A classification of the ‘troublesomeness’ of transboundary aquifers in the SADC region

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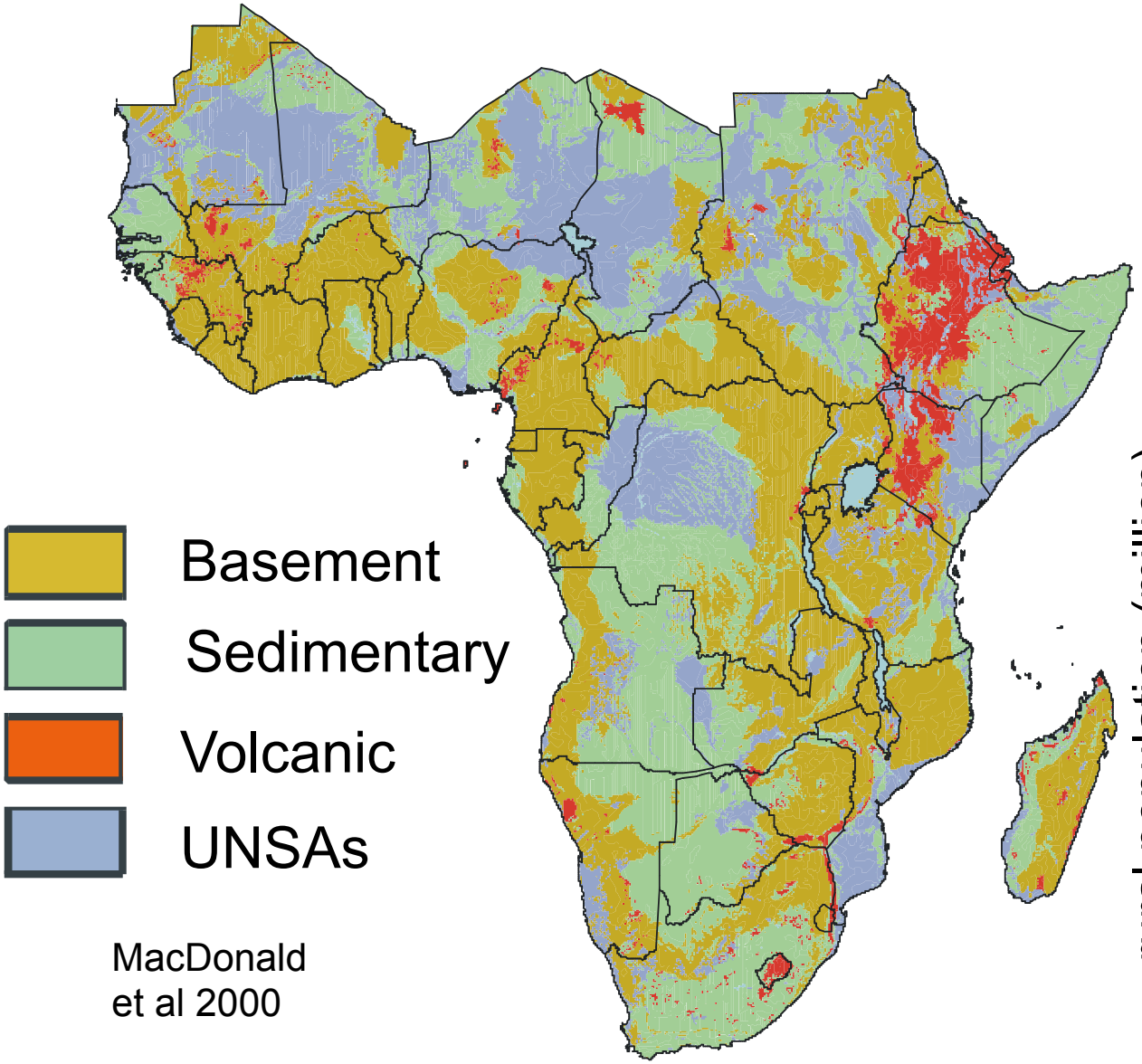
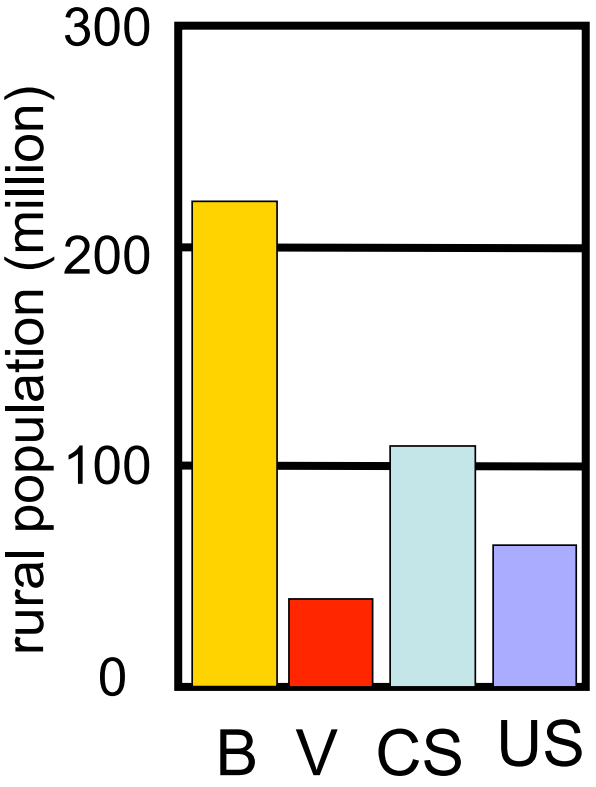
Groundwater dependence

