Numerical modeling for groundwater management and protection - The case of the Nyanzare well field in Gitega, Burundi

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B 2.3 Groundwater Resources

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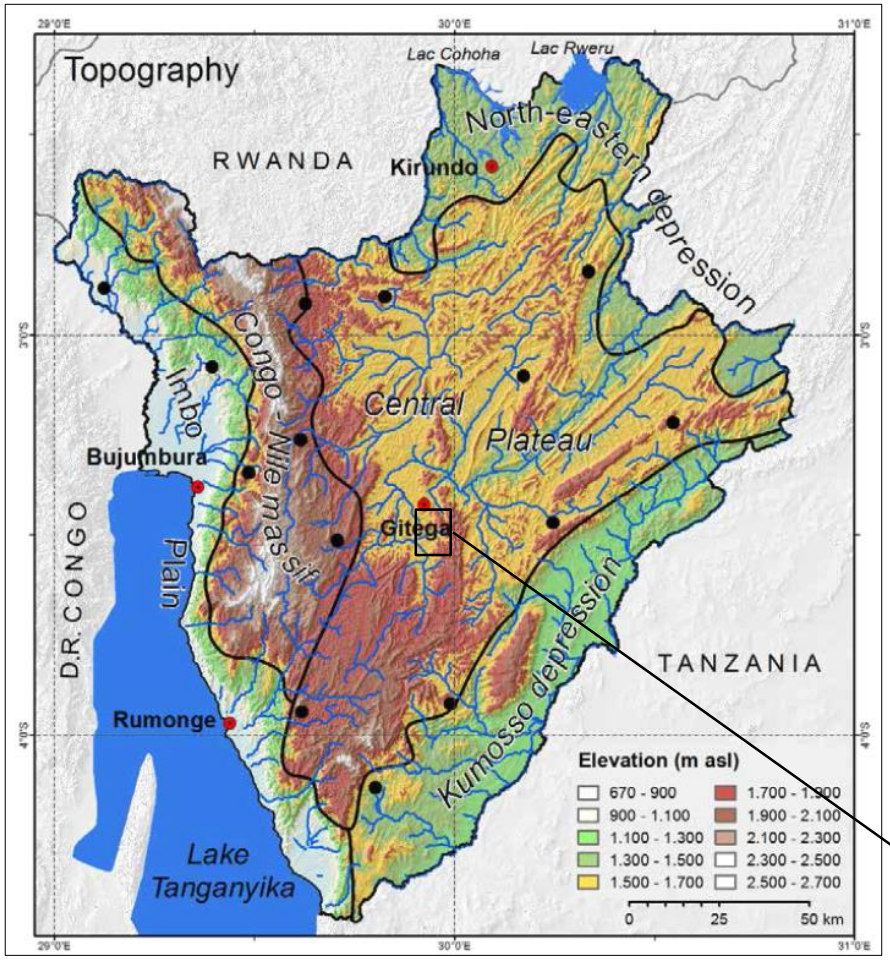
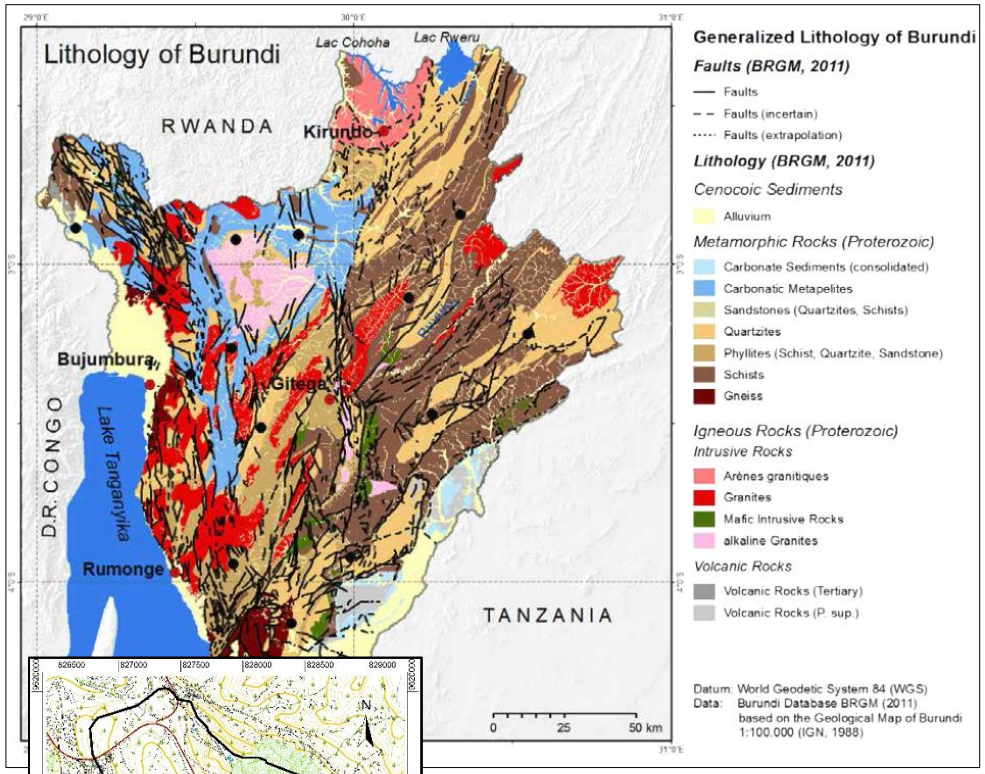
Context

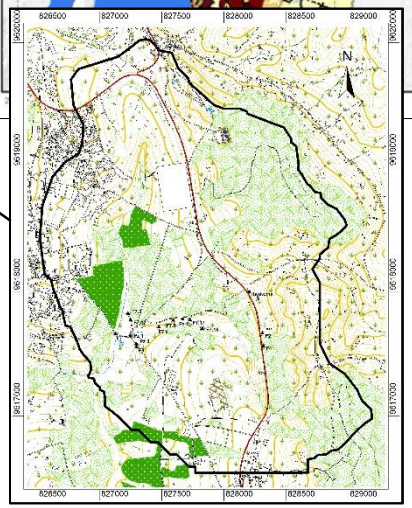
Cooperation Project “Management and Protection of Groundwater Resources in Burundi” (GPES) of the BGR and the Institut Géographique du Burundi (IGEBU)

