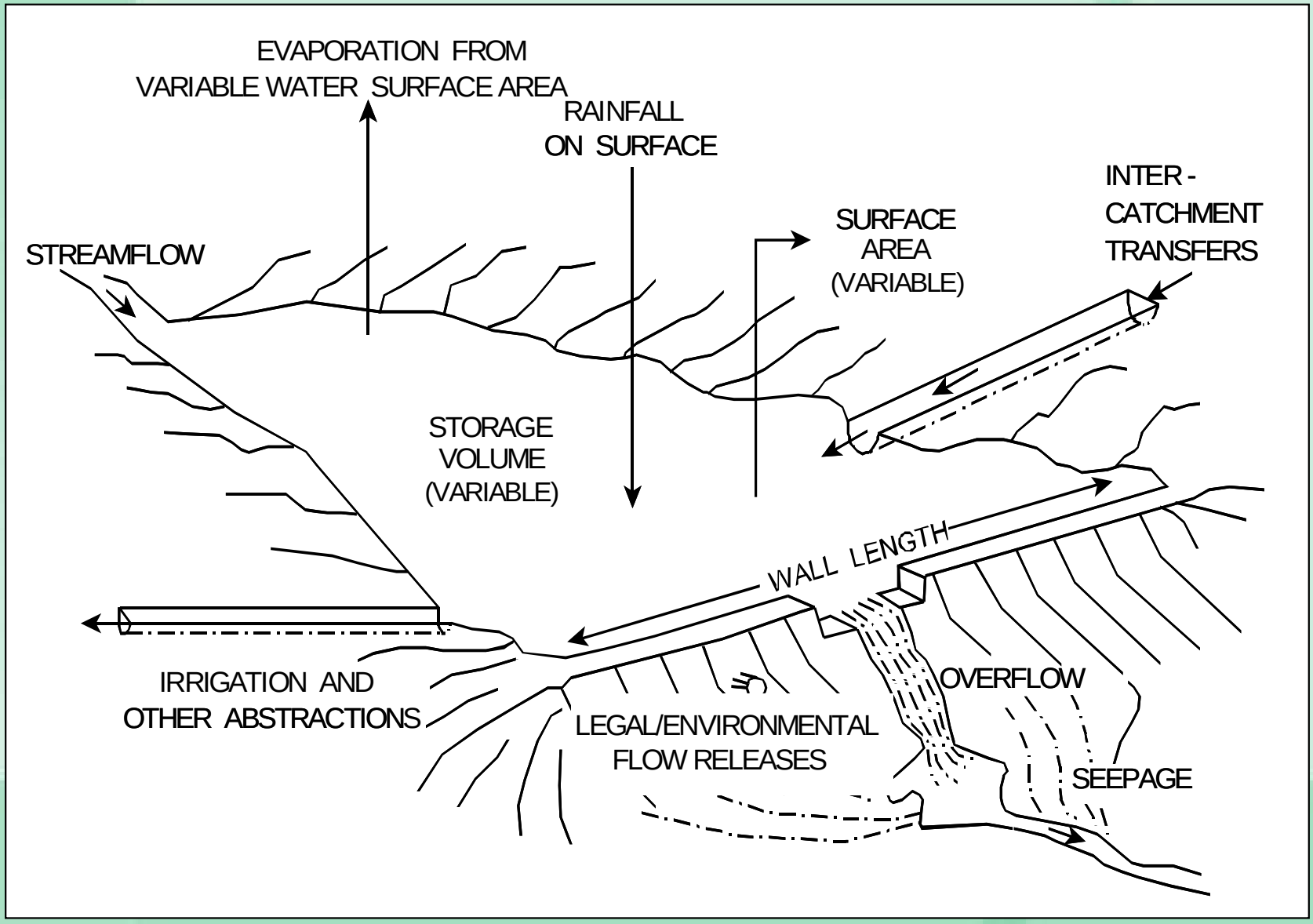


Schematic of Irrigation Water Demand and Scheduling Options Available in ACRU

(after Schulze, 1995 and updates)



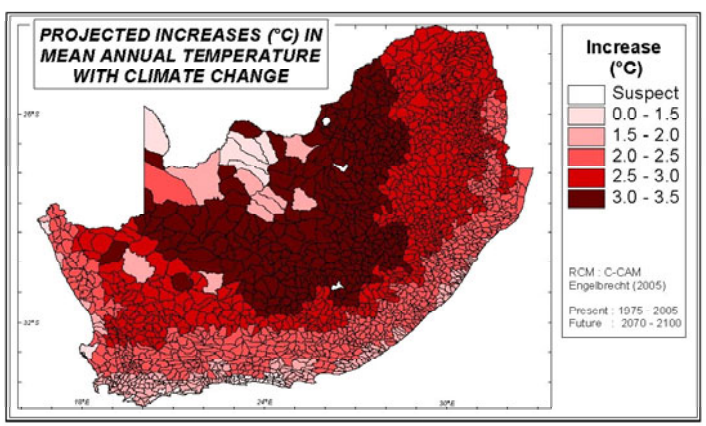
Schematic of the Reservoir Water Budget in ACRU *(after Schulze, 1995)*

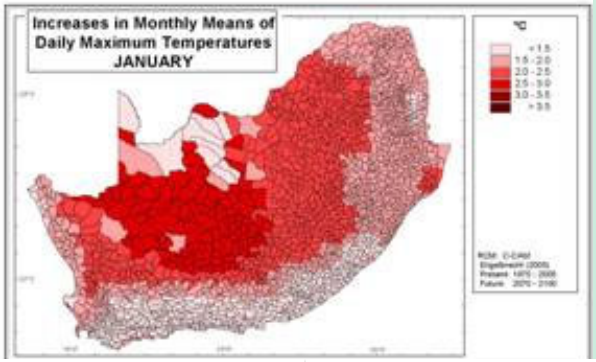


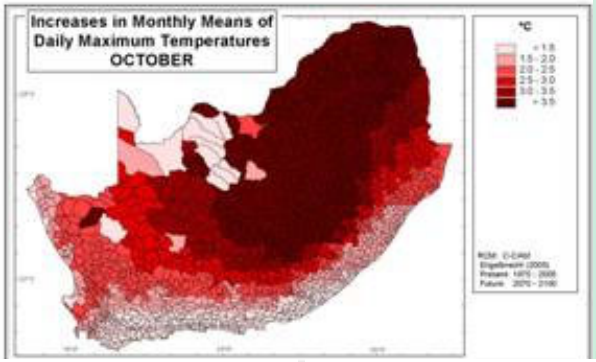
WHAT DO WE HAVE TO CONSIDER IN THE WATER RESOURCES SECTOR IN REGARD TO CLIMATE CHANGE?

