Simulating groundwater level fluctuations in the Quaternary aquifer of Bamako, Mali

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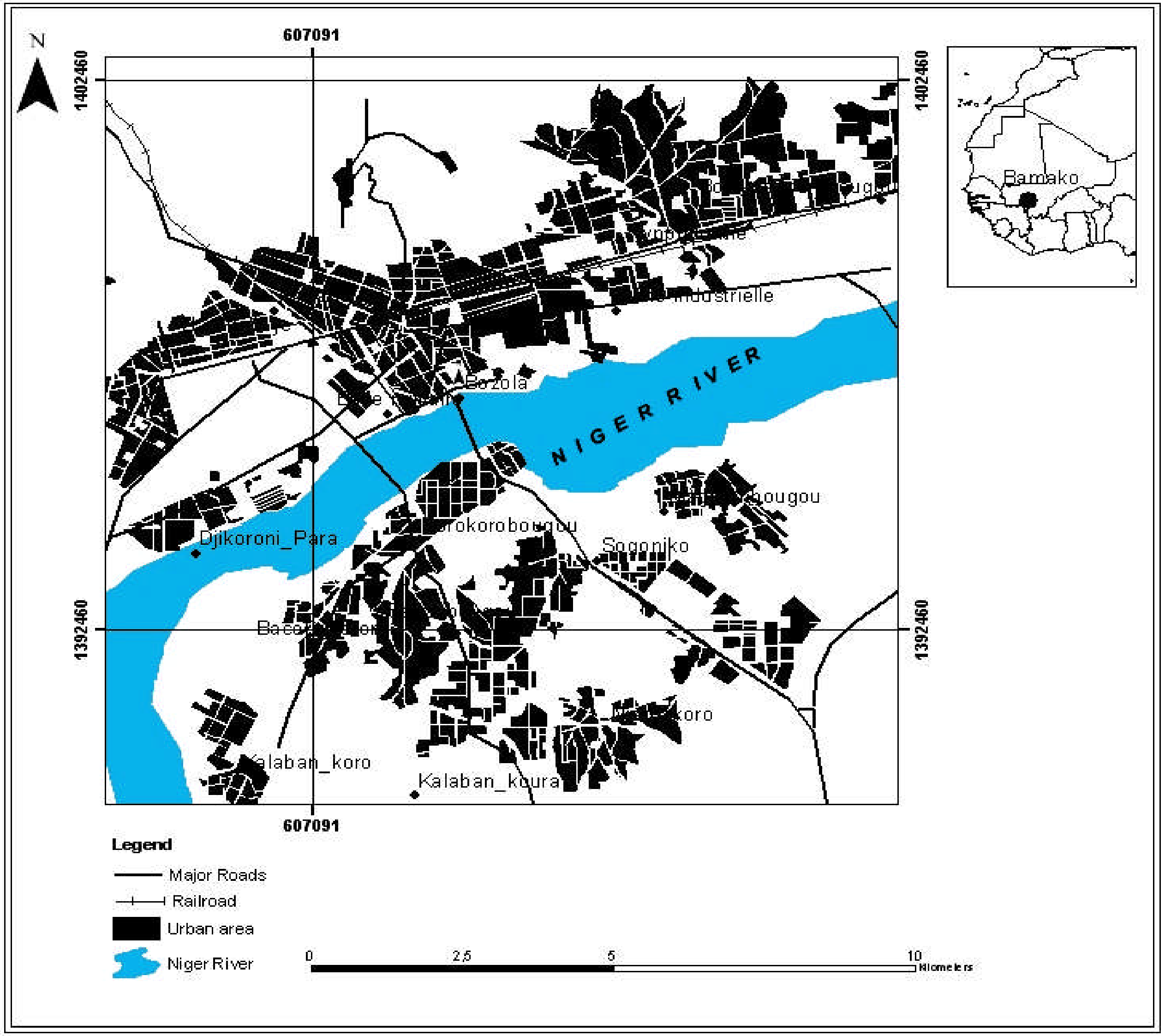
- Pollution and contamination of the quaternary aquifer in Bamako has been discussed in many fora but with respect of groundwater flow , characterizations have been limited to piezometric maps. Increased evapotranspiration demand under warmer temperatures serves to reduce the groundwater recharge rate.

Objectives

- Simulating groundwater flow of the quaternary aquifer of Bamako
- Prediction of water level fluctuations over the time

Introduction



Map of Bamako

- **Bamako, capital city of Mali is located in the valley of the Niger River. It occupies an area of approximately 400 km2. The city developed out on the left and right banks of the Niger River , near the sandstone hills dated from the late Precambrian which dominates the city over more than 100 m in elevation.**

Water Supply

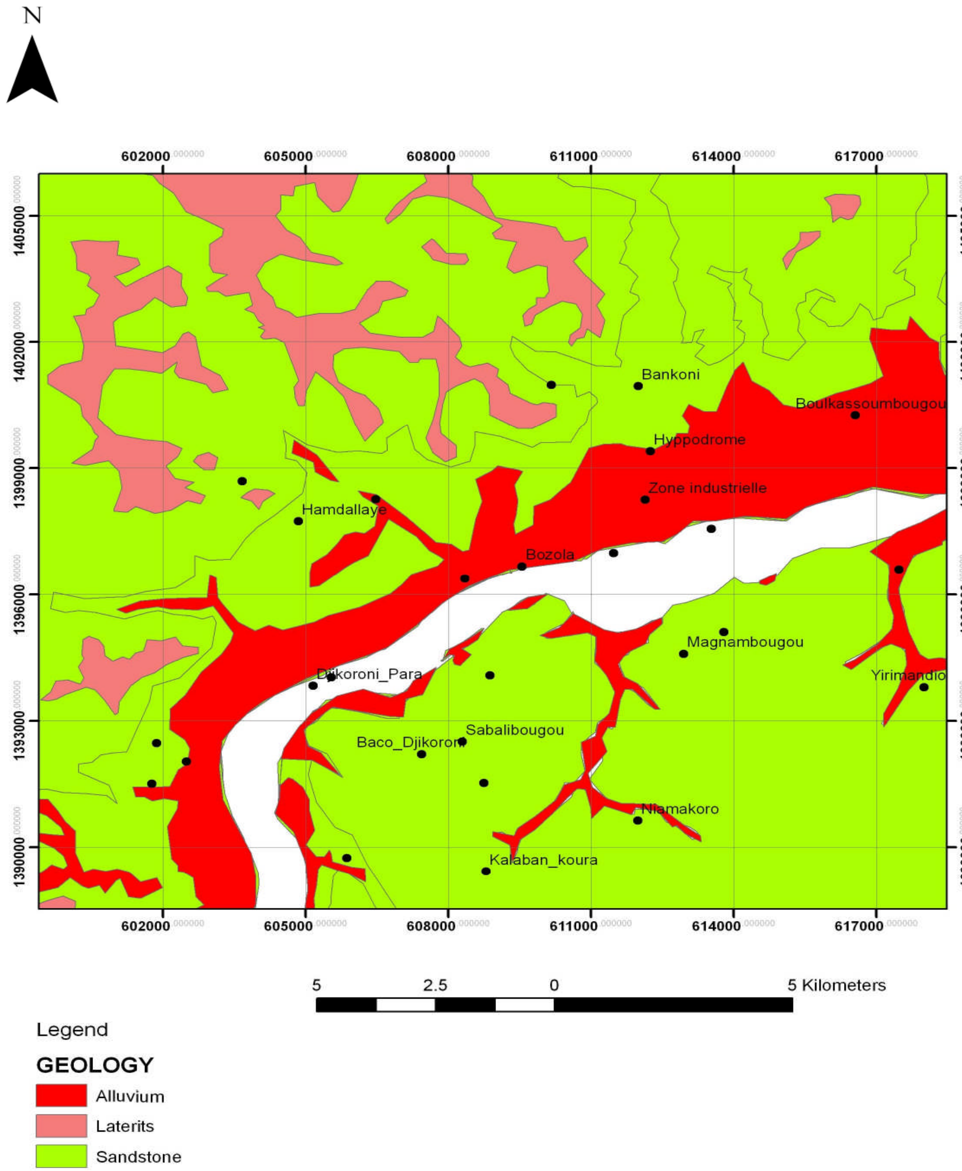
- The water supply of Bamako City is assured by the National Company of Water Supply which treats and distributes water from the Niger River. But with the extension of the City only 60% can access this water. The remaining part uses water from deep aquifers trough boreholes or from shallow wells.

