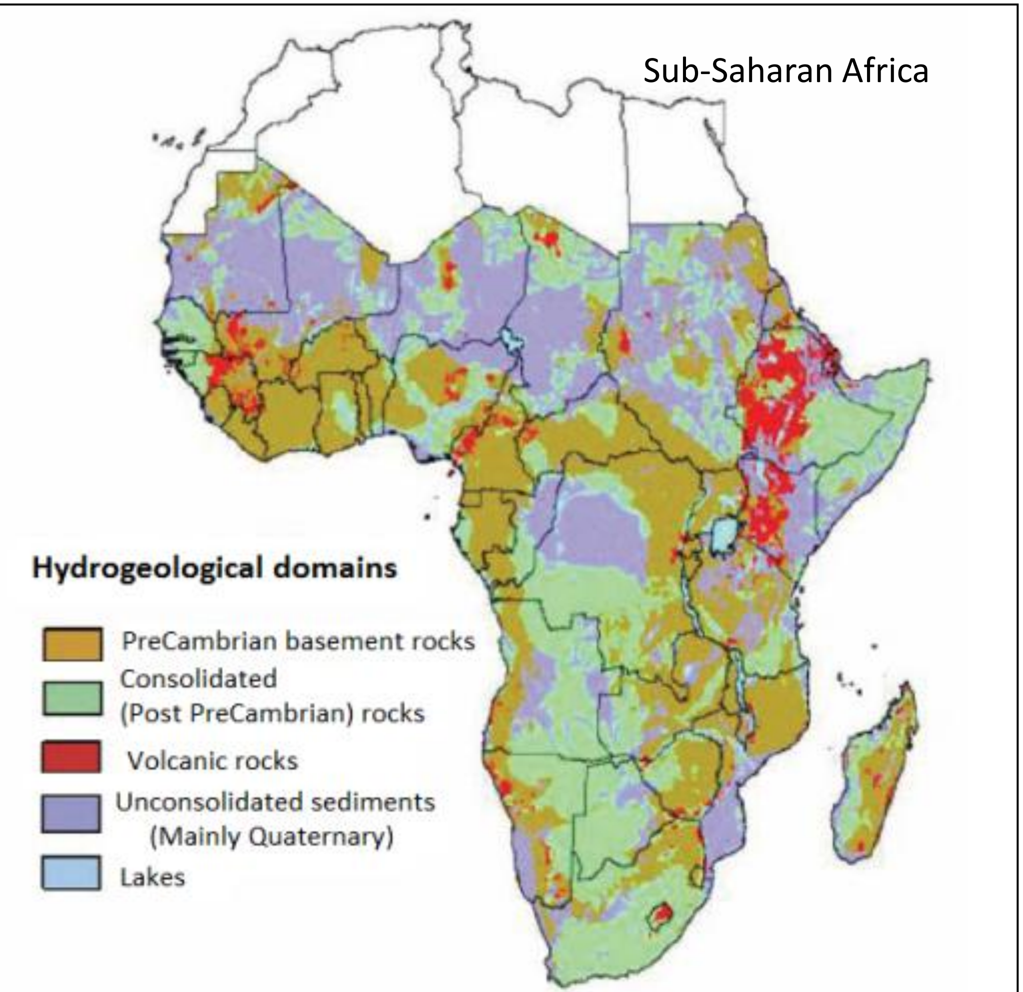
NERC/ESRC/DfID Unlocking the Potential for Groundwater for the Poor (UPGro)

Resource limitations to sustainability of groundwater well-points in basement complex regions of sub-Saharan Africa

GROUNDWATER IN BEDROCK/REGOLITH REGIONS OF RURAL MALAWI AND ZIMBABWE – CAN RESOURCES SATISFY DEMAND?

D. MUDIMBU [1], M. LEWIS [2], G. CHAVULA [3], S. SUNGURO [4], R. OWEN [5], J. DAVIES [2], N.S. ROBINS [2] and W.G. BURGESS [6]

Southern Africa Basement Complex Aquifer Resources



Hydrogeological provinces of Southern Africa and Sub-Saharan Africa. Source (BGS, 2000)

- Basement complex aquifers often the only means of supplying water to a large number of rural communities and local authorities.
- Estimated more than 60% rural communities in Southern Africa rely on groundwater from Basement Aquifers (Nicol, 2002).
- In southern Africa, basement aquifers constitute approximately 55% of the land area (UNEP and WRC, 2009).

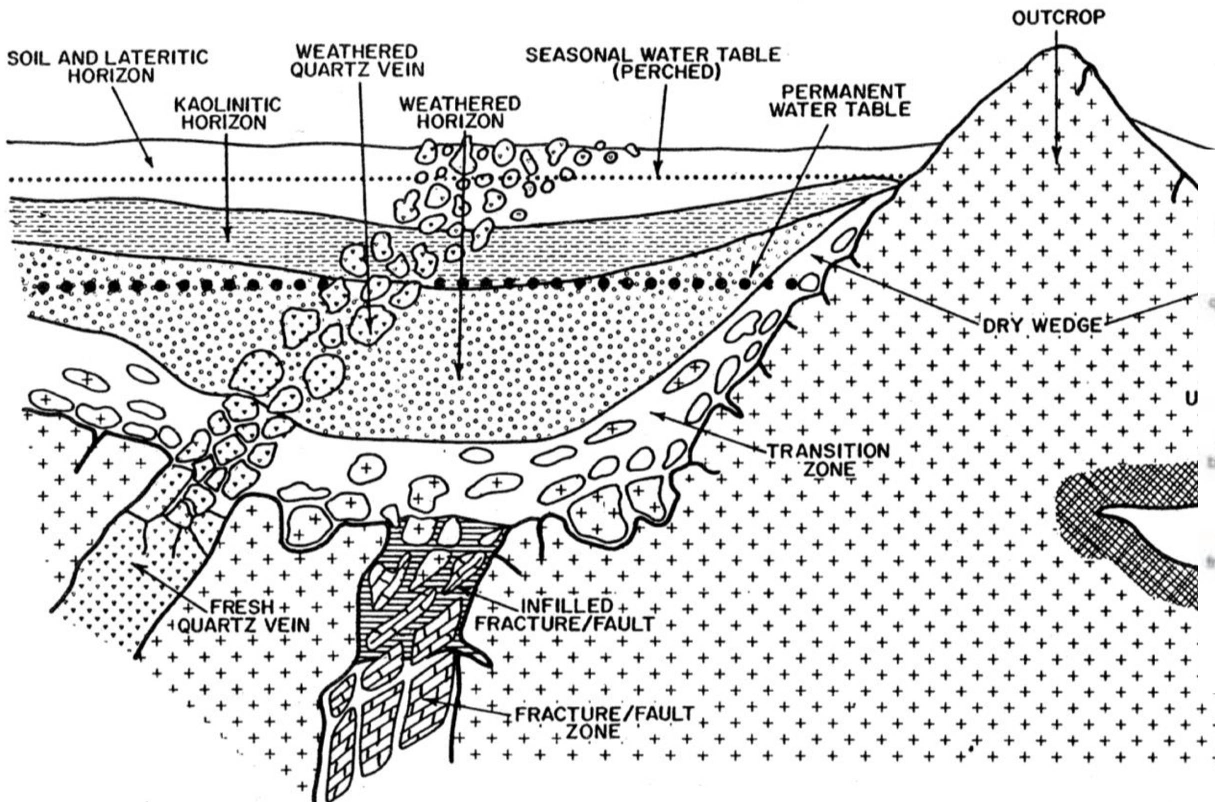
Outcrop area (km^2) in SADC countries for major basement types and total coverage of basement (% area)

