University of Daloa
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République de Côte d'Ivoire
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International Conference
Sediment Transport Modeling in Hydrological Watersheds and Rivers
Conférence Internationale
Modélisation du transport de sédiments dans les bassins-versants et dans les rivières
14-16.11.2012 Istanbul, Turkey/Turquie

*Theme :*

# Numerical simulation of the hydro-sedimentary phenomena in the reservoirs of Côte d'Ivoire: the case of Lake Taabo

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# Outline

- I - Introduction
  - Problems related to surface water flows and solid transport in Côte d'Ivoire (motivation of the study)
  - Objectives of the present research activities
- II - Site and Methods
- III - Results and discussion
- IV - Conclusion, recommendations and further challenges

# I - Presentation of Côte d'Ivoire

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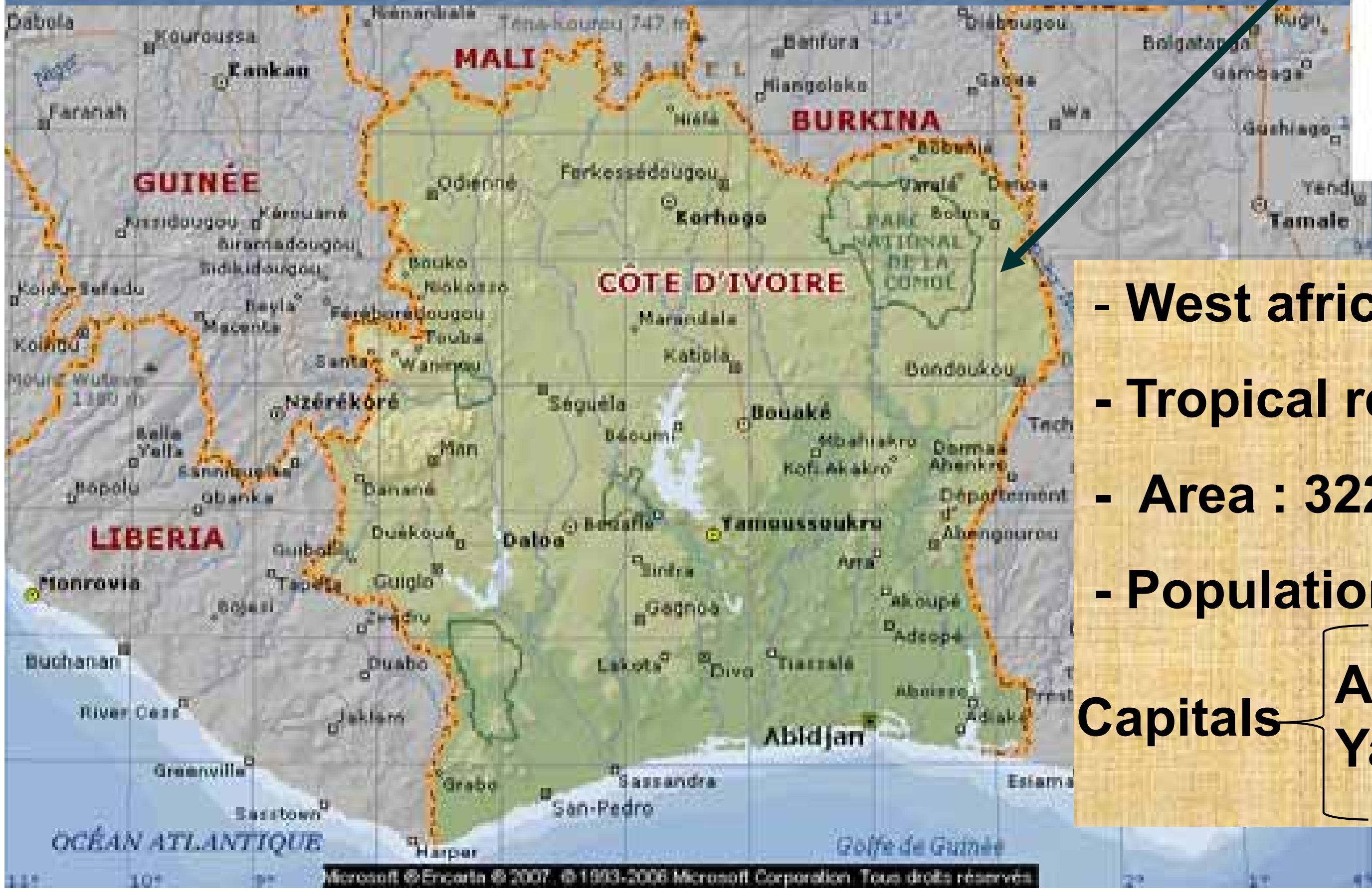


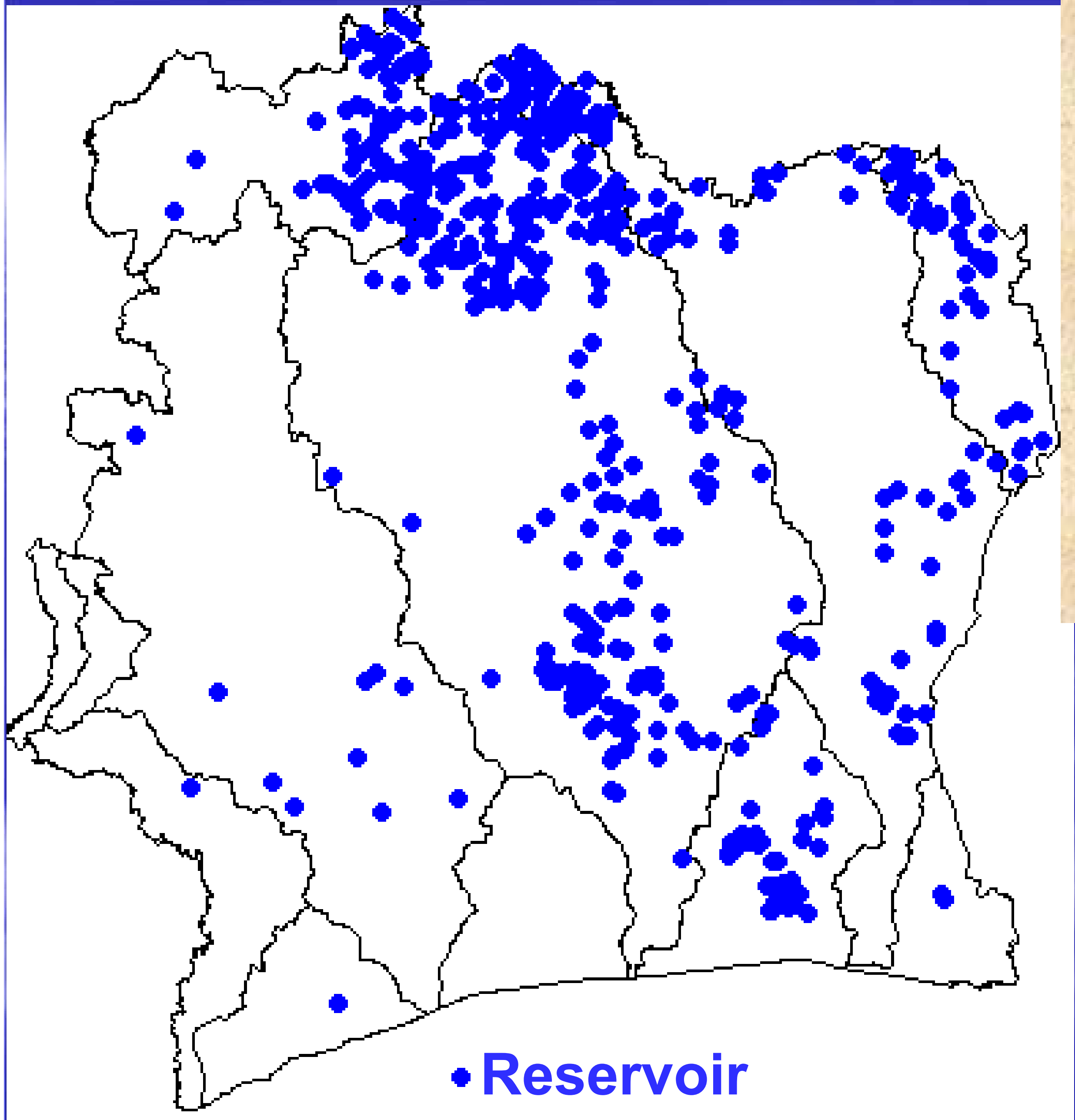

- West african country
- Tropical region
- Area : 322 462 km²
- Population : 21 Millions (2009)

Capitals:
- Abidjan (economic)
- Yamoussoukro (Politic)

**In Côte d'Ivoire (west africa), agricultural activities, rapid and uncontrolled urbanization are increasing suspended sediment yield.**

**That is the main cause for serious flooding in urban areas, silting up of reservoirs and harbours and deterioration of water quality.**