Geology

- **The geology is essentially represented by sandstone which constitute the bedrock of quaternary lateritic and alluvium deposits.**
- **Dolerites are injected through the wide range of faults of the bedrock**

The principal directions of fractures are:

- **N 110°-N140°; N 0°-N20°, N 80°-N100°, N 30°-N70°and N 150°-N170°**



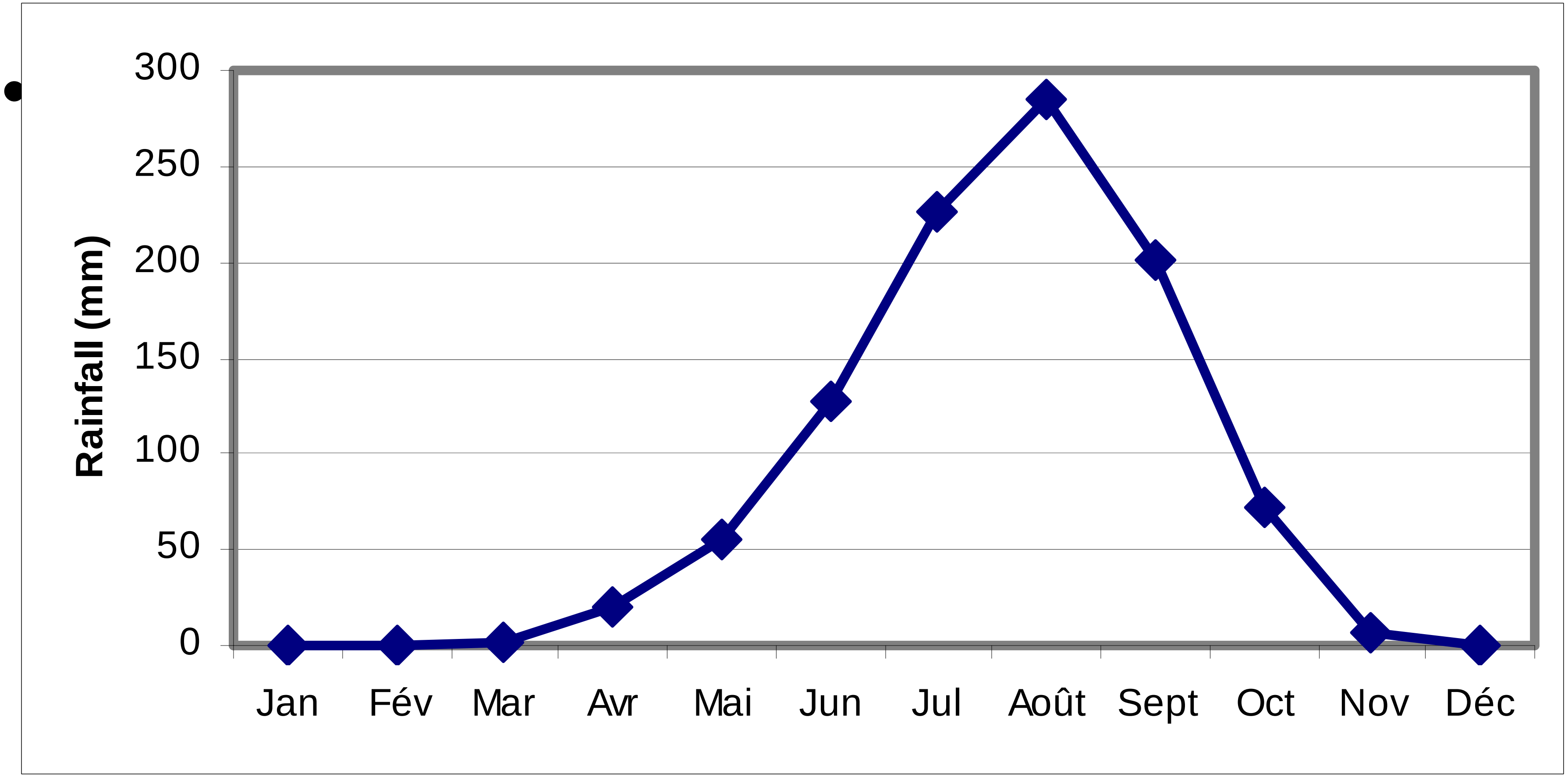
Hydrogeology

- **The Hydrogeological conditions are directly related to the geological and tectonic structure of the area. Therefore two aquifer compose the hydrogeology of the city area:**

Deep fractured aquifer in the fractured or fissured sandstone, the thickness varies from 10 to 100m .The hydrogeology of this aquifer is very complex. No reliable researches have been made on this aquifer. However it provides a great amount of safe drinking water through the deep boreholes specially in the peripheral areas of the city.