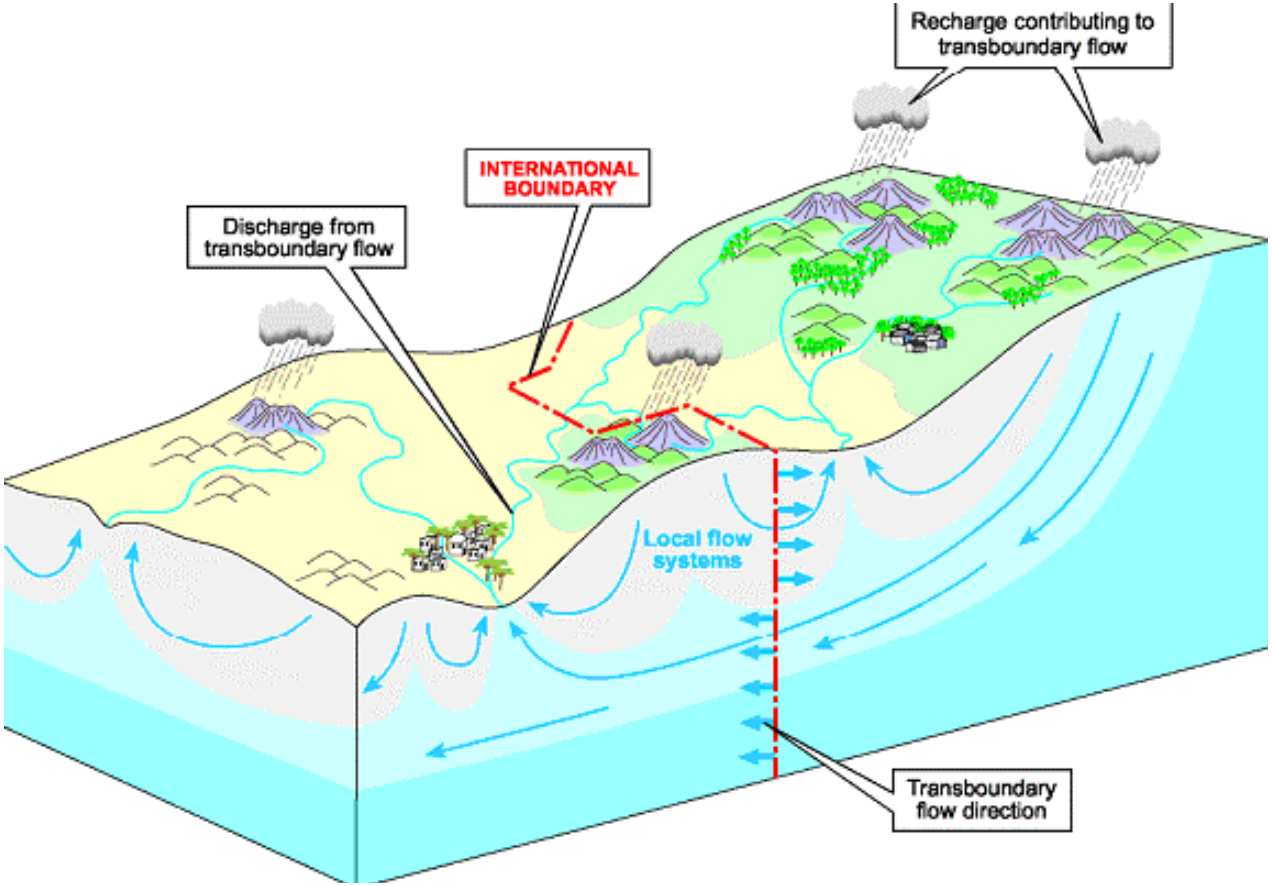


MacDonald
et al 2000

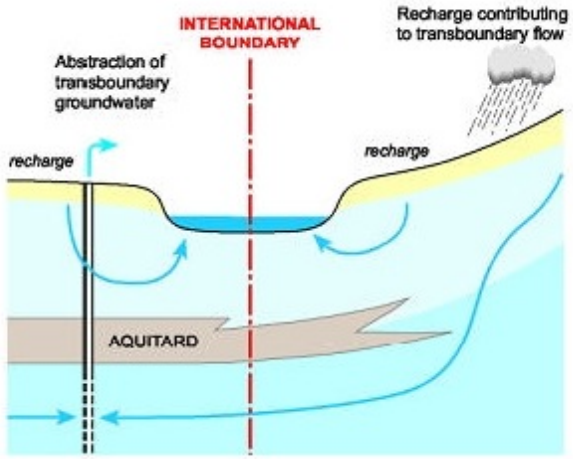


Eckstein & Eckstein (2003) defined six types of TBA:

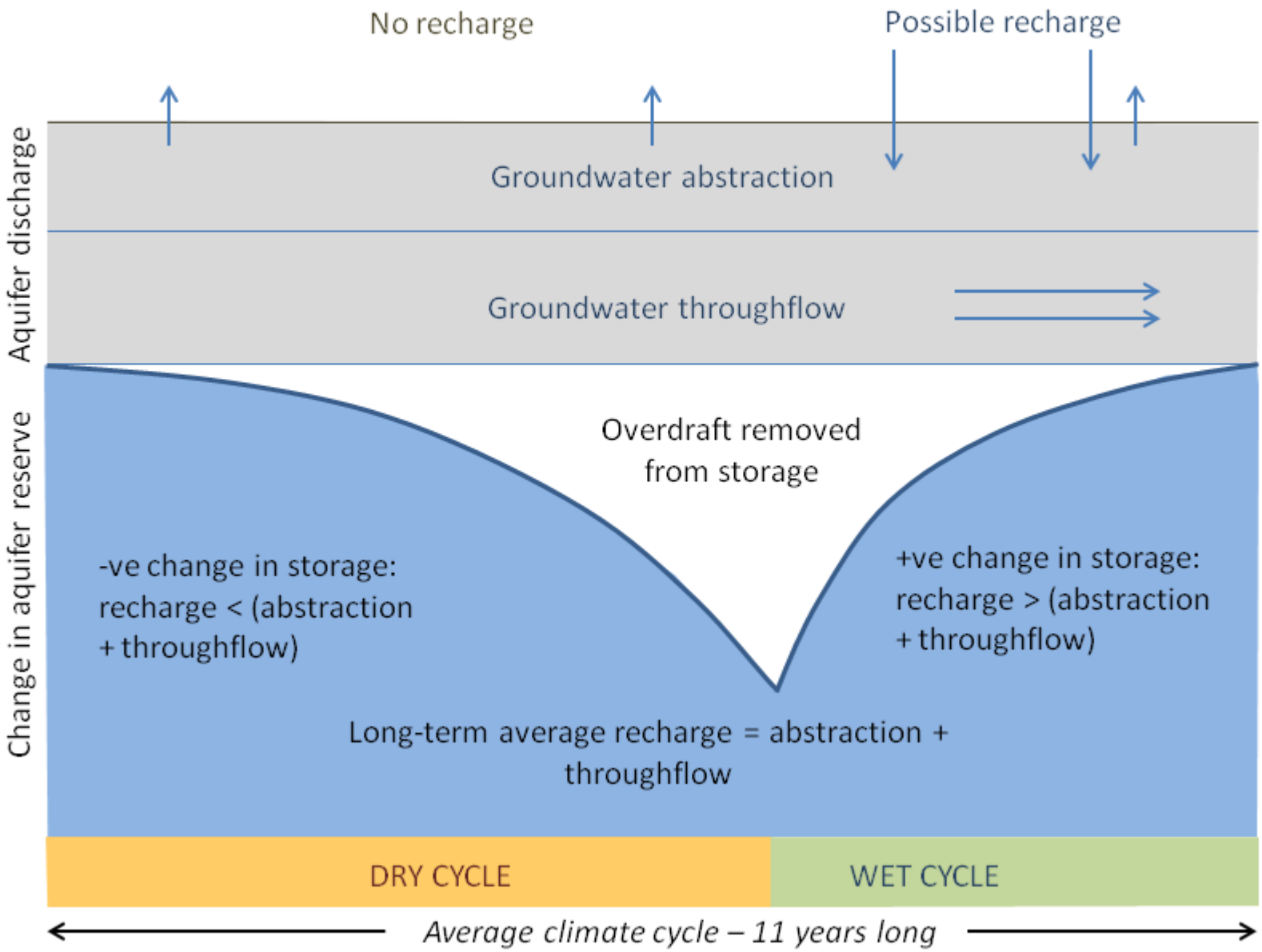
1. An unconfined aquifer that is linked hydraulically with a river, both of which flow along an international border (i.e., the river forms the border between two states).
2. An unconfined aquifer intersected by an international border and linked hydraulically with a river that is also intersected by the same international border.
3. An unconfined aquifer that flows across an international border and that is hydraulically linked to a river that flows completely within the territory of one state.
4. An unconfined aquifer that is completely within the territory of one state but that is linked hydraulically to a river flowing across an international border.
5. A confined aquifer, unconnected hydraulically with any surface body of water, with a zone of recharge (possibly in an unconfined portion of the aquifer) that traverses an international boundary or that is located completely in another state.
6. A transboundary aquifer unrelated to any surface body of water and devoid of any recharge.

