Hydrogeological controls on groundwater recharge to a deeply weathered crystalline aquifer: A case study from the Makutapora groundwater basin, Tanzania

E. Zarate*[1,2], D. Hobley[1], A.M. MacDonald[2], R.T. Swift[2,3], J. Chambers[2], J.J. Kashaigili[4], E. Mutayoba[5], R.G. Taylor[6], M.O. Cuthbert[1]

[1]: School of Earth & Ocean Sciences, Cardiff University, Main Building, Park Pl, Cardiff CF10 3AT, UK

[2]: British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK

[3]: University of Liege, Urban and Environmental Engineering, 4000 Liege, Belgium

[4]: Sokoine University of Agriculture, P.O. Box 3013, Morogoro, Tanzania

[5]: Mbeya University of Science and Technology, P.O Box 131, Mbeya, Tanzania

[6]: Department of Geography, University College London, London, WC1E 6BT, UK

NERC SCIENCE OF THE ENVIRONMENT | CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD | solid living changing EARTH OCEAN

Research Context

- Drylands are forecast to be **increasingly water stressed** in coming decades
- **Groundwater** is often the **most reliable resource** in these regions
- However **spatio-temporal controls** on **groundwater recharge** poorly understood
- **Superficial geology** may play a key role

Study area – The Makutapora Basin

- Makutapora wellfield supplies water to the capital city – **Dodoma**
  - Population grown **2.1%** in last 10 years – to 500,000
  - Groundwater abstraction now **exceeds 50 000 m^3** per day
  - Abstraction expected to **increase substantially**
- However – **groundwater levels are higher** than they were in 1990s
- Is abstraction sustainable?
  - What are the **hydrogeological conditions** that can sustain this abstraction?
  - Recharge from recent months/years or long term storage?