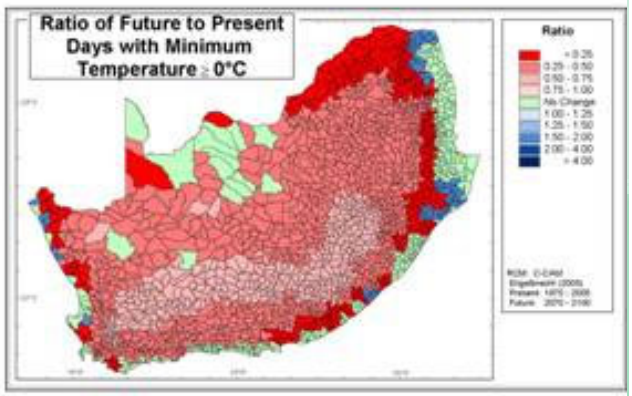
(c) Meaningful water management issues

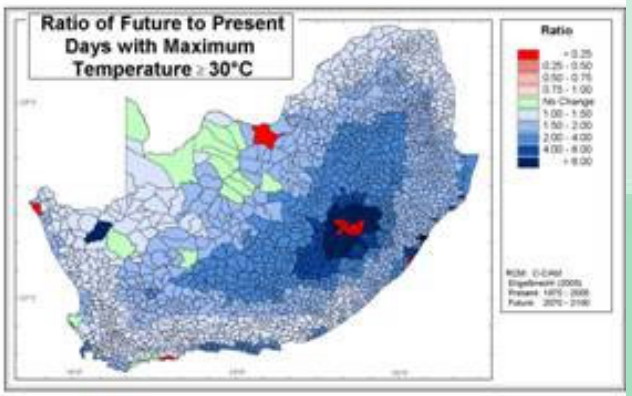
DETAIL "EXPLODES" FROM ANNUAL TO MONTHLY TO DAILY VALUES: TEMPERATURE

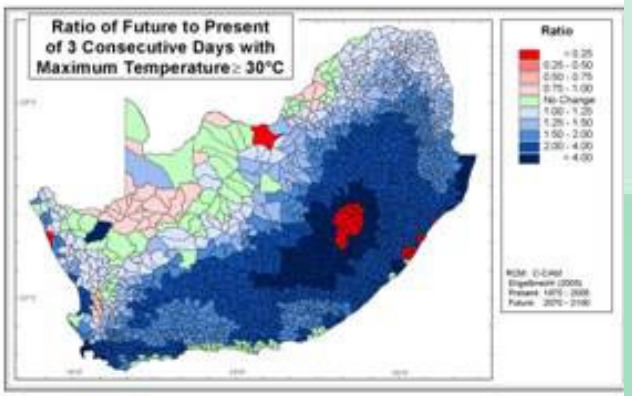




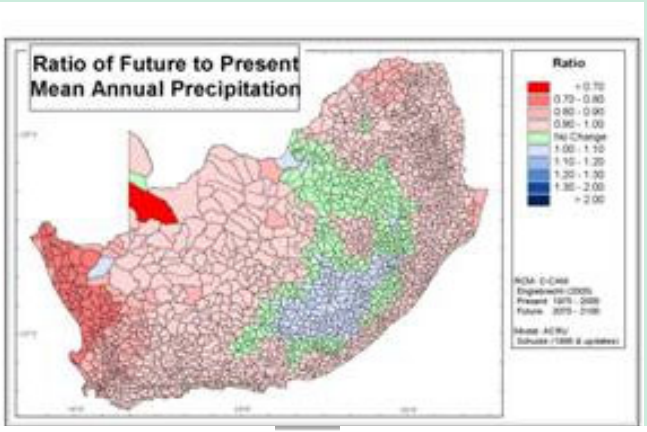


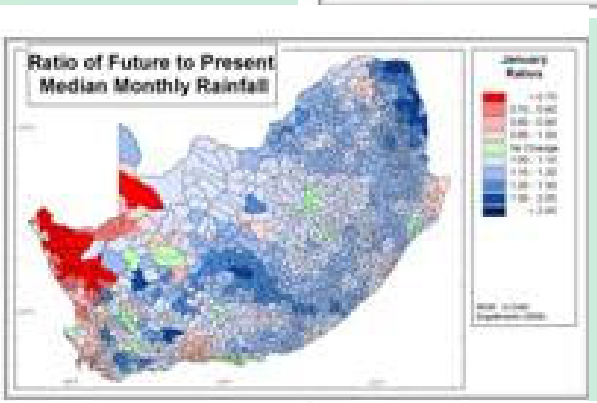


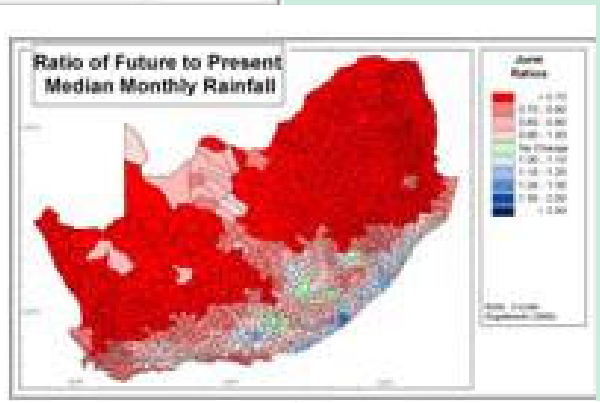


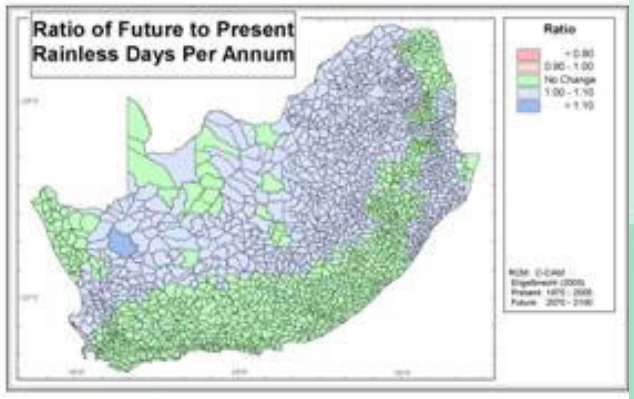


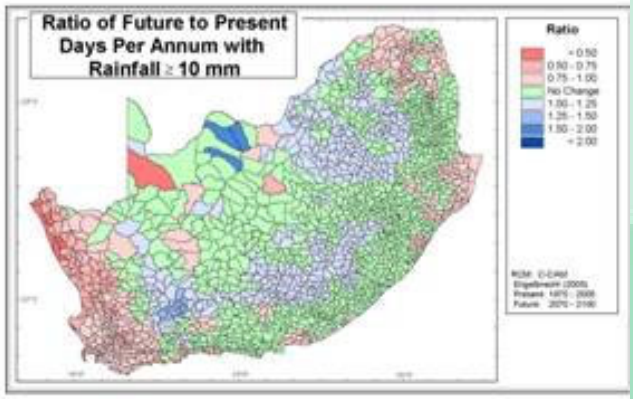
DETAIL "EXPLODES" FROM ANNUAL TO MONTHLY TO DAILY VALUES: RAINFALL

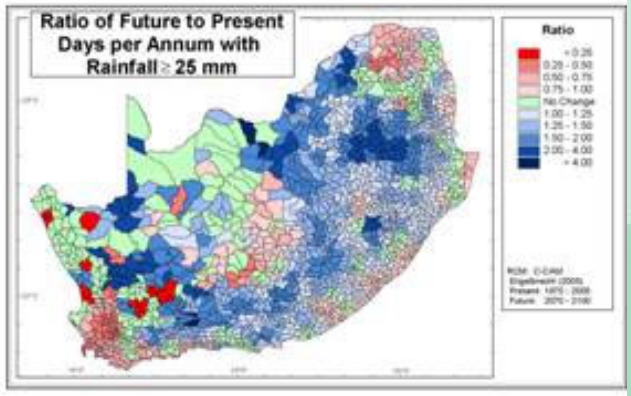


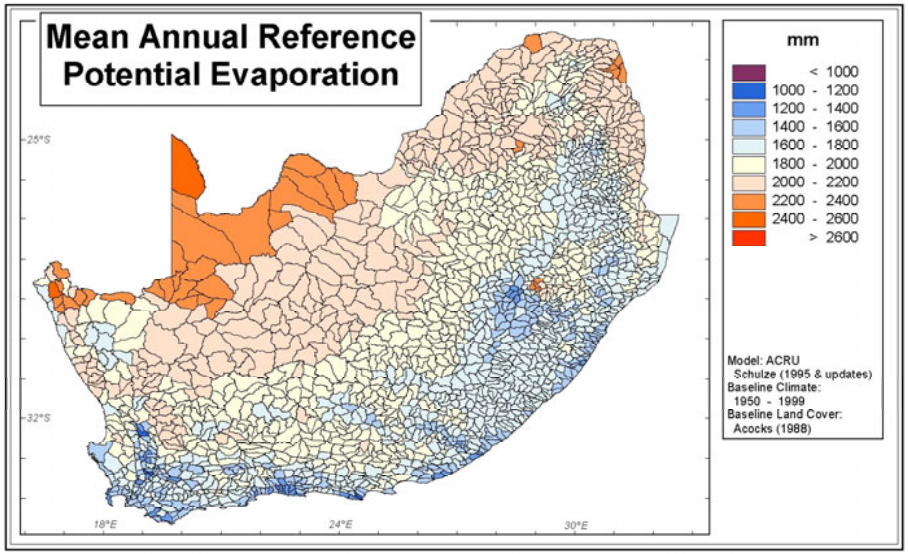


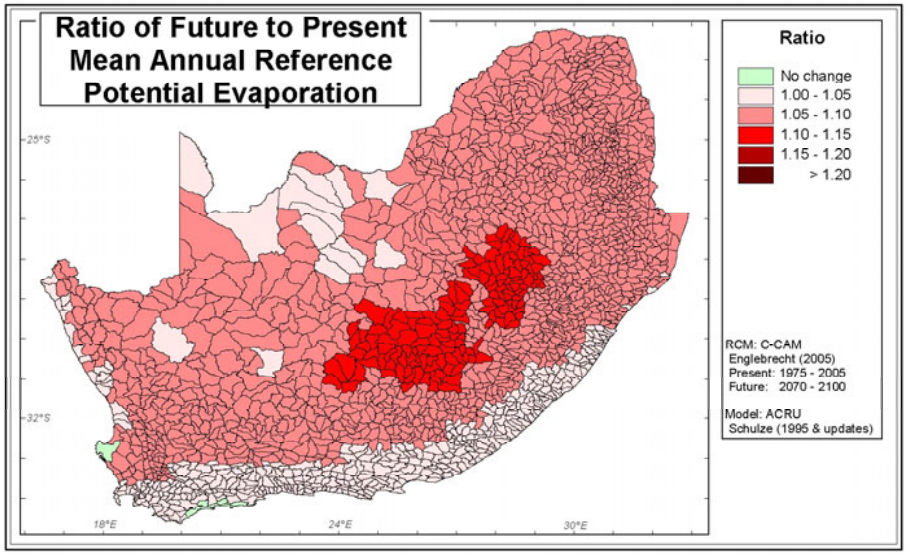


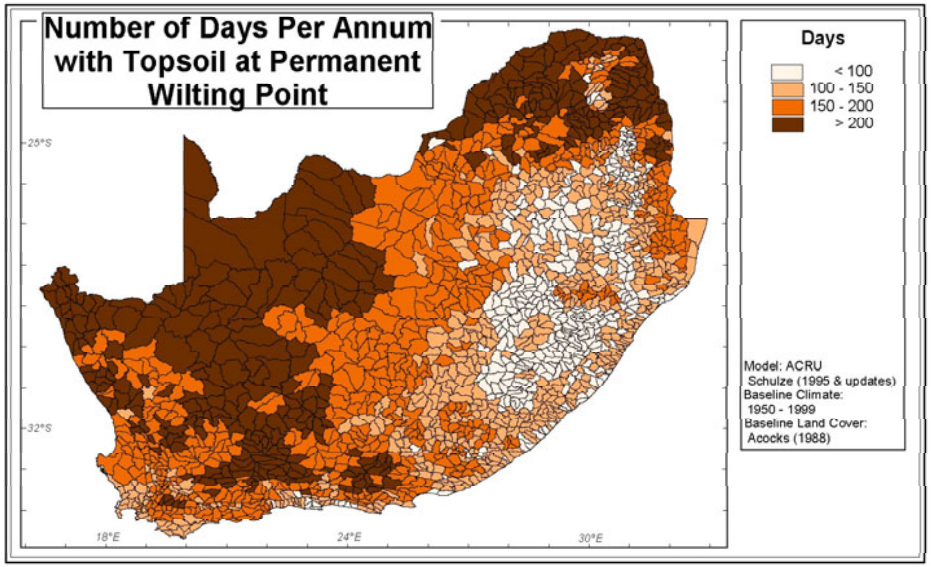


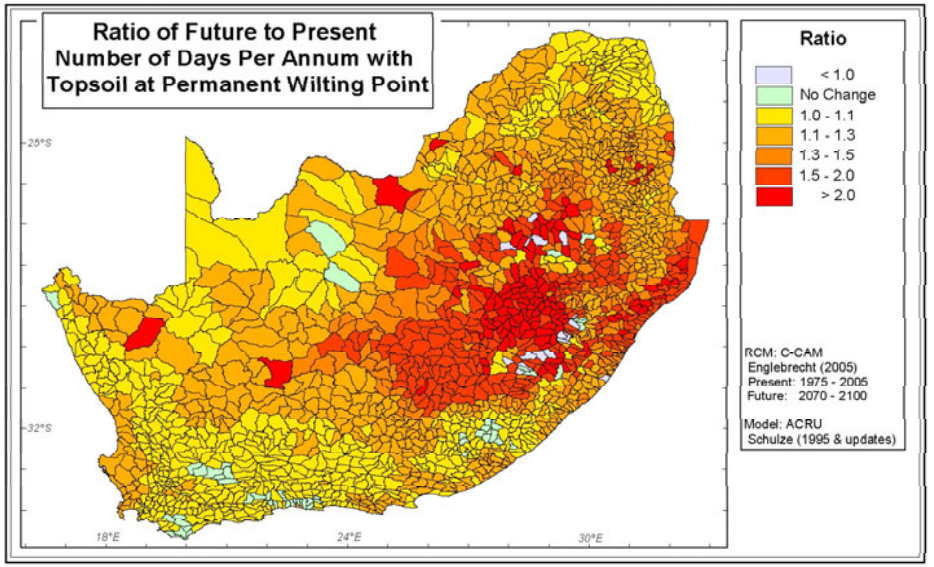


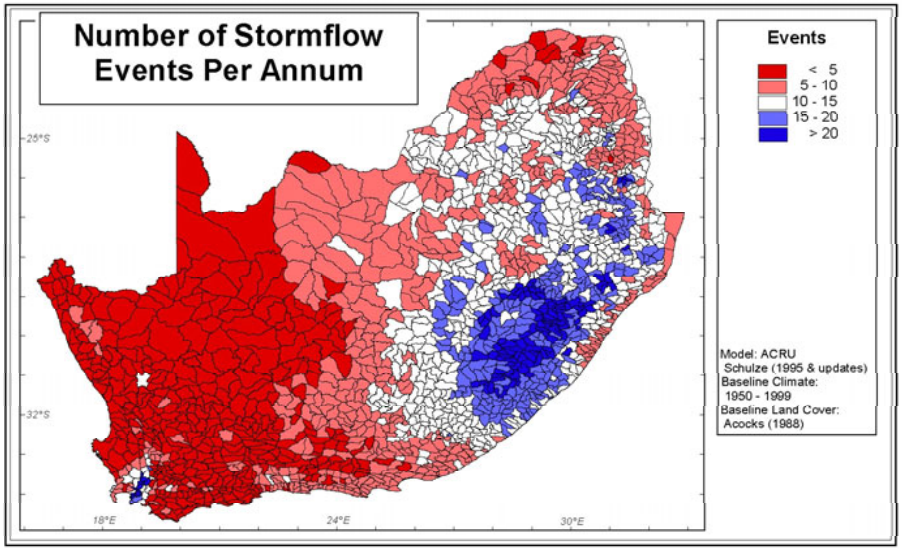


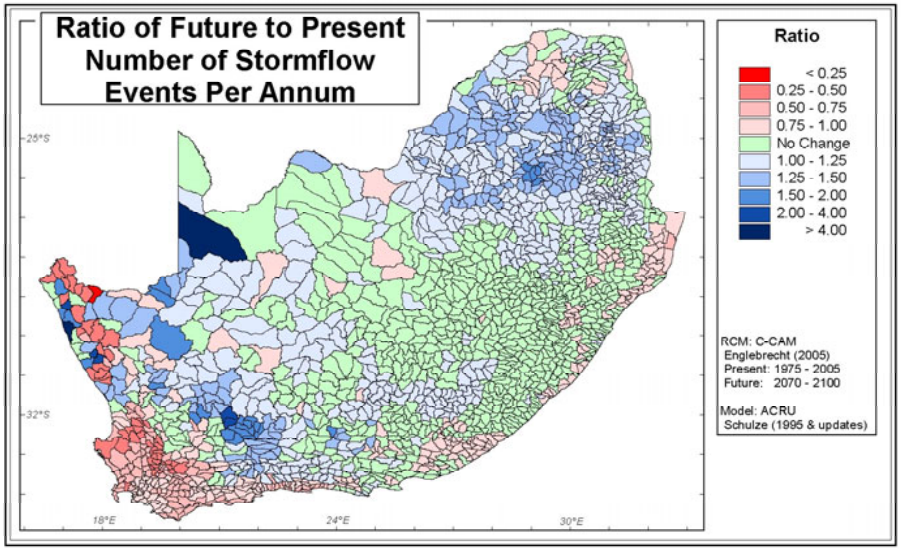

Mean Annual Reference Potential Evaporation
mm
< 1000
1000 - 1200
1200 - 1400
1400 - 1600
1600 - 1800
1800 - 2000
2000 - 2200
2200 - 2400
2400 - 2600
> 2600
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

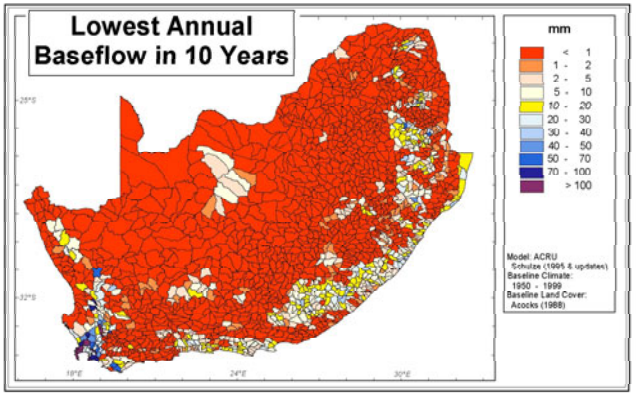

Ratio of Future to Present Mean Annual Reference Potential Evaporation
Ratio
No change
1.00 - 1.05
1.05 - 1.10
1.10 - 1.15
1.15 - 1.20
> 1.20
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

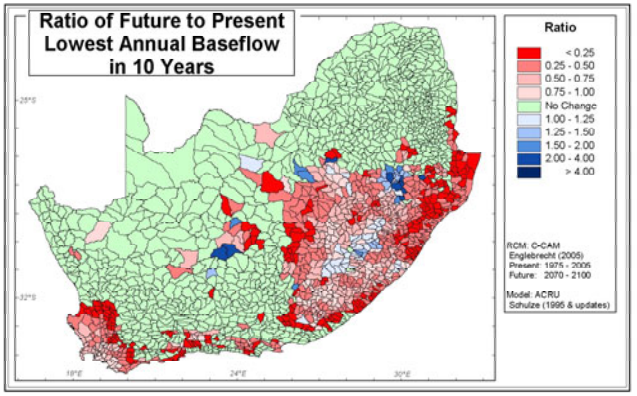

Number of Days Per Annum with Topsoil at Permanent Wilting Point
25°S
32°S
18°E
24°E
30°E
Days
< 100
100 - 150
150 - 200
> 200
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)

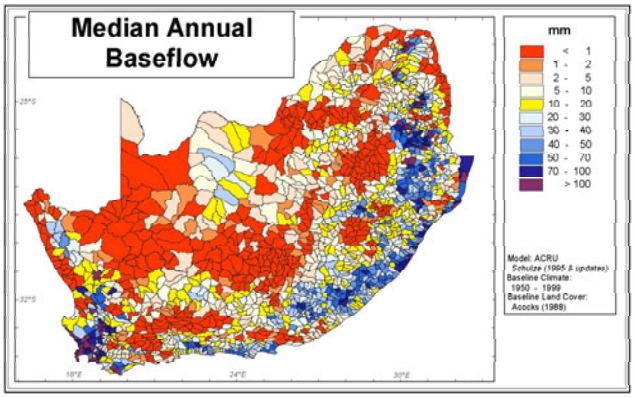

Ratio of Future to Present Number of Days Per Annum with Topsoil at Permanent Wilting Point
25°S
32°S
18°E
24°E
30°E
Ratio
< 1.0
No Change
1.0 - 1.1
1.1 - 1.3
1.3 - 1.5
1.5 - 2.0
> 2.0
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)

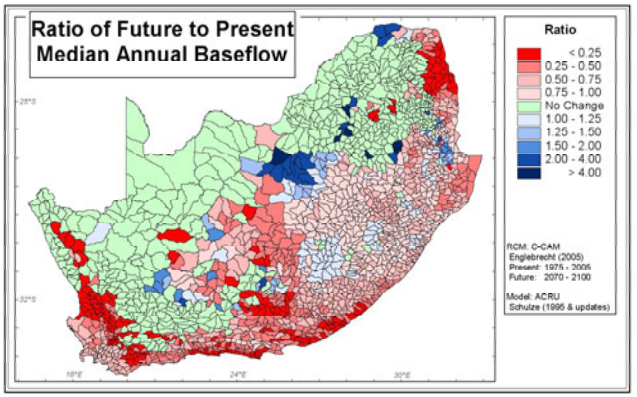

Number of Stormflow Events Per Annum
Events
< 5
5 - 10
10 - 15
15 - 20
> 20
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

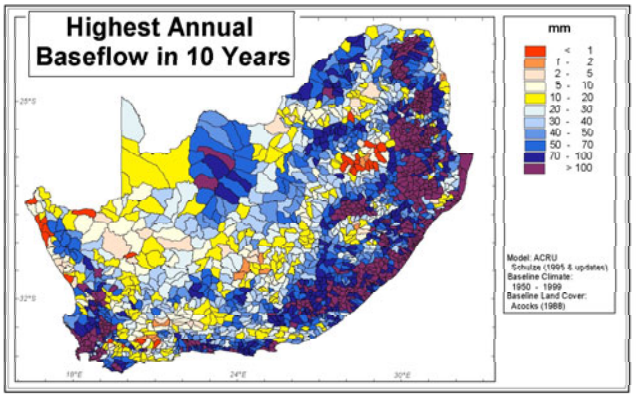

Ratio of Future to Present Number of Stormflow Events Per Annum
Ratio
< 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
No Change
1.00 - 1.25
1.25 - 1.50
1.50 - 2.00
2.00 - 4.00
> 4.00
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

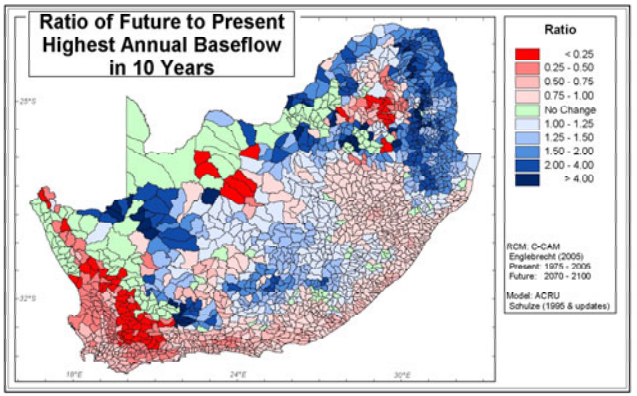

Lowest Annual Baseflow in 10 Years
mm
< 1
1 - 2
2 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 70
70 - 100
> 100
Model: ACRU Schulze (1995 & updates)
Baseline Climate: 1950 - 1999
Baseline Land Cover: Acocks (1988)