1. **Drastic drop in the rainfall due to climate variability in the early 1970s**
2. **Drop in the flows of the rivers (30 to 40%)**
3. **Construction of many reservoirs all over the country to face water stress**




578 reservoirs (1996) :

- water supply
- Agriculture
- Cattle
- Hydroelectricity
- Flow regulation
- Others

# Reservoirs location in Côte d'Ivoire

**More than 25% of the 578 reservoirs no longer work because they are filling up by sediments.**

**The accelerated silting up of the reservoirs causes floods, significant modifications of the physicochemical parameters and a fast and massive development of aquatic plants.**

**In spite of the dangers linked to the silting up of the reservoirs, only very few and recent studies try to explain the hydrodynamic and sedimentological processes which take place in the rivers and reservoirs of Côte d'Ivoire (Kouassi *et al.*, 2007; *Adopo et al.*, 2008).**

# I - Introduction (Objectives)

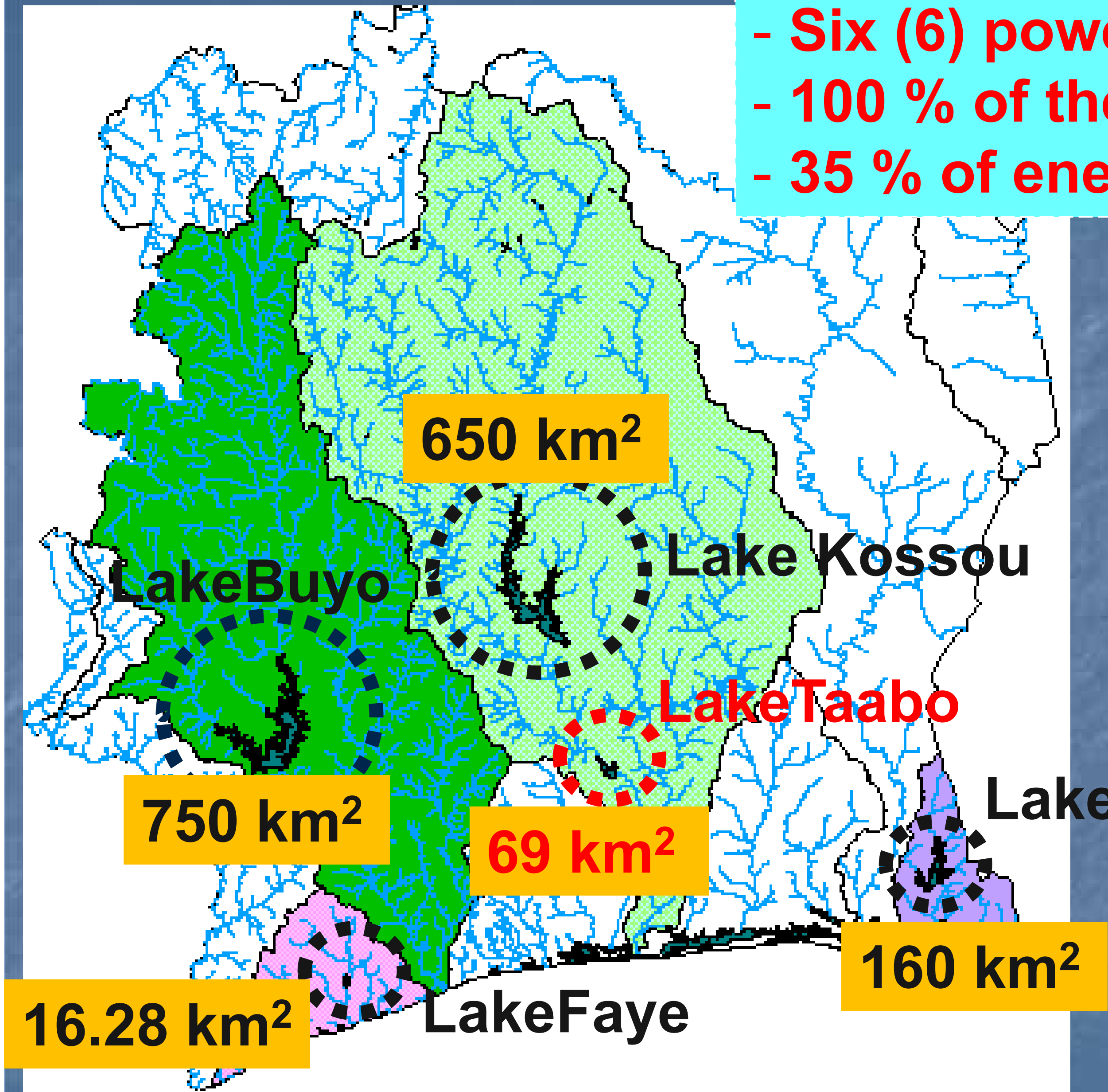
**Main objectif: Characterize the sedimentation phenomena in rivers and reservoirs in Côte d'Ivoire in order to find adequate solution to prevent desasters**

***Sediment transport over Lake Taabo:***

**Simulate the hydrosedimentary functioning of Lake Taabo in order to quantify the sediment deposits.**

***Specifics Objectives : Take into account:***

1. The main terms of the water balance (inflows, outflows, rainfall and evaporation) over Taabo Lake ;
2. The physicochemical parameters and mainly the suspended sediment concentrations and the temperature of LakeTaabo;
3. The sediments and the bottom morphology of the lake.



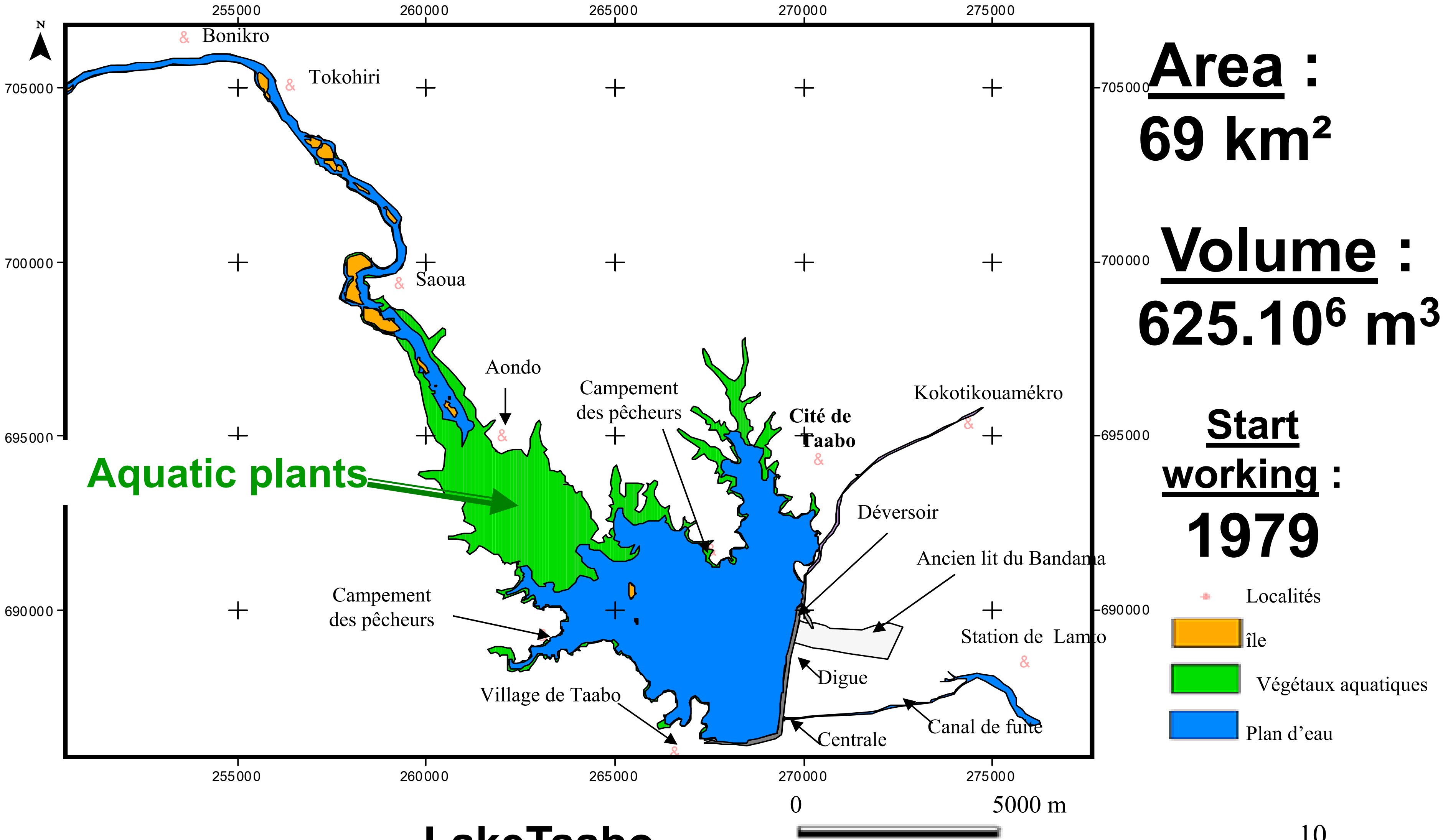

- Six (6) power Plants
- 100 % of the electricity till 1995
- 35 % of energy now

Choice of Taabo Lake :

- Availabity of data (river flows, water level, rainfall, wind volocity, etc.)