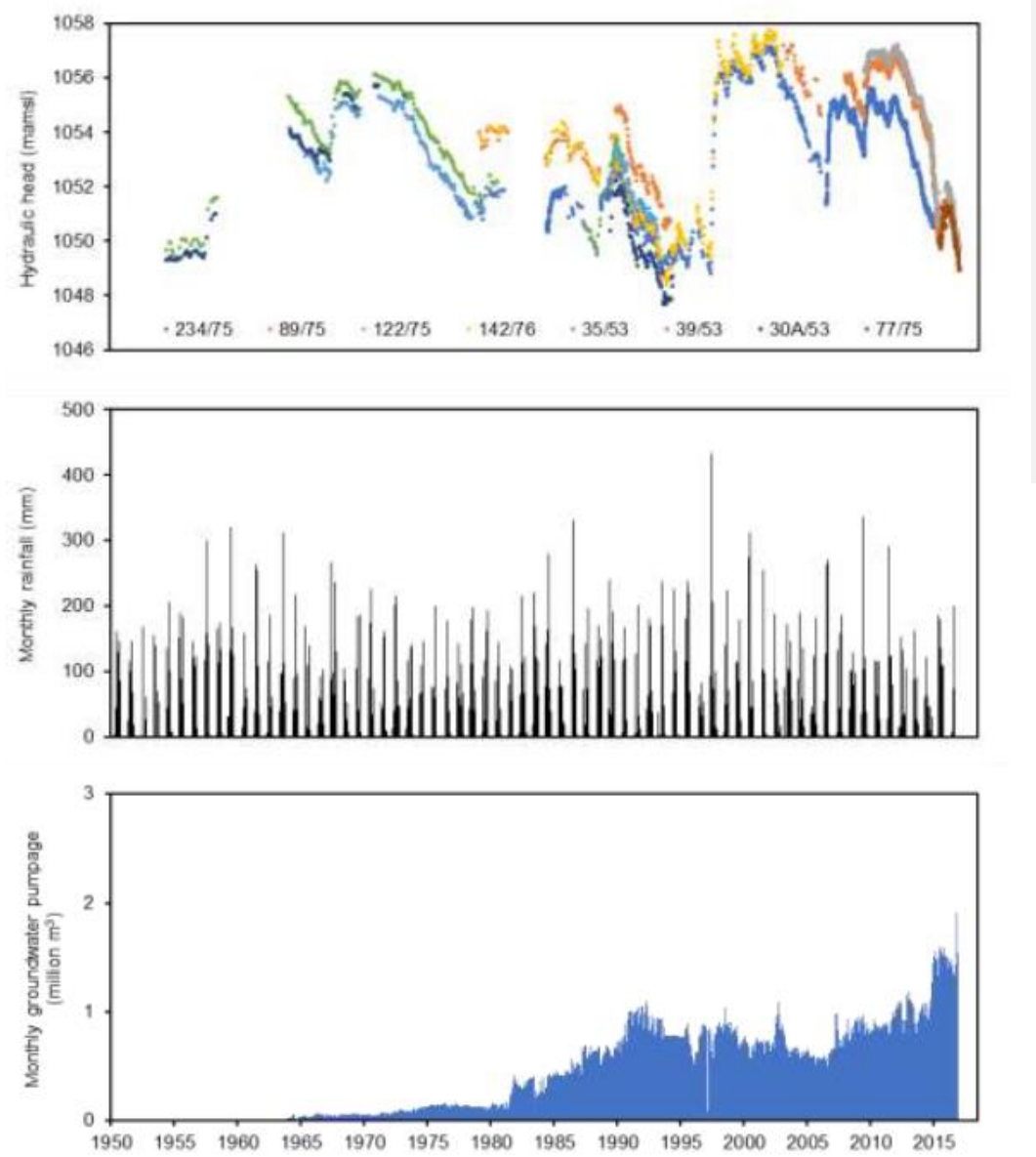
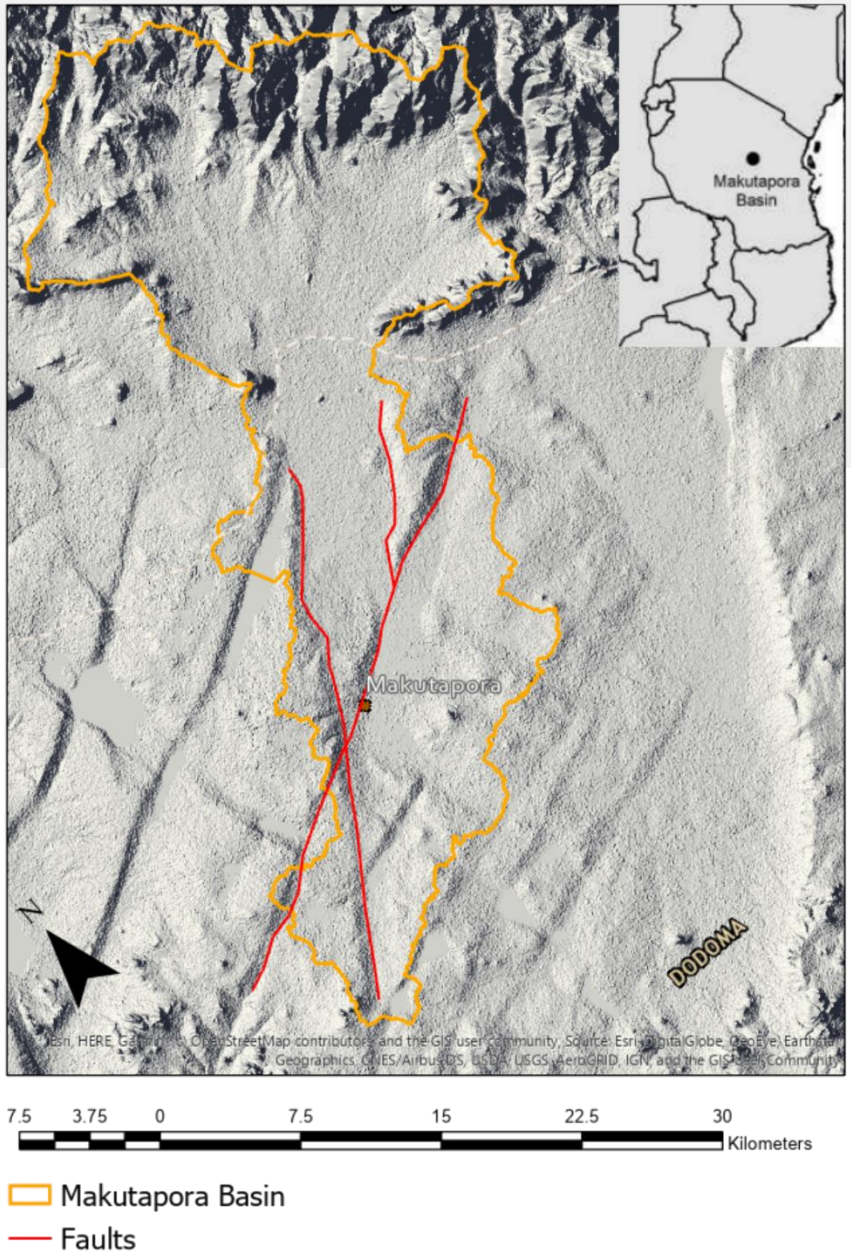


Figure 1: Time series of groundwater-level observations from 8 monitoring wells in the Makutapora Wellfield (top), monthly precipitation from the Dodoma Airport Meteorological Station (middle) and monthly groundwater abstraction in the Makutapora Basin (bottom) (Seddon, 2018)