- One of the main objects: Assistance for setting up protection zones of the Gitega city water supply catchment
- Specific objectives of this study are:
  - Estimation of groundwater resources
  - Estimation of groundwater flow velocities
    - ➢ Evaluate travel times for protection zones
  - Provide a well field management tool
    - ➢ Project the aquifer response (water levels) to management alternatives
    - ➢ Predicting the response to stress (reduced recharge, increased withdrawal)

Study area

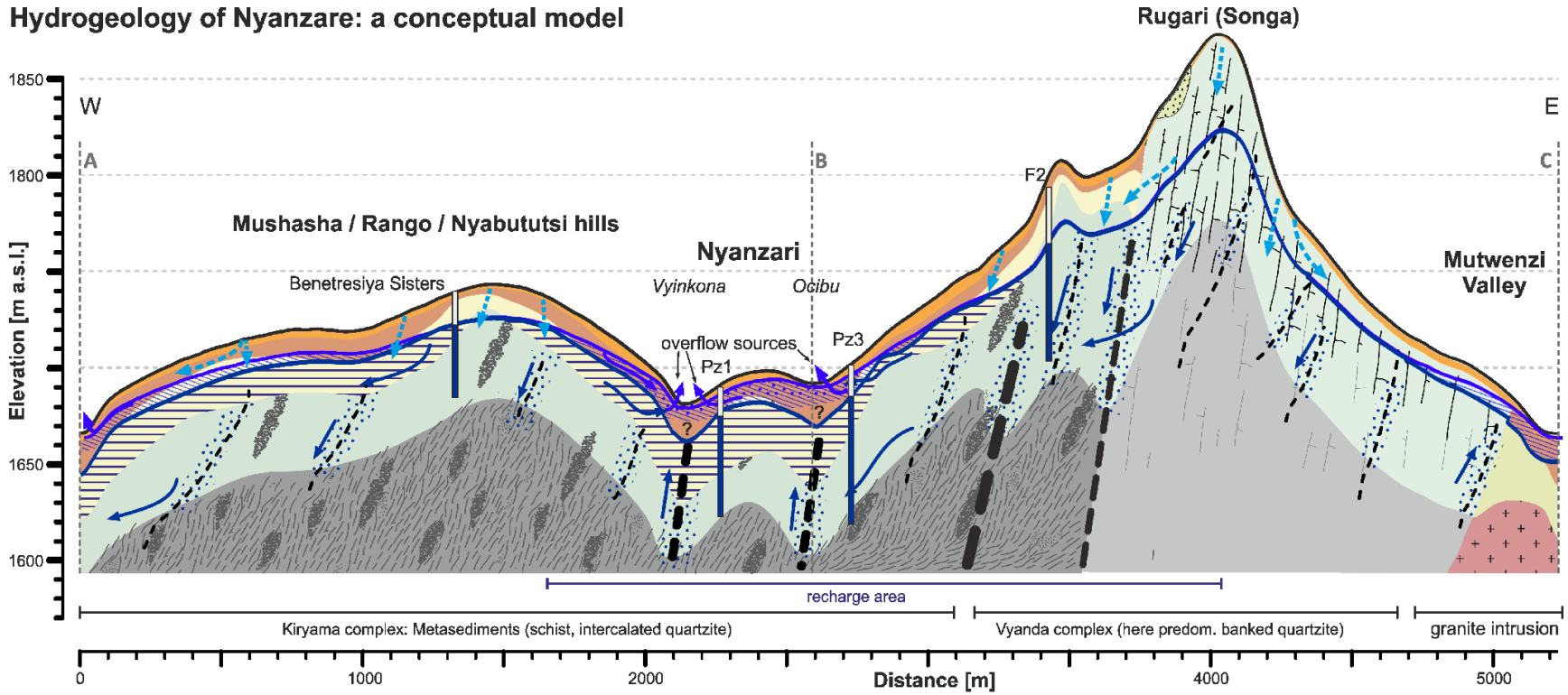




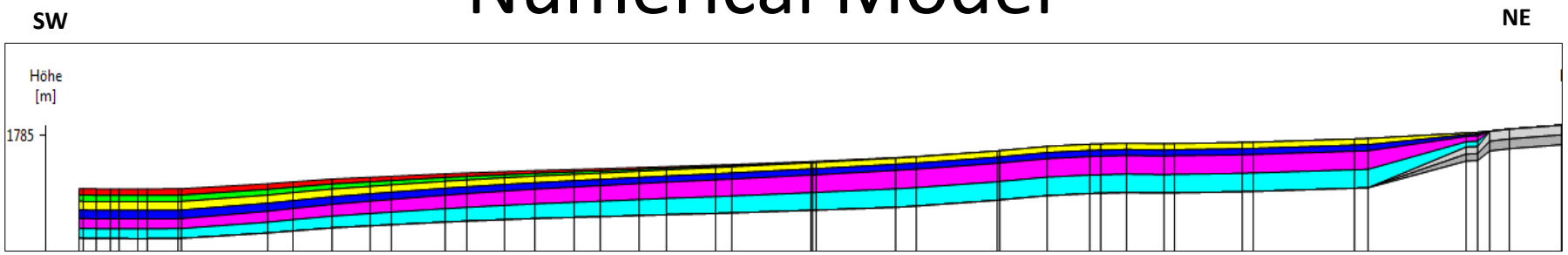


Model area of the Nyanzare valley

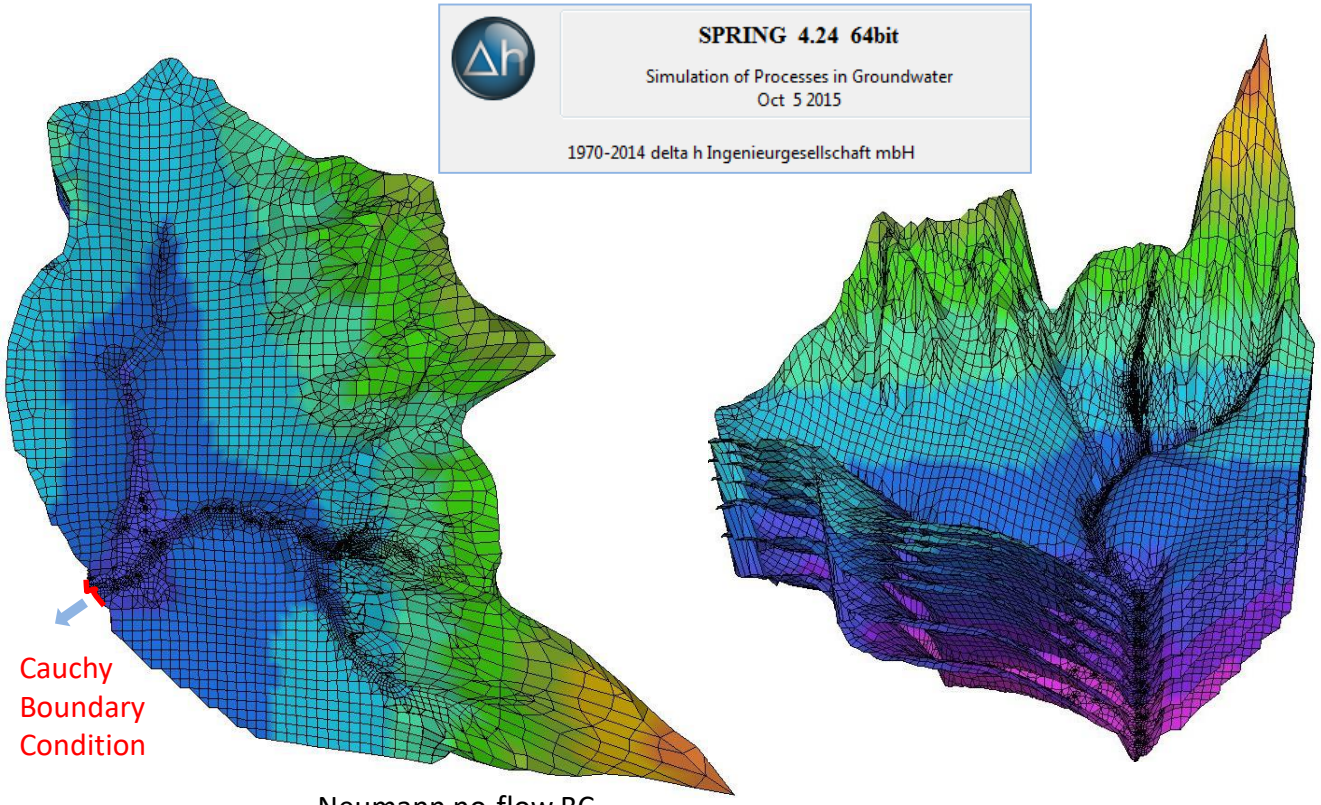
Conceptual Model



Numerical Model



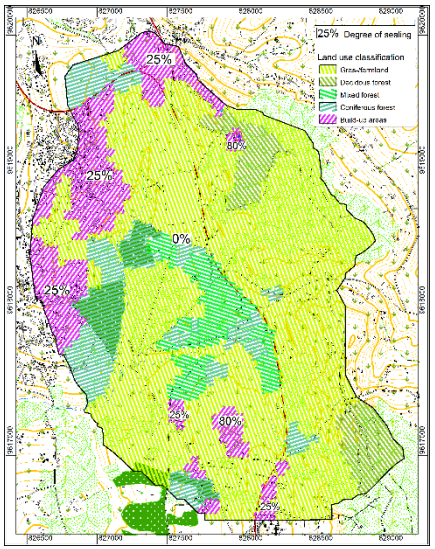
- 6.1 km²(3.4 x 2.4 km)
- 4 lithological units transferred into 8 grid element layers
- 6734 elements per layer (triangles & rectangles)
- Grid refinements around wells and tectonic features (valleys)