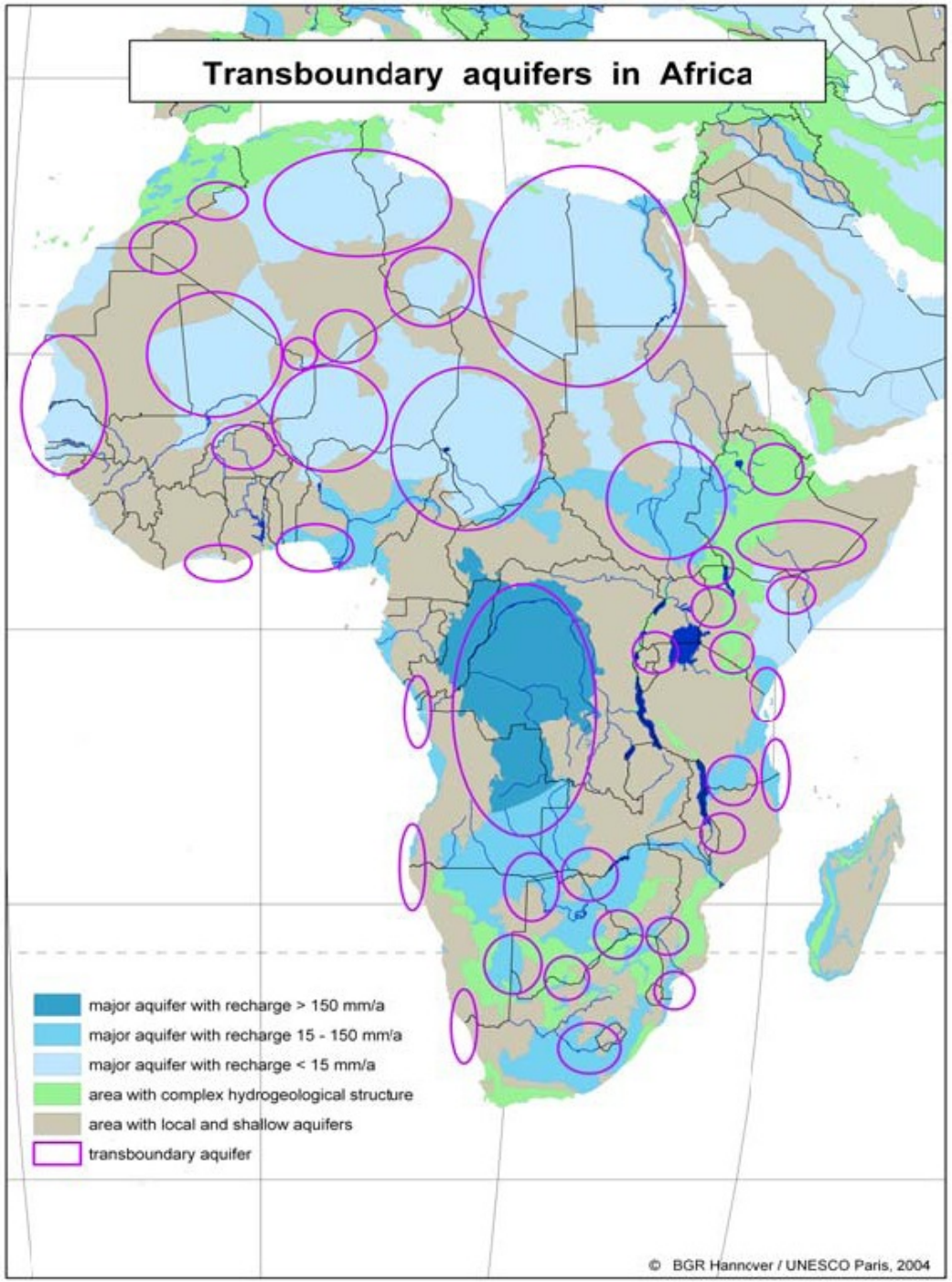


… but TBAs are by no means straightforward…

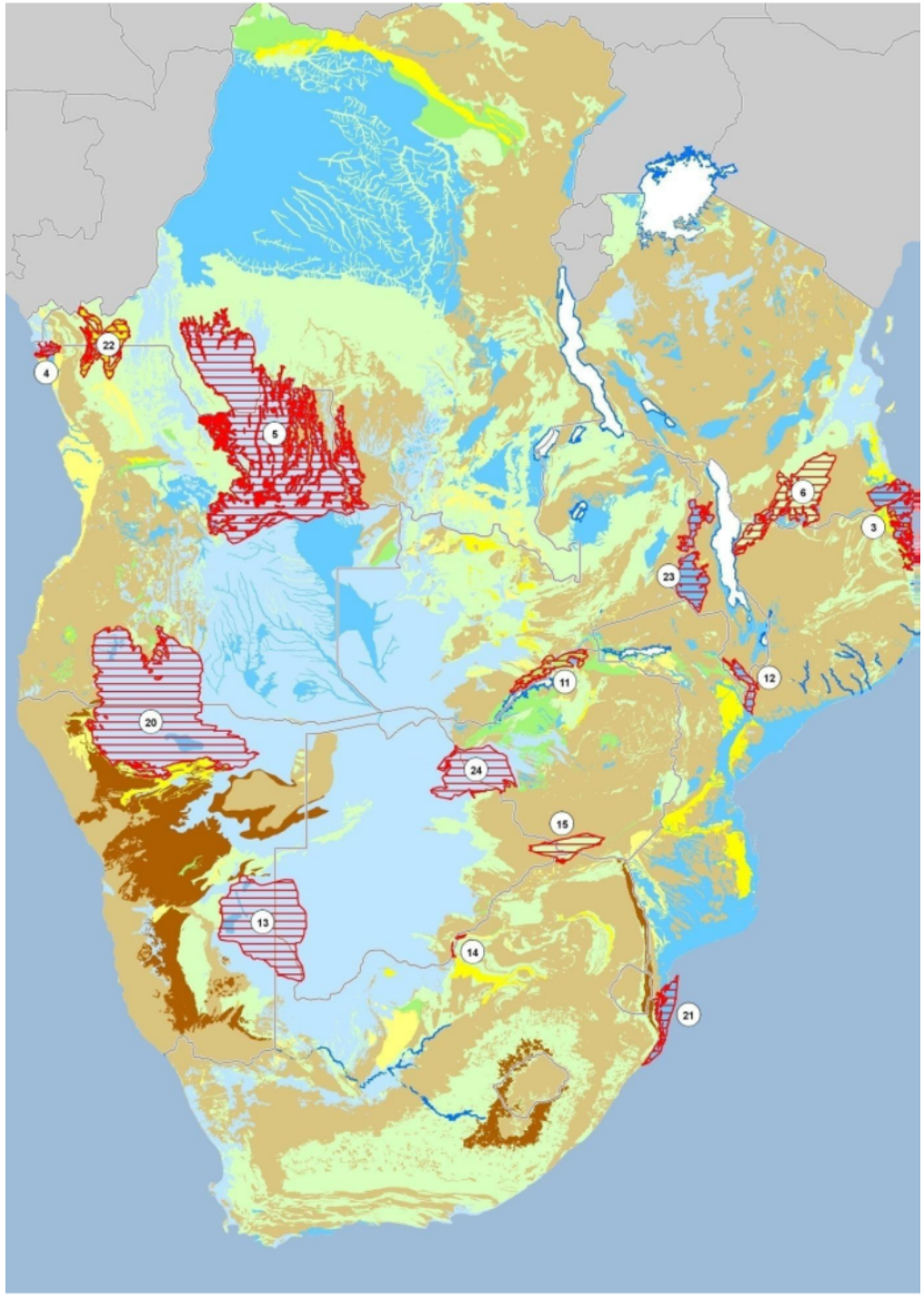


| WRA | Normal range (mm) | High (mm) | Years: potential rainfall recharge occurs in years when actual rainfall >high rainfall (blue squares) | | |


No recharge
Possible recharge
Aquifer discharge
Groundwater abstraction
Groundwater throughflow
Change in aquifer reserve
Overdraft removed from storage
-ve change in storage: recharge < (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