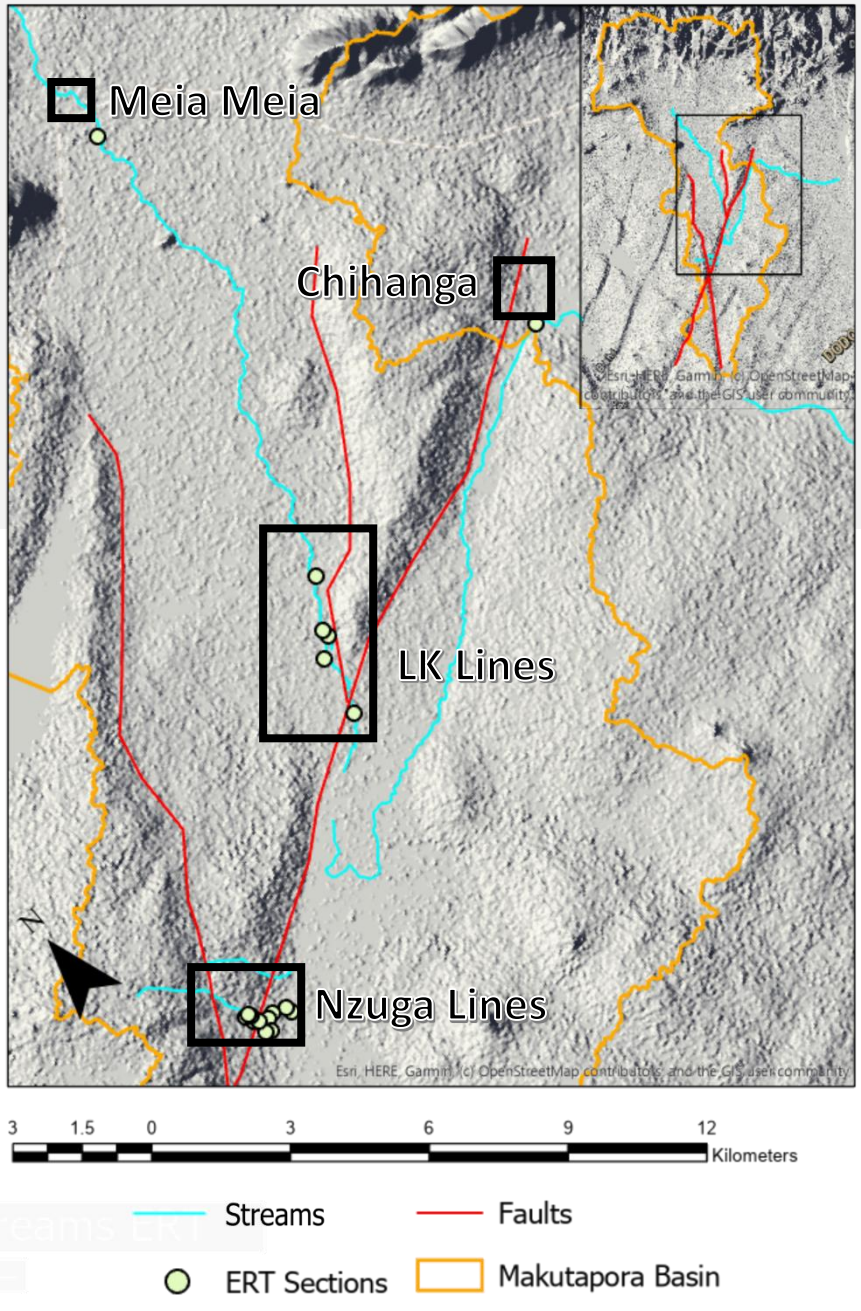
Study area – The Makutapora Basin

- Groundwater abstracted from aquifer **comprising deeply weathered granite** overlain by unconsolidated superficial deposits
- Evidence of **extensive faulting** in basin- Linear features trending SW-NE & NW-SE
  - Extension of the eastern branch of **East African Rift System**
  - Wellfield constrained by **normal faults** – most boreholes situated on downthrown hanging wall
  - Recent **tectonic activity**