# Hydroelectric dams location in Côte d'Ivoire

# II - Site and methods (Site)




**LakeTaabo**

**Area :** 69 km²

**Volume :** 625.$10^6$ $m^3$

**Start working :** 1979

# II – Site and methods (Input data)

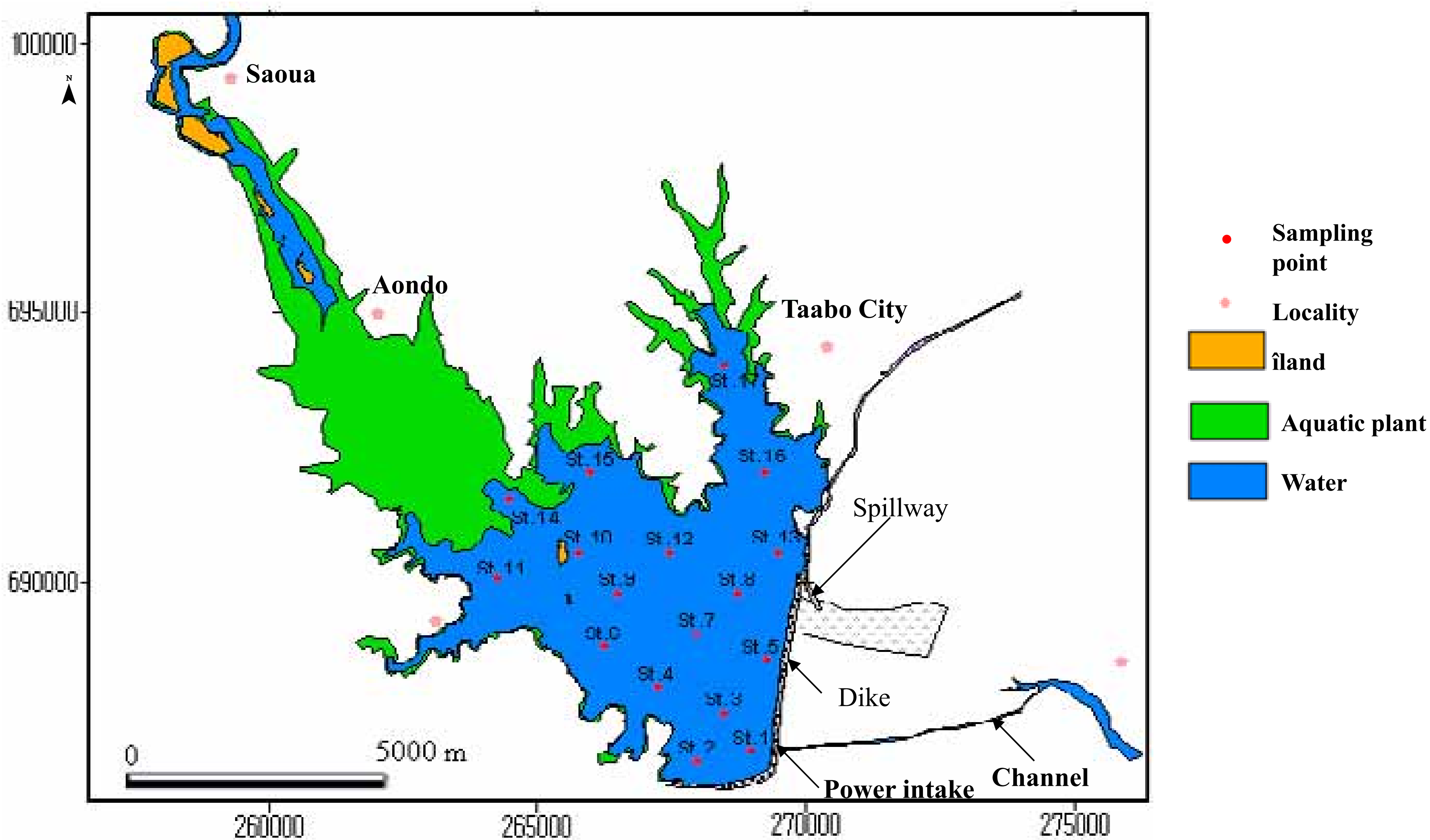
**Field observations according to the hydrological seasons**

- Bathymetric servey
- Water sampling for suspended sediment concentrations evaluation
- Turbidity
- Sediment sampling for grain size evaluation
- Water Temperature
- Evaporation was calculated by Penman method

**Others main data**

- Rainfall, Inflows, Outflows, water level, wind velocity were given by the *Power Plant Company* and the *National Water Resources Agency*.

# II – Site and methods (Input data)






**Sampling points in LakeTaabo**

## 2-D Numérical model of the sedimentation with Mike 21

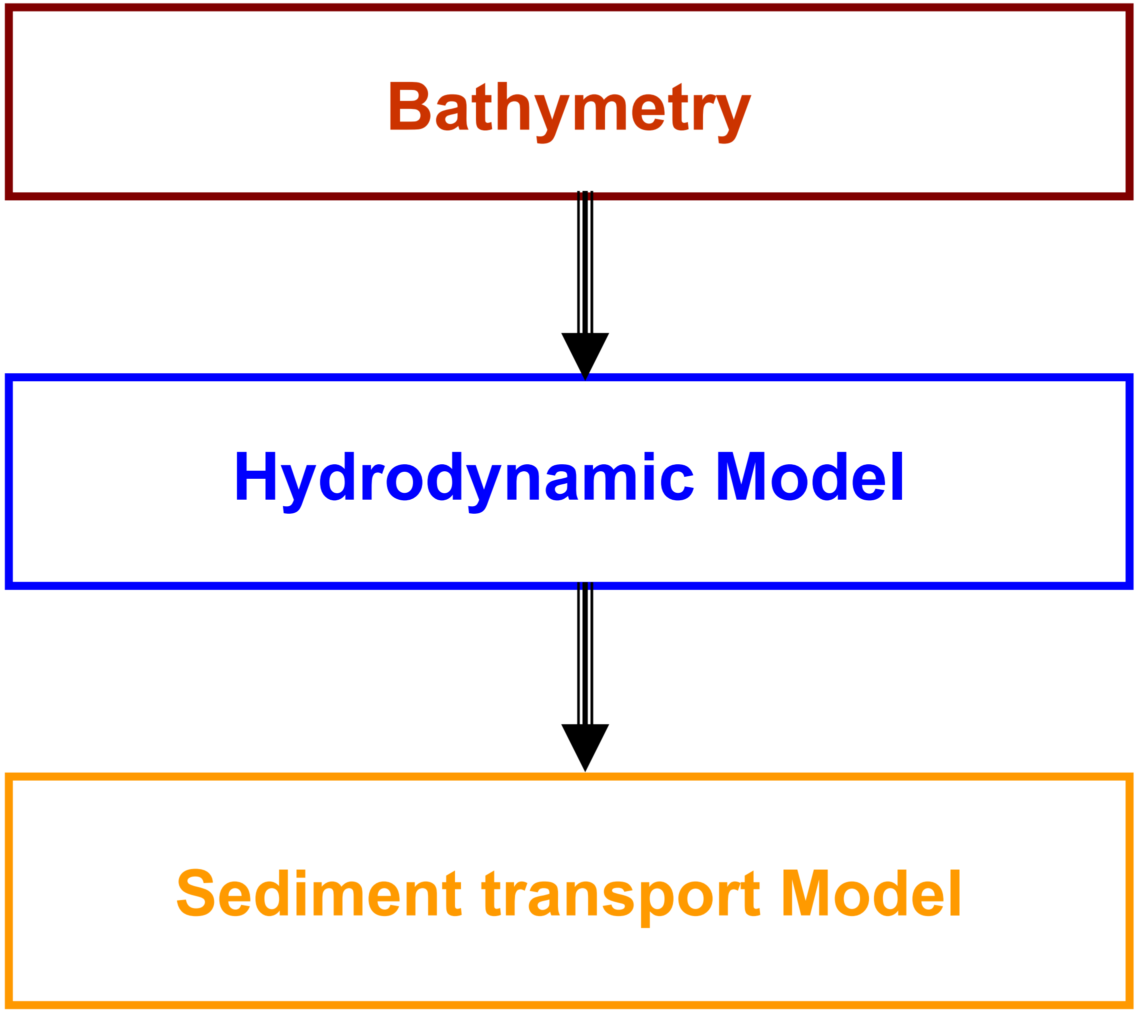



**Illustration of the main steps of the numerical model**

***Mike 21 is a software of the Danish Hydraulic Institute (DHI)***

## Calculation periods (characteristic period in each season)

- **October 2004 (short rainy season)**

- **Fevrier 2005 ( Long dry season)**

- **June 2005 (Long rainy season)**

- **August 2005 (short dry season).**

# Hydrodynamic and sediment transport model

**The model is based on the solution of the two-dimensional incompressible Reynolds Averaged Navier-Stokes equations.**

***The following equations integrated over the vertical describe the flow, water level variation and sediment transport (DHI 2003):***