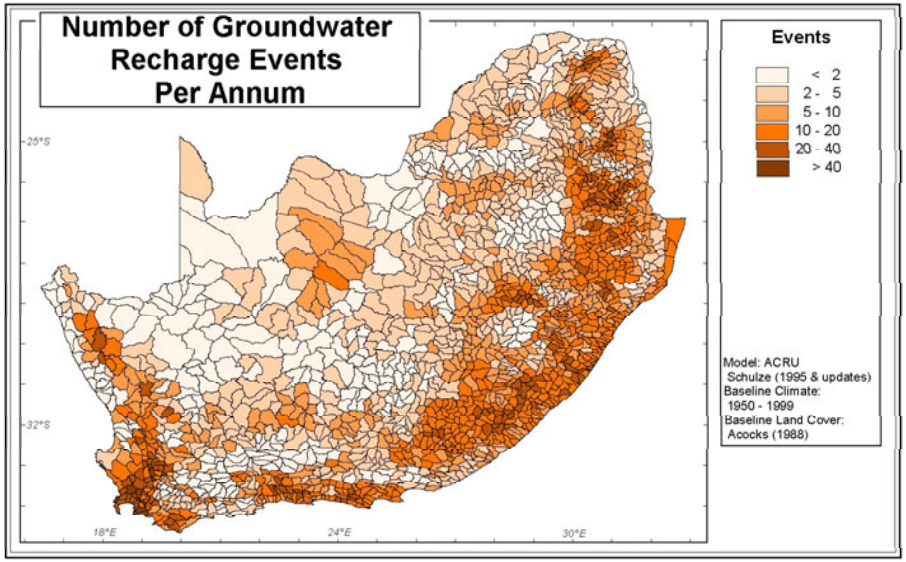

Ratio of Future to Present Lowest Annual Baseflow in 10 Years
Ratio
< 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
No Change
1.00 - 1.25
1.25 - 1.50
1.50 - 2.00
2.00 - 4.00
> 4.00
RCM: C-CAM Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU Schulze (1995 & updates)

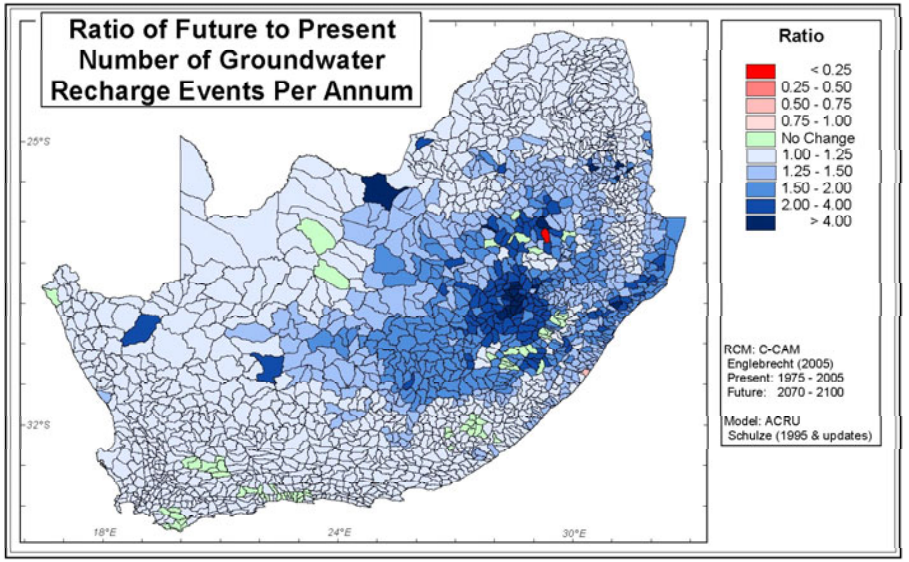

Median Annual Baseflow
mm
< 1
1 - 2
2 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 70
70 - 100
> 100
Model: ACRU Schulze (1995 & updates)
Baseline Climate: 1950 - 1999
Baseline Land Cover: Acocks (1988)

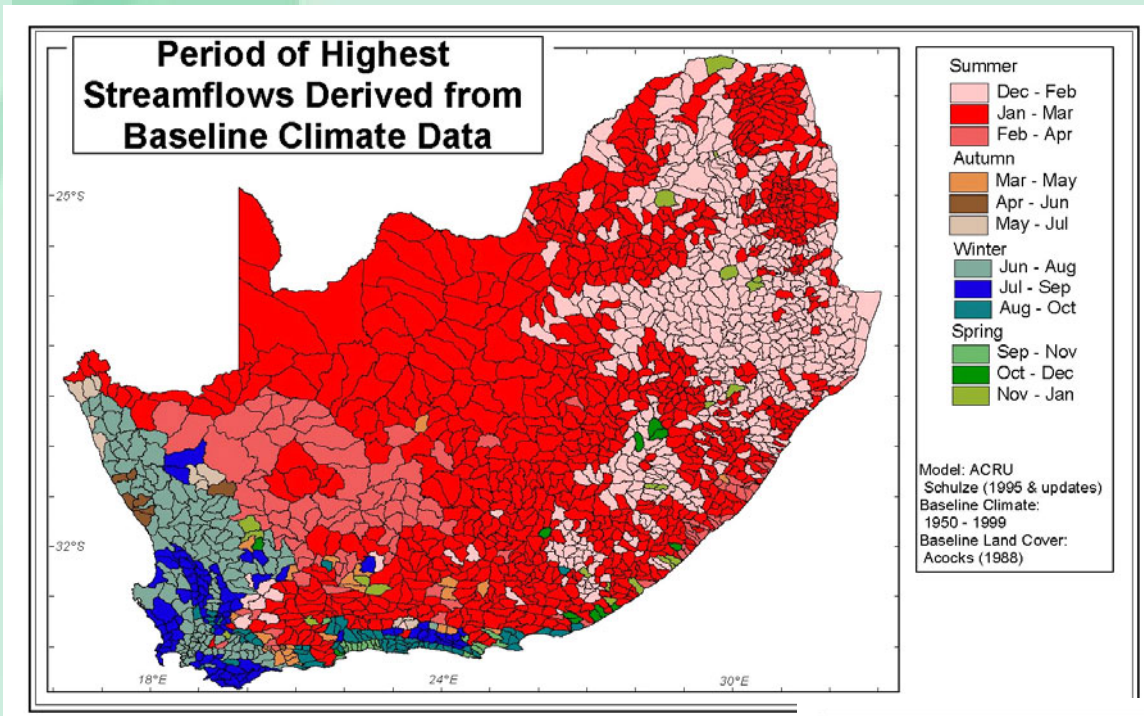

Ratio of Future to Present Median Annual Baseflow
Ratio
< 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
No Change
1.00 - 1.25
1.25 - 1.50
1.50 - 2.00
2.00 - 4.00
> 4.00
RCM: C-CAM Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU Schulze (1995 & updates)

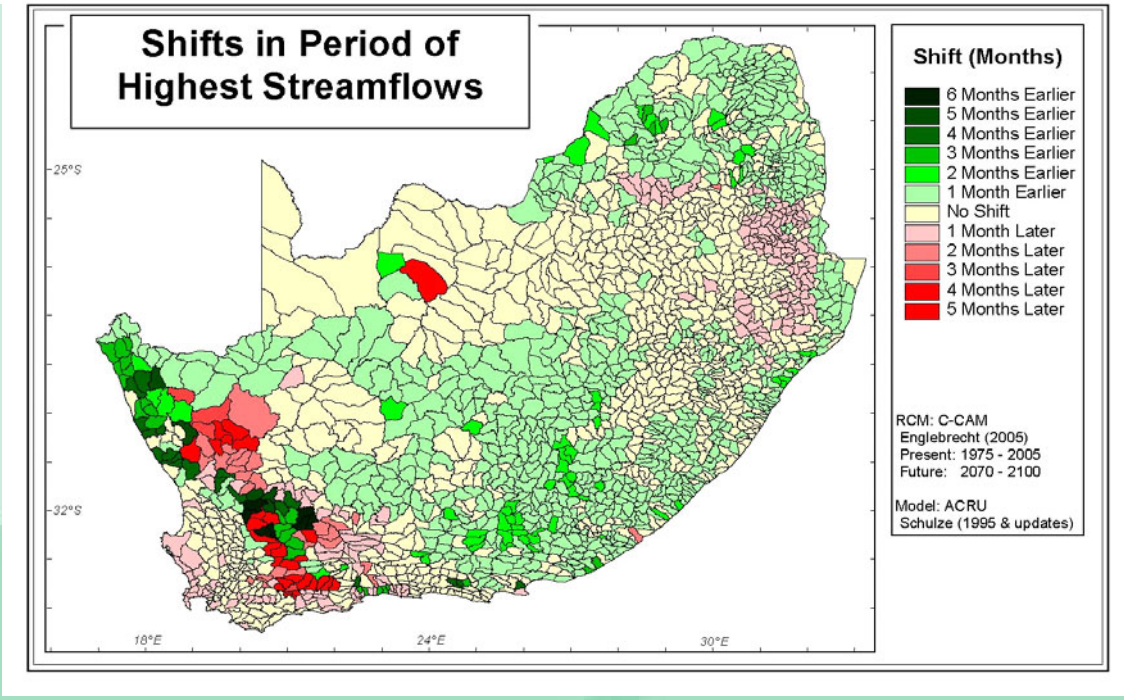

Highest Annual Baseflow in 10 Years
mm
< 1
1 - 2
2 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 70
70 - 100
> 100
Model: ACRU Schulze (1995 & updates)
Baseline Climate: 1950 - 1999
Baseline Land Cover: Acocks (1988)

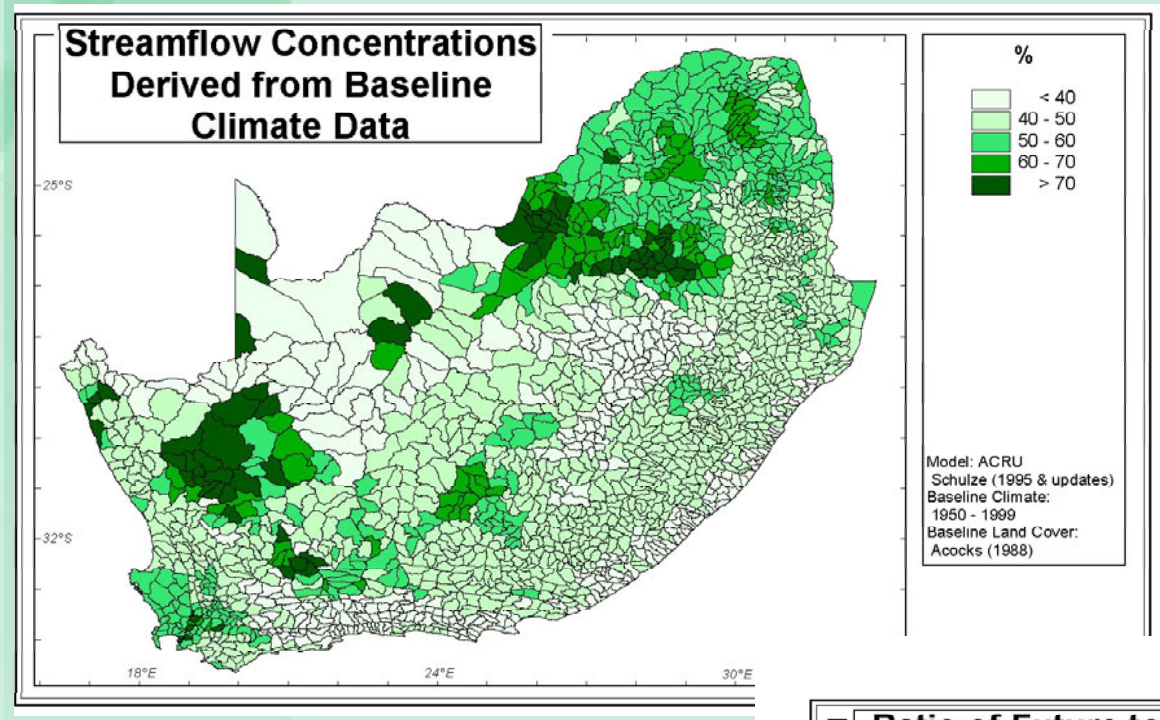

Ratio of Future to Present Highest Annual Baseflow in 10 Years
Ratio
< 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
No Change
1.00 - 1.25
1.25 - 1.50
1.50 - 2.00
2.00 - 4.00
> 4.00
RCM: C-CAM Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU Schulze (1995 & updates)

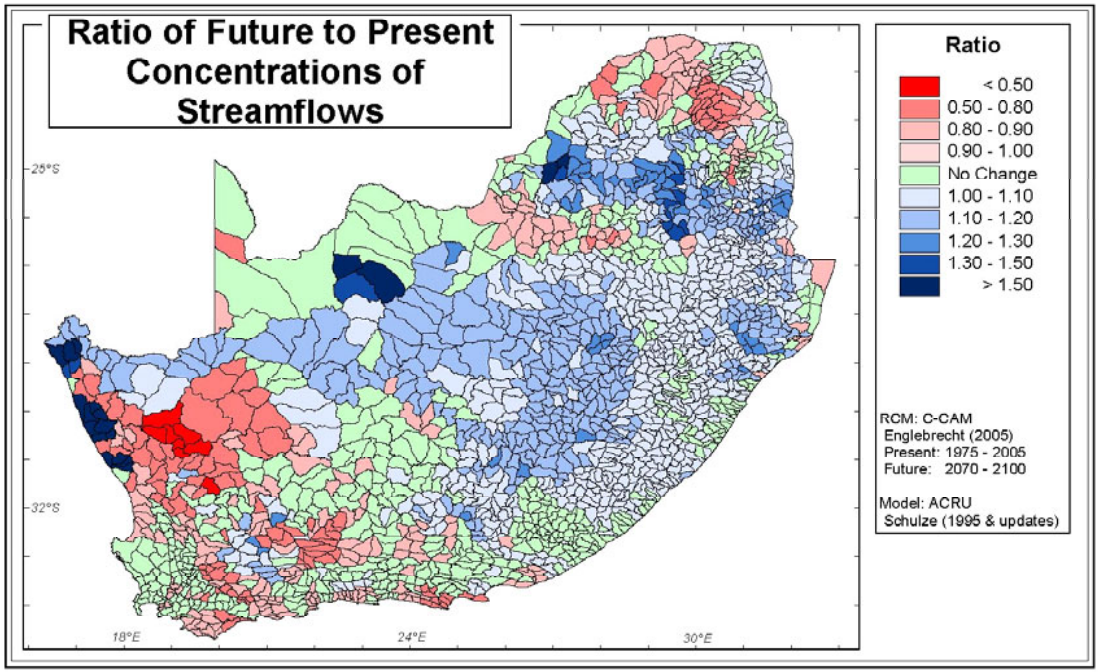

Number of Groundwater Recharge Events Per Annum
Events
< 2
2 - 5
5 - 10
10 - 20
20 - 40
> 40
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

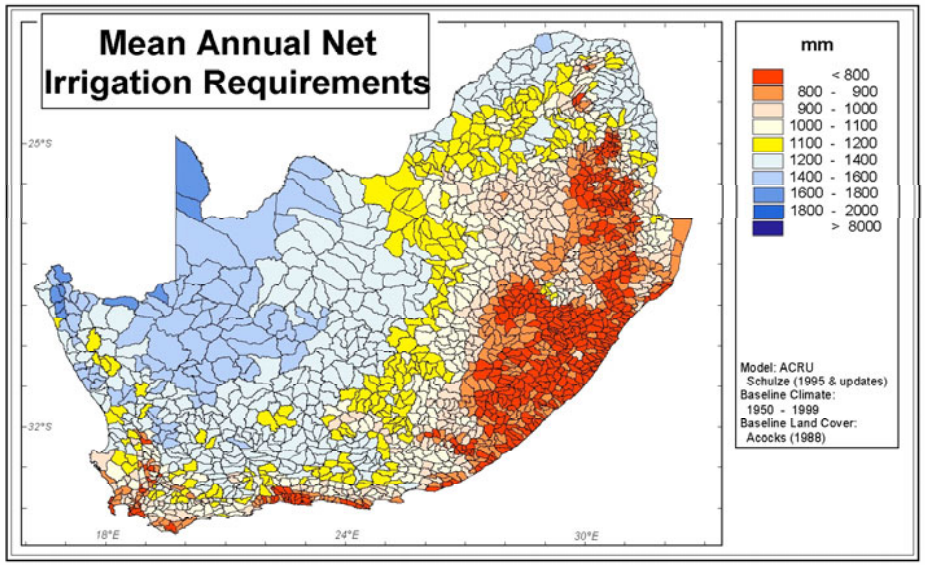

Ratio of Future to Present Number of Groundwater Recharge Events Per Annum
Ratio
< 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
No Change
1.00 - 1.25
1.25 - 1.50
1.50 - 2.00
2.00 - 4.00
> 4.00
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