	Area of basement outcrop (km^2)	% cover in country
Angola	287 792	27
Botswana	60 239	12
D R Congo	739 030	28
Madagascar	282 025	56
Malawi	**60 592**	**74**
Mozambique	366 502	54
Namibia	294 405	41
South Africa	369 722	33
Swaziland	12 252	82
Tanzania	455 902	61
Zambia	363 904	57
Zimbabwe	**221 368**	**66**

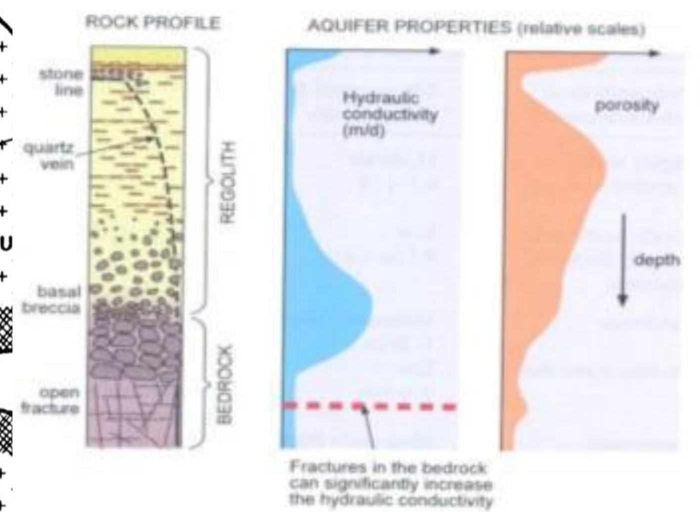
Southern Africa Basement Complex Aquifer

- Hydrogeological characteristics – poor storage, low yields, low primary porosity and permeability
- Developed within the weathered overburden and fractured bedrock of crystalline rocks
- Regional occurrence
- Fractured zones occurring along lineaments important drilling targets
- Variable groundwater quality – Fluoride and high salinity are common problems

Schematic Presentation of Water Bearing Structures in Granite/Gneiss rocks



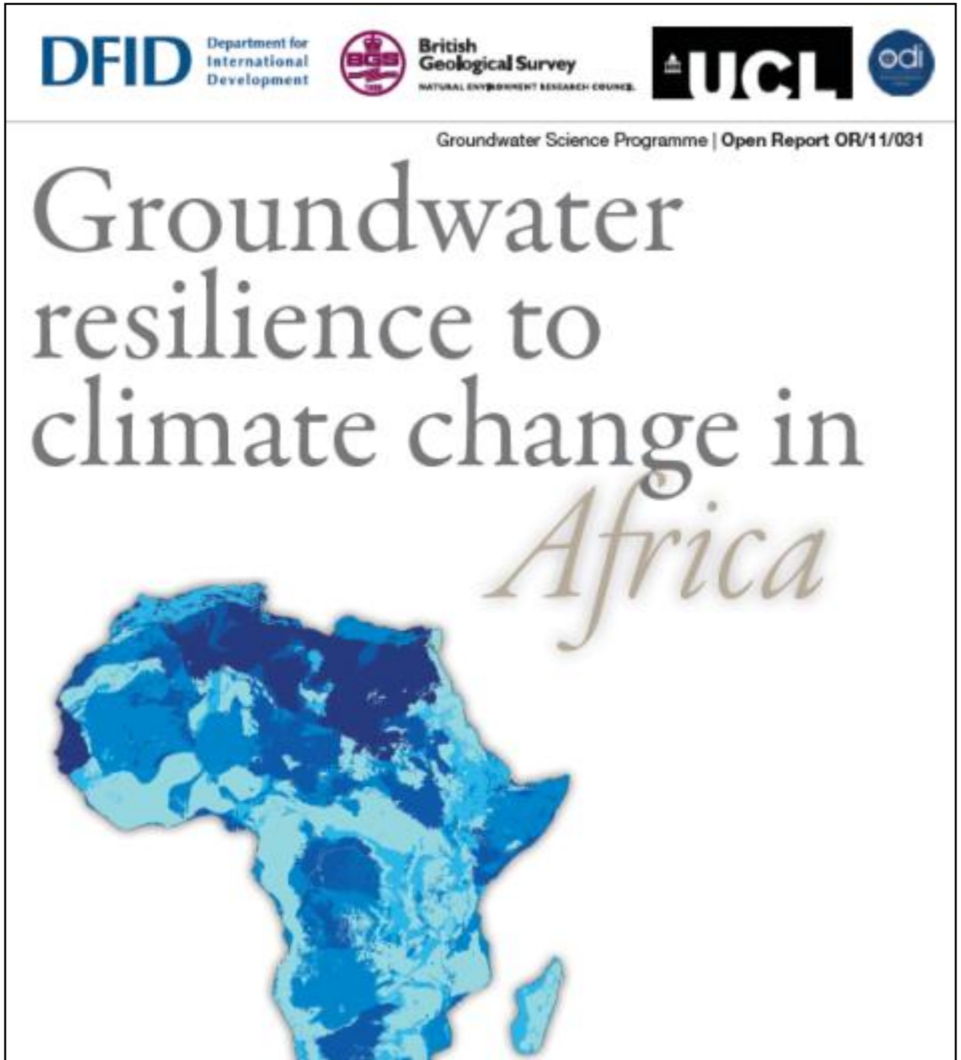
Source: Hydrogeology National Water Master Plan, Government of Zimbabwe 1985