**continuity equation**

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0$$

***Momentum equation in x direction (horizontal)***

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{p.q}{h}\right) + gh\frac{\partial \zeta}{\partial x} = -\frac{g.p\sqrt{p^2 + q^2}}{C^2 h^2} + f.V.V_x - \frac{h}{\rho_w}.\frac{\partial p_a}{\partial x} + \Omega.q + \frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h.\tau_{xx}\right) + \frac{\partial}{\partial y}\left(h.\tau_{xy}\right)\right]$$

***Momentum equation in y direction (vertical)***

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{p.q}{h}\right) + g.h.\frac{\partial \zeta}{\partial y} = -\frac{g.q\sqrt{p^2 + q^2}}{C^2 h^2} + fVV_y - \frac{h}{\rho_w}.\frac{\partial p_a}{\partial y} - \Omega.p + \frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h.\tau_{xy}\right) + \frac{\partial}{\partial y}\left(h.\tau_{yy}\right)\right]$$

**Mass transport equation**

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = \frac{1}{h}\frac{\partial}{\partial x}\left(hDx\ \frac{\partial c}{\partial x}\right) + \frac{1}{h}\frac{\partial}{\partial y}\left(hDy\ \frac{\partial c}{\partial y}\right) + Q_L C_L \frac{1}{h} - S$$

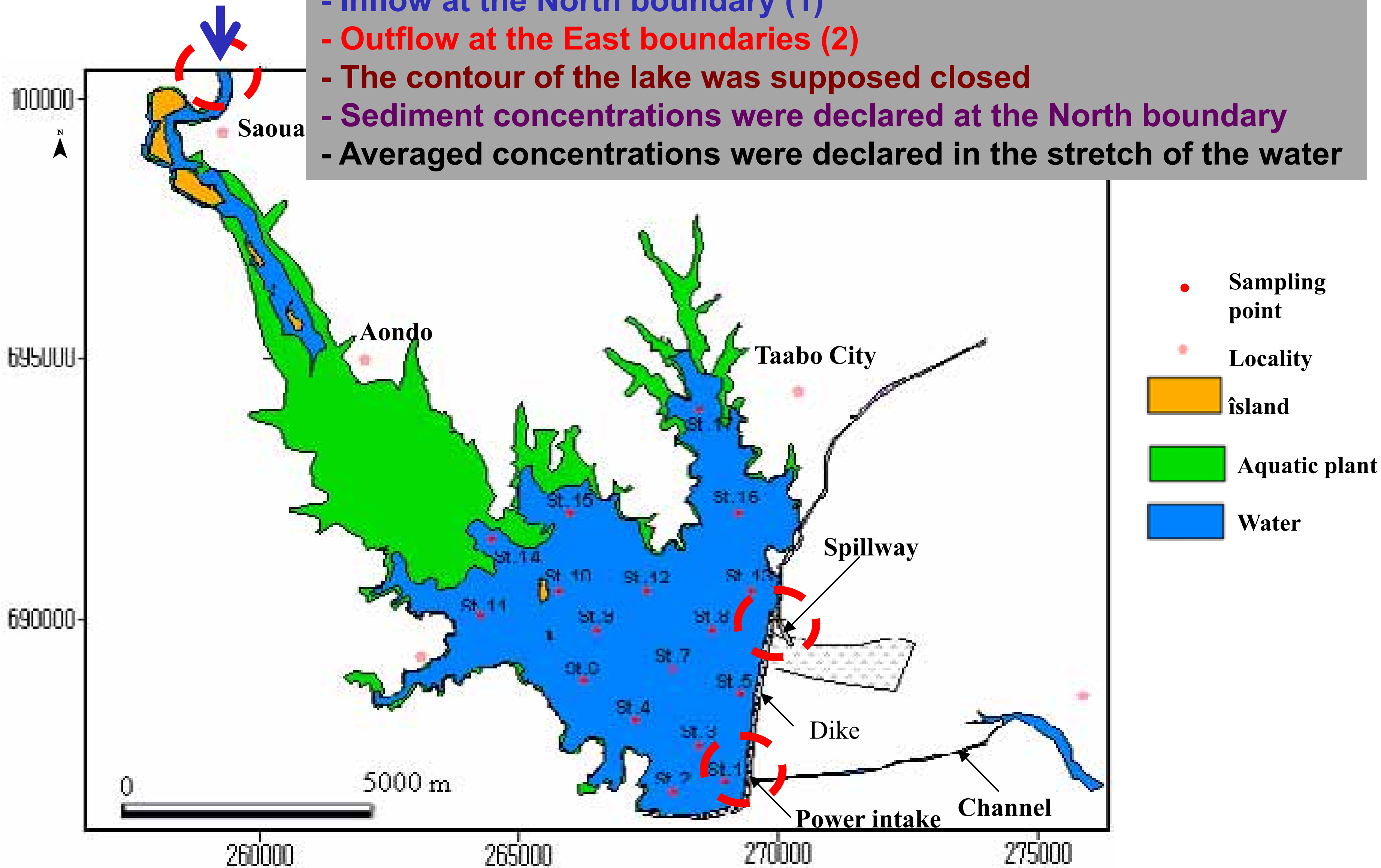
# Hydrodynamic and mass transport model

## Definition of the Symbols

| | |
|---|---|
| $\zeta(x,y,t)$ | : **Surface elevation (m)** |
| $p(x,y,t) = V_x(x,y,t).h(x,y,t)$ | : **Flux density in x direction ($m^3$/s/m)** |
| $q(x,y,t) = V_y(x,y,t).h(x,y,t)$ | : **Flux density in y direction ($m^3$/s/m)** |
| $h(x,y,t)$ | : **Water depth (m)** |
| $g$ | : **Acceleration due to gravity (m/$s^2$)** |
| $C$ | : **Chezy resistance ($m^{1/2}$/s)** |
| $f\ (V)$ | : **Wind friction factor** |
| $V, V_X, V_y\ (x,y,t)$ | : **Wind speed and components in x and y directions (m/s)** |
| $p_a(x,y,t)$ | : **Atmospheric pressure (N/m²)** |
| $\rho_w$ | : **Density of water (kg/$m^3$)** |
| $\Omega(x,t)$ | : **Coriolis parameter, latitude dependent (1/s)** |
| $\tau_{xx}, \tau_{yy}, \tau_{xy}\ (x,y,t)$ | : **Components of effective shear stress (N/m²)** |
| $(x,y)$ | : **Space coordinates (m)** |
| $t$ | : **Time (s)** |
| *u,v* | : **Depth averaged flow velocities (m/s)** |
| *Dx, Dy* | : **Dispersion coefficients ($m^2$/s)** |
| *C(x, y, t)* | : **Depth averaged sediment concentration (m)** |
| *S* | : **Accretion/erosion term (kg/ $m^3$/s)** |
| $Q_L$ | : **source discharge per unit horizontal area ($m^3$/s/ $m^2$)** |
| $C_L$ | : **concentration of source discharge (kg/ $m^3$)** |

# II – Site and methods (Boundary conditions)

- Inflow at the North boundary (1)
- Outflow at the East boundaries (2)
- The contour of the lake was supposed closed
- Sediment concentrations were declared at the North boundary
- Averaged concentrations were declared in the stretch of the water



# Results and discussion

# Turbidity and Suspended sediment concentration

| Season | Turbidity (NTU) | | SSC (mg.L$^{-1}$) | |
|---|---|---|---|---|
| | Average | σ | Average | σ |
| Short rainy season (October 04) | 26,66 | 3,33 | 17,76 | 2,26 |
| Long dry season (February 05) | 14,63 | 0,45 | 5,47 | 0,33 |
| Long rainy season (June 05) | 23,25 | 1,22 | 14,85 | 1,57 |
| Short dry season (August 05) | 15,78 | 0,46 | 9,91 | 0,46 |
| Average | 19,85 | | 12 | |
| σ (inter-season ) | 6,07 | | 5,38 | |