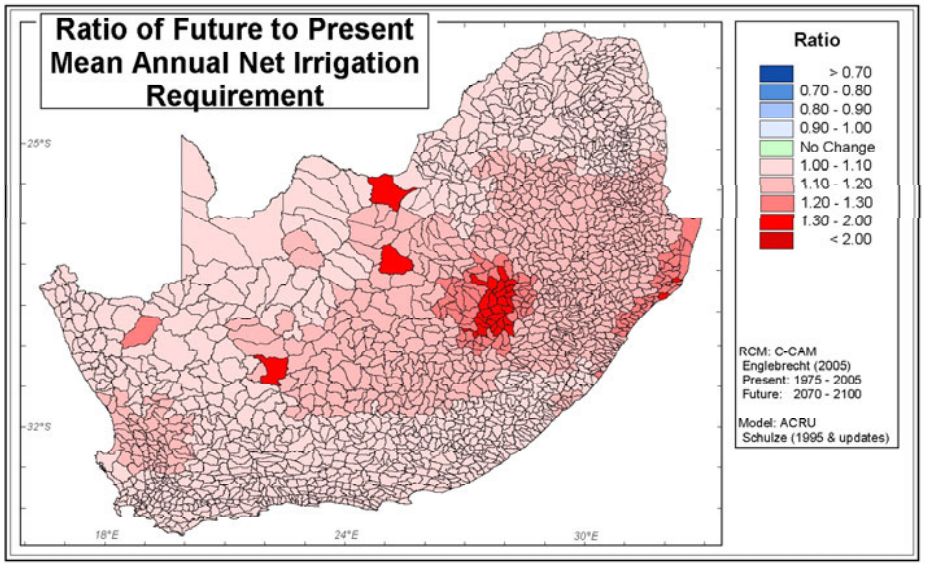

Period of Highest Streamflows Derived from Baseline Climate Data
25°S
32°S
18°E
24°E
30°E
Summer
Dec - Feb
Jan - Mar
Feb - Apr
Autumn
Mar - May
Apr - Jun
May - Jul
Winter
Jun - Aug
Jul - Sep
Aug - Oct
Spring
Sep - Nov
Oct - Dec
Nov - Jan
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)

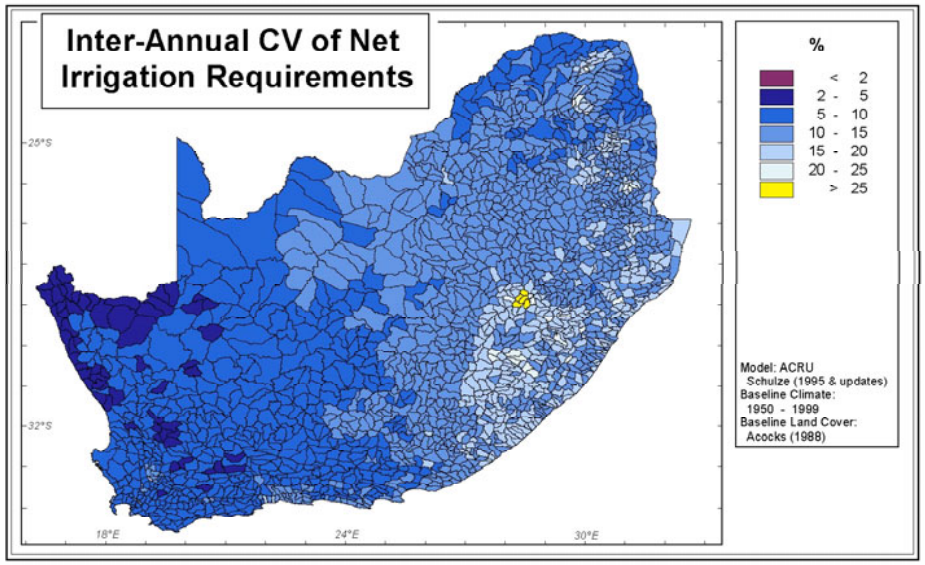

Shifts in Period of Highest Streamflows
25°S
32°S
18°E
24°E
30°E
Shift (Months)
6 Months Earlier
5 Months Earlier
4 Months Earlier
3 Months Earlier
2 Months Earlier
1 Month Earlier
No Shift
1 Month Later
2 Months Later
3 Months Later
4 Months Later
5 Months Later
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)

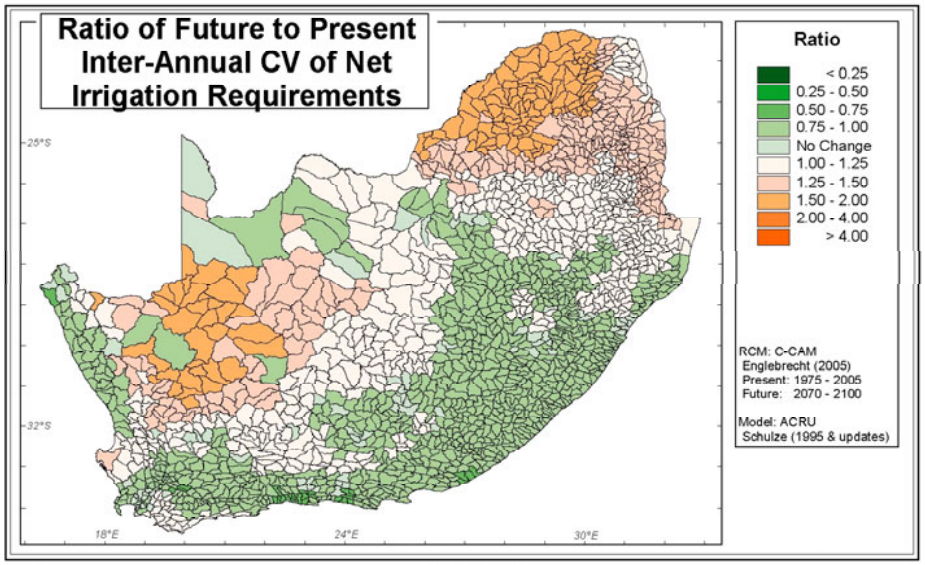

Streamflow Concentrations Derived from Baseline Climate Data
%
< 40
40 - 50
50 - 60
60 - 70
> 70
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

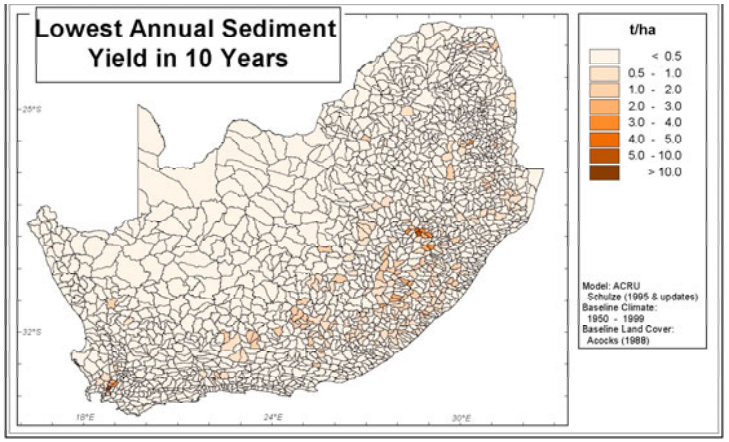

Ratio of Future to Present Concentrations of Streamflows
Ratio
< 0.50
0.50 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
1.30 - 1.50
> 1.50
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

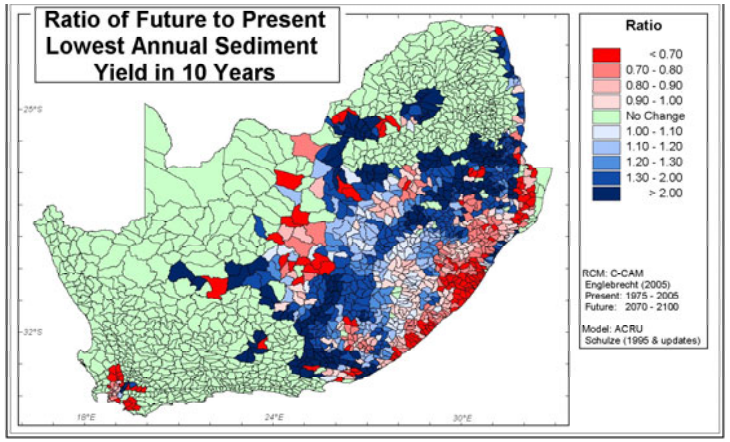

Mean Annual Net Irrigation Requirements
mm
< 800
800 - 900
900 - 1000
1000 - 1100
1100 - 1200
1200 - 1400
1400 - 1600
1600 - 1800
1800 - 2000
> 8000
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

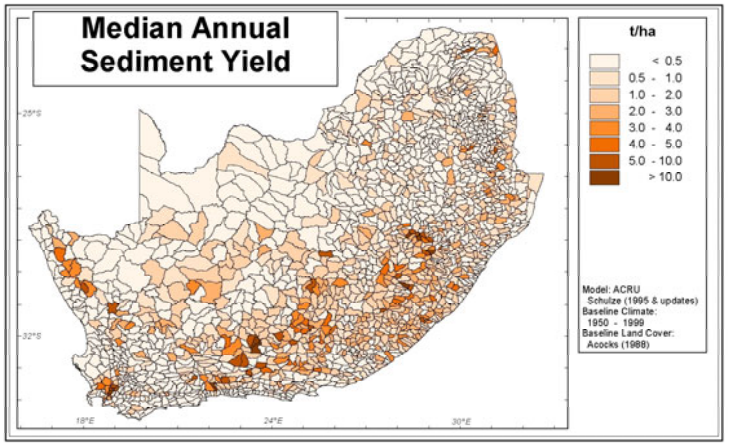

Ratio of Future to Present Mean Annual Net Irrigation Requirement
Ratio
> 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
1.30 - 2.00
< 2.00
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

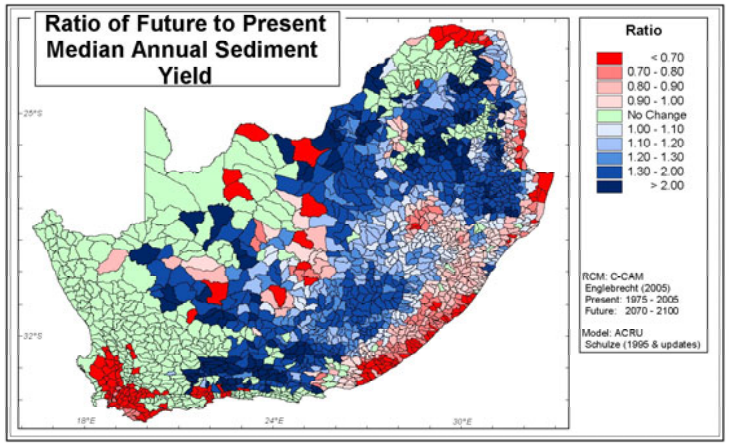

Inter-Annual CV of Net Irrigation Requirements
%
< 2
2 - 5
5 - 10
10 - 15
15 - 20
20 - 25
> 25
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

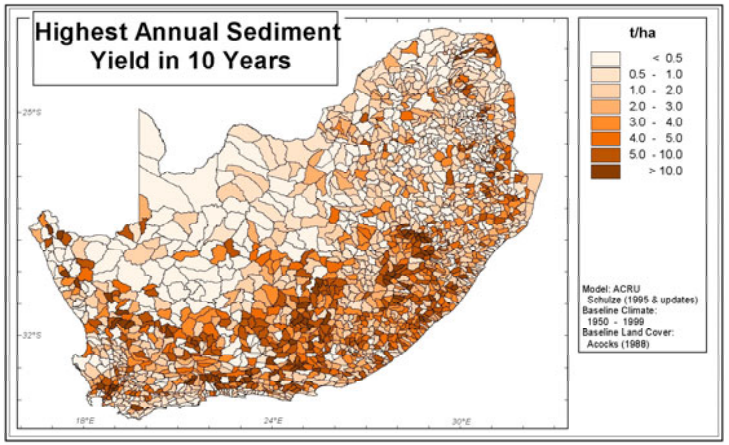

Ratio of Future to Present Inter-Annual CV of Net Irrigation Requirements
Ratio
< 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
No Change
1.00 - 1.25
1.25 - 1.50
1.50 - 2.00
2.00 - 4.00
> 4.00
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

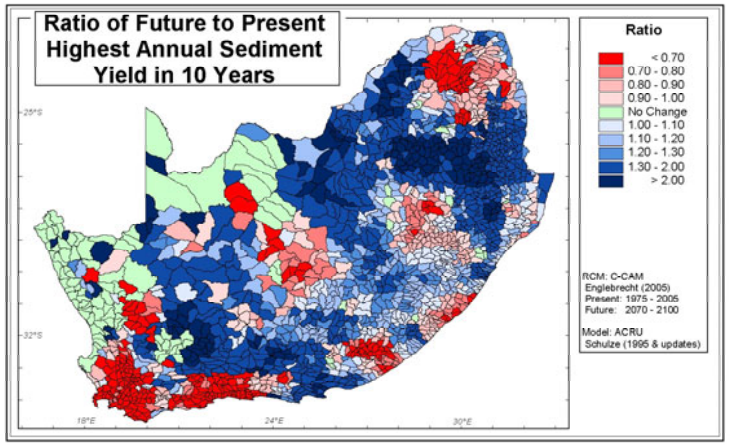

Lowest Annual Sediment Yield in 10 Years
t/ha
< 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 10.0
> 10.0
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

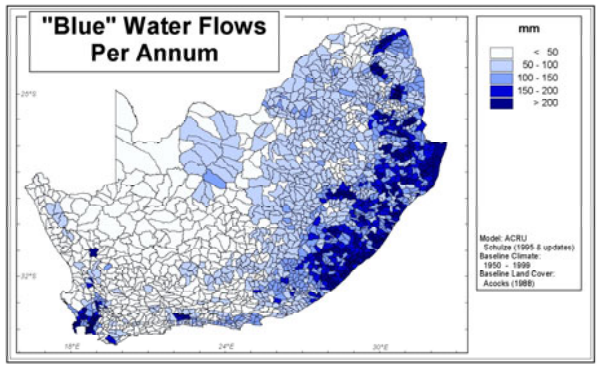

Ratio of Future to Present Lowest Annual Sediment Yield in 10 Years
Ratio
< 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
1.30 - 2.00
> 2.00
RCM: C-CAM
Engelbrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

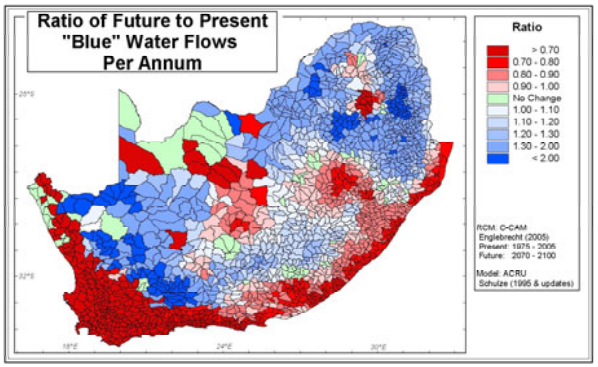

Median Annual Sediment Yield
t/ha
< 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 10.0
> 10.0
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