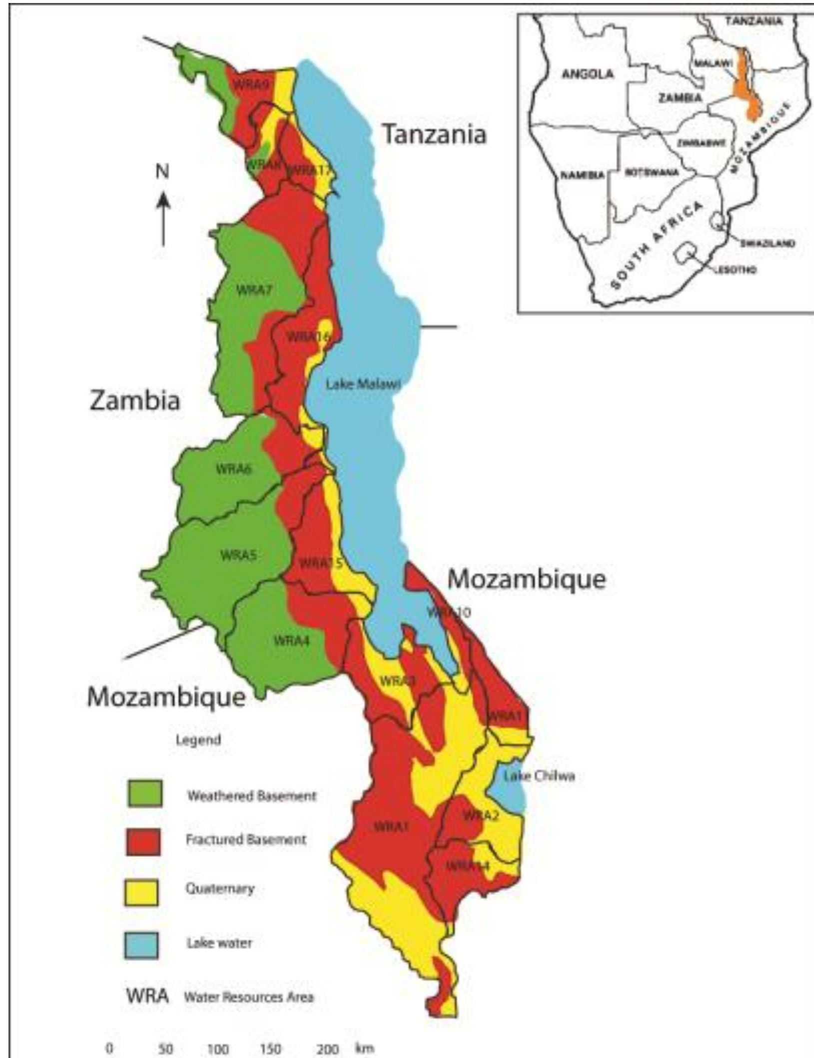
Profile of Precambrian Basement Complex Aquifer (Chilton and Foster, 1995)

Resource limitations to sustainability of groundwater well-points in basement complex regions of sub-Saharan Africa

Perception of water surfeit *v* **concern of limited resource ?**



MacDonald et al 2011



Robins, Davies & Farr HJ 2013

The Malawi Story

Hypothesis: That the groundwater resource is not matching demand in some higher demand areas of rural Malawi