σ : standard deviation

## Sedimentary facies

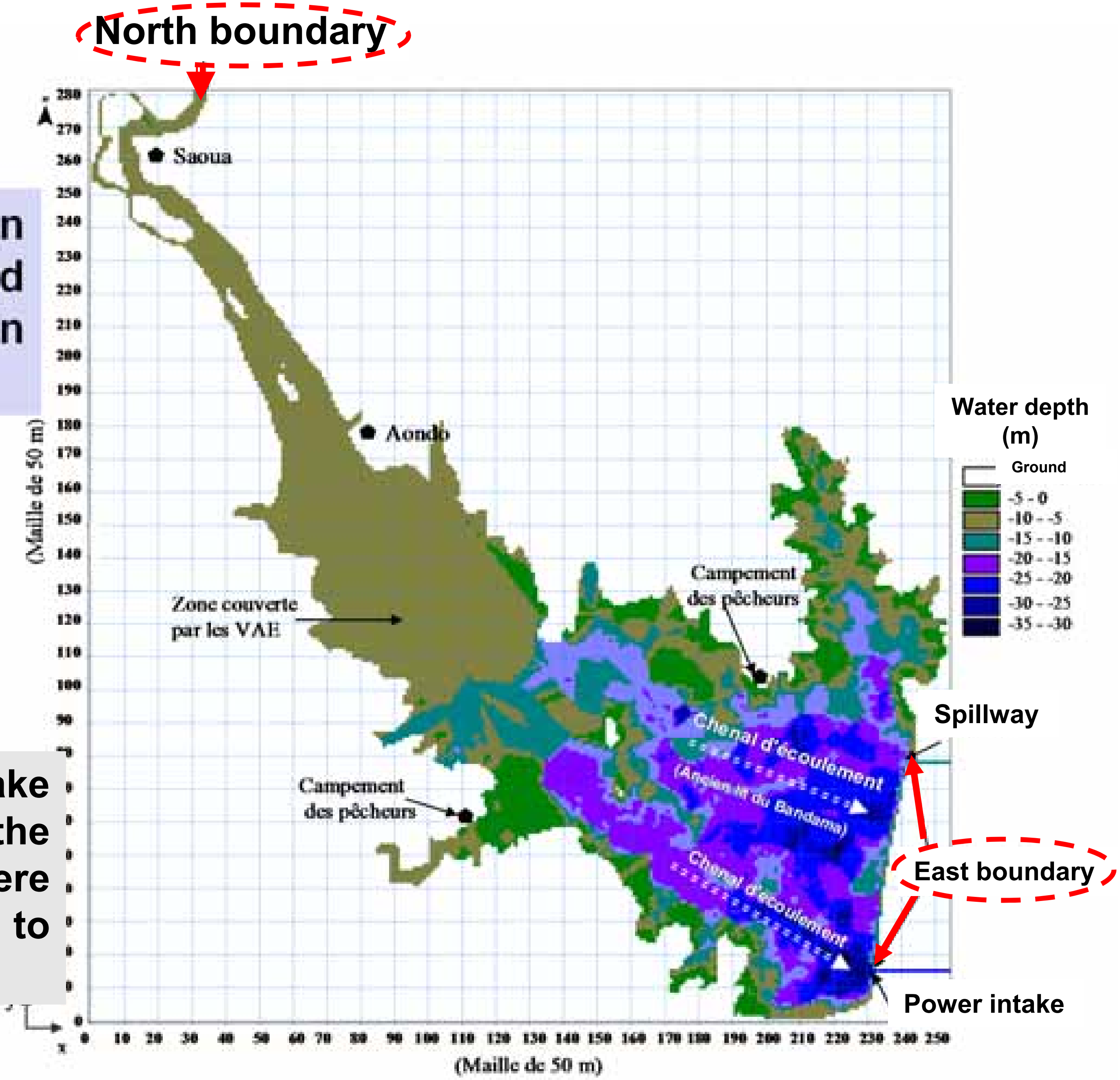
**The granulometric analyses showed that the sediments in the bottom of Lake Taabo were ranged from silts to coarse grains.**

- **Silts (mud);**
- **Mixed sediments (mud and sand);**
- **Fine cohesive sediments;**
- **Coarse sediments.**

# Bathymetry of Taabo Lake

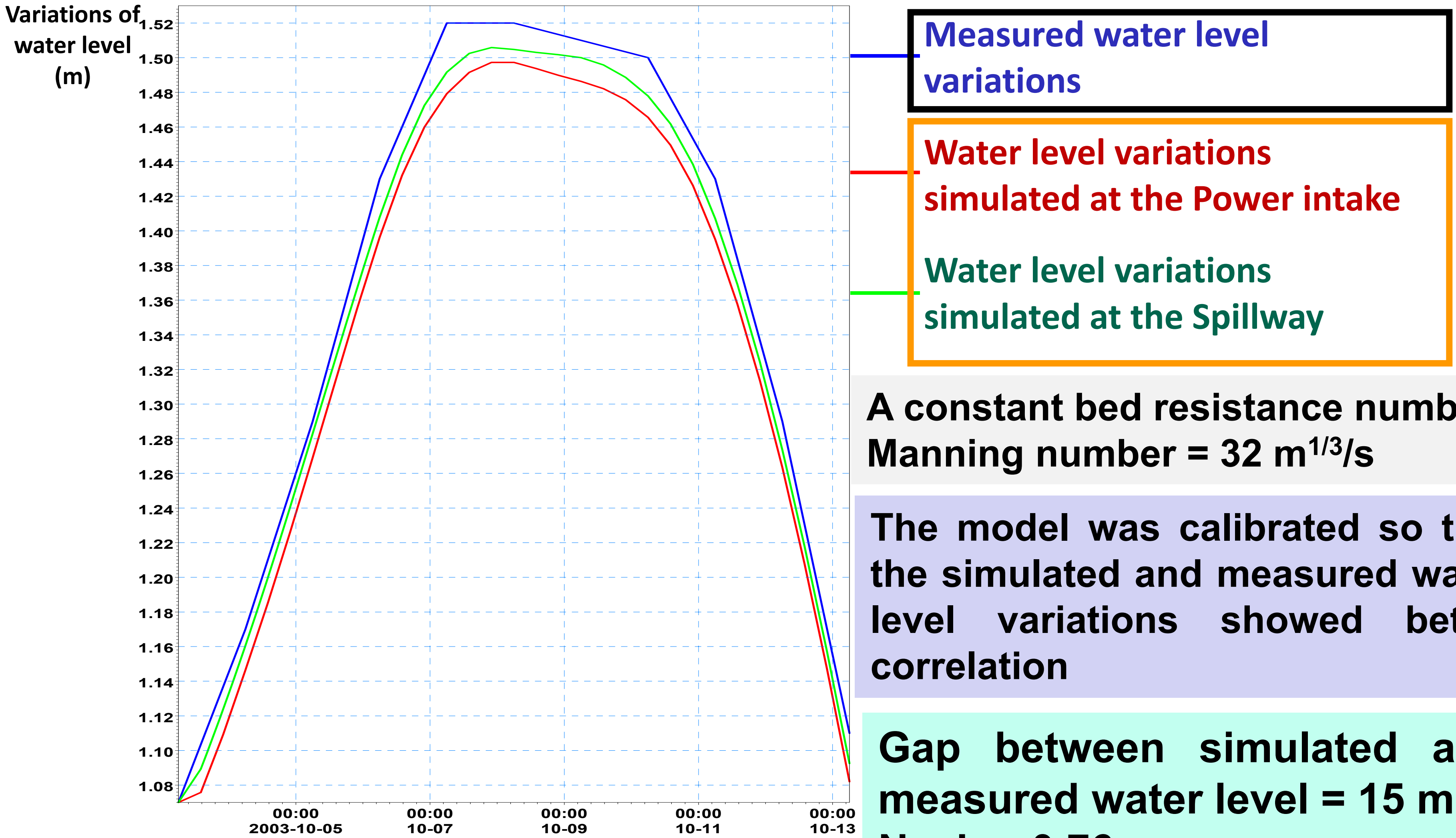
IDW interpolation under ArcView and exported to Mike 21 in ASCII format

*Δx = Δy = 50 m*




The bathymetry of Lake Taabo showed that the highest depths were around 30 m and next to the power intake.