TBAs identified in Africa by ISARM-Africa



TBAs on the SADC Hydrogeological Map

Name	TBA No.	Member States	River Basin	Aquifer Characteristics	References from the SADC Groundwater Archive at: www.sadcgwarchive.net
Coastal Sedimentary Basin	3	Tanzania, Mozambique	Ruvuma	Tertiary to Quaternary age alluvial sands and gravels of the Ruvuma Delta, overlieing Cretaceous-age sedimentary strata. High permeability sediments that primarily draw water from the Ruvuma River and its tributaries.	Ferro & Bouman, 1987.; Lachelt, 2004.; Coster 1960.
Coastal Sedimentary Basin	4	D R Congo, Angola	Congo	Tertiary to Quaternary age alluvial sands and gravels of the Congo delta. High permeability sediments that primarily draw water from the Congo River and its tributaries.	Schermerhorn, L.J.G., 1961. , Snel, M.J., 1957.
Congo Intra-cratonic Basin	5	D R Congo, Angola	Congo	Tertiary alluvial sands and gravels – high yield porous sediments that draw water directly from the Congo River.	Snel, M.J., 1957.
Karoo Sandstone Aquifer	6	Tanzania, Mozambique	Ruvuma	Karoo sandstones beneath basaltic volcanics. Double porosity confined aquifer, yields enhanced by fracturing	Ferro & Bouman, 1987; Lachelt, 2004; Coster, 1960; Carl Bro, Cowiconsult , Kampsax-Kruger, CCKK, 1982.
Middle Zambezi Aquifer	11	Zambia and Zimbabwe	Zambezi	Upper Karoo sandstones beneath basaltic volcanics. Double porosity confined aquifer, yields enhanced by fracturing	Yachiyo Engineering Co Ltd, 1995; JICA, 1988; Interconsult, 1985.
Shire Valley Aquifer	12	Malawi, Mozambique	Zambezi	Tertiary to Quaternary and Recent alluvial sands and gravels. High yield, very porous sediments that draw water from the river.	Smith-Carington, A.K. & Chilton, P.J., 1983. Ferro & Bouman, 1987; Lachelt, 2004.
Kalahari/Karoo Basin	13	Botswana, Namibia, South Africa	Orange River	Kalahari Beds sands, cretes and clays over Karoo sandstones, mudstones, shales and coals, with alluvial sands and gravels along the Molopo River.	van Veelen & Baker, 2009; Christelis & Struckmeier, 2001; JICA, 2002; Geohydrology Division, 1993; Frommurze, 1937; Vegter, 2001; Peck, 2009.
Ramotswa Dolomite Basin	14	Botswana, South Africa	Limpopo	Karst Transvaal Dolomite aquifer	Farr & Baron, 1978; Farr, *et al*., 1979; Key 1983; Frommurze, 1937; Vegter, 2001.
Tuli Karoo Sub-basin	15	Botswana, South Africa, Zimbabwe	Limpopo	Upper Karoo sandstones beneath basaltic volcanics. Double porosity confined aquifer, yields enhanced by fracturing	Interconsult, 1985; Water Surveys Botswana (Pty) Ltd, 2007; Wellfield Consulting Services , British Geological Survey and CSIR Environmentek, 2008; MacDonald Shand Consortium, 1991; CSIR Environmentek, 2003; Botha *et al*., 1998; Frommurze, 1937; Vegter, 2001.
Cuvelai and Ethosha	20	Angola, Namibia	Etosha – Cuvelai	Kalahari Sediments with crete deposits	Government of the Republic of Angola and Government of the Republic of Namibia, 2004; Mendelsohnet *et al*., 2000; Christelis & Struckmeier, 2001.
Coastal Sedimentary Basin	21	Mozambique, South Africa	Maputo, Umbeluzi, Incomati, Limpopo	Tertiary to Quaternary-age alluvial sands and gravels of the Inkomati and Limpopo deltas overlieing Cretaceous-age sedimentary strata. High permeability sediments that primarily draw water from the Inkomati and Limpopo Rivers and tributaries.	Ferro & Bouman, 1987; Lachelt, 2004; Frommurze, 1937; Vegter, 2001; Cobbing *et al*. 2008.
Dolomitic	22	D R Congo, Angola	Congo	Karst dolomite aquifer	Snel, 1957.
Sands and gravel/ weathered Basement aquifer	23	Malawi, Zambia	Zambezi	Quaternary palaeo-fluvial sands and gravels deposited by pre-rifting valleys derived from weathered Basement.	Yachiyo Engineering Co Ltd, 1995; Smith-Carington & Chilton, 1983.

TBA analysis includes the assessment of the hydrogeological situation. Data comparison and harmonisation across the border is the main technical challenge. Non-technical challenges include the socio-economical and political situation in the border region.

The assessment of shared groundwater comprises:

- Delineation and description, inventory and characterisation
- Classification, diagnostic analysis and zoning.
- Data harmonisation and information management.

CLASSIFICATION

troublesome - could pose a threat to international relationships and would benefit from shared management through international co-operation,

could potentially become troublesome, i.e. may yet be poorly understood due to data scarcity, and

unlikely to become troublesome - politically dormant and not likely to benefit from international management.

i.e. ACTIVE – MODERATELY ACTIVE - INACTIVE

CLASSIFICATION CATEGORIES (listed as tables)

- Groundwater flow and vulnerability
    1. Natural flow
    2. Induced flow
    3. Aquifer vulnerability
- Groundwater knowledge and understanding
    1. Groundwater Quantity
    2. Groundwater Quality
    3. Vulnerability
- Governance capability
    1. Management
    2. Knowledge
    3. Monitoring
- Socio-economic/water demand capability
    1. Demography
    2. Land Use
    3. industry
- Environmental capability
    1. Hydrology
    2. Sustainability
    3. Climate

TABLES

Example 1 COLUMNS: TBA; code; member state; geology (lithology and depth); hydrogeology (type and permeability); recharge (potential and river proximity); aquifer summary; score