Robins, N., Davies, J., & Farr, J., 2013, Hydrogeology Journal

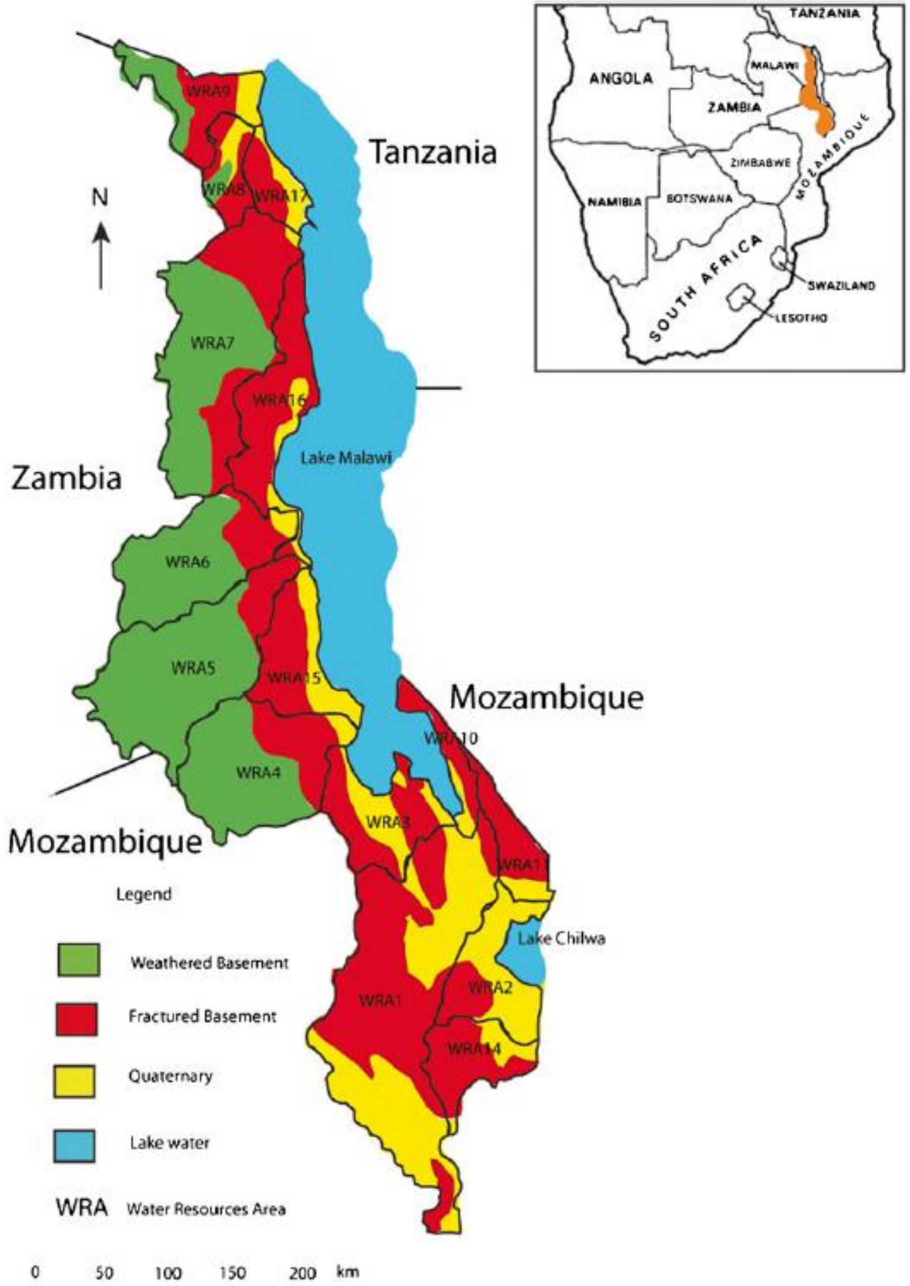


Fig. 1 Water resource areas (WRAs) in Malawi and outline geology

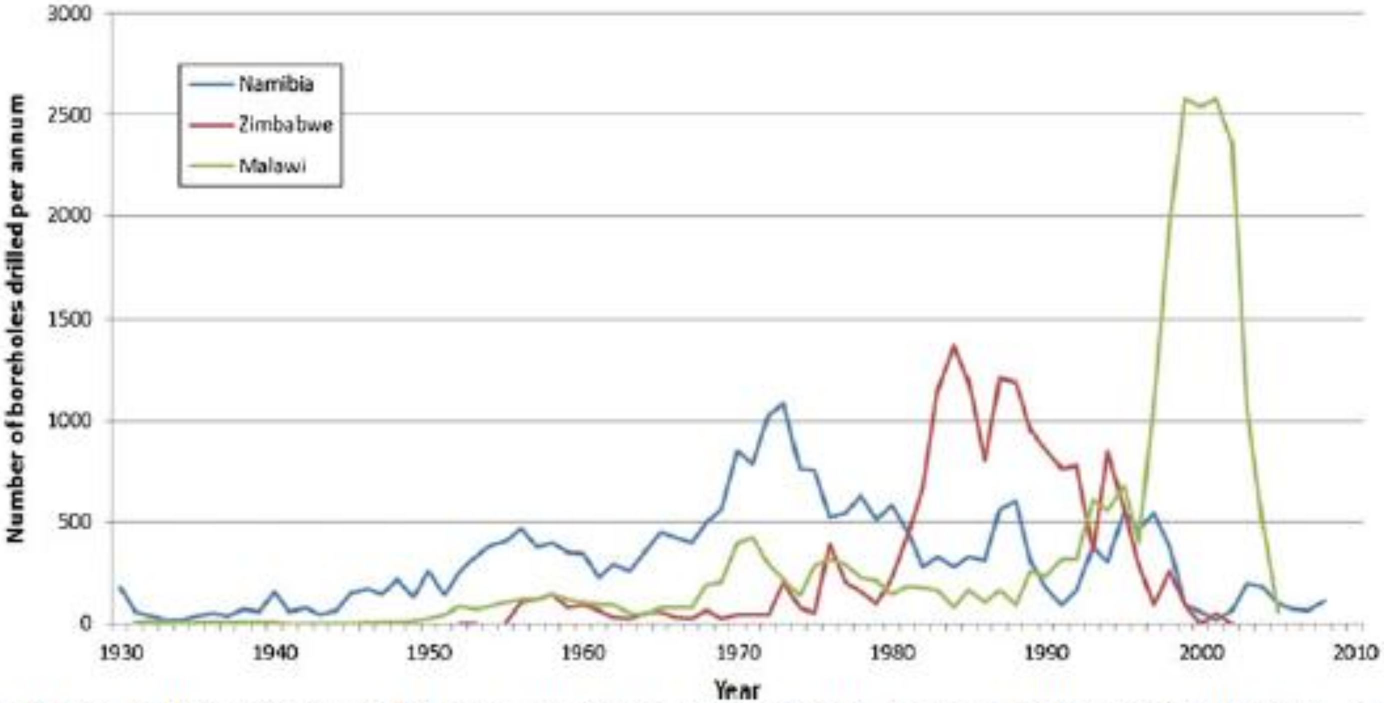


Fig. 3 Annual borehole drilling returns in Malawi, Zimbabwe and Namibia between 1930 and 2010 based on data returned to Government