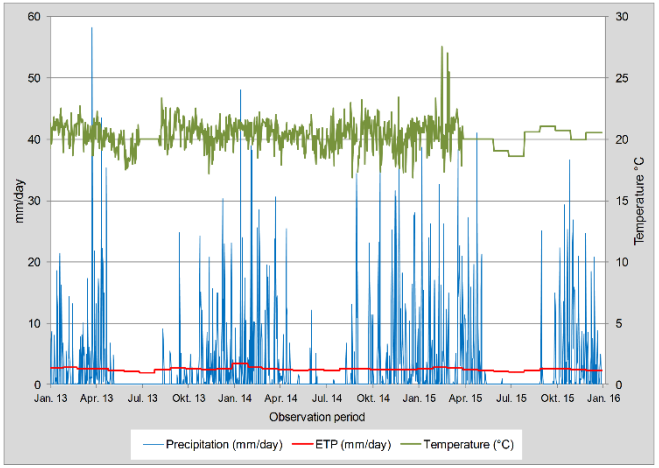
Transient GW Recharge

Method: Soil water balance

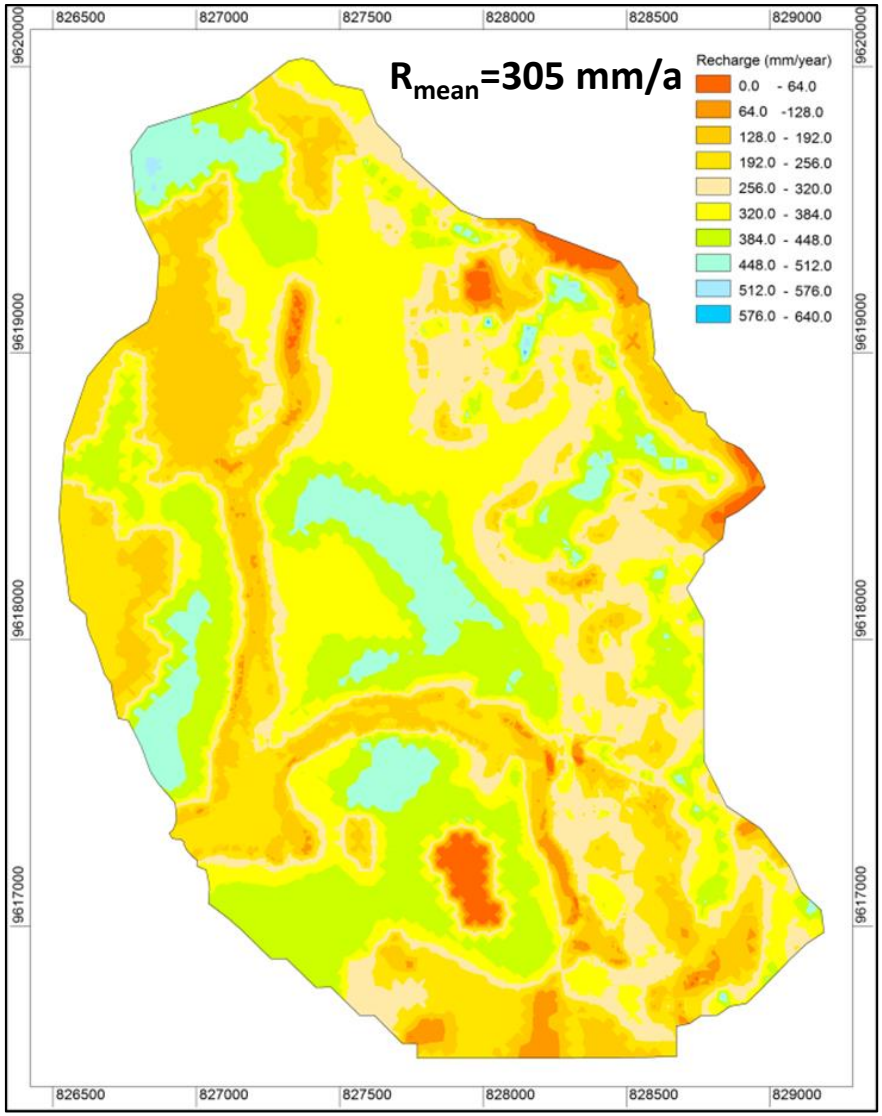
- Spatial data
  - DEM → relief energy (surface runoff based on Schroeder & Wyrwich)
  - Initial hydraulic heads (depth to water table, capillary rise)
  - Soil type
    - Field capacity
    - Permanent wilting point
  - Land use
    - Effective root depth (farm-/grassland, forests)
    - Degree of sealing (build up areas)

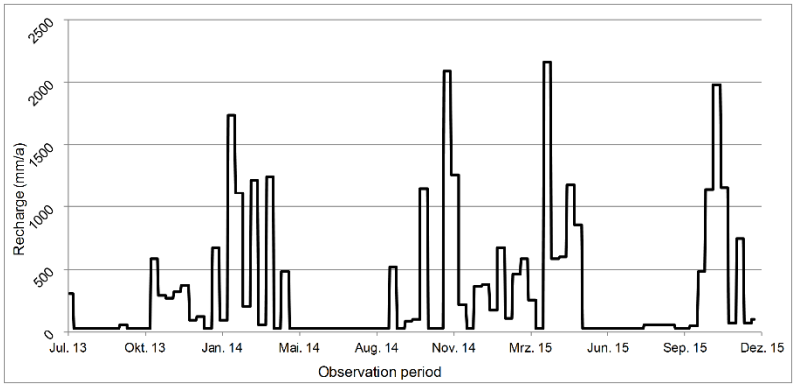


- Transient climate data:
  - Precipitation
  - Temperature (T)
  - Potential Evaporation (ETP):
    Thornthwaite (1948) based on temperature and latitude