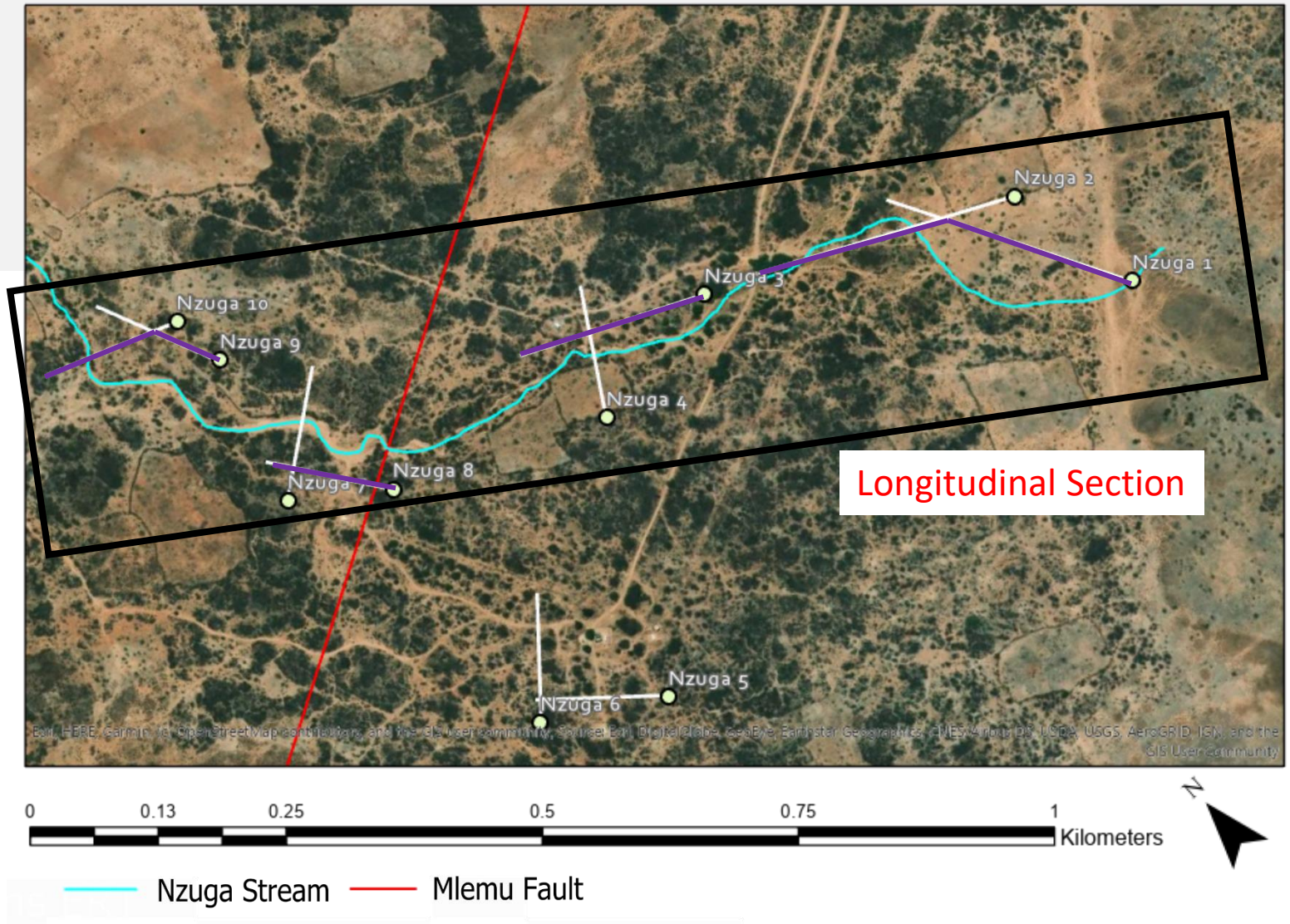


Geophysical Surveys

- Groundwater abstracted from aquifer **comprising deeply weathered granite** overlain by unconsolidated superficial deposits
- Electrical Resistance Tomography (ERT) used to study near surface superficial geology
- **Dipole Dipole** method
- Various electrode spacings
- A total of **17 ERT sections** were conducted within the basin
  - 5 Lines along the Little Kinyasungwe (LK) river
  - 10 Lines along the smaller Nzuga stream
  - A line at both the Meia Meia (inlet) and Chihanga (outlet) gauging stations