# Hydrodynamic model : 1srt simulation




A constant bed resistance number
Manning number = 32 $m^{1/3}/s$

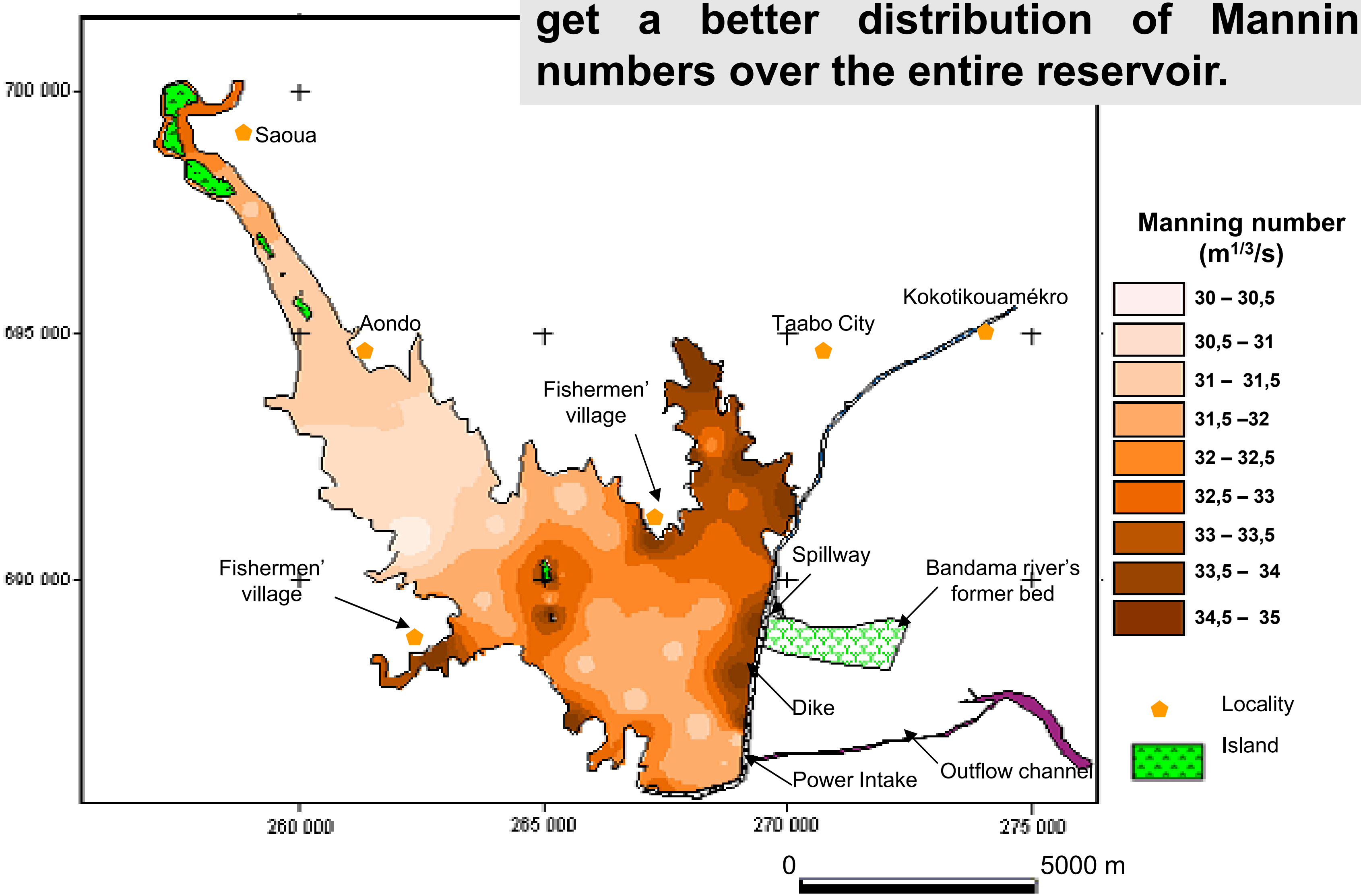
The model was calibrated so that the simulated and measured water level variations showed better correlation

Gap between simulated and measured water level = 15 mm
Nash = 0.76
$R^2$ = 0.81

**Comparison between simulated and measured water level variations at the free surface of Lake Taabo from 03 to 13 october 2003**