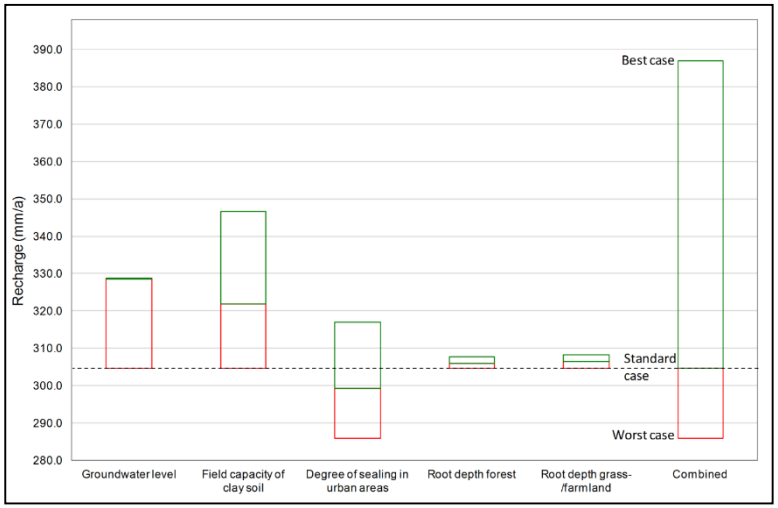


Transient GW Recharge





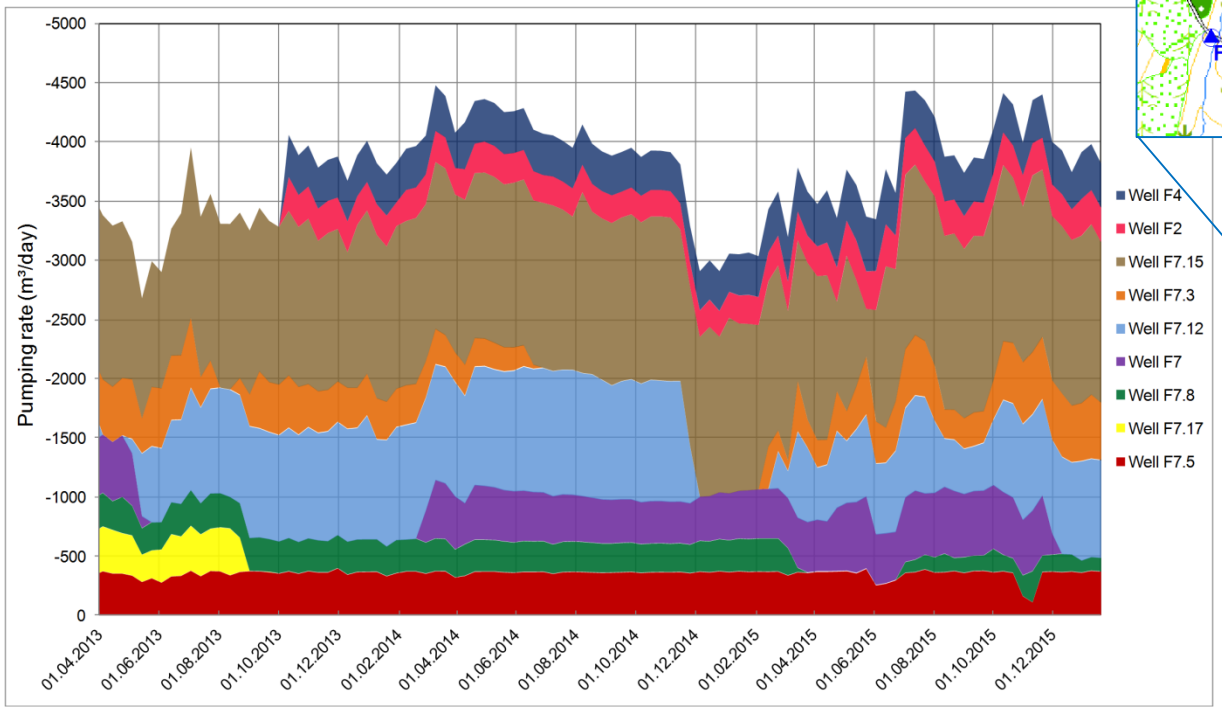
Variation of recharge in time

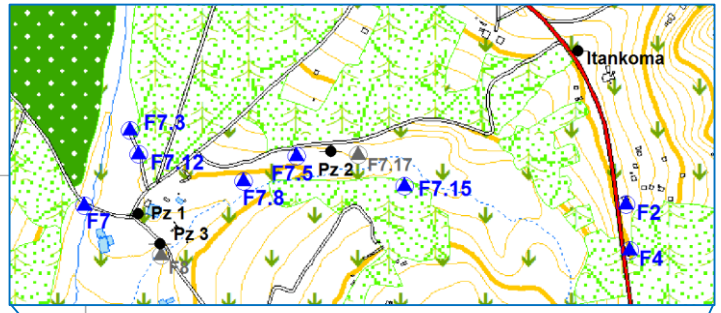


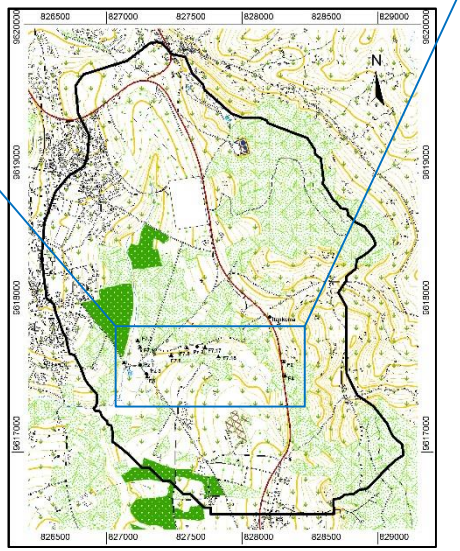
Sensitivity analysis

Pumping Wells

Pumping rates during observation period (01.2013 – 01.2016)