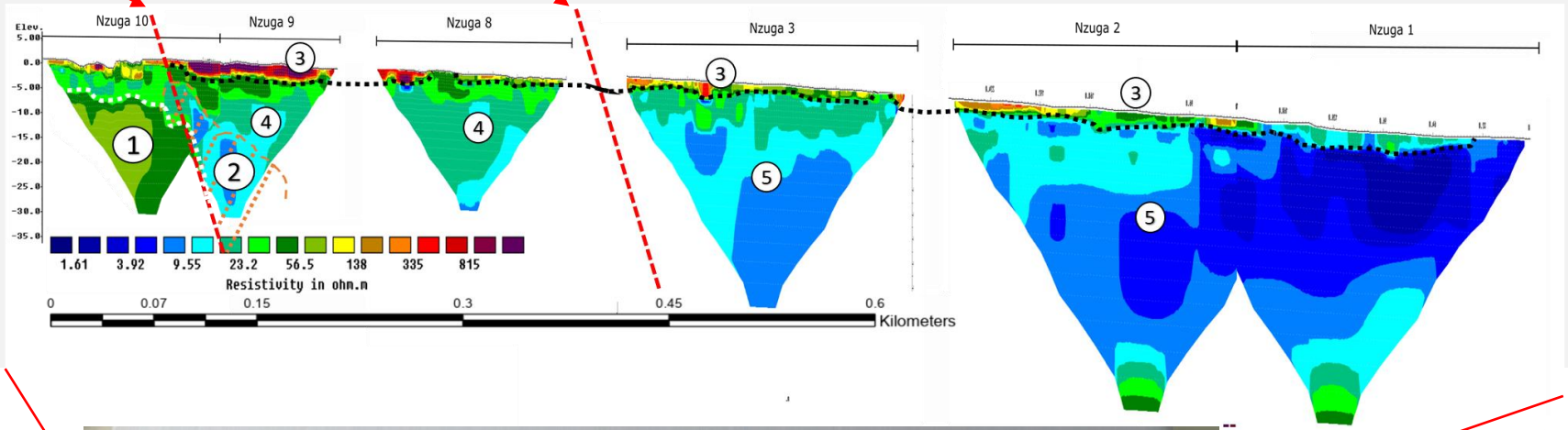
Nzuga ERT Sections



Nzuga Sections

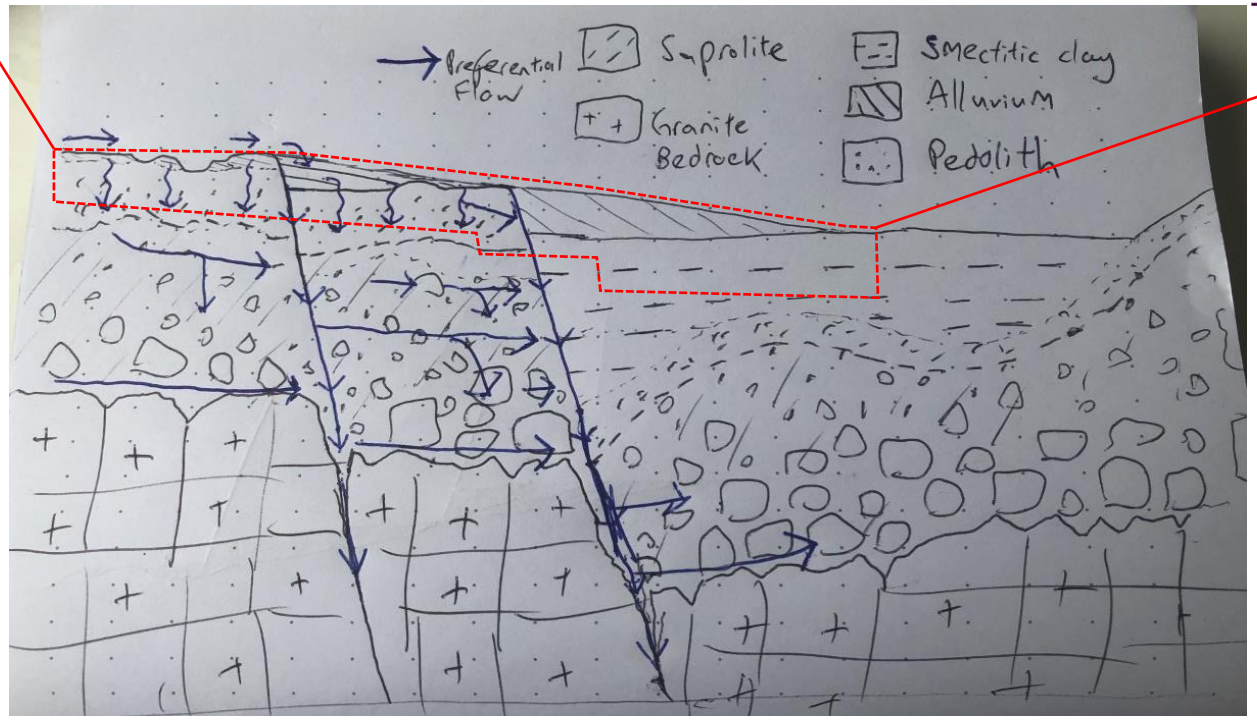
Fault – From field observations

Fault – Inferred from DEM