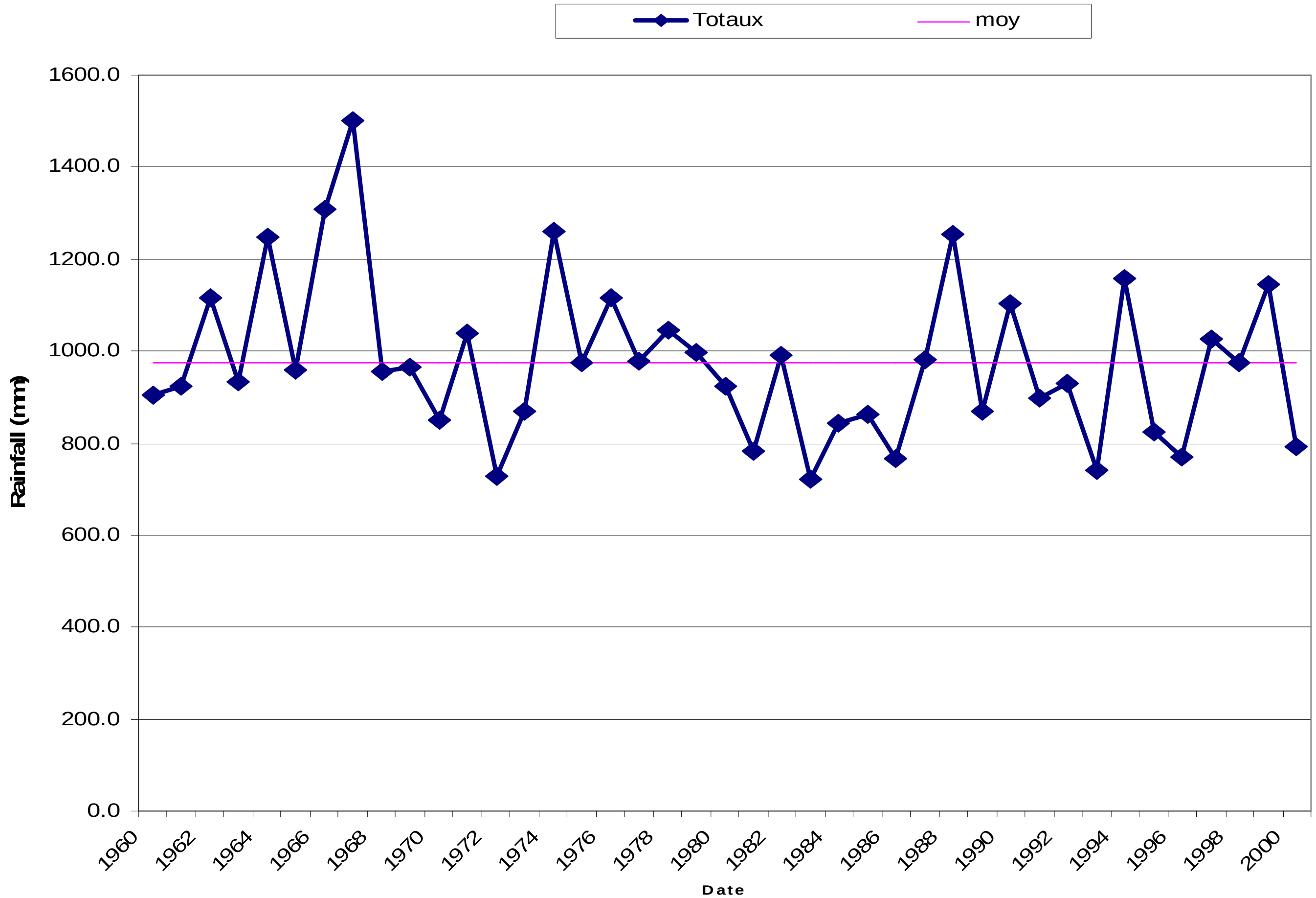
Quaternary water table aquifer with a thickness varying from 2 to 30m is constituted by laterits, alluvium, deposits. It is affected by seasonal fluctuations

Evolution of Rainfall in Bamako



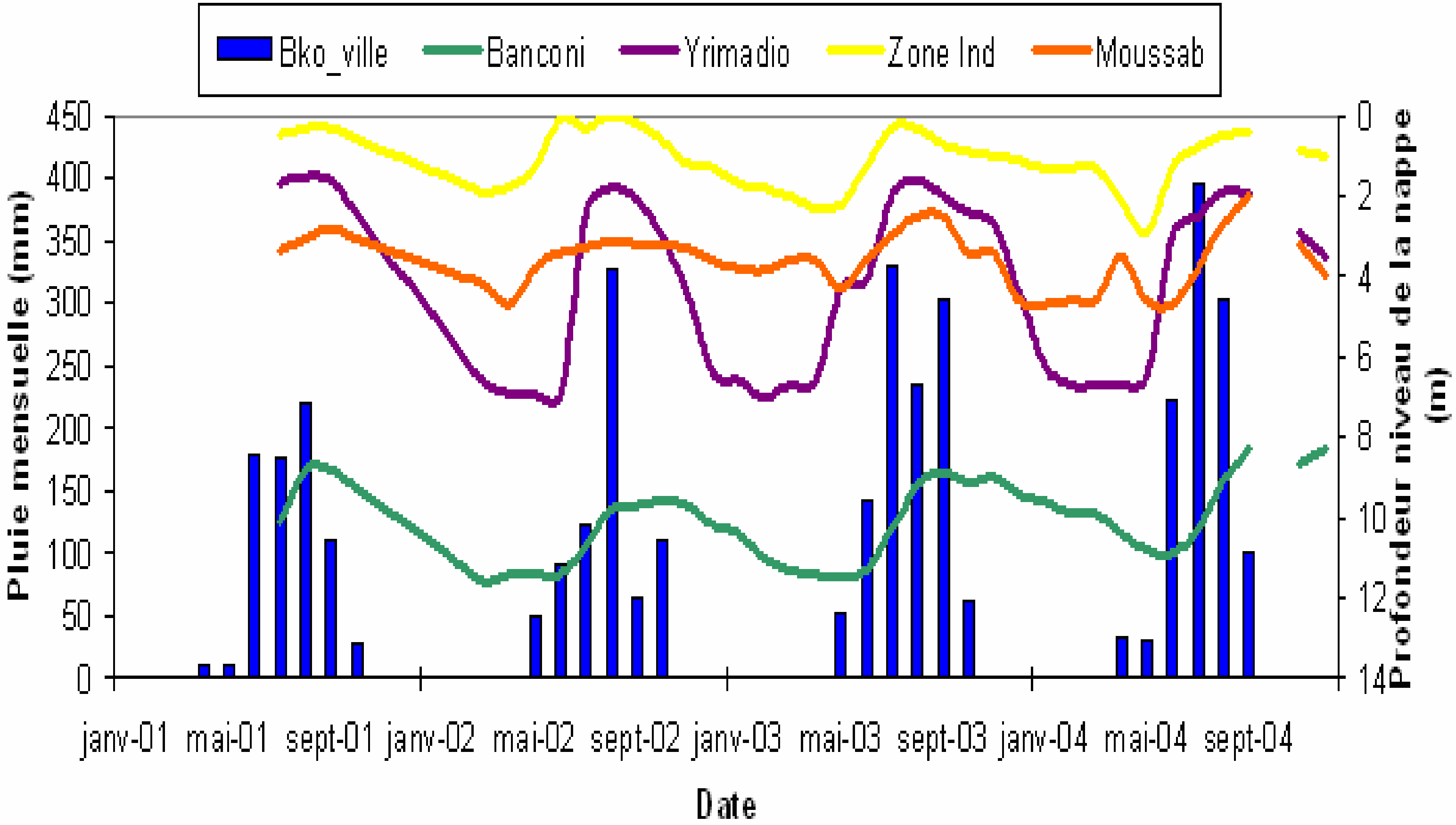
High values of rainfall are observed in July August and September