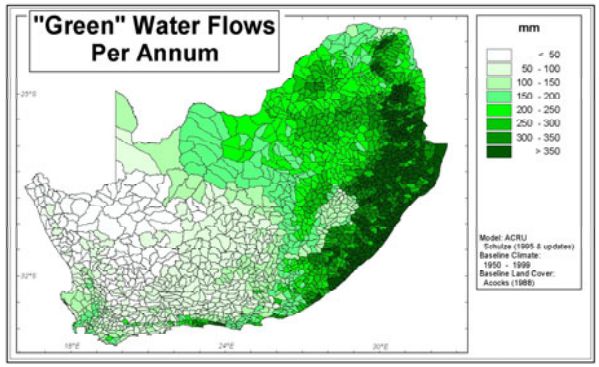

Ratio of Future to Present Median Annual Sediment Yield
Ratio
< 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
1.30 - 2.00
> 2.00
RCM: C-CAM
Engelbrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

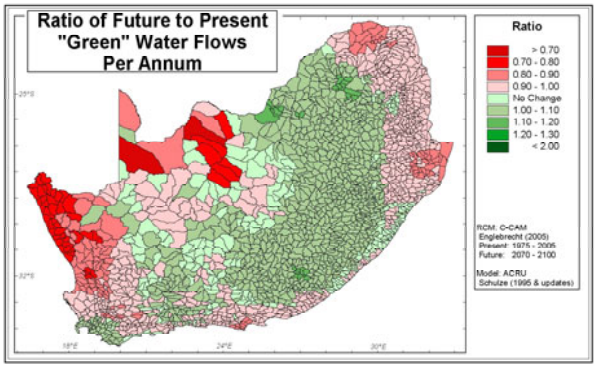

Highest Annual Sediment Yield in 10 Years
t/ha
< 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 - 10.0
> 10.0
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)
25°S
32°S
18°E
24°E
30°E

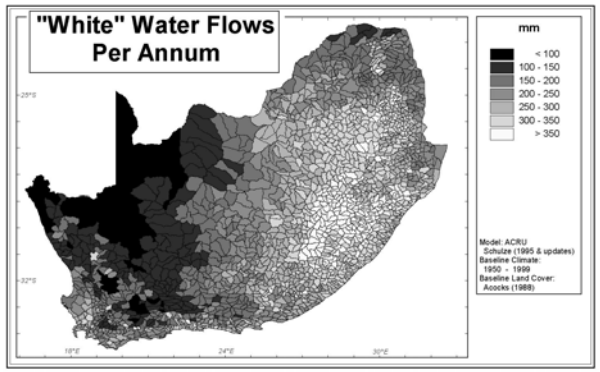

Ratio of Future to Present Highest Annual Sediment Yield in 10 Years
Ratio
< 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
1.30 - 2.00
> 2.00
RCM: C-CAM
Engelbrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)
25°S
32°S
18°E
24°E
30°E

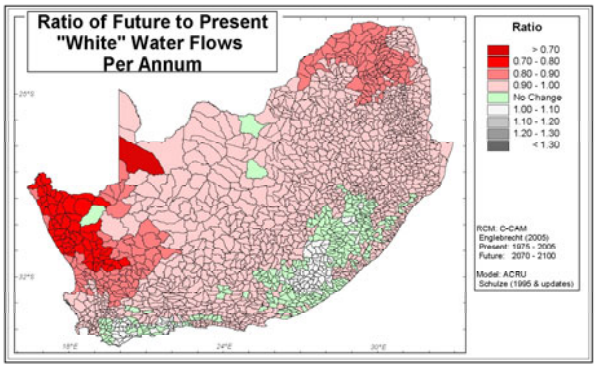

"Blue" Water Flows
Per Annum
mm
< 50
50 - 100
100 - 150
150 - 200
> 200
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)


Ratio of Future to Present
"Blue" Water Flows
Per Annum
Ratio
> 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
1.30 - 2.00
< 2.00
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)


"Green" Water Flows
Per Annum
mm
< 50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
300 - 350
> 350
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)

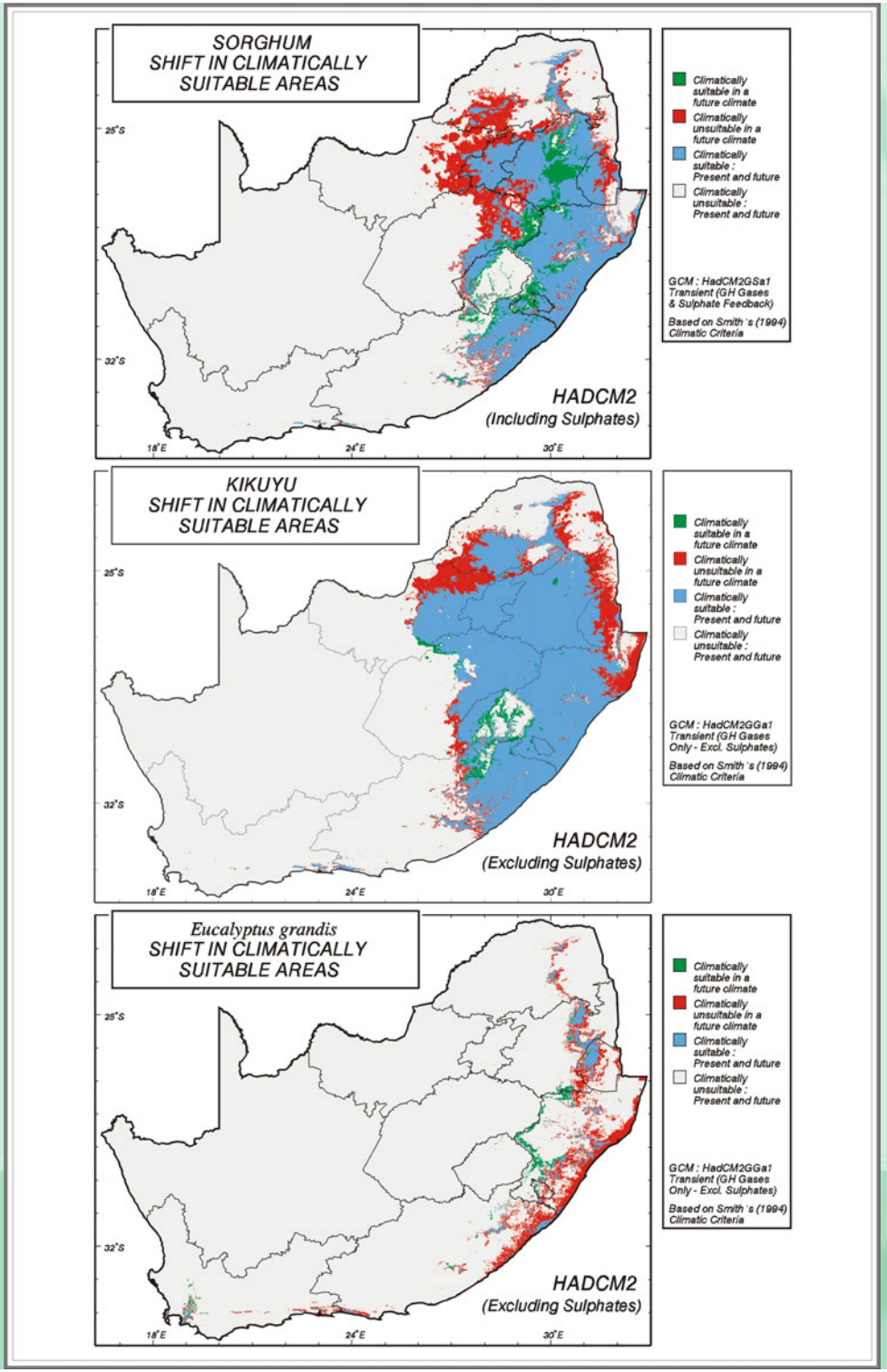

Ratio of Future to Present
"Green" Water Flows
Per Annum
Ratio
> 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
< 2.00
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)


"White" Water Flows
Per Annum
mm
< 100
100 - 150
150 - 200
200 - 250
250 - 300
300 - 350
> 350
Model: ACRU
Schulze (1995 & updates)
Baseline Climate:
1950 - 1999
Baseline Land Cover:
Acocks (1988)


Ratio of Future to Present
"White" Water Flows
Per Annum
Ratio
> 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
No Change
1.00 - 1.10
1.10 - 1.20
1.20 - 1.30
< 1.30
RCM: C-CAM
Englebrecht (2005)
Present: 1975 - 2005
Future: 2070 - 2100
Model: ACRU
Schulze (1995 & updates)

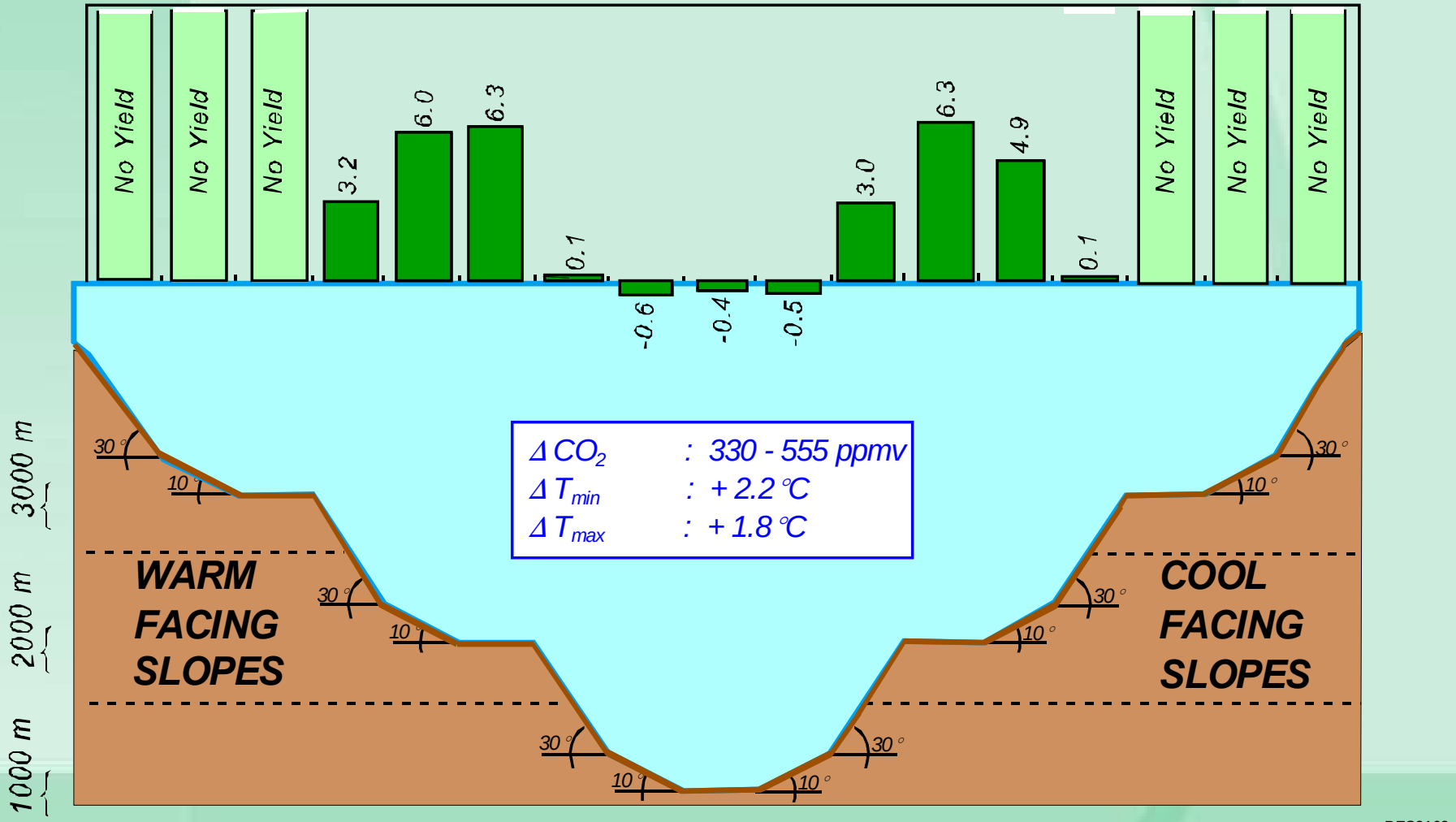
ADDITIONAL DIMENSIONS WHICH WATER RESOURCES MANAGERS HAVE TO CONSIDER WITH CLIMATE CHANGE

1. ***WATER RESOURCES PLANNERS CANNOT VIEW CLIMATE CHANGE IMPACTS ON HYDROLOGY IN ISOLATION, WITHOUT CONSIDERING ADDITIONAL IMPACTS IT MAY HAVE ON SHIFTS IN LAND USE***


SORGHUM
SHIFT IN CLIMATICALLY
SUITABLE AREAS
25°S
32°S
18°E
24°E
30°E
HADCM2
(Including Sulphates)
Climatically suitable in a future climate
Climatically unsuitable in a future climate
Climatically suitable : Present and future
Climatically unsuitable : Present and future
GCM : HadCM2GSa1 Transient (GH Gases & Sulphate Feedback)
Based on Smith 's (1994) Climatic Criteria
KIKUYU
SHIFT IN CLIMATICALLY
SUITABLE AREAS
25°S
32°S
18°E
24°E
30°E
HADCM2
(Excluding Sulphates)
Climatically suitable in a future climate
Climatically unsuitable in a future climate
Climatically suitable : Present and future
Climatically unsuitable : Present and future
GCM : HadCM2GGa1 Transient (GH Gases Only - Excl. Sulphates)
Based on Smith 's (1994) Climatic Criteria
Eucalyptus grandis
SHIFT IN CLIMATICALLY
SUITABLE AREAS
25°S
32°S
18°E
24°E
30°E
HADCM2
(Excluding Sulphates)
Climatically suitable in a future climate
Climatically unsuitable in a future climate
Climatically suitable : Present and future
Climatically unsuitable : Present and future
GCM : HadCM2GGa1 Transient (GH Gases Only - Excl. Sulphates)
Based on Smith 's (1994) Climatic Criteria

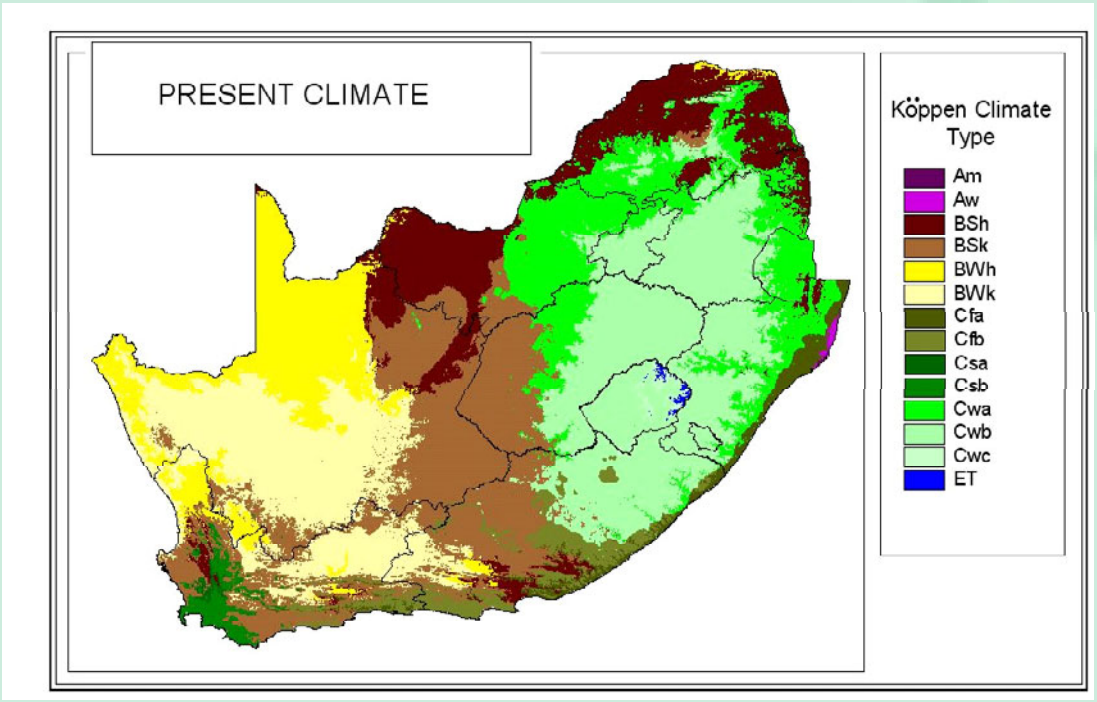
MAIZE : CHANGE IN YIELD (t/ha) - CERES 3.0 MODEL