Key

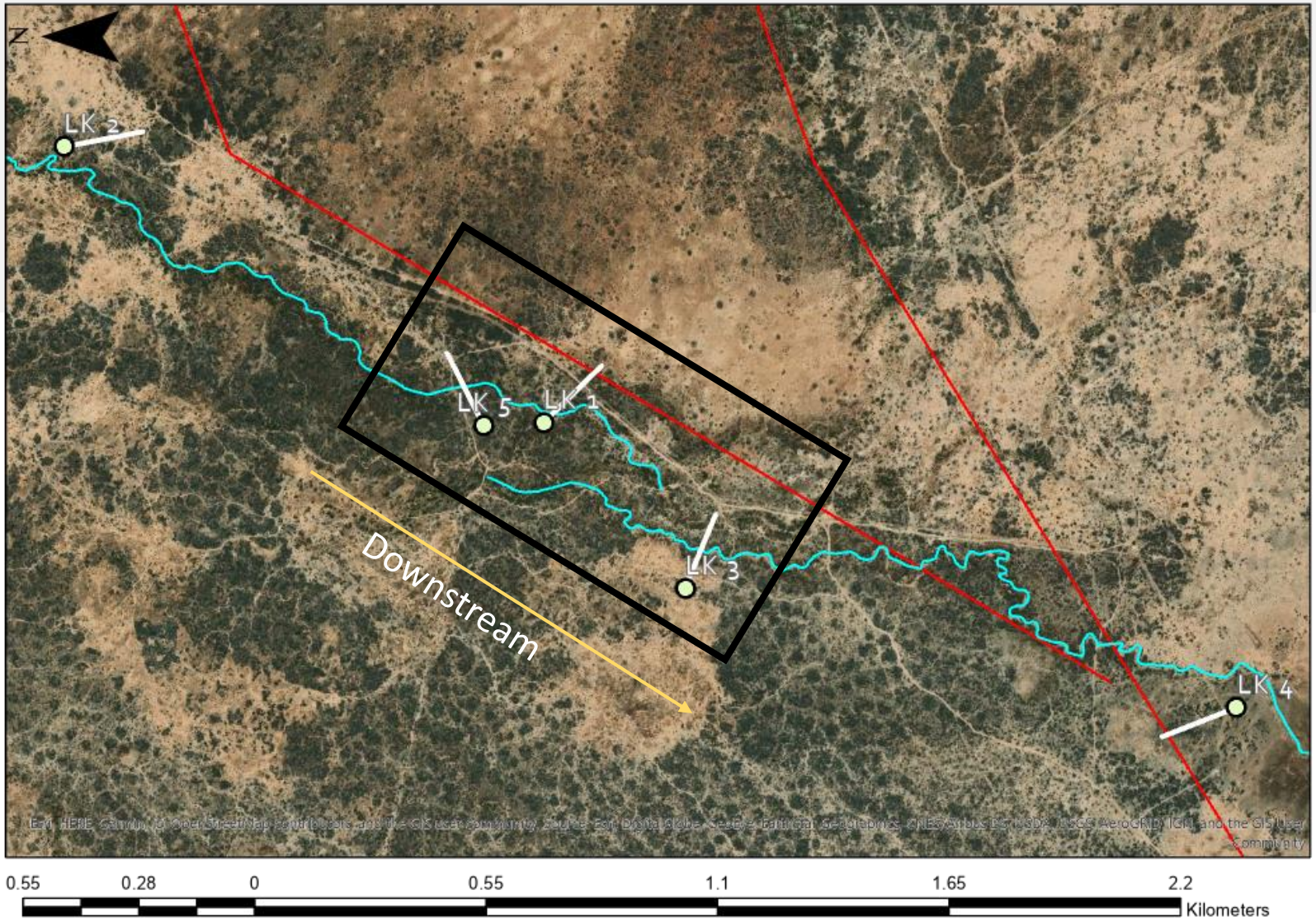
1. Weathered Saprolite
2. Permeable fractured zone
3. Superficial alluvial deposits
4. Pedolith
5. Smectite clay