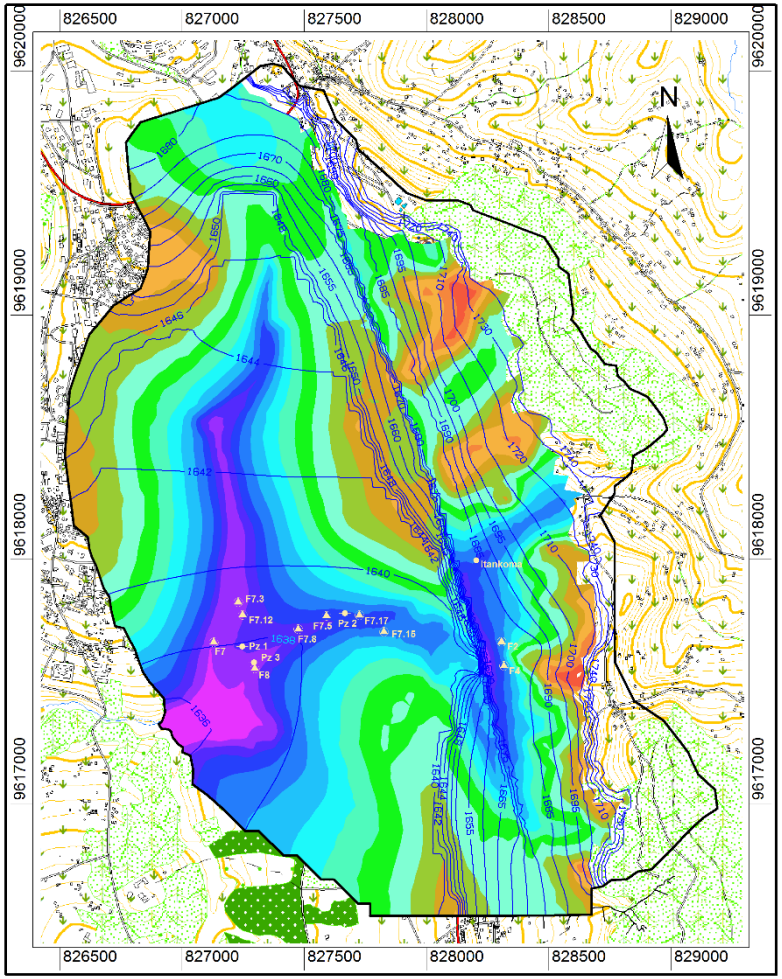




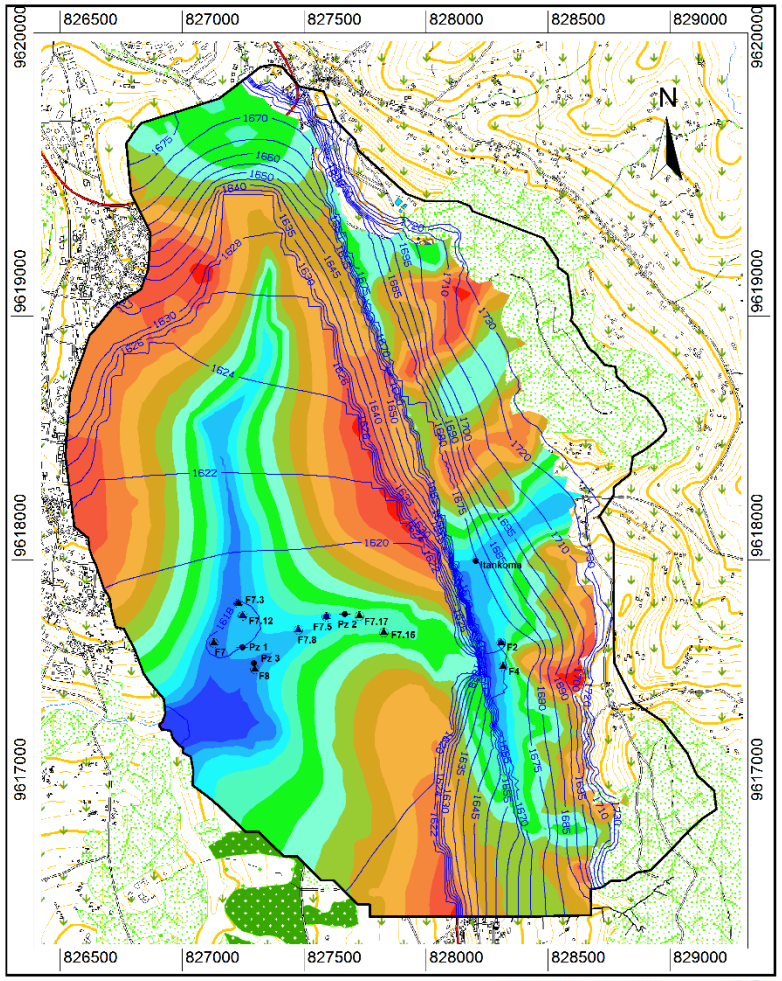
- Withdrawal of 4000 m³/d
- Frequent interruptions

Steady-state Calibration

Pre-pumping



Post-pumping



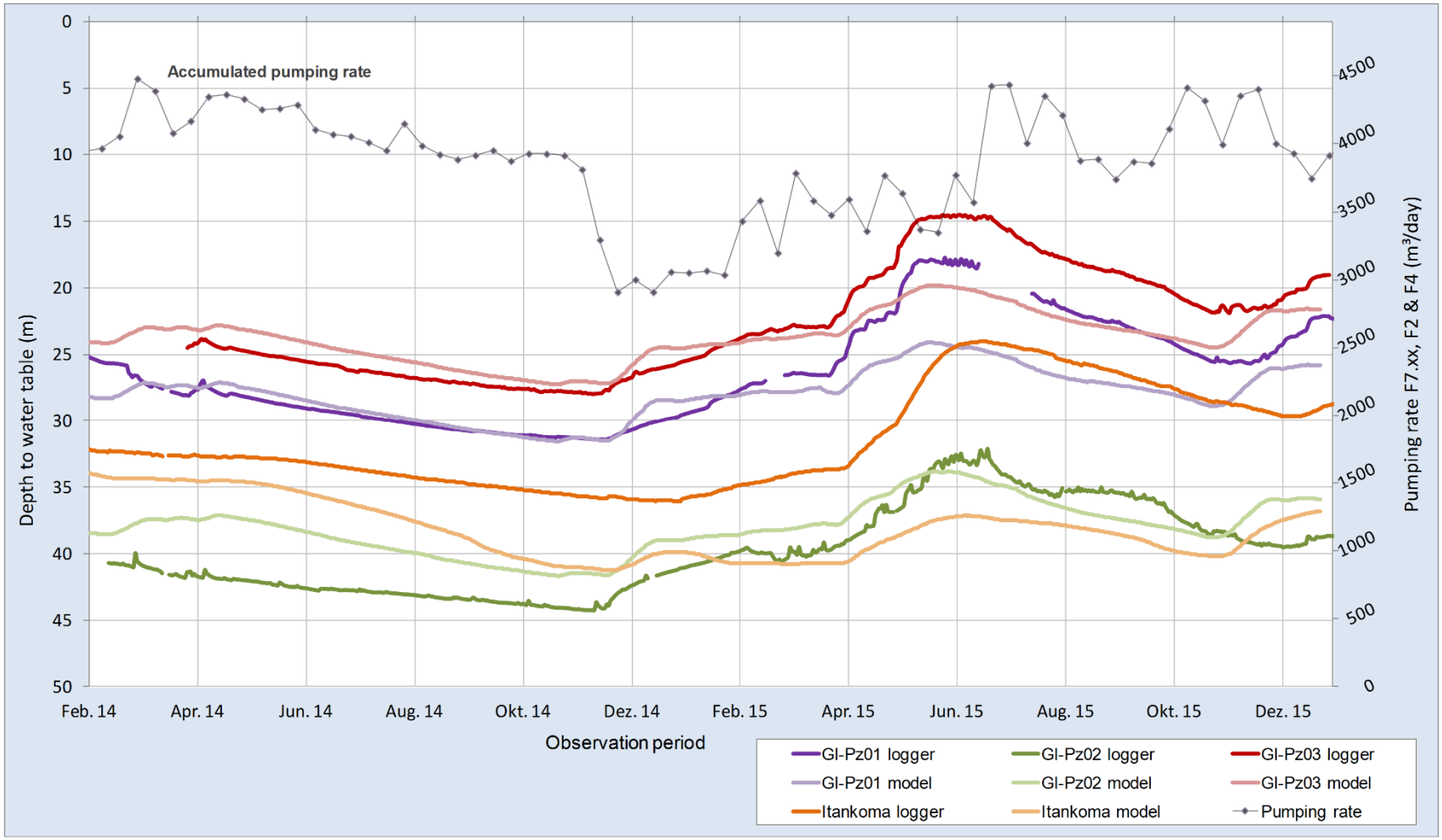
LEGEND

Depth to water table (m)