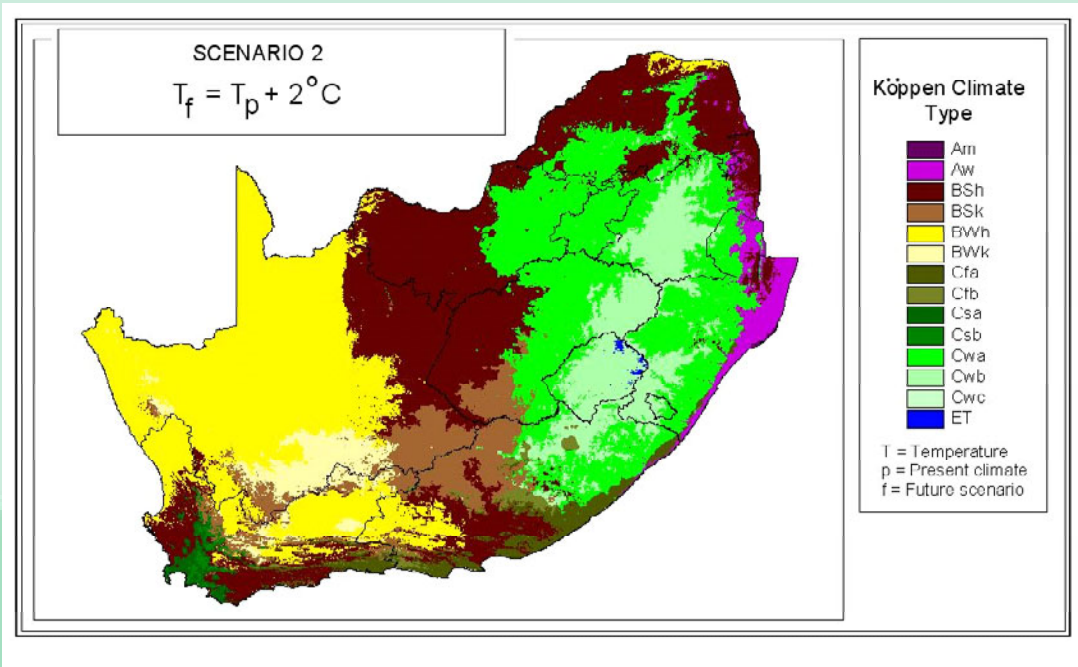
X2CO$_2$ SCENARIO minus PRESENT CLIMATE



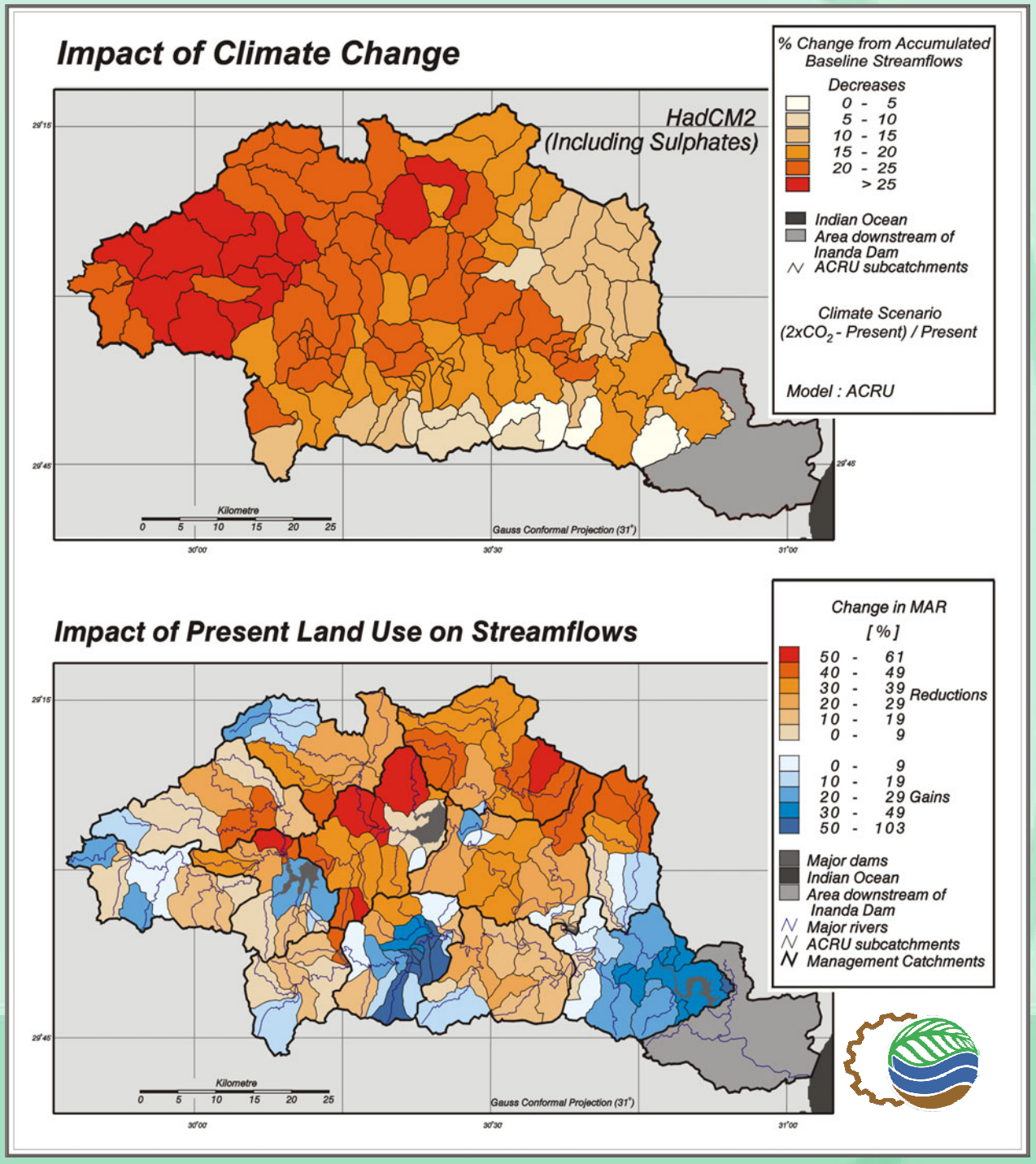
RES2162

2. HYDROLOGICAL BASELINES WILL SHIFT WITH CLIMATE CHANGE

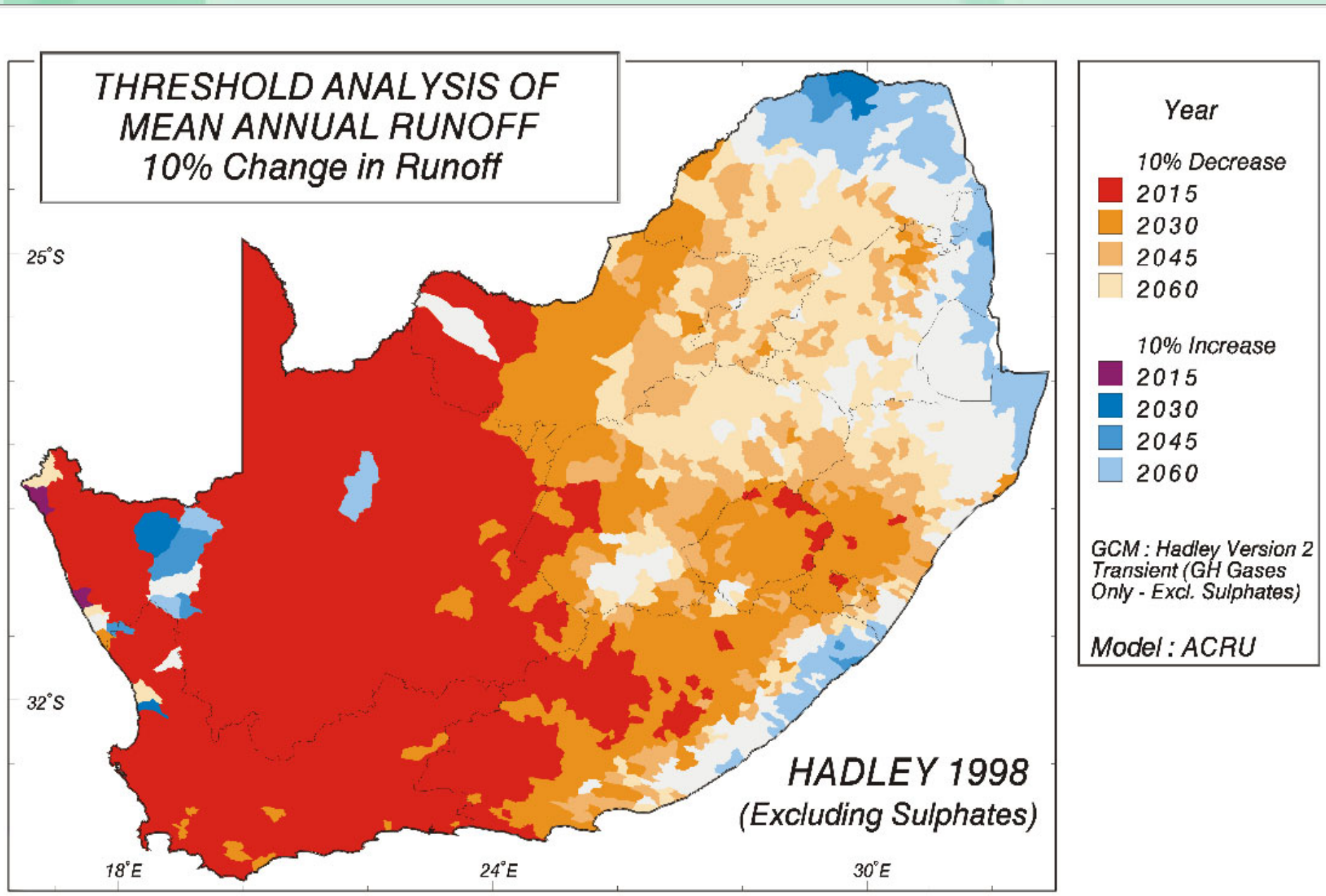

PRESENT CLIMATE
Köppen Climate Type
Am
Aw
BSh
BSk
BWh
BWk
Cfa
Cfb
Csa
Csb
Cwa
Cwb
Cwc
ET


SCENARIO 2
$T_f = T_p + 2^{\circ}C$
Köppen Climate Type
Am
Aw
BSh
BSk
BWh
BWk
Cfa
Cfb
Csa
Csb
Cwa
Cwb
Cwc
ET
T = Temperature
p = Present climate
f = Future scenario

3. CLIMATE CHANGE IMPACTS ARE LIKELY TO BE SUPERIMPOSED UNI-DIRECTIONALLY ON ALREADY EXISTING COMPLEX MULTI-DIRECTIONAL LAND USE IMPACTS


Impact of Climate Change
HadCM2
(Including Sulphates)
% Change from Accumulated Baseline Streamflows
Decreases
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
> 25
Indian Ocean
Area downstream of Inanda Dam
ACRU subcatchments
Climate Scenario
(2xCO2 - Present) / Present
Model : ACRU
29°15
29°45
30°00
30°30
31°00
Kilometre
0 5 10 15 20 25
Gauss Conformal Projection (31°)
Impact of Present Land Use on Streamflows
Change in MAR
[%]
50 - 61
40 - 49
30 - 39
20 - 29
10 - 19
0 - 9
Reductions
0 - 9
10 - 19
20 - 29
30 - 49
50 - 103
Gains
Major dams
Indian Ocean
Area downstream of Inanda Dam
Major rivers
ACRU subcatchments
Management Catchments

5. IMPACTS OF CLIMATE CHANGE MAY BE FELT SOONER THAN WE WOULD WISH, WITH REPERCUSSIONS NOT SPREAD EVENLY ACROSS THE COUNTRY


THRESHOLD ANALYSIS OF
MEAN ANNUAL RUNOFF
10% Change in Runoff
25°S
32°S
18°E
24°E
30°E
HADLEY 1998
(Excluding Sulphates)
Year
10% Decrease
2015
2030
2045
2060
10% Increase
2015
2030
2045
2060
GCM : Hadley Version 2
Transient (GH Gases
Only - Excl. Sulphates)
Model : ACRU

6. CLIMATE, WATER AND ECOSYSTEMS

- *Freshwater is an essential driver of terrestrial and aquatic ecosystems*
- *The environment is a legitimate water user*
- *Water for the environment is NOT a competing resource*
- *Providing water for the environment = providing water for people (directly and indirectly)*