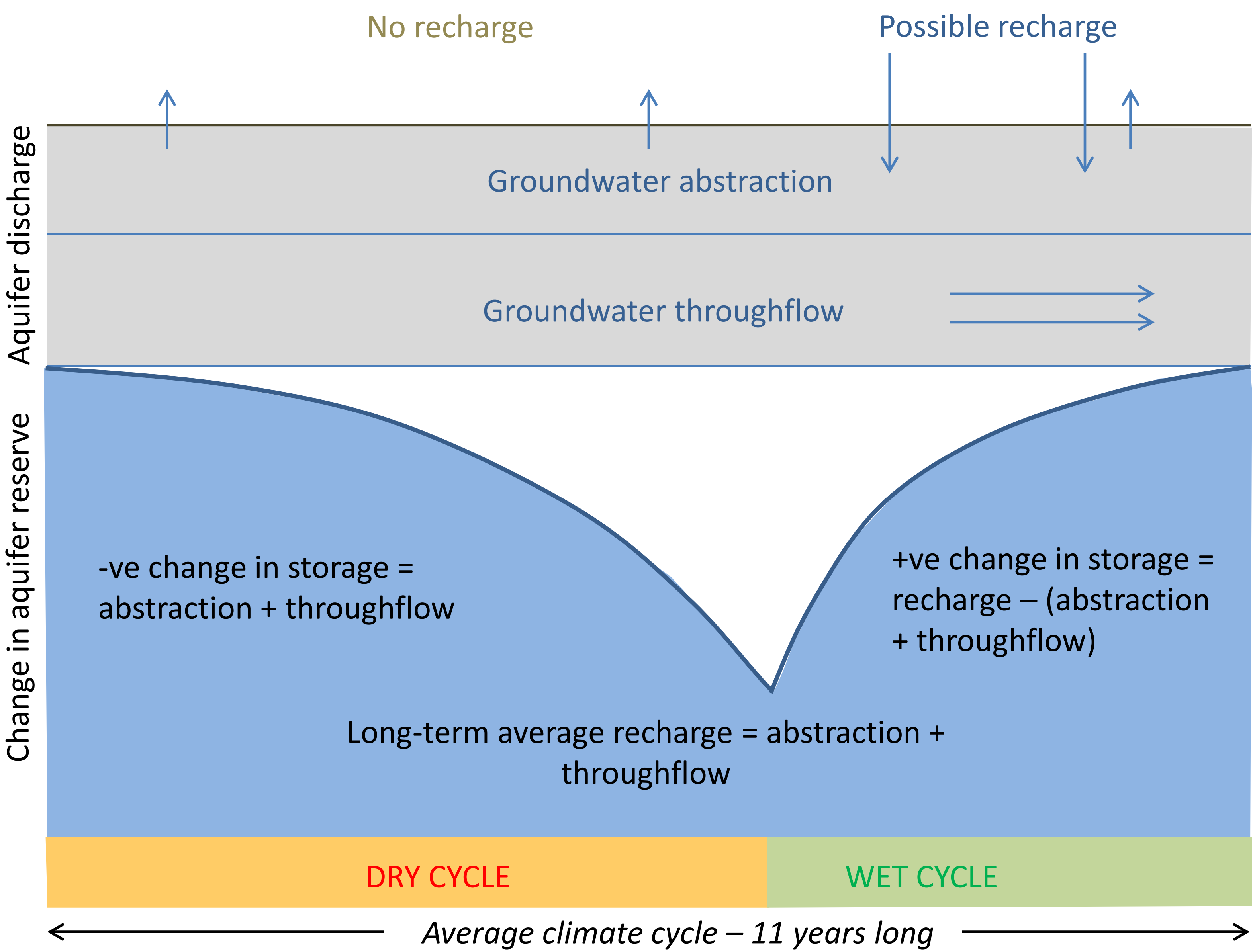
Available populations of data for selected attributes

Attribute	Fractured basement	Weathered basement
Borehole Identity	2015	6084
Water Levels	1016	4290
Driller's Water Strike Levels	144	376
Borehole Depths	1090	4058
Borehole Yields	1043	4365
Lithological Logs	324	756
Specific Capacities	222	1577
Transmissivities	222	1577

Malawi

- An 11-year climatic cycle (incl. a wet and dry period)
  - necessitates overdraft from groundwater storage during the dry-cycle years
  - episodic rainfall recharge in the wetter part of the cycle
- Groundwater hydrograph data are sparse
  - sufficient to evaluate the long-term renewable recharge
- fractured and weathered basement aquifer types in 15 water management areas in Malawi.
- The long term recharge is given by the sum of Darcian throughflow and dry-season depletion of storage.

Robins et al, 2013


No recharge
Possible recharge
Aquifer discharge
Groundwater abstraction
Groundwater throughflow
Change in aquifer reserve
-ve change in storage = abstraction + throughflow
+ve change in storage = recharge – (abstraction + throughflow)
Long-term average recharge = abstraction + throughflow
DRY CYCLE
WET CYCLE
Average climate cycle – 11 years long

The Basic Water balance

- The general (Malawi methodology) approach being applied to assess the groundwater resource requires computation of
  - *a. Current groundwater abstraction*
  - *b. Groundwater flux (throughflow), Q_f*
  - *c. Long-term average recharge*
  - *d. Available (accessible) storage*

- ***Groundwater resource status*** is determined as
  - ***Sustainable*** where (a) + (b) < (c) + (d)
  - ***Limited*** where (a) + (b) > (c) + (d)

*The 'Malawi analysis' identifies 4 'resource limited' WRAs (*Robins, Davies & Farr, 2013)

reality of limited resource ?