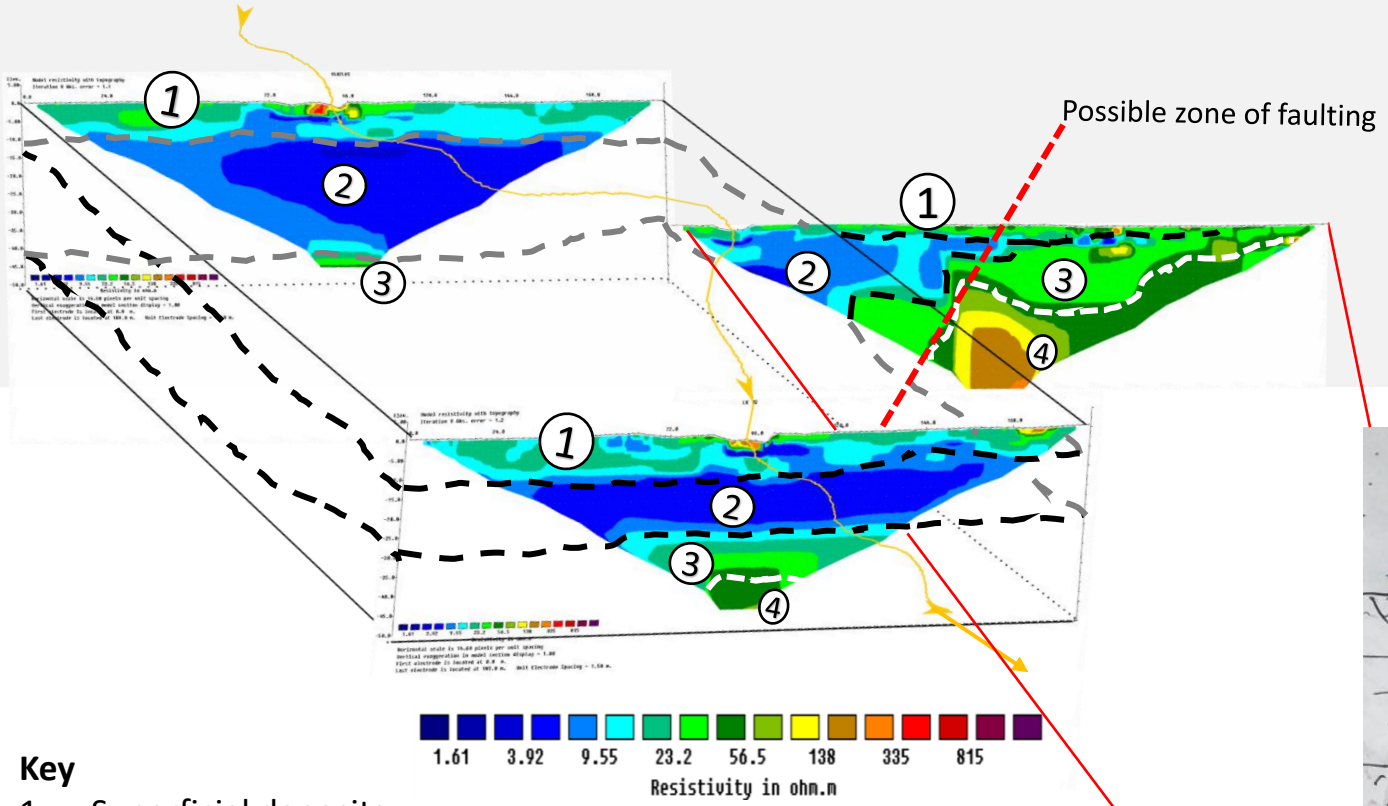
Conceptual Model 1

- Zones of active faulting provide **permeable pathways** enabling greater recharge to occur
- Superficial sand deposits may act as **collectors and stores** that **slowly feed recharge** into these fault zones