CONNECTIVITY & VARIABILITY: DRIVING THE VITALITY OF AQUATIC ECOSYSTEMS

Naiman et al. 1992

7. WATER AND HEALTH

Water is Involved in Transmission of Diseases

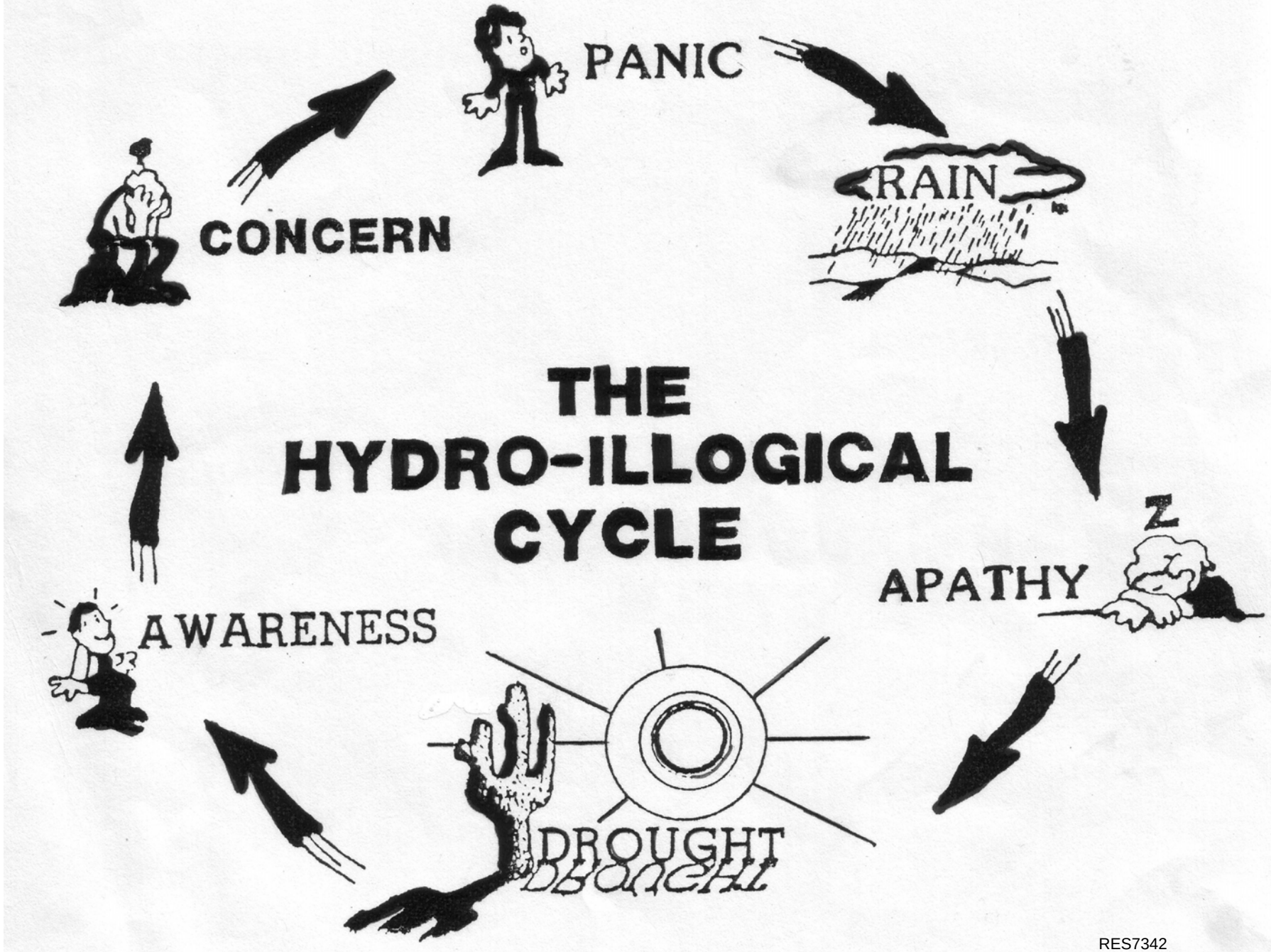
- ***Water-borne diseases***
  - contamination by faeces, infected urine, bacteria
  - direct transmission through drinking
- ***Water-washed diseases***
  - from inadequate personal hygiene, often because of water scarcity
- ***Water-based diseases***
  - parasites whose hosts live in/near water
- ***Water-related diseases***
  - borne by insect vectors, habitats in/near water (e.g. malaria)
- ***Water-dispersed diseases***
  - infections whose agents proliferate in fresh water

NB: Variability of water availability/flows is often a major trigger to disease!

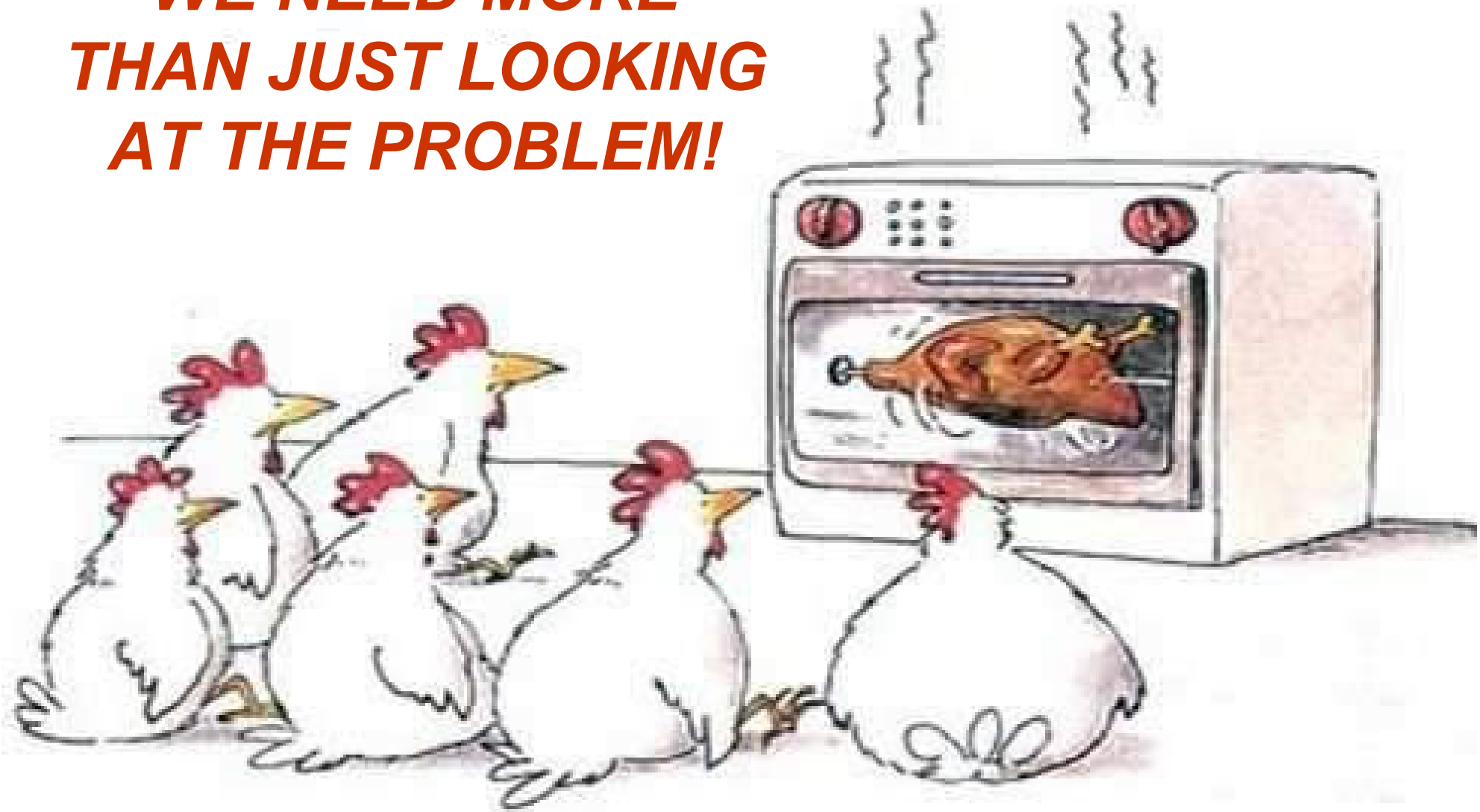
Climate change could exacerbate outbreaks!

WHERE TO NOW ?

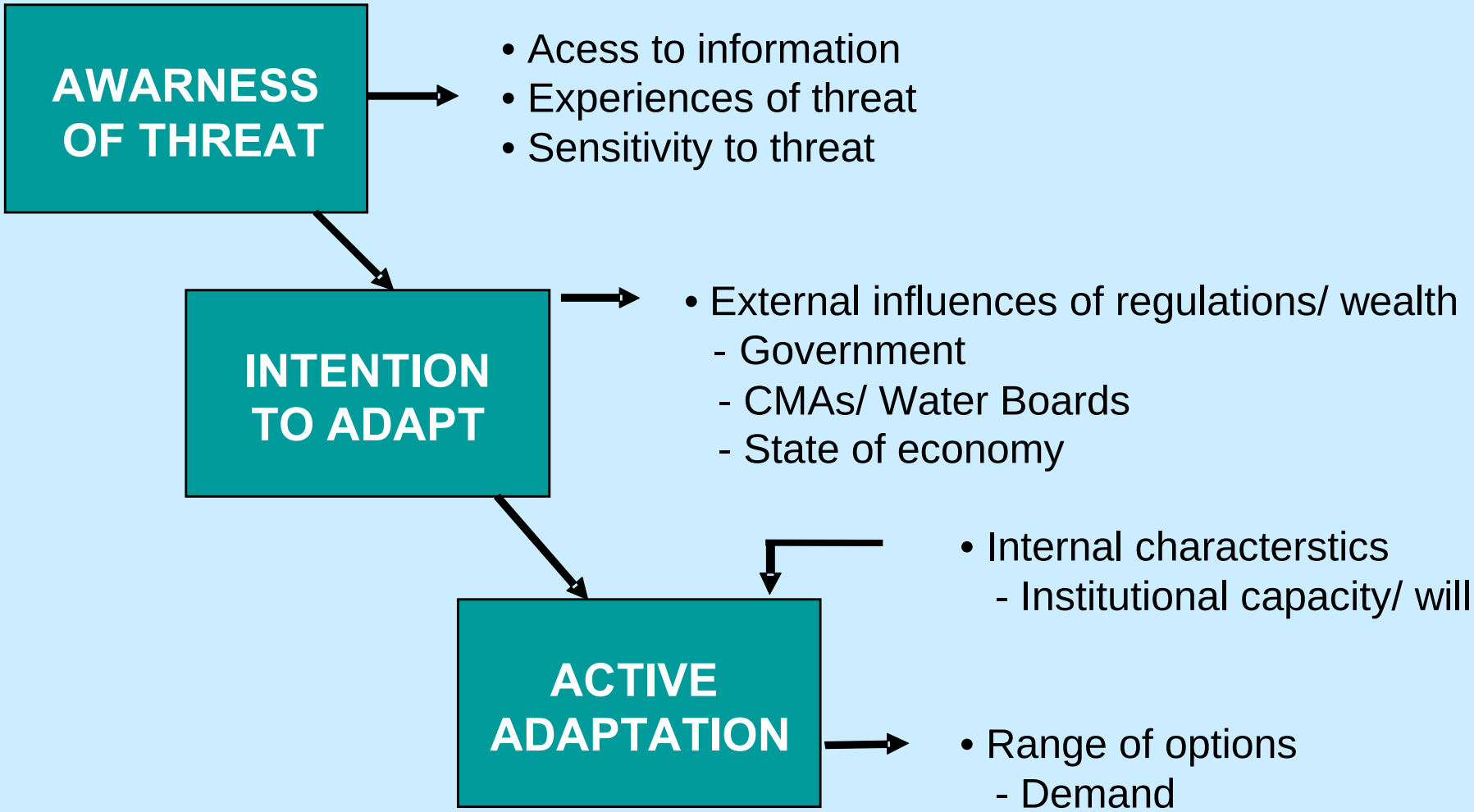
COPING WITH, AND ADAPTING TO, CLIMATE CHANGE


PANIC
RAIN
Z
APATHY
AWARENESS
CONCERN
THE
HYDRO-ILLOGICAL
CYCLE
DROUGHT
RES7342

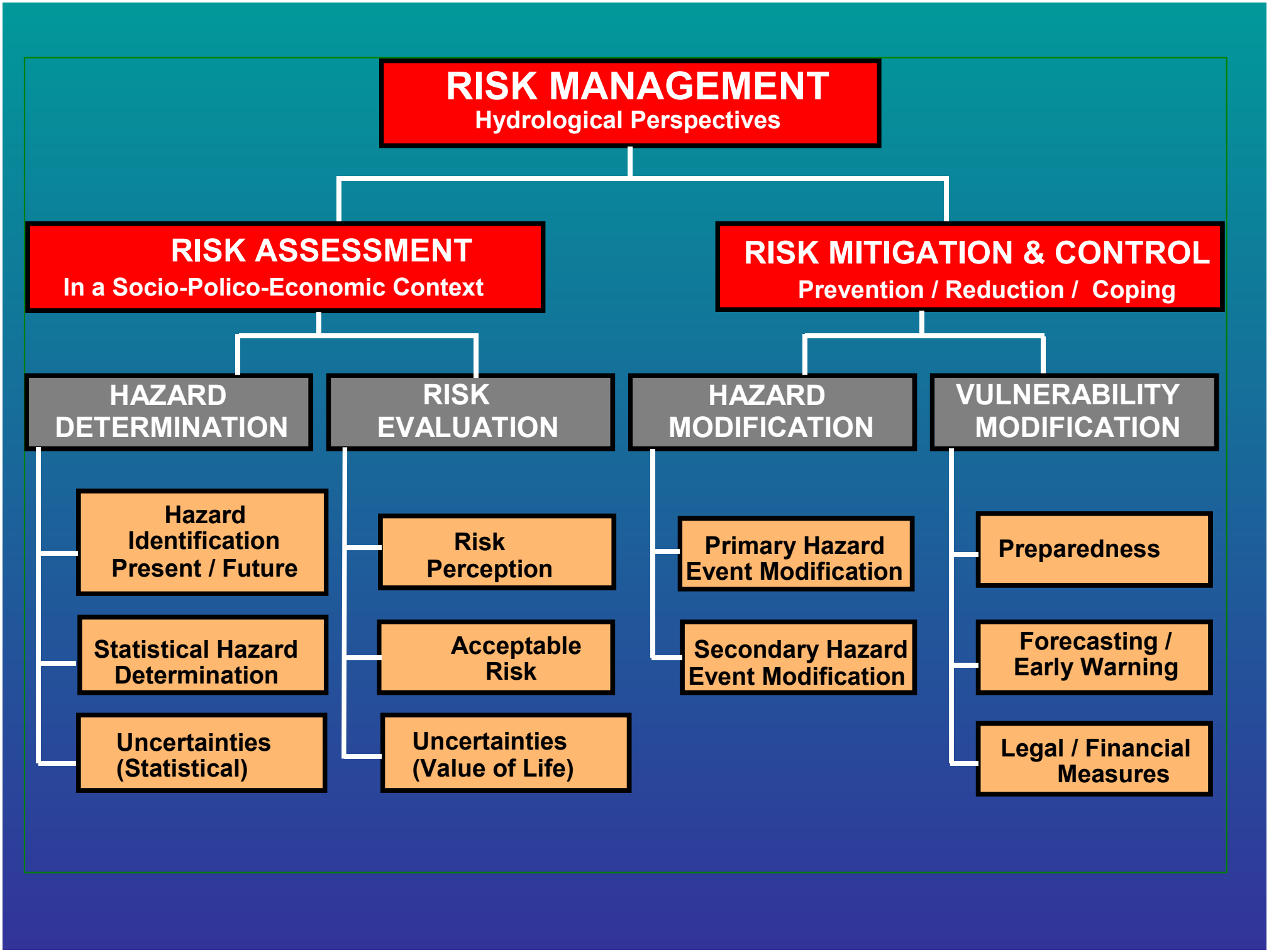
WE NEED MORE THAN JUST LOOKING AT THE PROBLEM!



THE ADAPTATION PROCESS



After Arnell (2005)


RISK MANAGEMENT
Hydrological Perspectives
RISK ASSESSMENT
In a Socio-Polico-Economic Context
RISK MITIGATION & CONTROL
Prevention / Reduction / Coping
HAZARD DETERMINATION
RISK EVALUATION
HAZARD MODIFICATION
VULNERABILITY MODIFICATION
Hazard Identification Present / Future
Statistical Hazard Determination
Uncertainties (Statistical)
Risk Perception
Acceptable Risk
Uncertainties (Value of Life)
Primary Hazard Event Modification
Secondary Hazard Event Modification
Preparedness
Forecasting / Early Warning
Legal / Financial Measures

DECISION FRAMEWORK ON CLIMATE VARIABILITY AND CLIMATE CHANGE

TYPE OF DECISION	CLIMATE		WEATHER
	Long Term (10-50yrs)	Medium Term (6-9mths)	Short term (0-7days)
	Decadal Changes	Seasonal Forecasts	Real Time → Week
Strategic			
Tactical			
Operational			

- Supply demand
- Reservoir safety
- Reservoir sizing
- Land management
- Operating rules
- Water orders
- Water allocation
- Demand management
- Irrigation scheduling
- Flood warning
- Field operations

S.A. ADAPTATION FRAMEWORK: CLIMATE CHANGE IMPACTS ON THE WATER SECTOR

TIME FRAME	LEGAL AND POLICY	INSTITUTIONAL AND MANAGEMENT	MONITORING, RESEARCH AND INFORMATION
LONG TERM Years to Decades (e.g. climate change)	*International* *National Water Resource Strategy* *National Climate Change Response Strategy* *More Specific Policy Requests* *Enforcing/Policing Policy*	*Catchment Management Agencies* *Risk Management Governance* *Infrastructure* *Water Licencing* *Enforcement and Compliance*	*MONITORING* *Networks and General Data* *RESEARCH* *General Capacity Building* *Climate Models* *Hydrological Modelling* *Specific Research Requirements* *INFORMATION* *Education/Training* *Communication*

BUT… THE DEVIL LIES IN THE DETAIL!