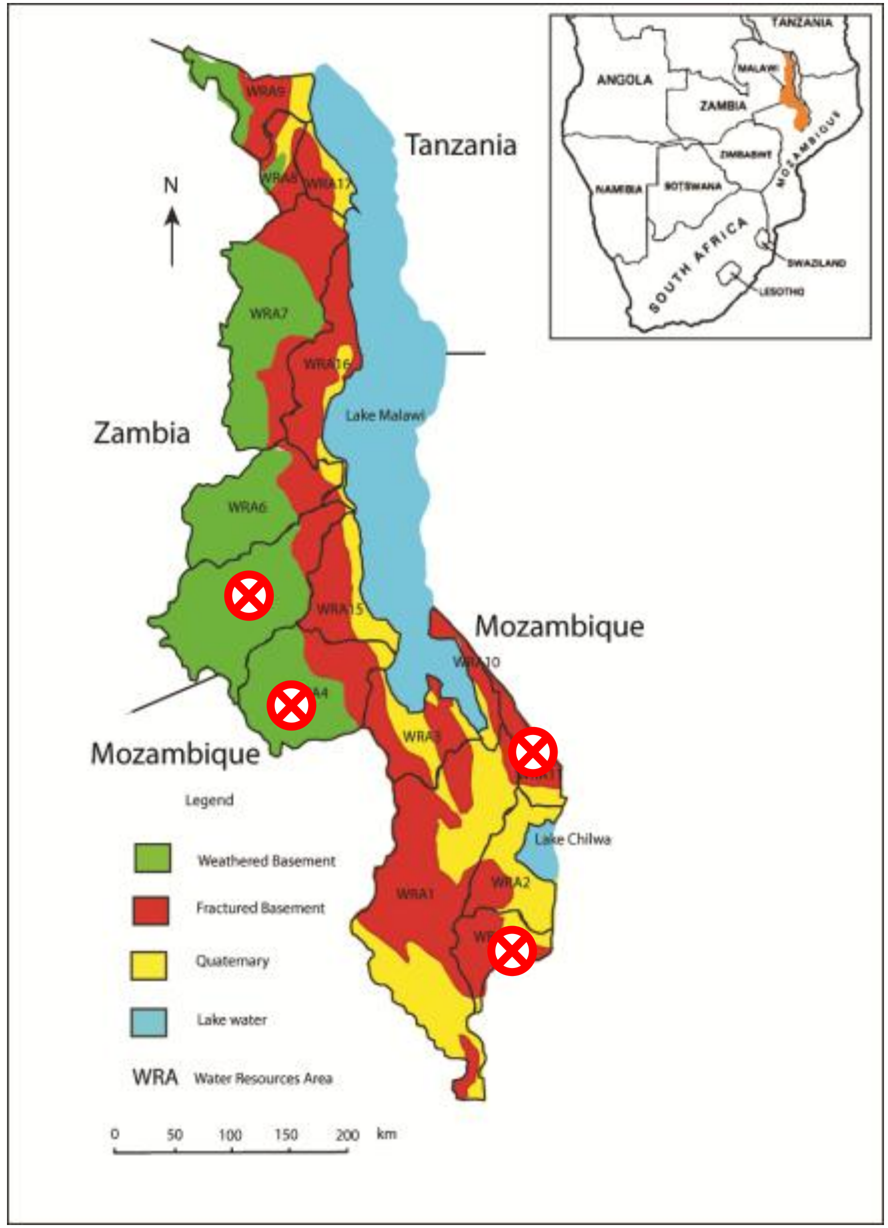
'Resource-limited' WRAs

5

4

11

14



Malawi Conclusions

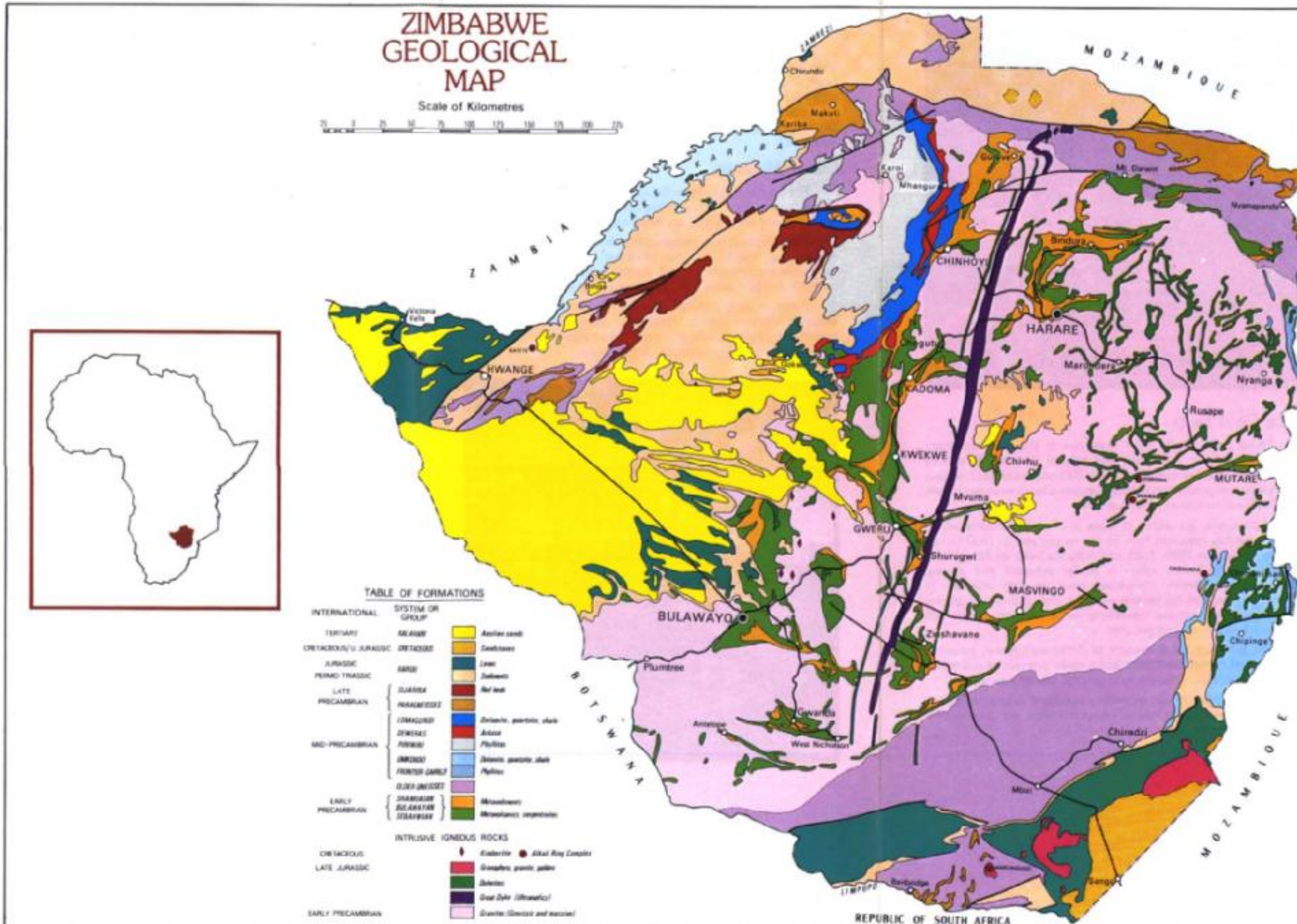
- As well as hydrogeological factors such as depth to water, permeability and borehole construction, the following are important regarding resource availabilty:
  - Water quality
  - Water committee (funds collection & trained to repair)
  - Size of village
  - Proximity to other sources

The Zimbabwe Story

A preliminary analysis of groundwater resource limitation in the Masvingo province, southern Zimbabwe using the Malawi approach.