ROWS: each TBA separated by country

Transboundary Aquifer	TBA Code	Member State	Geology		Hydrogeology		Recharge		Aquifer Summary
			Lithology	Depth	Type	Permeability	Potential	River Proximity	
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	Medium to high/ seasonal	Adjacent to distant	Tertiary to Quaternary age alluvial sands and gravels with fresh groundwater of Ruvuma Delta, overlying Cretaceous-age mariolcrete with brackish to saline water. High permeability sediments mainly drew water from the Ruvuma River. Little TBA through-flow, flow mainly towards the coast, possible marine saline intrusion
		Mozambique	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	Medium to high/ seasonal	Adjacent to distant	
Congo Delta Coastal Sedimentary Basin Aquifer	4								
Congo/Zambezi Basins Benguela Ridge Watershed Aquifer	5								
Tundulu/ Mariamba Basin Karoo Sandstone Aquifer	6		basaltic	Shallow-medium	Unconfined semi-confined	Secondary fractured	Moderate/ periodic	Adjacent to near	porosity and fractured permeability. The Ruvuma River forms the international boundary between the Tundulu and Mariamba parts of this basin. The prospects for transboundary flow are poor.
Middle Zambezi Rift Upper Karoo Aquifer	11		basaltic	Shallow-medium	Semi-confined	Secondary fractured	Low to moderate/ periodic	Adjacent to near	Lower and Upper Karoo sandstones and siltstones underlie basalts within the down-faulted Zambezi Rift graben. The aquifer has some primary porosity and fractured permeability. The Zambezi River forms the international boundary between the upstream Zambian basin and the downstream Zimbabwe basin. The prospects for transboundary flow are poor as the main source of groundwater, the river, forms the international boundary.
			basaltic	Shallow-medium	Semi-confined	Secondary fractured	Low to moderate / periodic	Adjacent to near	
Shire Valley Alluvial Aquifer	12			Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to near	Tertiary to Quaternary and Recent alluvial sands and gravels overlie Cretaceous age sandstones within the southern continuation of the Malawi Rift graben. High yields are obtained from the, very porous Shire River alluvial sediments Some large areas with salinised waters do occur.
				Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to near	
South West Kalahari Karoo Basin Aquifer	13		sediments	Medium - deep	Confined	Secondary fractured	Low/ periodic	Possible watershed	Thick Kalahari Beds sands, calcretes and clays confine productive Lower Karoo sandstones interbedded with mudstones, shales and coals. In Namibia, the Lower Karoo Stampriet Aquifer is a major source of water for domestic and agricultural use. Little development of this aquifer has been made in south western Botswana or the adjacent part of South Africa. Large parts of these areas have been demarcated as National Parks. Over-abstraction in Namibia may have caused a reduction in natural flow into areas of South Africa and Botswana within this aquifer.
			sediments	Medium - deep	Confined	Secondary fractured	Low to Moderate/ periodic	Possible watershed	
			sediments	Medium - deep	Confined	Secondary fractured	Low/ periodic	Possible watershed	
Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14		rw	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ periodic	Adjacent to distant	The Precambrian Transvaal Chuniy Dolomite forms an arcuate karstic aquifer between Zeerust, Ramotswa, Lobatse and Gaborone. Natural groundwater flow and discharge from are unlikely as groundwater occurs in a series of isolated basins. There is a minor risk of localised cross-border pollution.
			rw	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ periodic	Adjacent to distant	
Tuli Karoo Basin Aquifer	15		oo sandstones and	Shallow - deep	Unconfined to confined	primary; secondary fractured	High to moderate/ periodic	Alluvium along rivers; adjacent to near	The High porosity, high yield, unconfined sand and gravel alluvium sand river aquifers occur along the Shashe, Limpopo and Umzigwane rivers have been much developed a sources of irrigation water to such an extent that dry season flow along the
			oo sandstones and	Shallow - deep	Unconfined to confined	primary; secondary fractured	High to moderate/ periodic	Alluvium along rivers; adjacent to near	
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments Aquifer	20								
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	South Africa	Alluvium/ Sedimentary	Shallow-medium	Unconfined semi-confined	Primary	High/ seasonal	Adjacent to distant	marine saline intrusion
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	Karst limestone	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ seasonal	Adjacent to distant	The Congo River flows across the outcrop of the Precambrian age Schisto-Calcaire Dolomites via a series of cataracts. This karst weathered dolomite aquifer receives recharge from the river within DR Congo. Away from the river in Angola the dominant direction of flow is towards the river.
		Angola	Karst limestone	Shallow-medium	Unconfined semi-confined	Secondary karst	High/ seasonal	Near to distant	
		Malawi	Alluvium / weathered basement	Shallow-medium	Unconfined semi-confined	Primary / secondary fractured	Moderate/ periodic	Headwaters along watershed	

Example 2 COLUMNS: TBA; code; member state; demography (population and water sources); land use (irrigation and cattle); industry (irrigation and mining services); socio-economic capability; score