LEGAL AND POLICY

International
•Mobilise the implementation of the Kyoto Protocol in southern Africa
•Re-negotiate international water agreements with neighbouring states in light of Climate Change (CC)

National Water Resource Strategy
•NWRS must recognise the importance of CC and cater for it more explicitly
•NWRS needs to be updated routinely to address new finding on CC impacts
•NWRS needs to be provided with more "teeth" re. CC
•More co-participation required in the NWRS with political, social and economic sectors
•NWRS needs to define clearly the boundaries of accountability and responsibility between
-national
-CMA/WMA
-District Municipality and
-city specific
issues

National Climate Change Response Strategy (NCCRS)
•Department of Environmental Affairs and Tourism (DEAT) needs
-a more strategic approach to CC
-greater commitment to apply the NCCRS
-to develop more specific legislation re. CC

More Specific Policy Requests/Requirements
•Re. Risk Management
-review existing national disaster management legislation w.r.t. CC, e.g. fires, floods, droughts
-floodplain zoning and management; spatial considerations; urban areas
-dam safety and spillway standards
-property risk policies w.r.t predicted . . . .

INSTITUTIONAL & MANAGEMENT

Catchment Management Agencies (CMAs)
•Establish CMAs which will operate effectively re. Integrated Water Resources Management (IWRM) and including CC
•Improve co-ordination within and between CMAs re. activities, methodologies
•Ensure wider stakeholder participation

Risk Management
•Revise/improve risk management (RM) plans re. floods, droughts
•Set up an advisory to advise land owners in flood prone areas re. risks, flood probabilities
•Implement a State insurance scheme for disasters
•Develop policy on water restrictions

Governance
•Establish incentive schemes for initiatives in co-operative governance
•Ensure that institutions adapt to CC findings at all levels of government and the private sector

Infrastructure
•Need improved strategic plan for new infrastructure re. WRM
•Construct more dams in relevant areas to make provision for additional water needs with CC
•Review systems operations re. assurance of supply

Water Licensing
•Exercise more care in evaluating/awarding of licences to water users in light of CC
•Raise tariffs to fund effective IWRM

Enforcement/Compliance
•Enforce compliance with regulations/laws
•Increase enforcement re. controlling groundwater abstractions . . . .

MONITORING, RESEARCH & INFORMATION

Monitoring

1. Networks & General
•Revise the entire network of rainfall and streamflow gauges w.r.t. detection of CC, and adapt, if necessary
•Identify and maintain high quality flow gauges
-with long records
-on unaltered catchments
•Measure streamflow at all strategic points
•Improve monitoring of land use change
•Improve and regularly update WARMS database for better application in granting water use licences
•Create an independent Earth Systems monitoring agency for SA

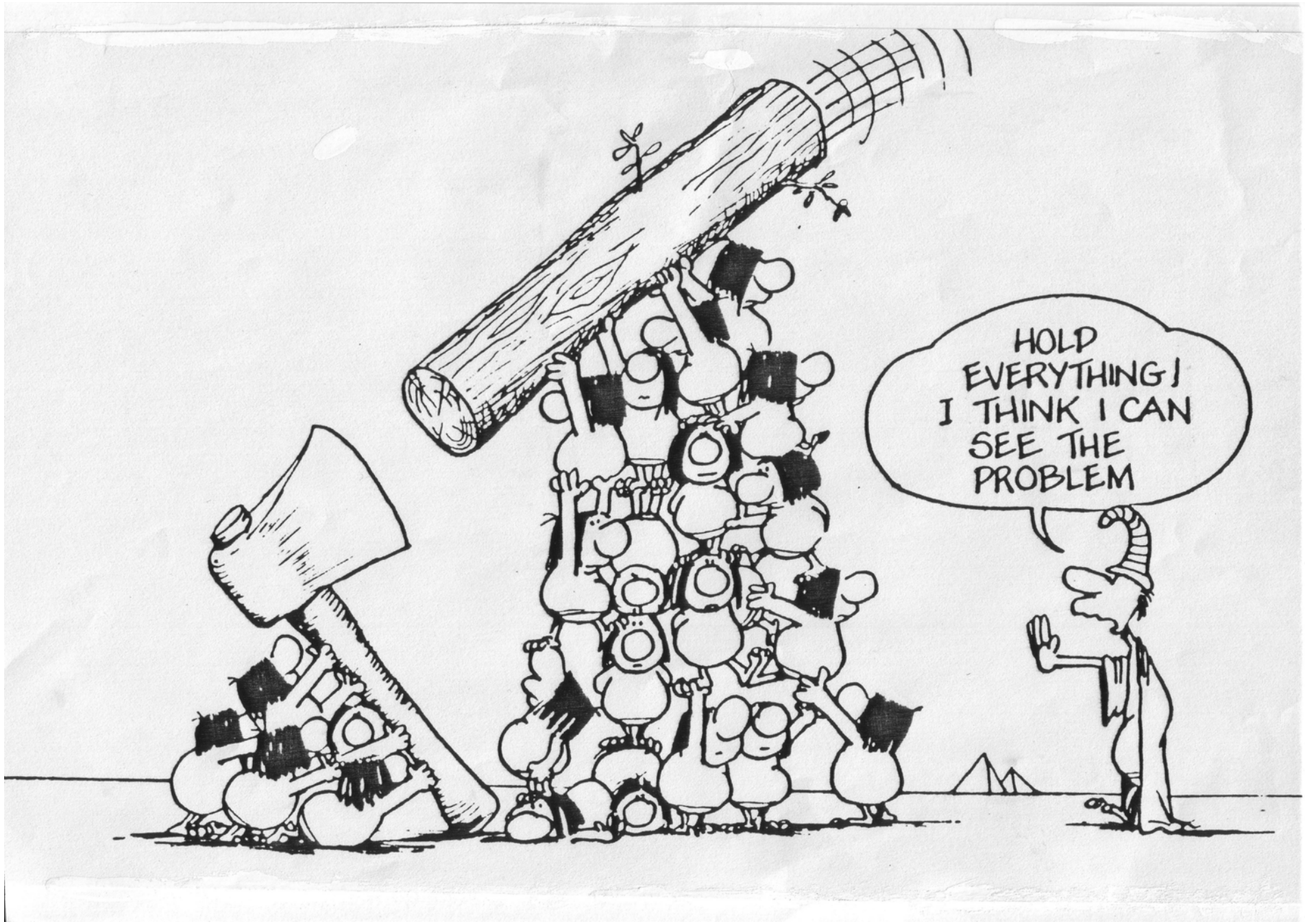
2. Data
•Ensure integrity of streamflow data
•Achieve greater integration of hydroclimatic and related databases
•Make data more readily available
•Ensure transparency in sharing data

Research

1. General Capacity Building
•Build more capacity re. CC research
•Create incentives for new techniques in CC related water research

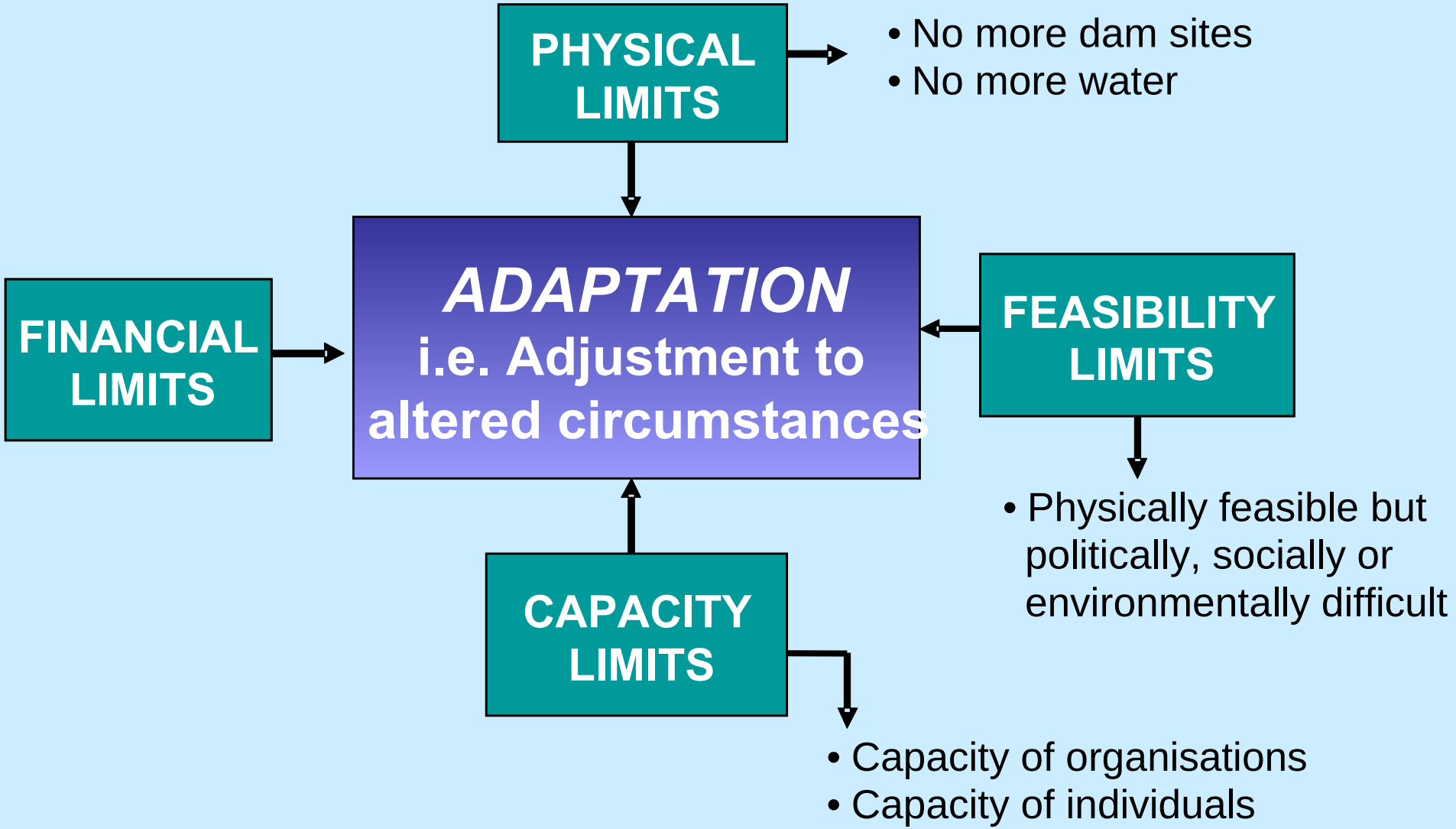
2. Climate Models
•Improve CC projections for SA, to increase confidence levels in their application to WR
•Improve downscaling techniques for application in SA

3. Hydrological Modelling
•Improve process representations in hydrological models for application in a range of hydroclimatic regimes (e.g. semi-arid zone)



RES7350

LIMITS TO ADAPTATION



After Arnell (2005)

PROCESS OF ADAPTATION: METHODS

- *INTEGRATED IMPACT ASSESSMENT* -

Vertically integrated

Global

↓

Regional

↓

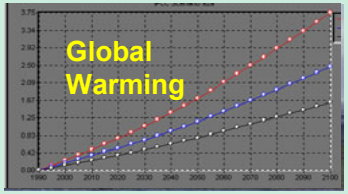
Local

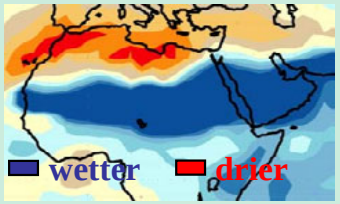
↓

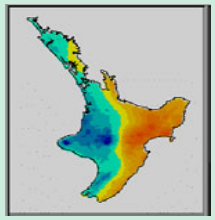
Sectoral

↓

Water



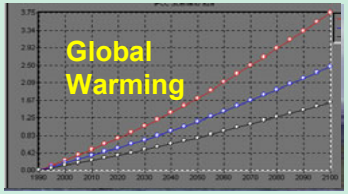




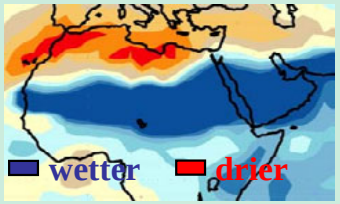
- *INTEGRATED IMPACT ASSESSMENT* -

Vertically integrated

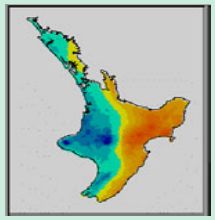
Global



Regional



Local



Sectoral

Water

- *INTEGRATED IMPACT ASSESSMENT* -

Horizontally integrated

Global

↓

Regional

↓

Local

|

Sectoral

[redacted]

[redacted]

[redacted]

coastal | **water** | **agriculture** | **health**

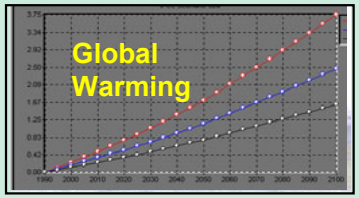
Coastal Risk

Flood Risk

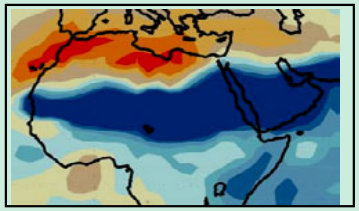
Drought Risk

Epidemic Risk

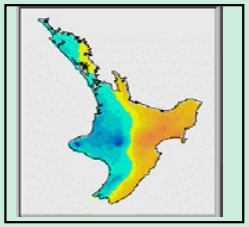
- *INTEGRATED IMPACT ASSESSMENT* -



Global



Regional



Local

I

Sectoral

coastal | **water** | **agriculture** | **health**

Coastal Risk

Flood Risk

Drought Risk

Epidemic Risk

RESEARCH IN CLIMATE CHANGE: WHERE TO IN FUTURE?

HOWEVER, IN OUR ADAPTATION STRATEGIES, WE NEED TO PLACE MORE EMPHASIS ON SECONDARY HYDROLOGICAL EFFECTS, e.g.

- ***Δ Magnitude/frequency of extreme events***
- ***Δ Seasonality of streamflows, re.***
  - **demand vs supply**
  - **effect on water pricing**
  - **effect on water resources infrastructure (construction? maintenance?)**
- ***Δ Inter-annual variability***
  - **vegetation dynamics → consequent hydrological responses**
- ***Δ Groundwater recharge***
- ***Effects of Δ land use ON water availability***
- ***Effects of Δ water availability ON land use***

EQUALLY, IN OUR ADAPTATION STRATEGIES, WE ALSO NEED TO PLACE MORE EMPHASIS ON TERTIARY (HIGHER ORDER) HYDROLOGICAL EFFECTS, e.g.

- ***Δ Water quality and consequences on***
  - purification costs - human health re. water-borne diseases
  - effect on water resources infrastructure (construction, maintenance)
- ***Δ Aquatic ecosystems***
  - environmental integrity - environmental goods & services
  - do we allow habitats to adapt, or do we become "protective"?
- ***Δ Potential for conflict over shared rivers***
  - rivers as international boundaries
  - rivers discharging to downstream countries
- ***The poor often living . . .***
  - on the floodplain, where vulnerability to flooding is high
  - on the watershed, where streams are more ephemeral

RES7340