LK ERT Sections



LK Sections

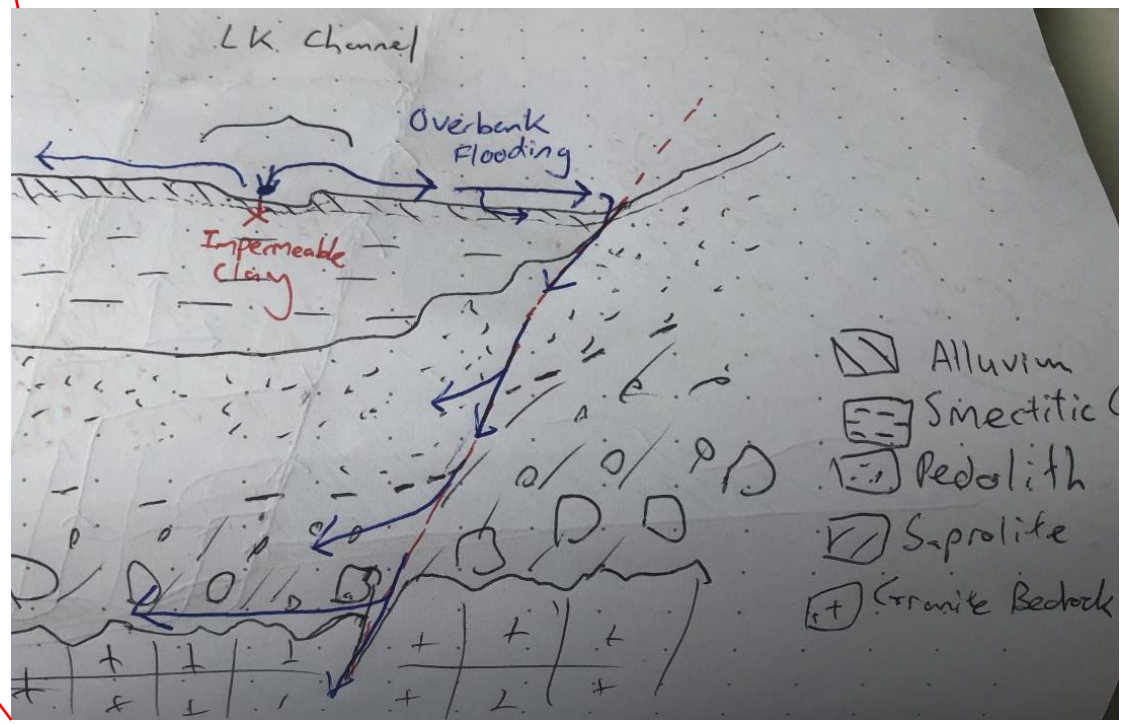


Key

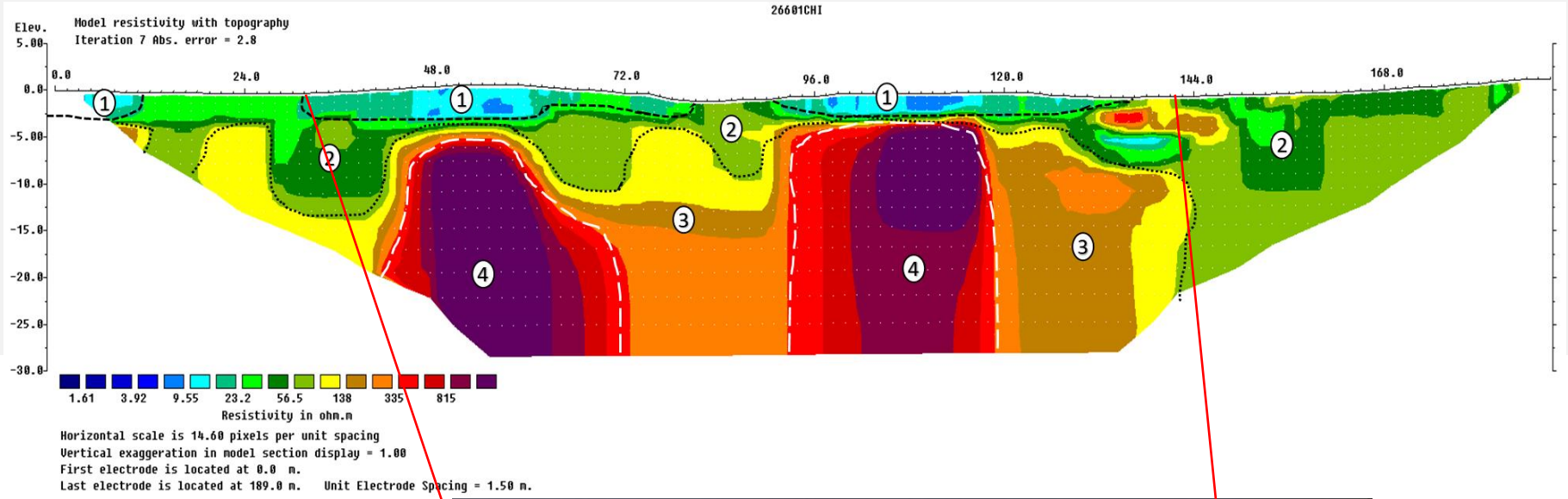
1. Superficial deposits
2. Smectite clay
3. Pedolith
4. Weathered Saprolite

Conceptual Model 2

- **Overbank flooding** during high intensity precipitation events inundating a greater area of the basin **increases the probability** of activating **permeable pathways**.

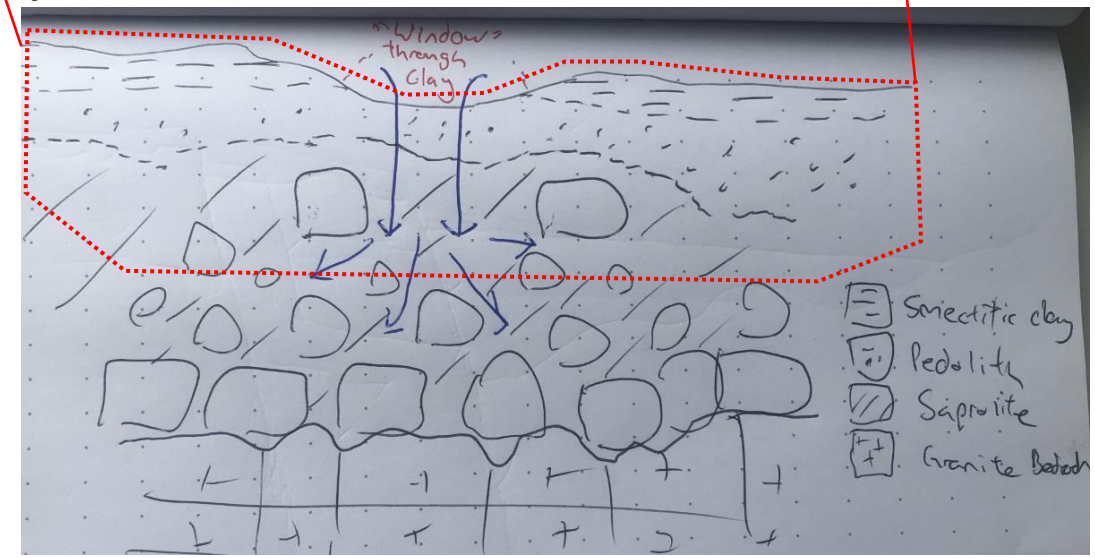


Chihanga Section



Key

1. Smectite clay
2. Pedolith
3. Weathered Saprolite
4. Weathered Granite



Conceptual Model 3

- **Windows** within layers of smectite clay **underlying ephemeral streams** may provide **pathways for focused recharge** via transmission losses

Summary

- Our results suggest that **configurations of superficial geology** may play a crucial role in controlling patterns, rates and timing of groundwater recharge in drylands
- Based on the geophysics, in conjunction with borehole logs, we develop conceptual models that hypothesize:
    1. Zones of active faulting **provide permeable pathways** enabling **greater recharge** to occur
    2. Superficial sand deposits may act as **collectors and stores** that **slowly feed recharge** into these fault zones
    3. **Windows within layers** of smectite clay underlying **ephemeral streams** may provide **pathways for focused recharge** via transmission losses
    4. **Overbank flooding** during **high intensity precipitation events** inundating a greater area of the basin **increases the probability** of **activating** such **permeable pathways**.
- This and future studies provide a physical basis to improve numerical models of groundwater recharge in drylands, and a conceptual framework to evaluate strategies (e.g. Managed Aquifer Recharge) to artificially enhance the availability of groundwater resources in these regions.