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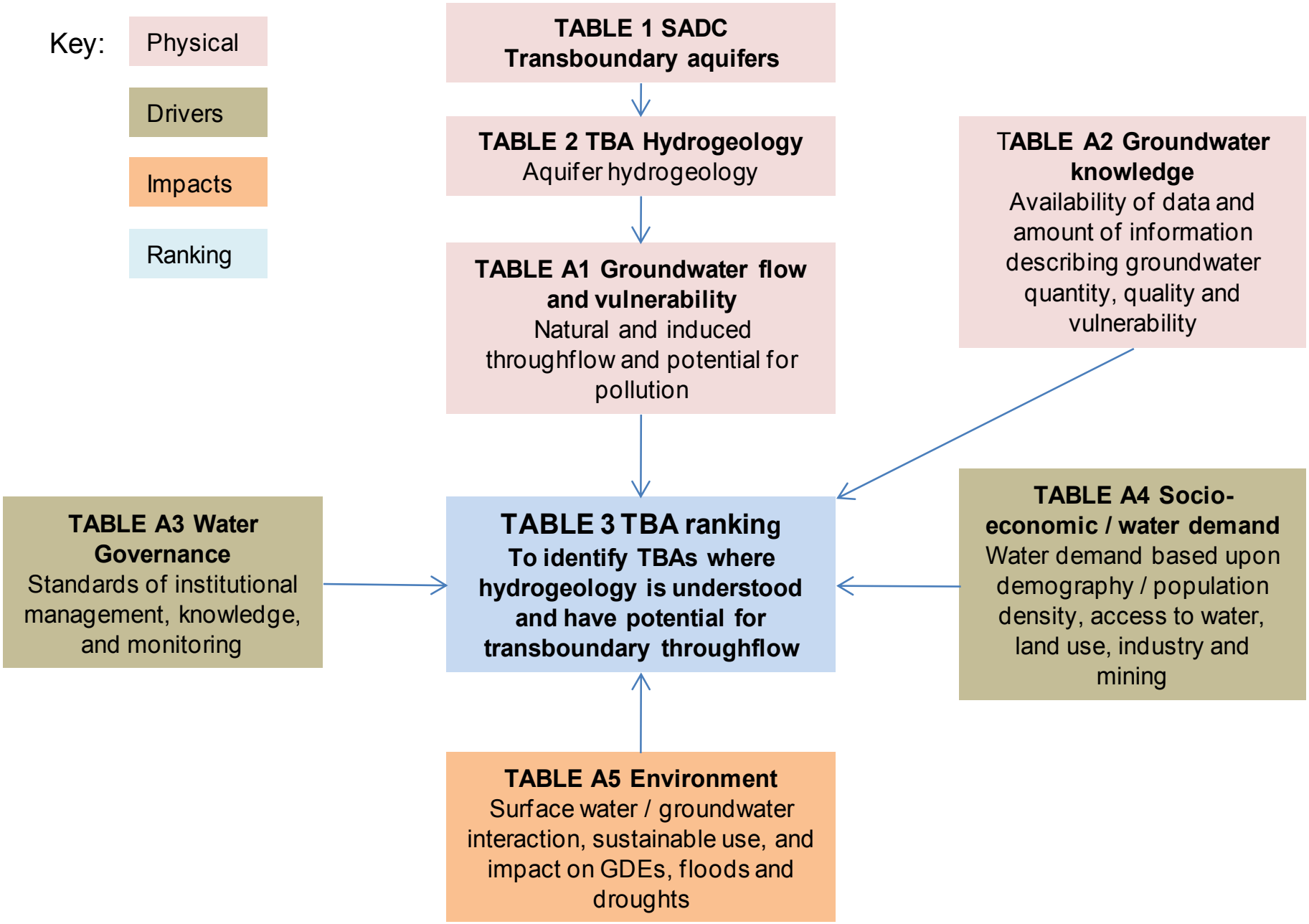
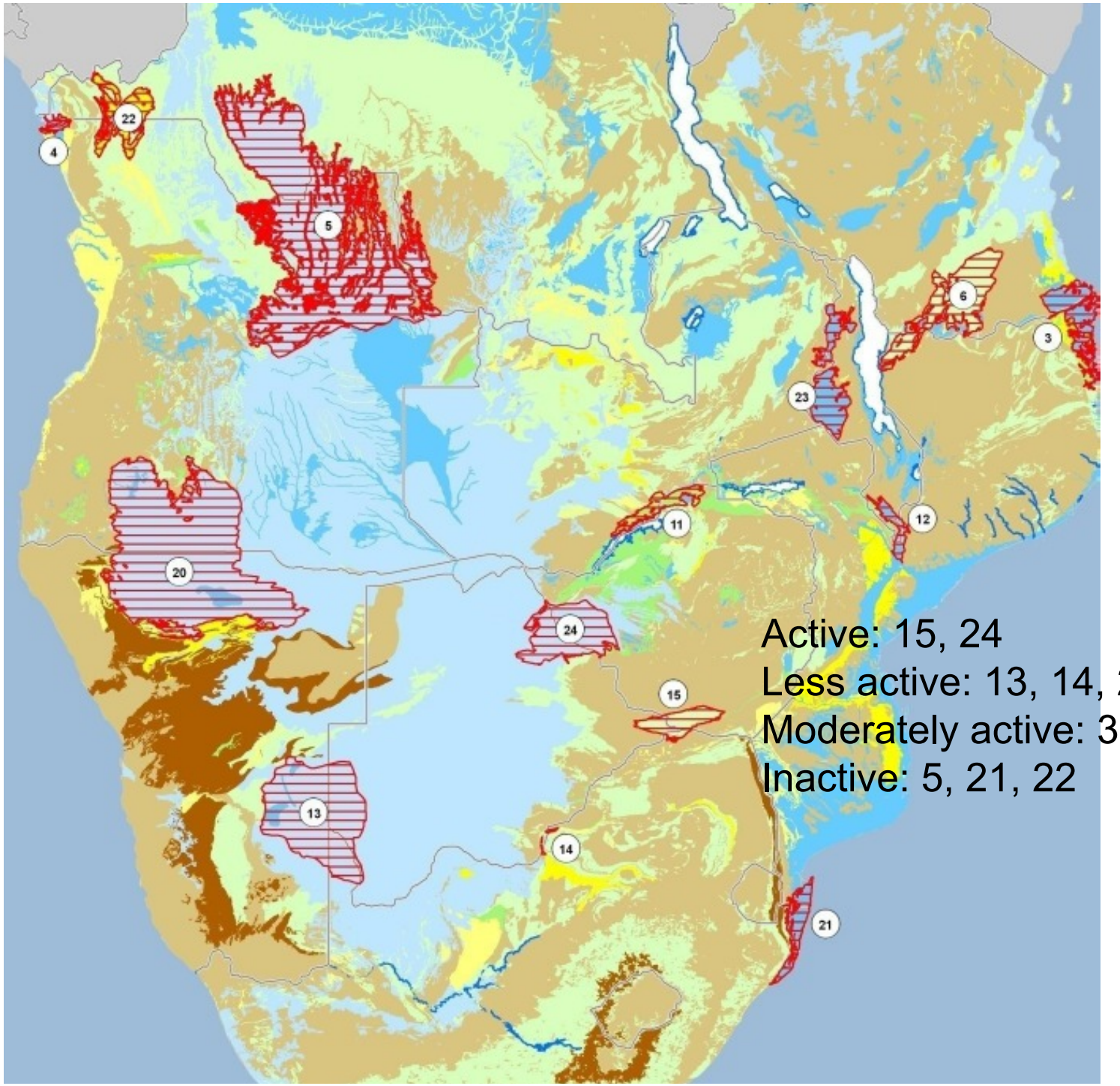