- 6.0 - 12.0
- 12.0 - 18.0
- 18.0 - 24.0
- 24.0 - 30.0
- 30.0 - 36.0
- 36.0 - 42.0
- 42.0 - 48.0
- 48.0 - 54.0
- 54.0 - 60.0
- 60.0 - 66.0
- 66.0 - 72.0
- 72.0 - 78.0
- 78.0 - 84.0
- 84.0 - 90.0

Hydraulic head (m)

Transient Calibration



Calibration of Hydr. Parameters

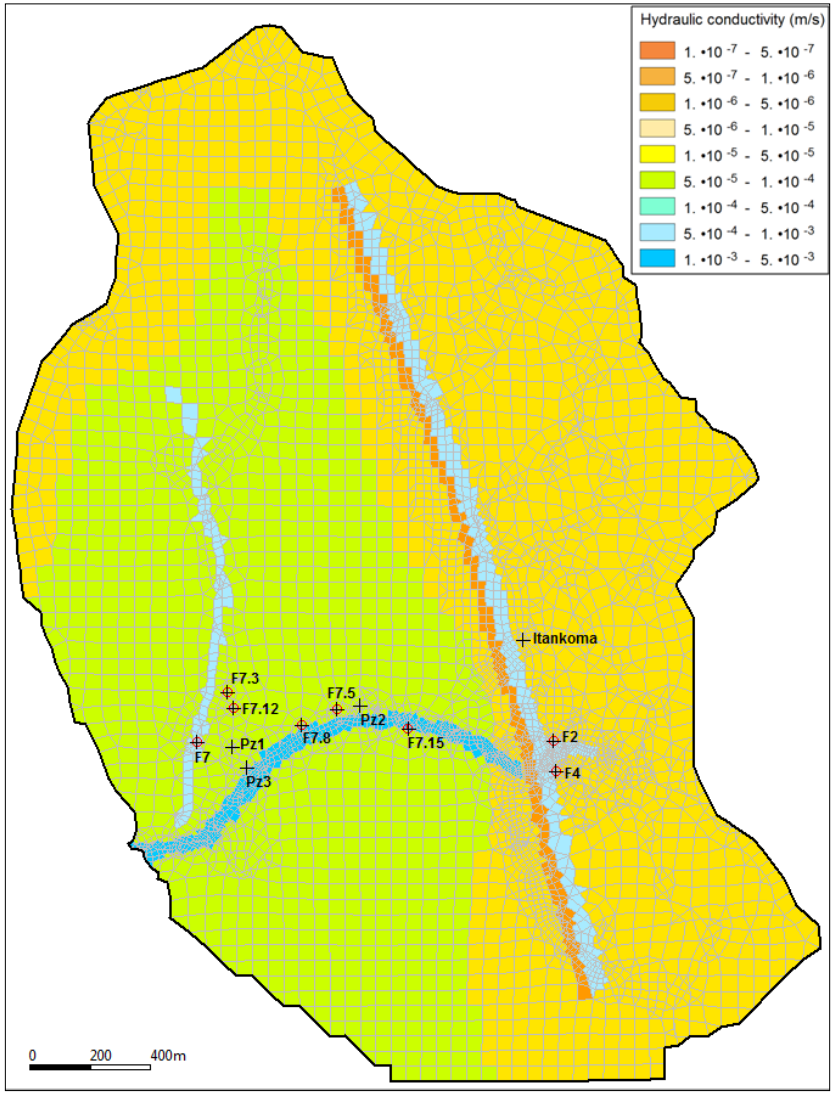


Table 4: Hydraulic parameters resulting from calibration

Zone/Lithology	Differentiation	Hydraulic conductivity K (m/s)	Anisotropy K_H/K_V	Effective Porosity (-)
Clay zone	-	5.0E-07	10	0.03
Schist saprolite	Valley / low slope	1.0E-05	10	0.04
	High slope area	1.0E-06		
Fractured schist saprock	1st order valley lineament	3.5E-03	1	0.04
	2nd order valley lineament	5.0E-04		
	Valley / low slope	9.0E-05		
	High slope	1.0E-06		
	Fault zone (conduit vs. barrier)	5.0E-04; 1.0E-07		0.04
Fractured quartzite saprock	-	1.0E-06	10	0.04

- Highly differentiated aquifer
- Lineaments determine flow field
- Identification of a fault (F2, F4)