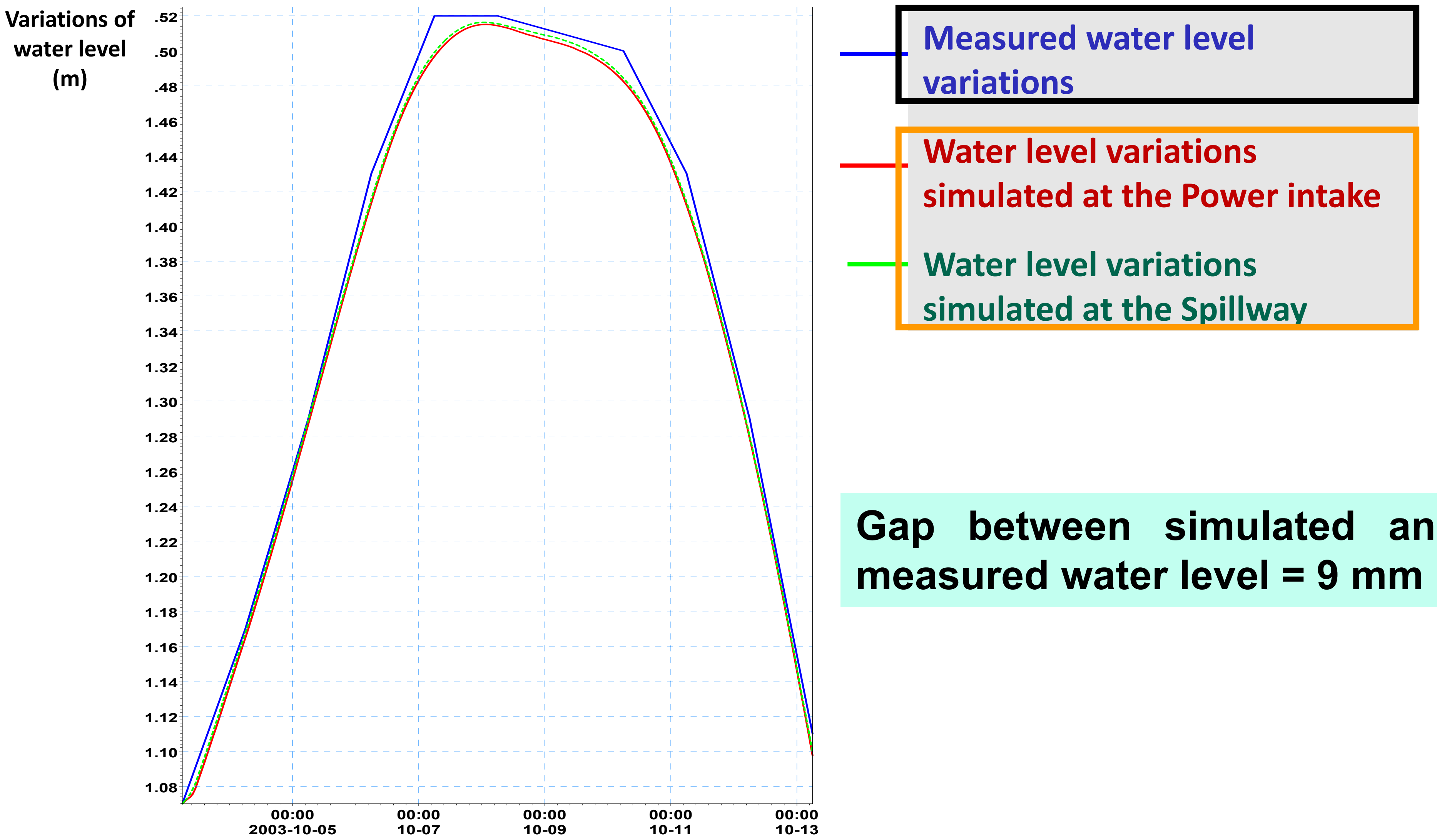
# Bed resistance number

**interpolation of the granulometric data to get a better distribution of Manning numbers over the entire reservoir.**




**Variation of the roughness in the bottom of LakeTaabo**

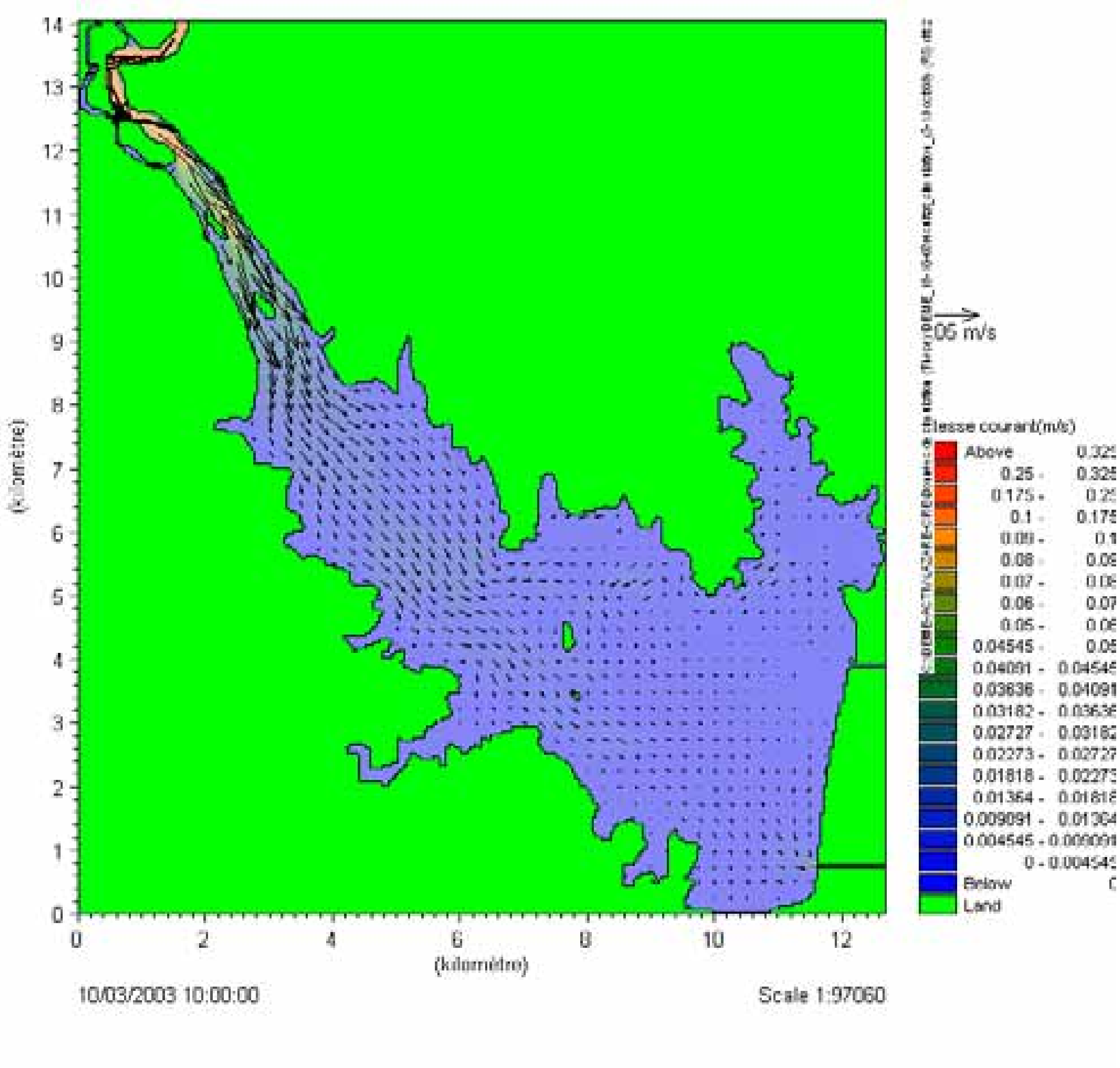
# Hydrodynamic model : calibration



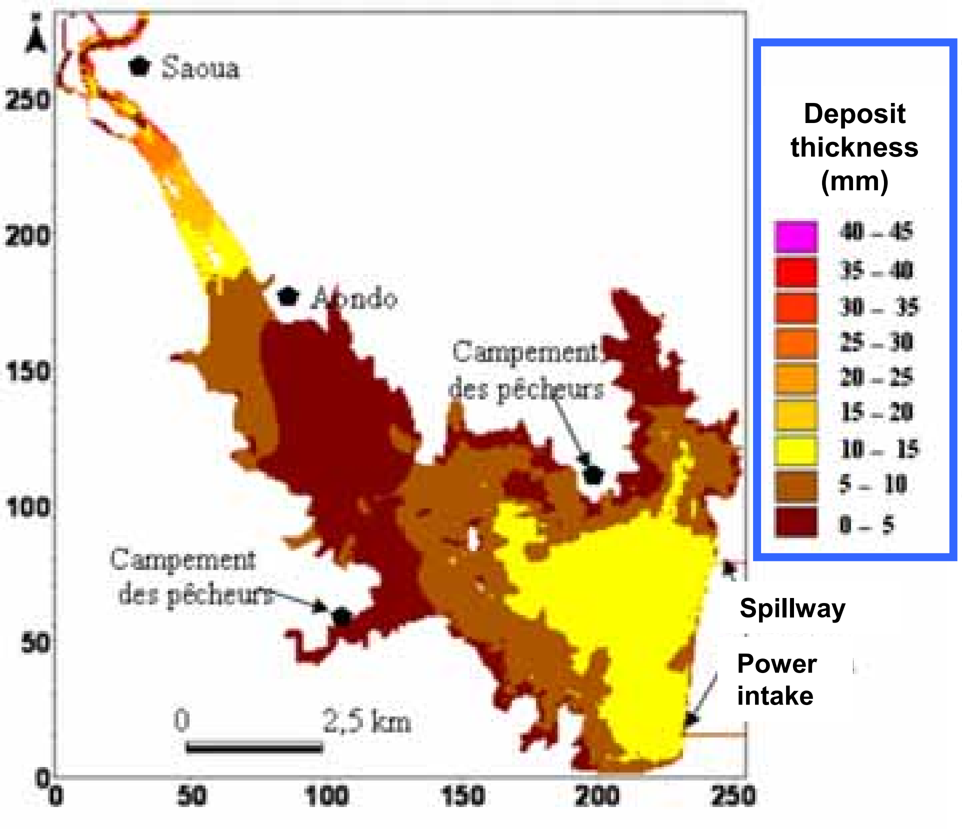

**Gap between simulated and measured water level = 9 mm**

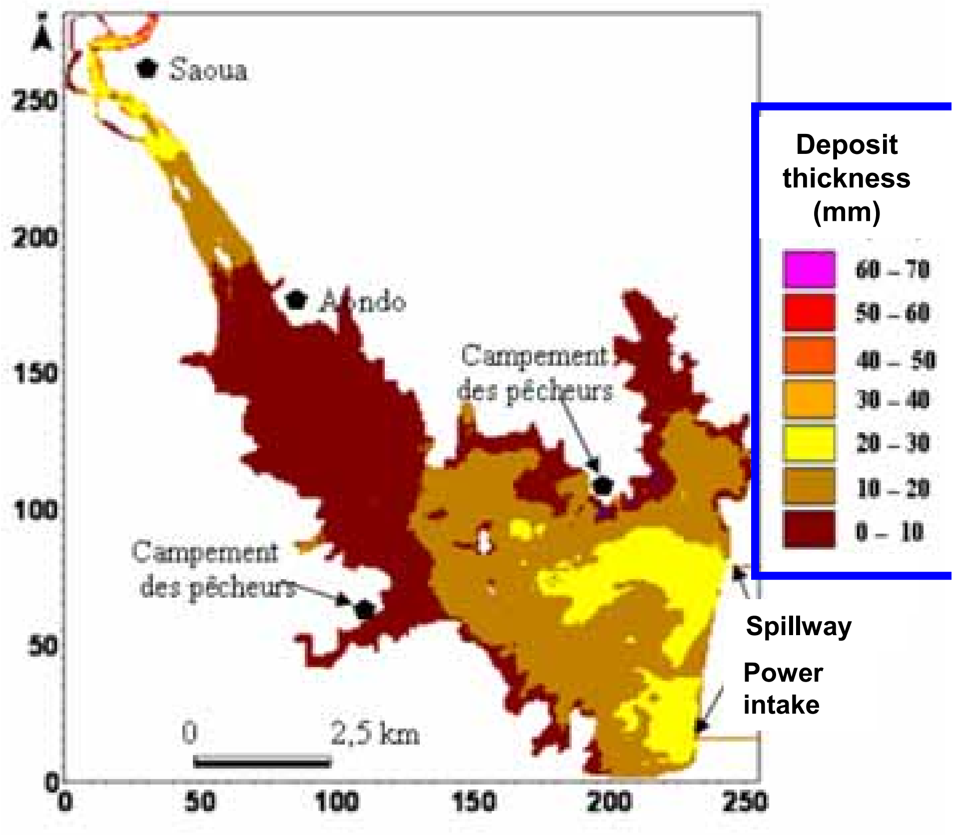
**Comparison between simulated and measured water level variations at the free surface of Lake Taabo from 03 to 13 october 2003**