Key:
Physical
Drivers
Impacts
Ranking
TABLE 1 SADC Transboundary aquifers
TABLE 2 TBA Hydrogeology
Aquifer hydrogeology
TABLE A1 Groundwater flow and vulnerability
Natural and induced throughflow and potential for pollution
TABLE A2 Groundwater knowledge
Availability of data and amount of information describing groundwater quantity, quality and vulnerability
TABLE A3 Water Governance
Standards of institutional management, knowledge, and monitoring
TABLE 3 TBA ranking
To identify TBAs where hydrogeology is understood and have potential for transboundary throughflow
TABLE A4 Socio-economic / water demand
Water demand based upon demography / population density, access to water, land use, industry and mining
TABLE A5 Environment
Surface water / groundwater interaction, sustainable use, and impact on GDEs, floods and droughts

RANKING TABLE:

Total score = sum of scores for Tables 4-7 x score Table 3. Rank A *Active* >200, B *Moderately Active* >100 and C *Inert*<100

Transboundary Aquifer	TBA No.	Country	Table 3	Table 4	Table 5	Table 6	Table 7	Total Score	Rank
Ruvuma Delta Coastal Sedimentary Basin Aquifer	3	Tanzania	4	6	6	11	15	152	B
		Mozambique	3	10	7	11	15	129	B
Congo Delta Coastal Sedimentary Basin Aquifer	4	D R Congo	3	6	6	9	13	102	B
		Angola	4	6	6	10	13	140	B
Congo/Zambezi Basins Benguela Ridge Watershed	5	D R Congo	3	6	6	9	9	90	C
		Angola	3	6	6	9	9	90	C
Tunduru/ Maniamba Basin Karoo Sandstone Aquifer	6	Tanzania	3	9	6	9	13	111	B
		Mozambique	3	9	7	8	13	111	B
Middle Zambezi Rift Upper Karoo Aquifer	11	Zambia	3	16	14	9	11	150	B
		Zimbabwe	3	16	12	6	11	135	B
Shire Valley Alluvial Aquifer	12	Malawi	4	12	10	10	14	184	B
		Mozambique	3	9	7	10	14	120	B
South West Kalahari/ Karoo Basin Aquifer	13	Botswana	4	18	12	8	9	188	B
		Namibia	5	18	16	12	10	280	A
		South Africa	4	18	12	6	9	180	B
Zeerust – Ramotswa - Lobatse Dolomite Basin Aquifer	14	Botswana	5	18	15	13	9	275	A
		South Africa	4	18	13	9	9	196	B
Tuli Karoo Basin Aquifer	15	Botswana	4	18	16	10	12	224	A
		South Africa	4	18	18	14	12	248	A
		Zimbabwe	4	16	10	12	12	200	A
Cuvelai Delta and Ethosha Pan Alluvial and Kalahari	20	Angola	5	6	8	8	13	175	B
		Namibia	5	16	16	12	13	285	A
Coastal Tertiary to Recent Sedimentary Basin Aquifer	21	Mozambique	3	8	7	8	10	99	C
		South Africa	3	14	9	9	10	126	B
Lower Congo Precambrian Dolomite Aquifer	22	D R Congo	3	6	6	7	12	93	C
		Angola	4	6	6	7	12	124	B
Sands and gravels of weathered Precambrian	23	Malawi	4	14	10	10	11	180	B
		Zambia	4	14	11	10	11	184	B
Eastern Kalahari Karoo Basin Aquifer	24	Botswana	5	18	13	10	9	250	A
		Zimbabwe	5	18	12	12	9	255	A

Active TBAs (likely to be the cause of friction between neighbouring states):
TBA 15, Tuli Karoo Basin Aquifer, and
TBA 24, Eastern Kalahari Karoo Basin Aquifer
Less active TBAs:
TBA 13, South West Kalahari/Karoo Basin Aquifer
TBA 14, Zeerust-Ramotswa-Lobatse Dolomite Basin Aquifer
TBA 20, Cuvelai Delta and Ethosha Pan Alluvial and Kalahari Sediments
Moderately active TBAs:
TBA 3, Ruvuma Delta Coastal Sedimentary Basin Aquifer
TBA 4, Congo Delta Coastal Sedimentary Basin Aquifer
TBA 6, Tunduru/Maniamba Basin Karoo Sandstone Aquifer
TBA 11, Middle Zambesi Rift Upper Karoo Aquifer
TBA 12, Shire Valley Alluvial Aquifer
TBA 23, Sands and gravels of weathered Precambrian Basement Complex
Inactive TBAs: (unlikely to become the cause of friction between neighbouring states):
TBA 5, Congo/Zambesi basins Benguela Ridge watershed Aquifer
TBA 21, Coastal Tertiary to Recent Sedimentary Basin Aquifer
TBA 22, Lower Congo Precambrian Dolomite Aquifer



Active: 15, 24
Less active: 13, 14, 20
Moderately active: 3, 4, 6, 11, 12, 23
Inactive: 5, 21, 22

See: Jeff Davies, Nick Robins, John Farr, James Sorensen, Philip Beetlestone and Jude Cobbing (2013) Identifying transboundary aquifers in need of international resource management in the Southern African Development Community region. *Hydrogeology Journal* **21**: 321-330