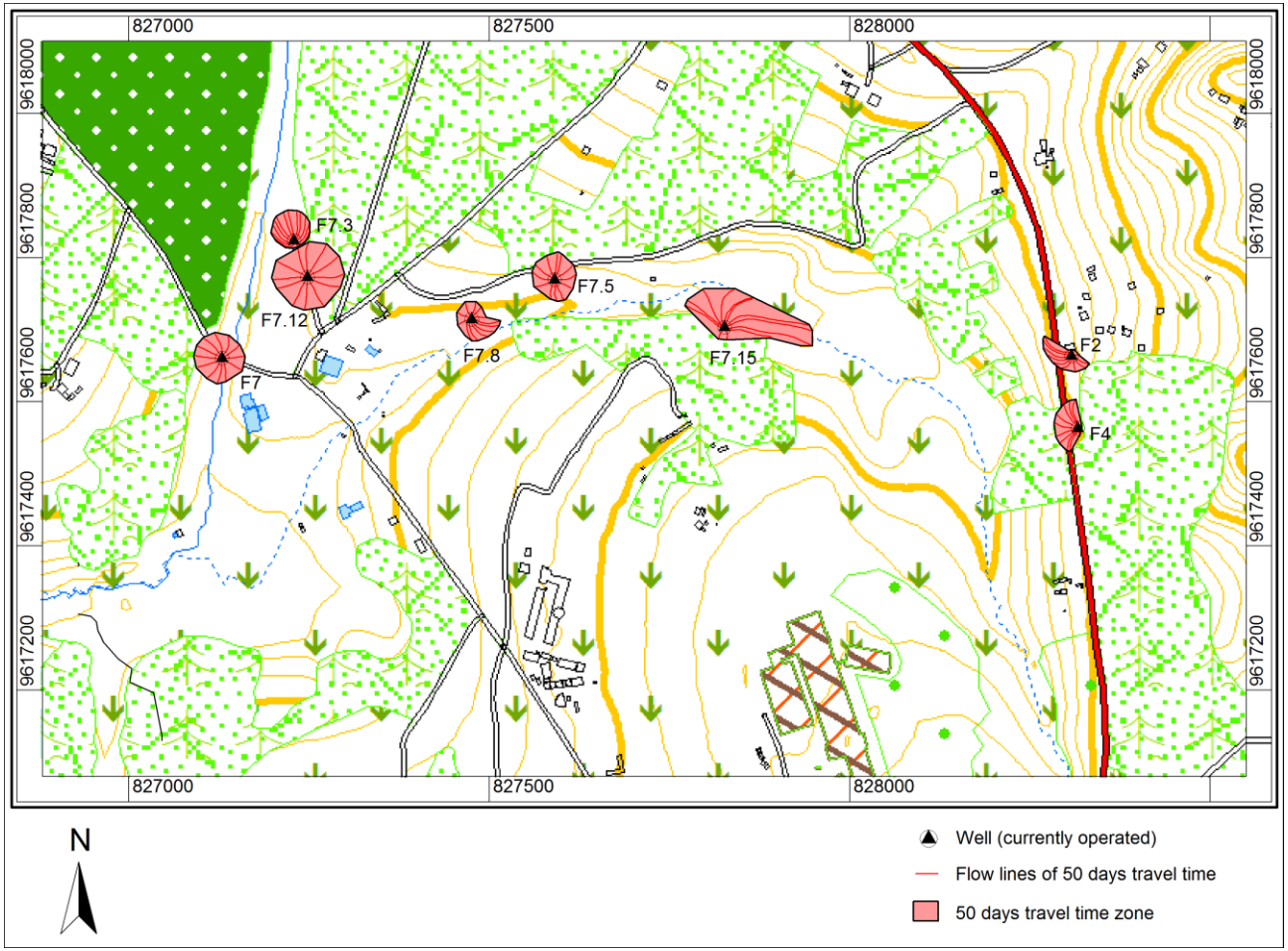
Protection Zones

<u>50-day isochrones</u>

Protection Zone 2:

- Prevents contamination by pathogens and other degradable substances

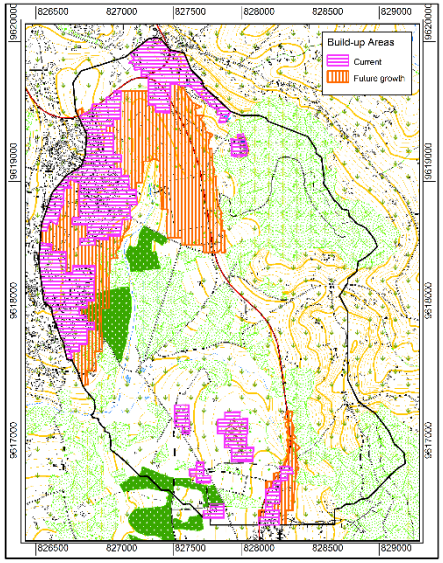
Result: ~ 50 m distance
125 m for F7.15



Future Scenarios

1. New well
   - Demand of Gitega city is still rising
   - Well F7.17 had technical problems, but high transmissivity
   - Adding a pumping rate of 1200 m³/day combined with continuing withdrawal of the other wells, exceeds mean recharge

2. Expansion of Urban Areas
   - Affecting recharge due to changes in land use towards more sealing and therefore less infiltration
   - Anticipated city expansion would reduce mean recharge rates by about 10 %
   - Reduction of travel time between urban areas and well field from 5 years to 3 years



3. Less recharge due to climate change
   - Precipitation data of 2005 (33 % less than observation period)
   - **Recharge is reduced by almost 75 %**
     - ➢ Water supply for Gitega cannot be preserved

Conclusion & Recommendations

- Numerical groundwater model was successfully calibrated on measured head values. It allows for:
  1. Characterisation of the aquifers hydraulic parameters (conductivity, eff. porosity)
  2. Estimation of groundwater recharge
  3. Identification of Protection zones for drinking water wells

- Indications were found for a hydraulically effective fault near the wells F2 and F4
  - ➢ Geophysical investigations and tracer tests needed for a better identification

- Recent pumping capacities of the existing wells already reach the limit of water availability in the catchment
  - Frequent technical malfunctions in the past have preserved the aquifer from larger water level decline
  - Low storativity of the aquifer
    - ➢ Unsustainable use cannot be maintained for a long time

Conclusion & Recommendations

- Future developments carry risks of an unsustainable use of the aquifer
  - An additional well is not recommended
  - If a series of low precipitation years occurs:
    - Recharge will be dramatically reduced
    - Pumping rate of the well field must be reduced accordingly to avoid drying out of the pumps
  - Expansion of build-up areas will result in:
    - Reduction of groundwater recharge & water availability
    - Reduced travel times of anthropogenic contaminants towards the drinking water wells

- Groundwater model can be updated and improved on future data

Many thanks for your attention!

Further details on the BGR homepage:

http://**www.bgr.bund.de**/EN/Themen/Wasser/Projekte/laufend/TZ/Burundi/burundi_fb_en