Annual Rainfall 1960-2000



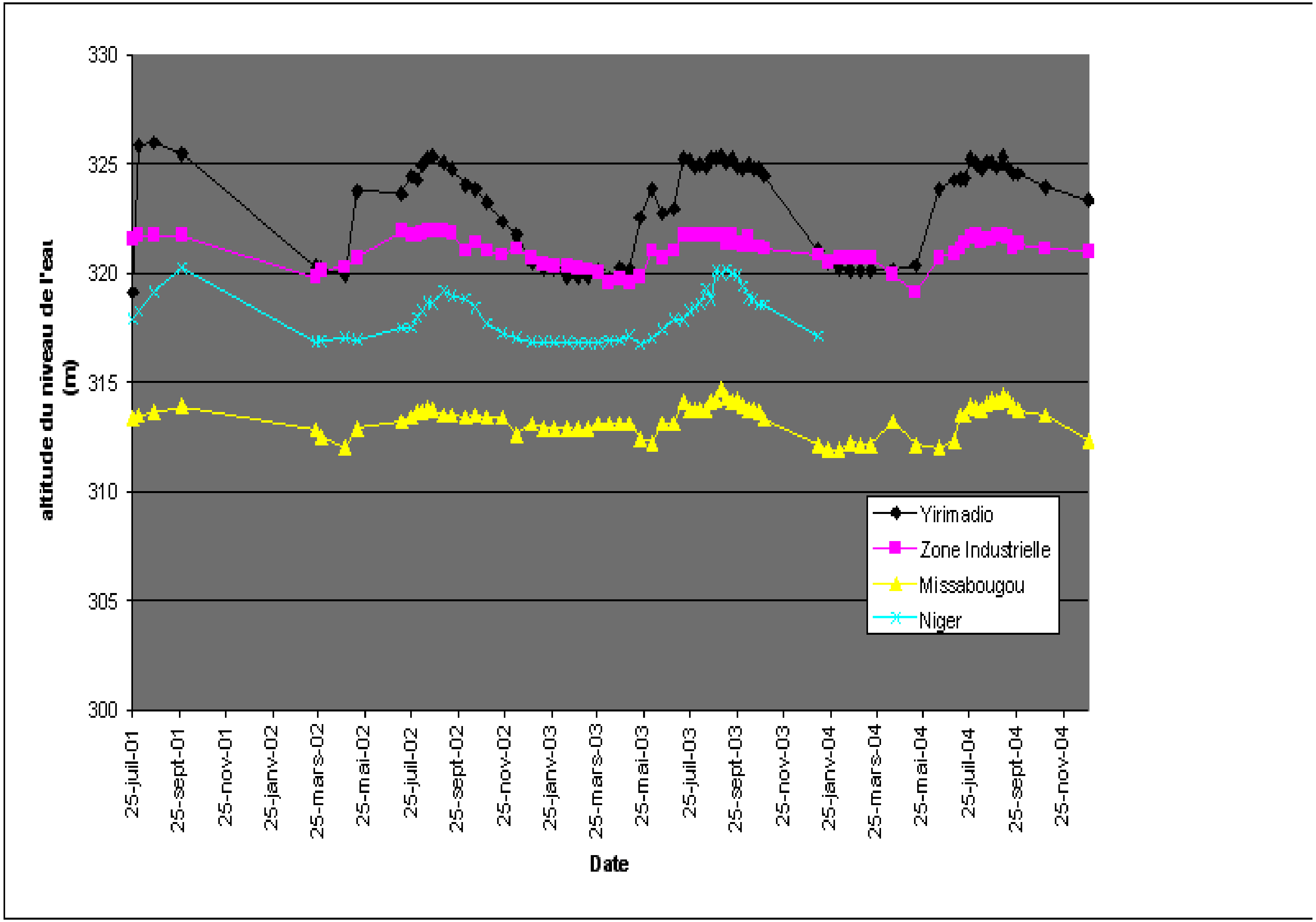
Decrease of mean annual rainfall over time

Evolution of water level in monitoring well with rainfall



Water level elevations in monitoring wells increase with rainfall

Evolution of water level and Niger River Height over time



Groundwater modelling

- Since modeling of fractures is beyond the scope of present study because it is complex and detailed field data on fracture geometry is required. Therefore, underlying fractured layer is excluded from the model. This is single layer case

Ground-Water Flow Equation

- **The partial-differential equation of ground-water flow used in MODFLOW is (McDonald and Harbaugh,1988)**

$$\frac{\partial}{\partial x}(-K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(-K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(-K_{zz}\frac{\partial h}{\partial z})-w=S_s\frac{\partial h}{\partial t}$$

where

Kxx , K yy , and K zz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

h is the potentiometric head (L);

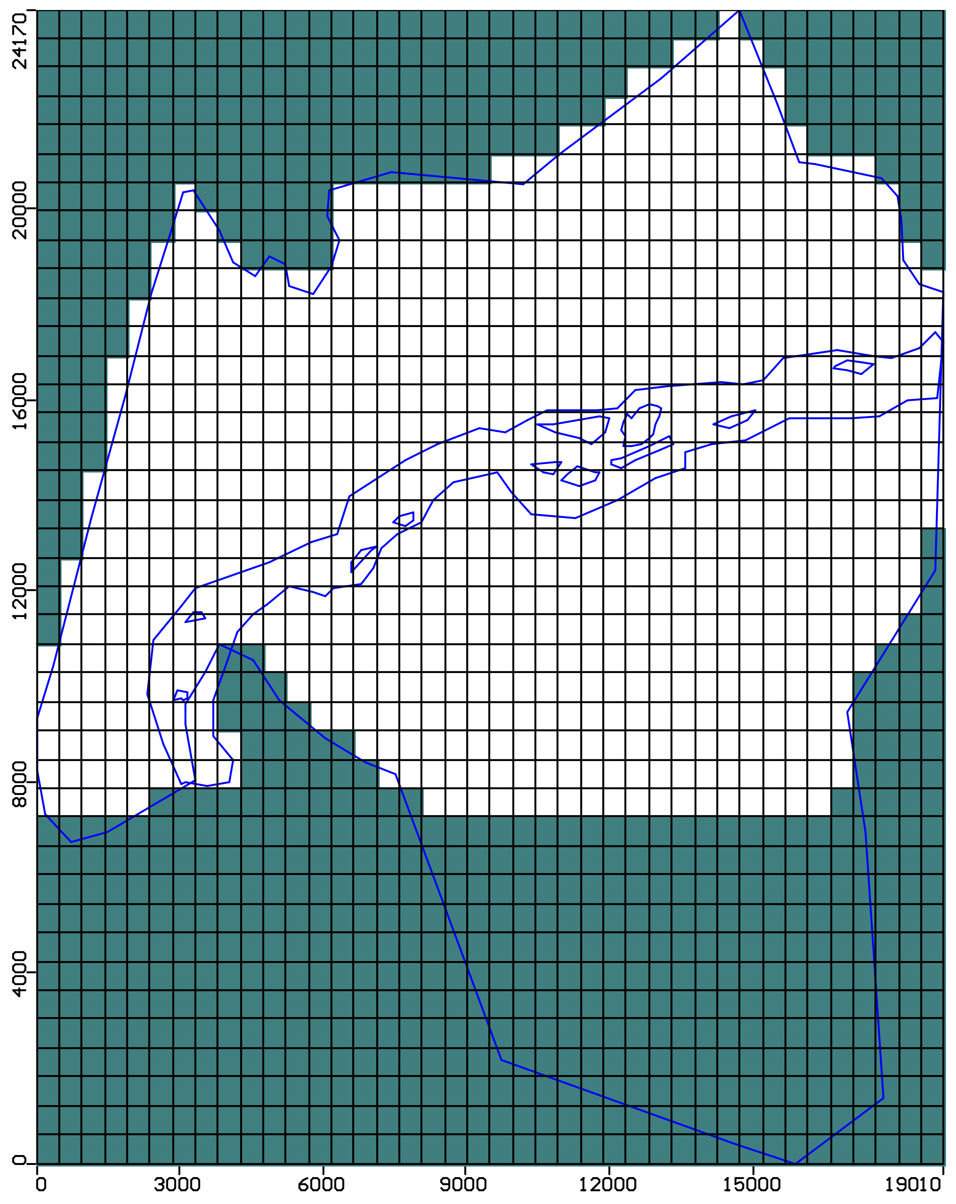
- **w: volumetric flux per unit volume represents source and /or sink of water**

Software used :Visual modflow

- Visual MODFLOW is a computer program based on USGS MODLOW code with pre and post processor. It simulates three-dimensional ground-water flow through a porous medium by using a finite-difference method. Groundwater flow within the aquifer is simulated using a block-centered finite-difference approach. The finite-difference equations can be solved using different solvers.