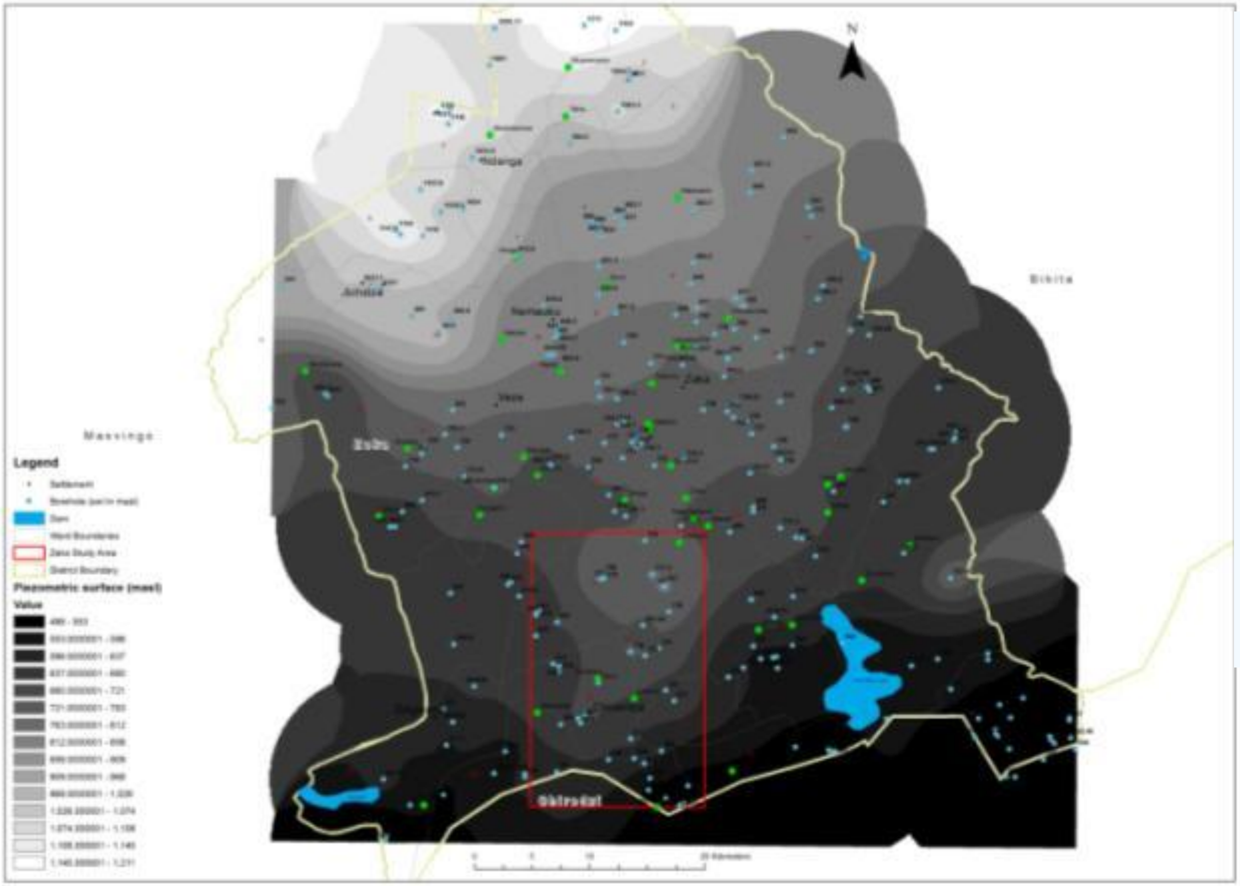
Modification of the methodology used in the Malawi

- Zimbabwe BCA regions are characterized by various landscape features resulting from a series of erosion cycles.
  - the African surface, Post African I and II & a more recent Pliocene surface.
  - characteristic castle kopjes, whalebacks, bornharts dot the landscape as remnants of the denudational processes becoming more prominent on moving away from the central axis.


ZIMBABWE
GEOLOGICAL
MAP
Scale of Kilometres
ZAMBEZI
MOZAMBIQUE
ZAMBIA
LAKE KARIBA
BOTSWANA
REPUBLIC OF SOUTH AFRICA
LIMPOPO
Kariba
Makuti
Karoi
Mhangura
Guruve
Mt Darwin
Bindura
CHINHOYI
HARARE
Marondera
Nyanga
Rusape
MUTARE
Chipinge
Victoria Falls
HWANGE
Chegutu
KADOMA
KWEKWE
Chivhu
Mvuma
GWERU
Shurugwi
MASVINGO
BULAWAYO
Zvishavane
Plumtree
Gwanda
West Nicholson
Chiredzi
Beitbridge
TABLE OF FORMATIONS
INTERNATIONAL
SYSTEM OR GROUP
TERTIARY
JURASSIC
PERMO-TRIASSIC
LATE PRECAMBRIAN
MID-PRECAMBRIAN
EARLY PRECAMBRIAN
INTRUSIVE IGNEOUS ROCKS
CRETACEOUS
LATE JURASSIC
EARLY PRECAMBRIAN