# Current distribution



# Sediment transport model : seasonal deposits



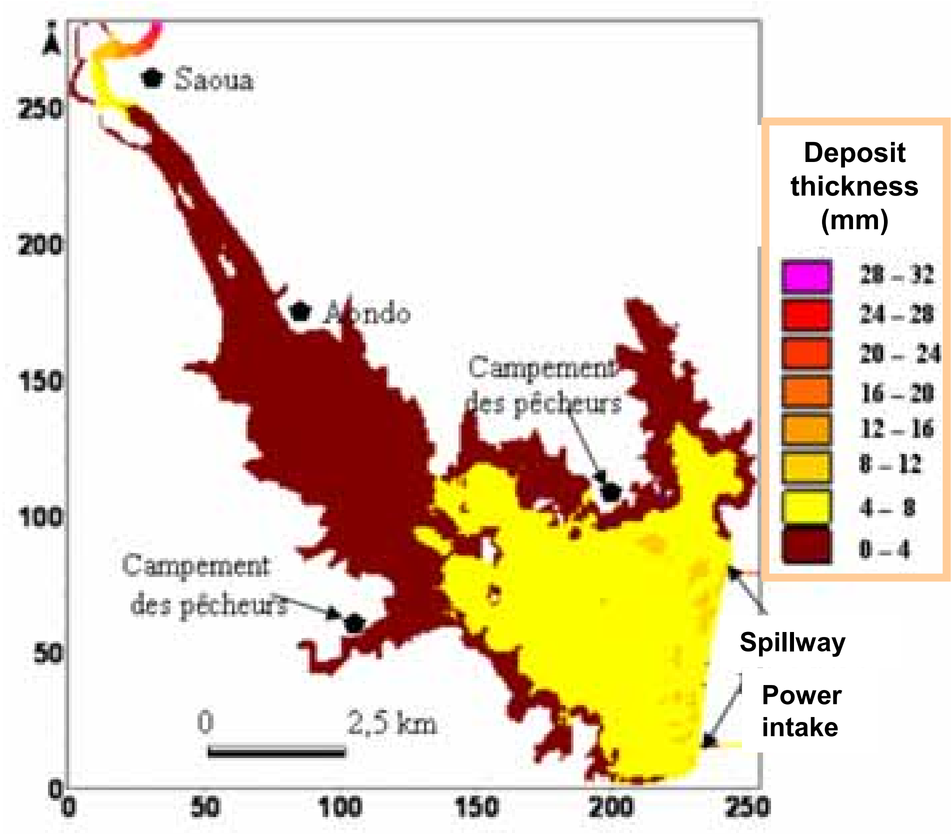




**a : Deposit thickness during the short rainy season (september - november)**

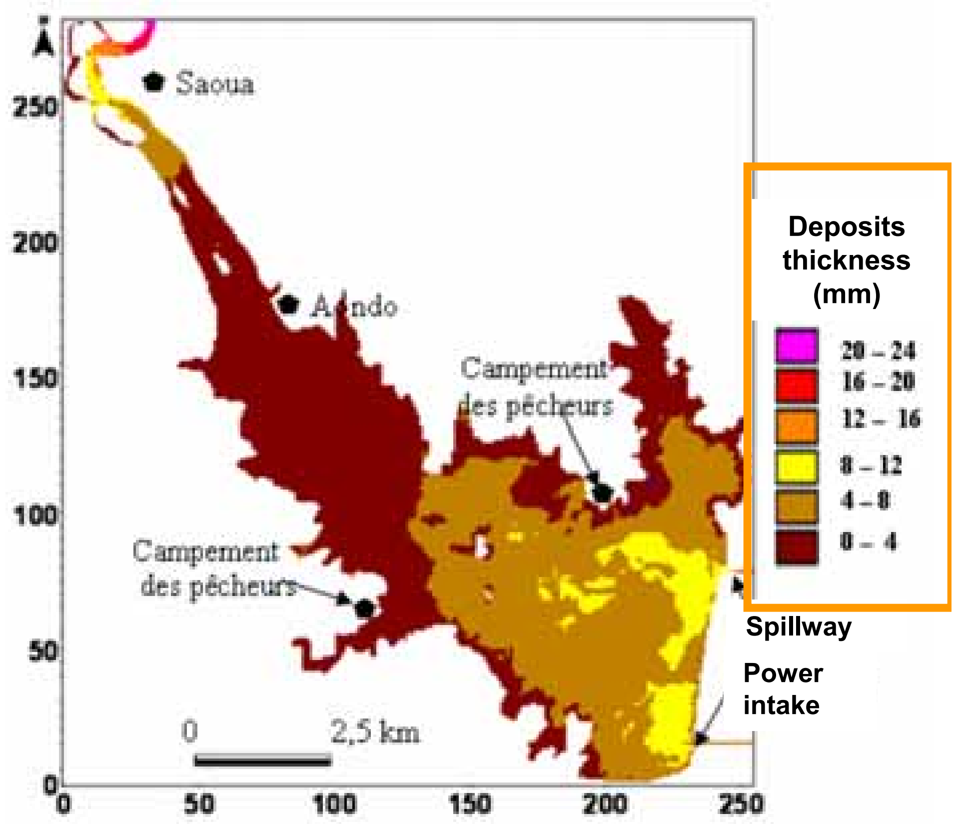
**b : Deposit thickness during the long rainy season (April - July)**

## Seasonal deposits in LakeTaabo

# Sediment transport model : seasonal deposits



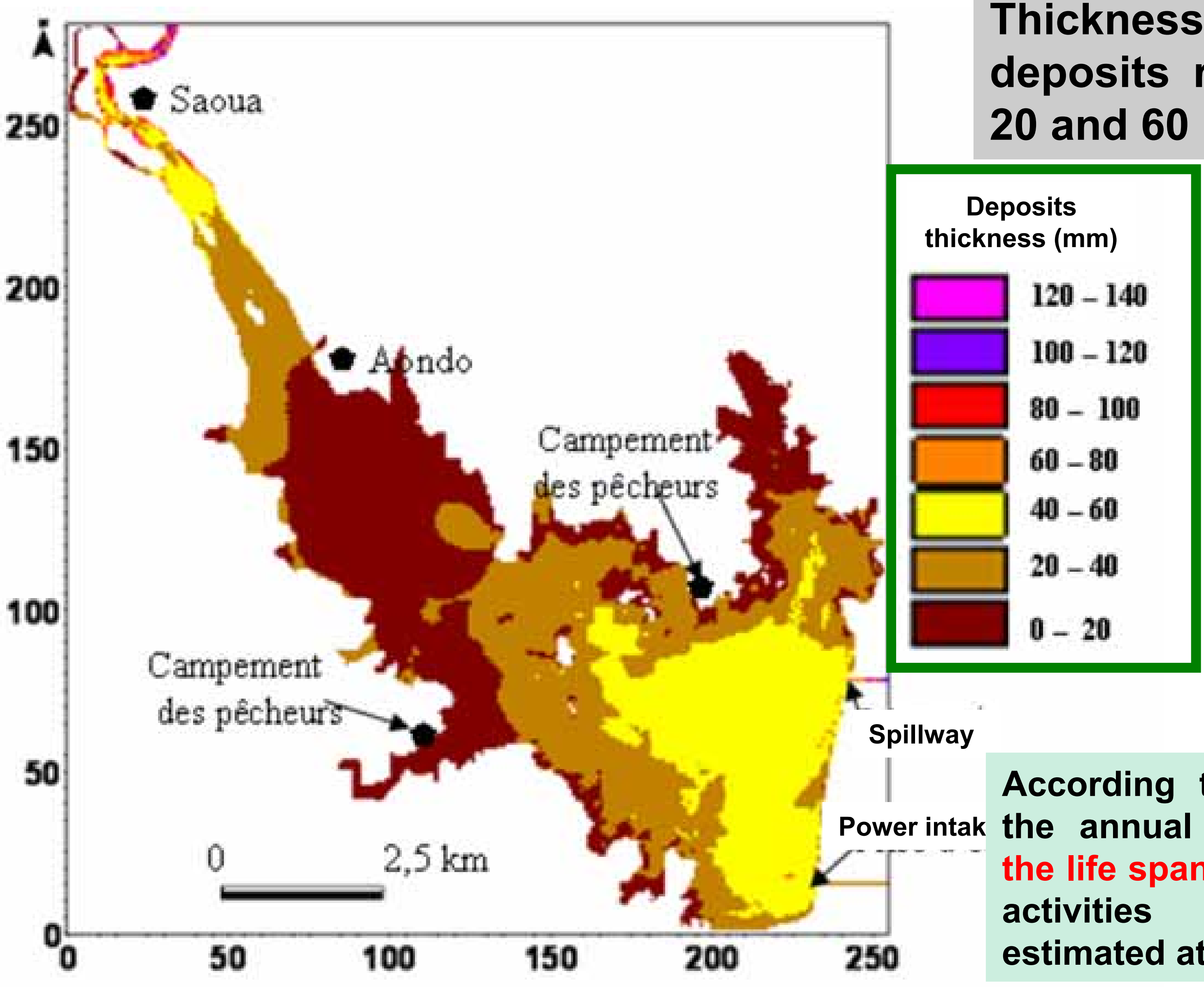

c : Deposit thickness during the short dry season (July - September)




d : Deposit thickness during the long dry season (November - April)

## Seasonal deposits in LakeTaabo

# Sediment transport model : Annual deposits




Thickness of annual deposits ranged between 20 and 60 mm

According to the thickness of the annual sediment deposits, the life span of the hydroelectric activities at Taabo was estimated at about 120 years.

Annual deposits in LakeTaabo

# CONCLUSION

# IV - CONCLUSION

**This study permitted to show some main features of the sedimentation process in Lake Taabo** ***(sediments characteristics, bathymetry, hydrodynamic functioning, sedimentation rate).***

**Further development of this study, by realizing bathymetric survey over the entire reservoir and measuring current velocities, is necessary to update the filling diagram (relation between water level, water surface and water volume).**

**Using a 3-D model will be interesting to take into account vertical dimension for a better simulation of the hydrodynamic functioning of the lake.**

**Great efforts concerning interdisciplinary approaches, as well as extensive and intensive field work are needed, in order to improve the knowledge of the functioning of Lake Taabo.**


Thank you