Modeled area

- Le modeled area include the build up area of City

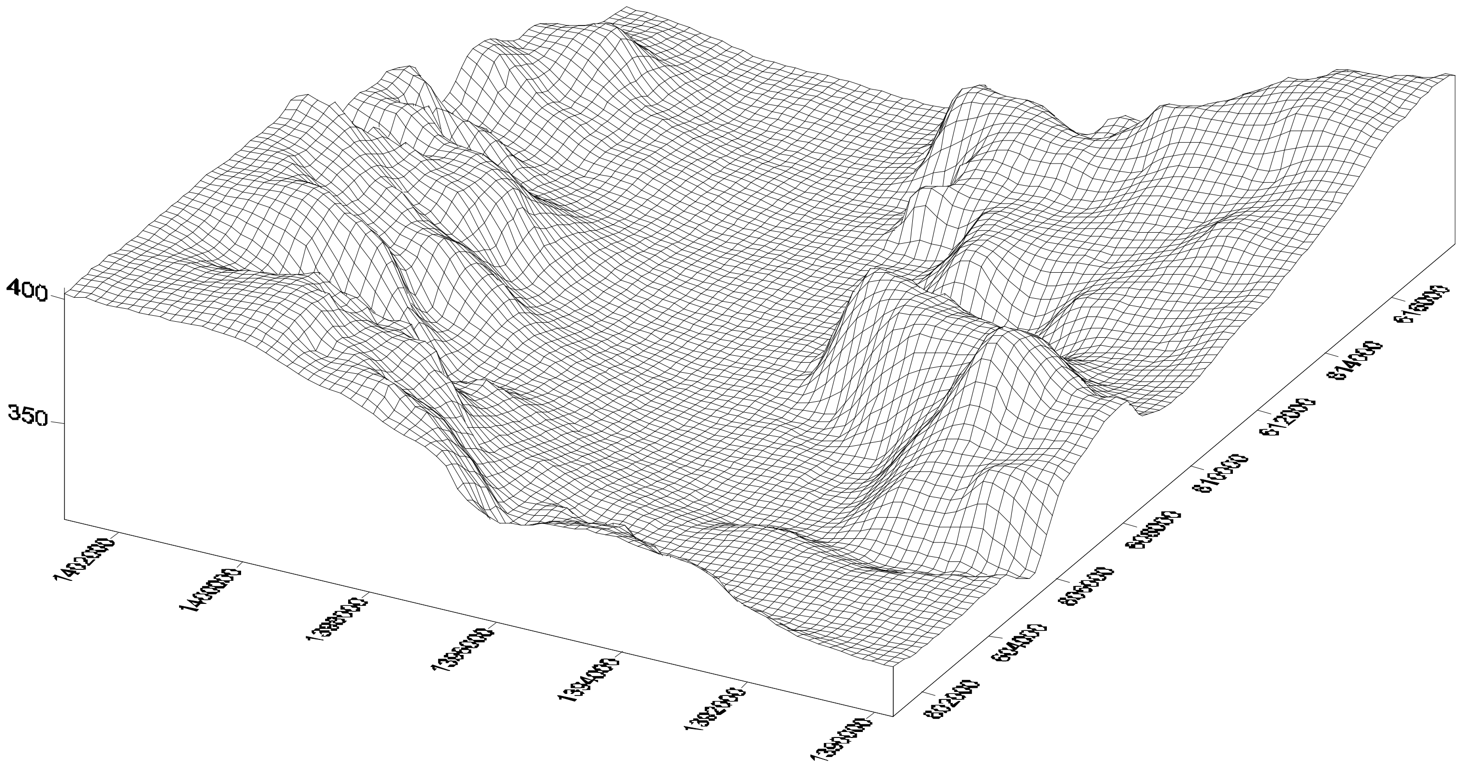


- **Input to the Model**

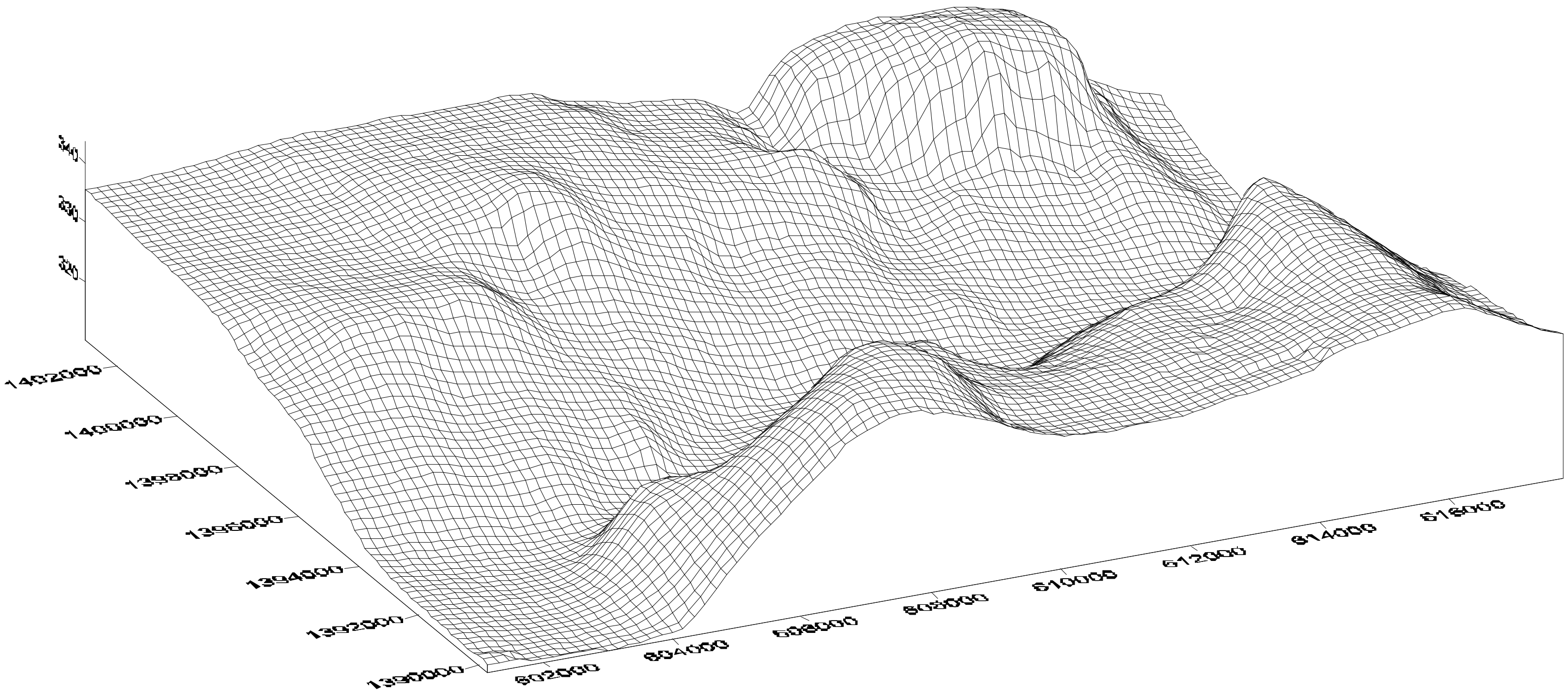
Geometry of the aquifer

- The ground surface and the aquifer bottom elevations have been inputted in the model.
- The topographic map of Bamako has been scanned after georeferencing and the contours values of the groundsurface elevations (according to sea level) have been digitizing using on screen digitized features on ERDAS IMAGINE 8.3
- Aquifer bottom elevations were been extracted with deep boreholes data