Zambezi Basin
Manyame Catchment
Mazowe Catchment
Sanyati Catchment
Seke
Gwayi Catchment
Save Catchment
Gutu
Mkgadikgadi Basin
Pungwe Basin
Runde Catchment
Zaka
Mzingwane Catchment
Chiredzi
Limpopo Basin
Legend
Basin Boundary
Catchment Boundary
Study site districts
Lakes and Dams
District Boundary
International Boundary

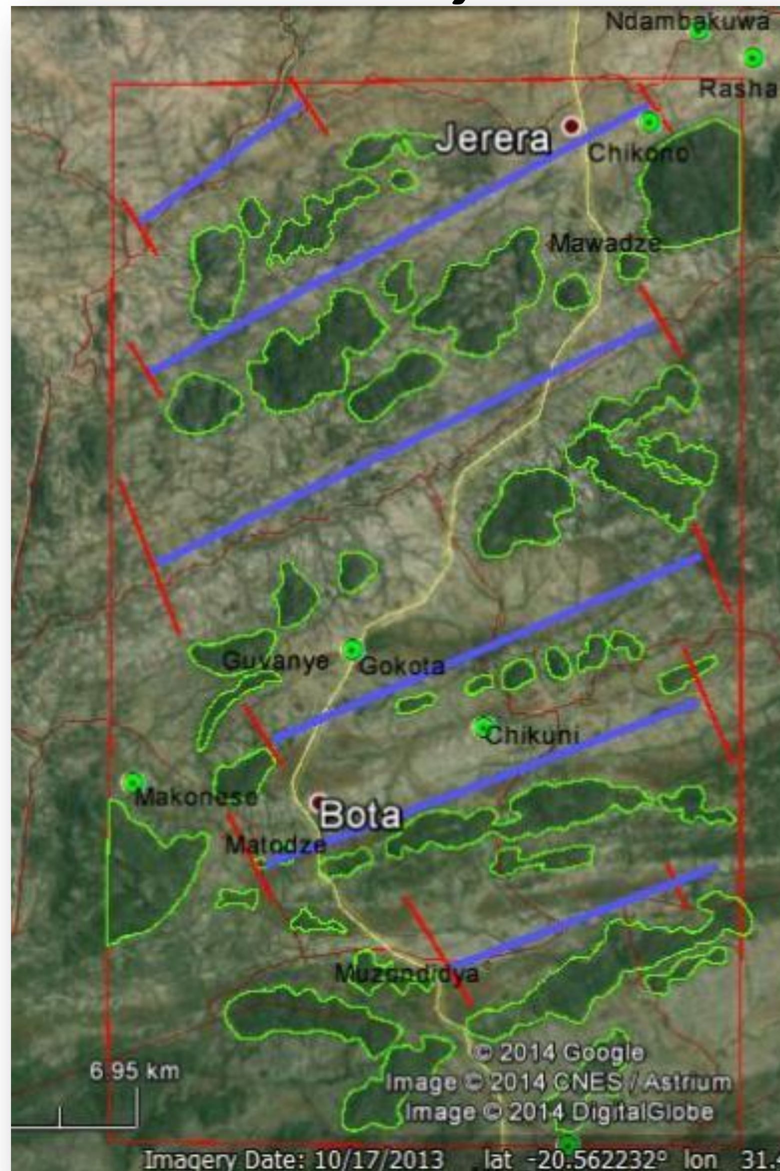
Groundwater flux (throughflow), Q_f



- Darcian Throughflow :
- Q_f = T.w.i along individual flow 'fronts', (as in the Malawi analysis) where:
  - *T, transmissivity*: from available data pumping test -UNICEF
  - *i, the hydraulic gradient* along a flow front - piezometric surface – 306 boreholes
  - *w, the width of a flow front*: measured from a sketch map of the groundwater contours.

Flow front – Zaka Study

- Identification of "flow lines/ groundwater stream tubes/micro aquifers" due to discontinuous surface with bornhardt outcrops.
- Bornhardt to surface area ratio of 1:5
- Summing up throughflow through individual micro-aquifers gives total groundwater flux for the study area



Zaka Analysis – the results

	Mean T = 20.73m²/day	*Mean T = 10m²/day*	*Mean T= 1.19m²/day*
–a. Current groundwater abstraction (l)	699,480	699,480	699,480
–b. Groundwater flux (throughflow), Qf in (l)	3,306,788	1,595,170	189,825
TOTAL VOLUME OUT	**4,006,268**	**2,294,650**	**889,305**
–c. Long-term average recharge (l)	4031	3394	2871
–d. Available (accessible) storage (l)	2,800,399	2,800,399	2,800,399
TOTAL VOLUME AVAILABLE (l)	**2,804,430**	**2,803,793**	**2,803,270**
GROUNDWATER RESOURCE STATUS (l)	**-1,201,839**	**509,142**	**1,913,965**

T= Transmissivity

Zimbabwe analysis conclusions

- Demand may be exceeding supply in various settings depending on
  - The local hydraulic properties for geohydrologic units.
  - Episodic recharge (in drought years - little or no recharge).
  - Where demand and hence abstraction is increasing (population growth)
- *Analysis is sensitive to T values – and these remain uncertain (limited data)*

Testing the Analysis

- Independent tests of the conclusion of the Malawi analysis
  - "Well Mapper" data collected through a borehole survey conducted in Malawi:
    - Borehole location, village, status of borehole
  - Use of the Well Mapper dataset did not support the Malawi conclusion of limited resources in the four water resource areas
  - Groundwater level monitoring Malawi yielded different results.

Challenges & Lessons learnt

- Lack of published measurements of boreholes drilled makes the estimation of hydraulic properties for geohydrologic units a challenge.
- Lack of a systematic borehole ID & registration process and data collection makes data sharing and analysis a challenge.
- The quantification of episodic recharge in arid to semi arid regions remains a challenge.
- Multi-annual monitoring of groundwater levels in southern Africa is sparse and barely adequate to demonstrate long-term trends.
- **Groundwater resource (water level) monitoring should be expanded and strengthened as a high priority.**

Thank You

Zikomo

Tatenda

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