Aquifer ground surface elevations



Aquifer bottom elevations



Hydraulic and physical proprieties

- Based on available data (CRDI 1990)

of pumping test:These values of hydraulic conductivities are in inputted in the model:

- Mean values of K in alluviums deposits :

8E-5 m/s

- Mean values of K lateritic deposits : 5E-5 m/s
- Value of 0.25 is imputed as Specific yield for both alluviums and lateritic deposits

Recharge

- Calculated by Thornthwaite water budget

Method

. 90 mm/Year in rainy season (July ,August and September)

.Recharge is null on the rest of the year

Evapotranspiration demand

- Recharge period ETP=300 mm
- Dry season ETP = 1500 mm

Boundary Conditions

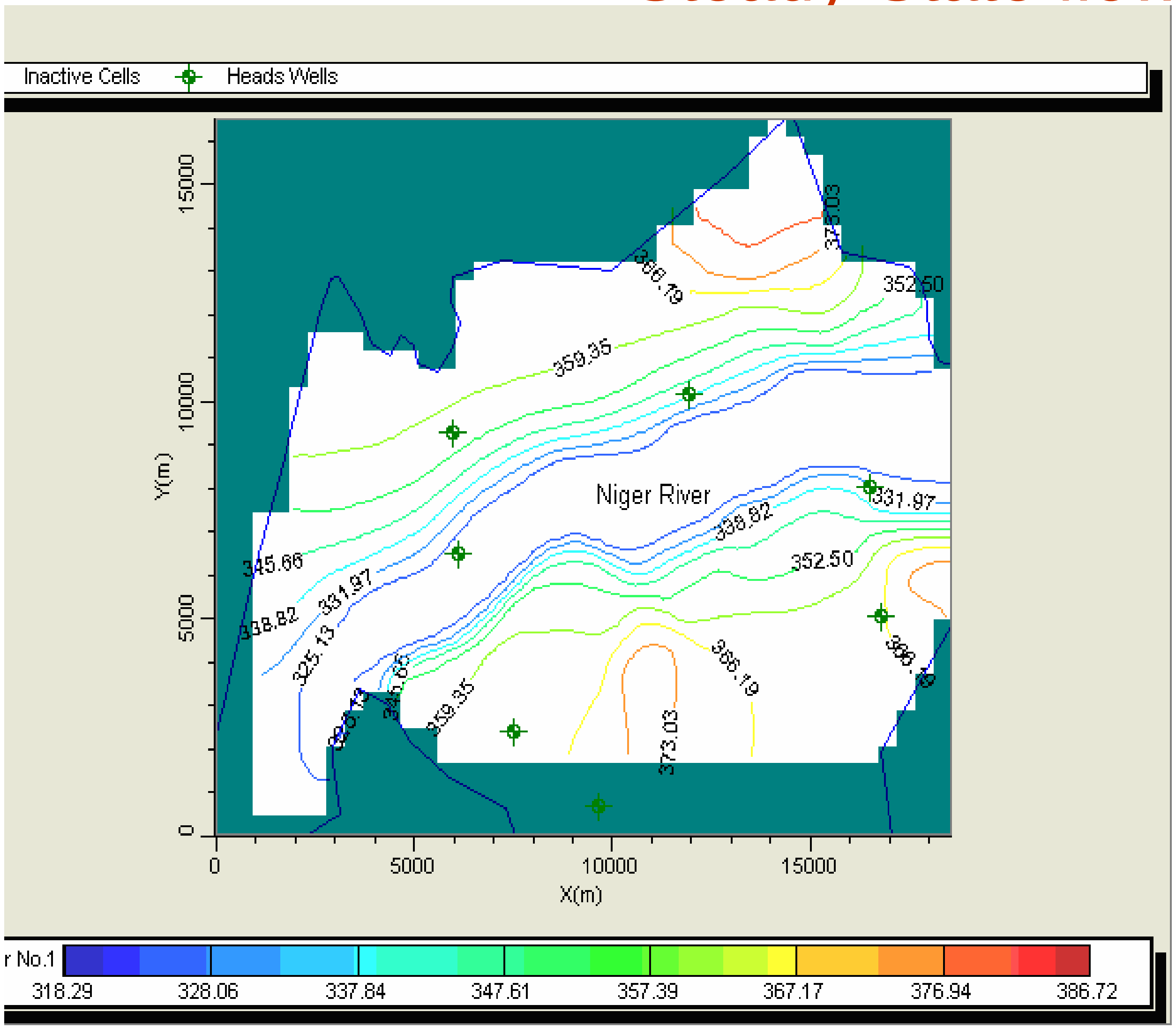
- Dirichlet Boundary condition : River Niger constant head of 317.6 (mean value from 20 years)
- No flow Boundary Est and west boundaries of the model corresponding to groundwater divide zones

Head observation values

- 8 shallow wells monitored from 2002 to 2004 (monitored 2 or 3 times per month UNESCO-UNEP project) were been used to calibrate the model

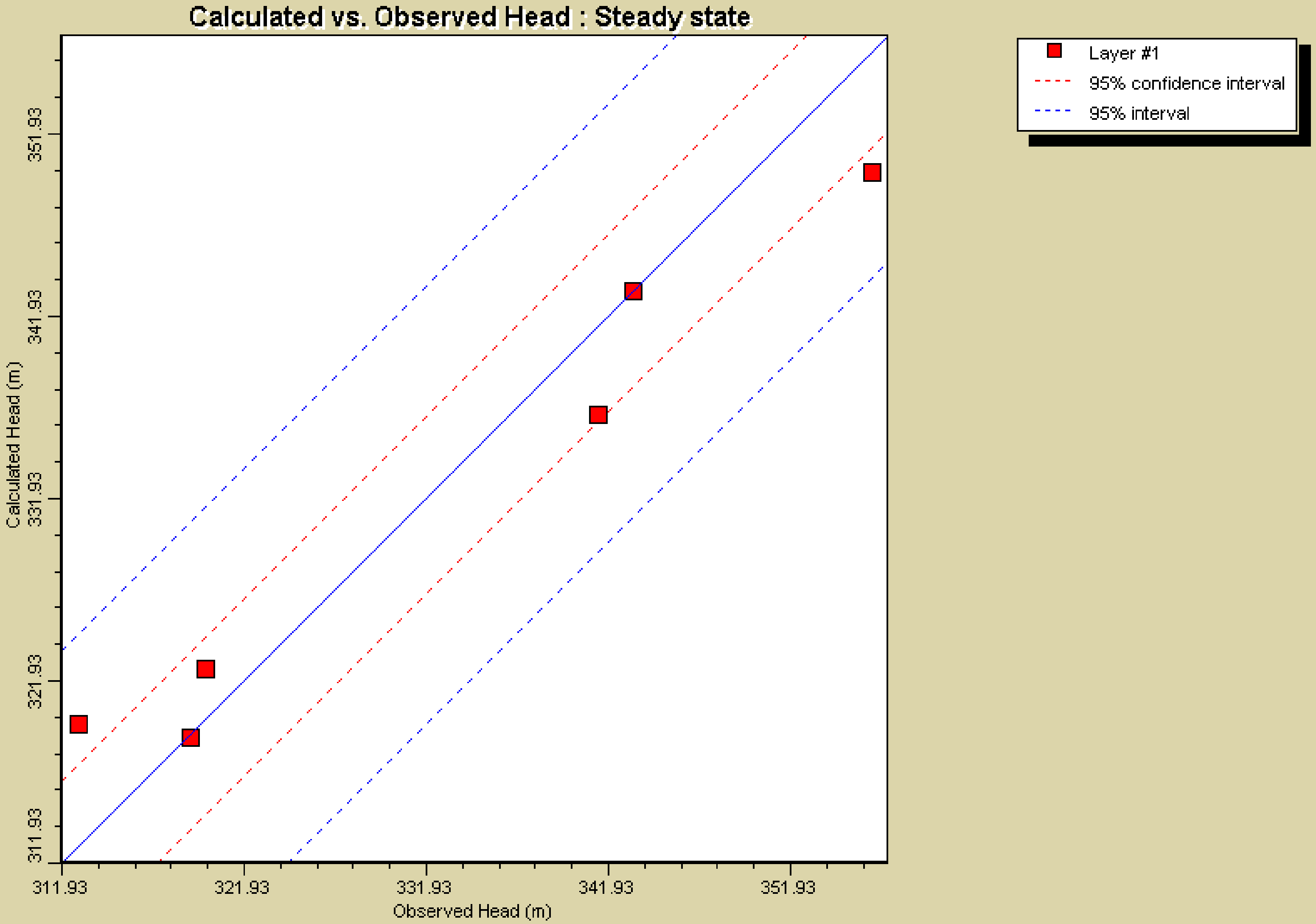
- Model Output

Steady-State flow



Groundwater modeled contour map shows that equipotentials are parallel to Niger River and flows converge to it. There is a leakage flow to the river.

Calibration



Num. of Data Points : 6
Max. Residual: 6.722 (m) at MISSABOUGOU/A
Min. Residual: -0.002 (m) at YIRIMADIO/A
Residual Mean : -0.368 (m)
Abs. Residual Mean : 3.543 (m)

Standard Error of the Estimate : 1.999 (m)
Root Mean Squared : 4.485 (m)
Normalized RMS : 10.272 (%)
Correlation Coefficient : 0.983

Transient Flow

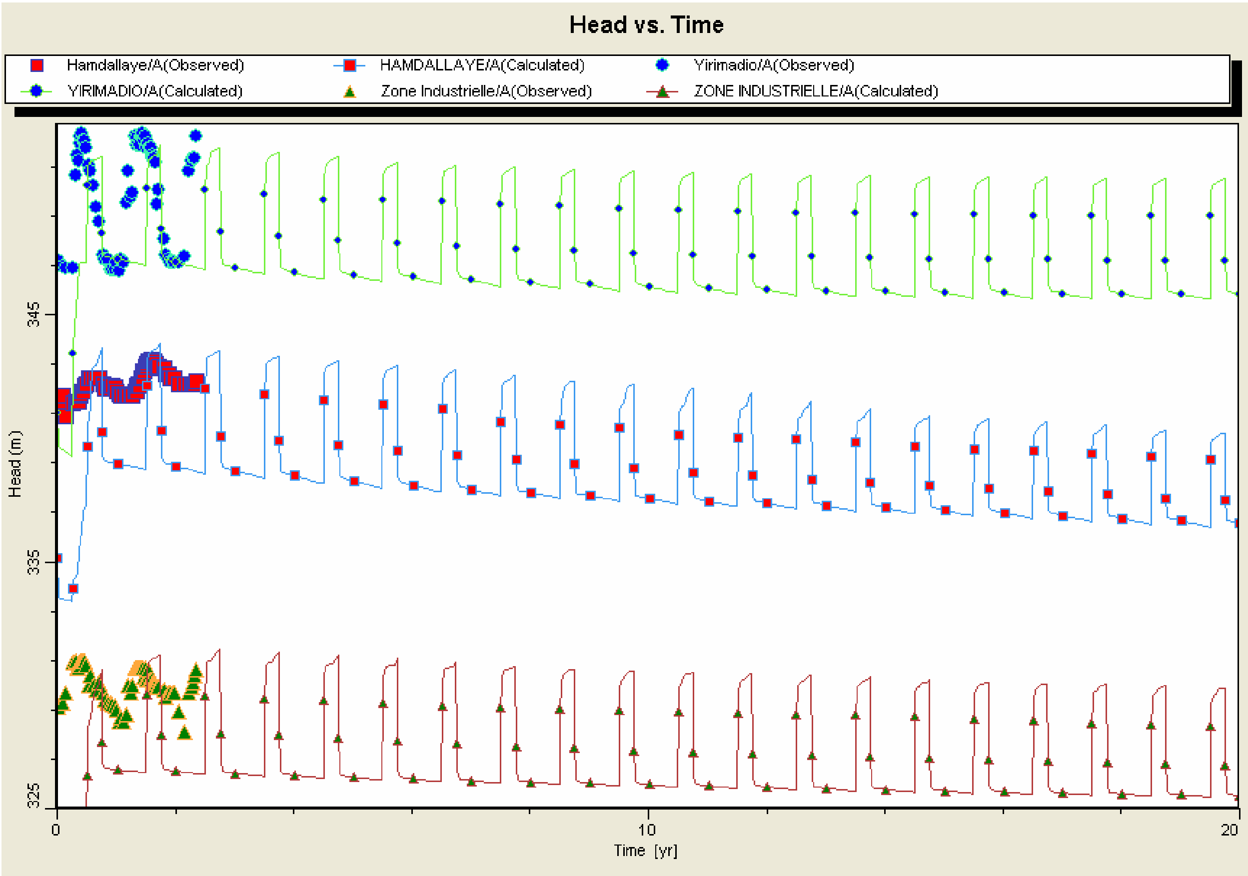
- 3 Recharge periods by year:

the 2st trimesters January-June: R = 0

3rd trimester July – September R= 90 mm

4th trimester October -December R=0

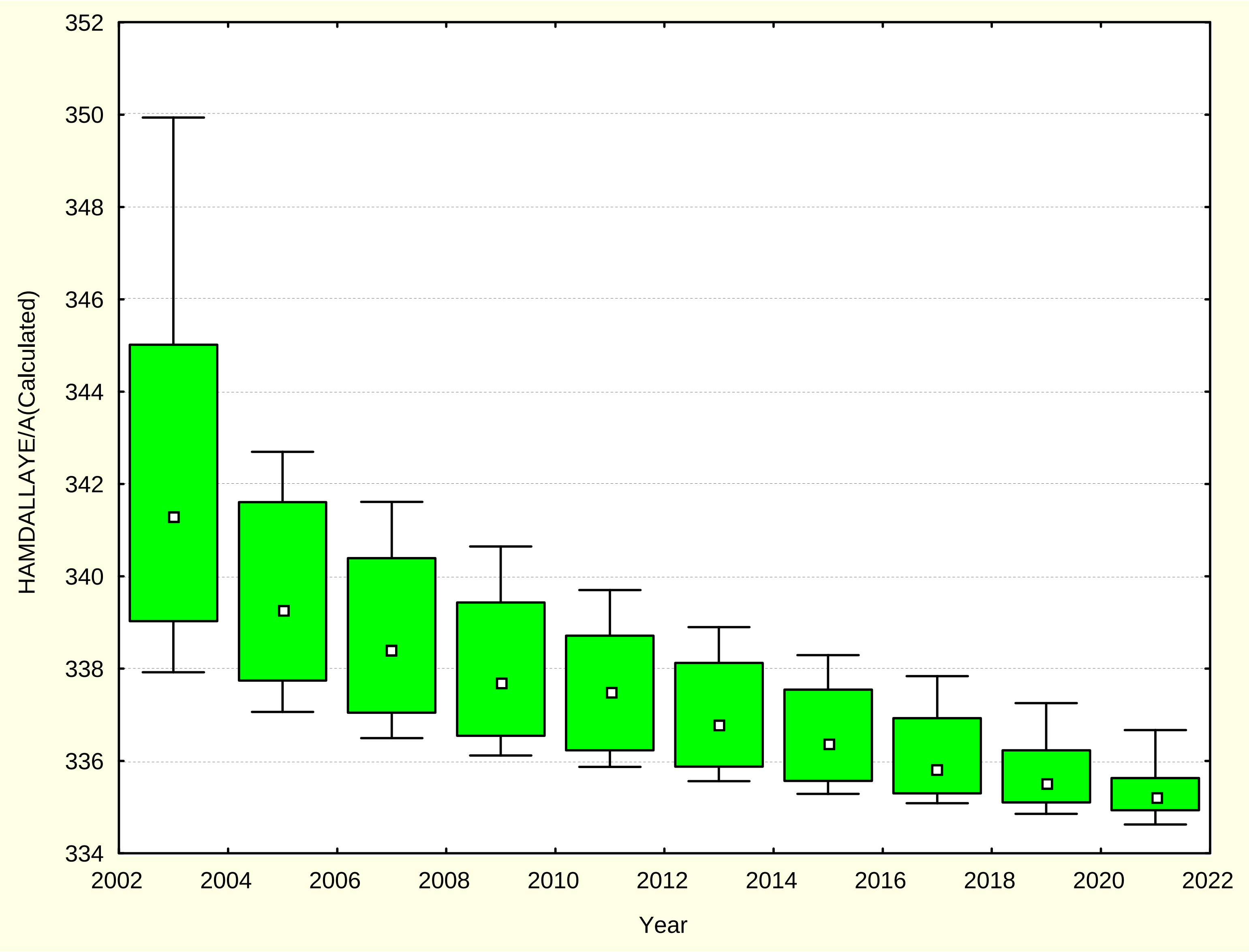
Times Series Plots



The transient flow plots showed in some wells difference from observed and calculated values of hydraulic heads. The values were mostly over estimated

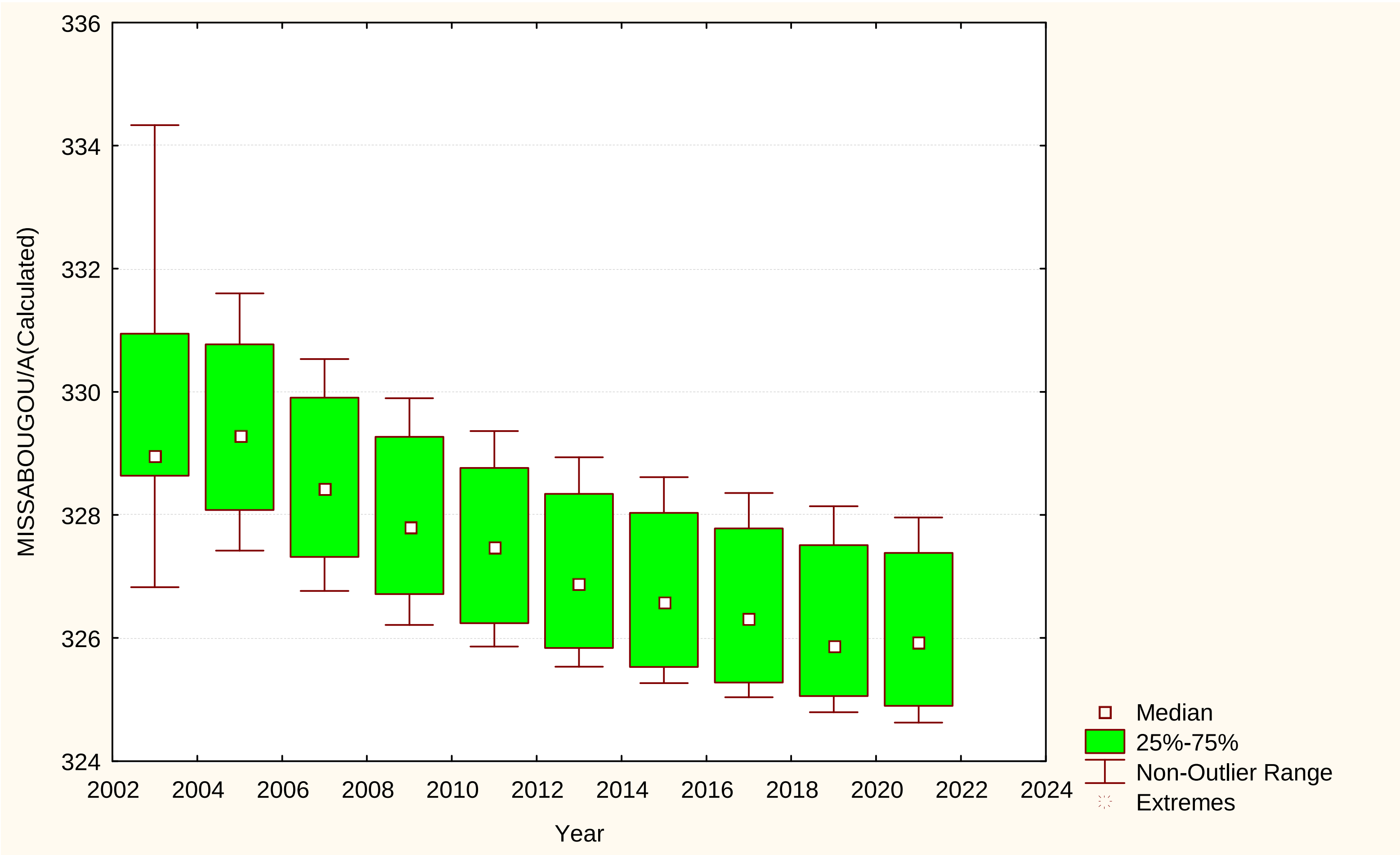
Observed water level and calculated of water level fluctuations from 2002 to 2022 in monitoring wells

Boxplots showing the evolutions of predicted hydraulic heads over time at Hamdallaye monitoring well



Annual Head Median values decrease with 6.5 m in 20 years (0.325 m/year)

Boxplots showing the evolutions of predicted hydraulic heads over time at Missabougou monitoring well



Annual Head Median values decrease with 4 m in 20 years (0.25 m/year)

- The prediction will not take into account the variability of the recharge and withdrawal water by the populations from the aquifer.

Recommendations to develop better simulation

1. Appropriate pumping test and slug test to determine hydraulic and physical proprieties of the aquifer.
2. Develop better methods for recharge computations
3. Appropriate piezometers because all observations wells were sometimes exploited
4. Expertise on fractured hydrodynamics
5. Estimation of discharge rate of exploited well.
6. Climate model is also required

Thank

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