

# Percolation efficiency of an artificial tank in semi-arid hard rock aquifer context, South India.

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## 1. WATER AVAILABILITY, USE AND MANAGEMENT

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### ABSTRACT

As many states in India, Andhra Pradesh is currently facing a general overuse of the groundwater resource mainly due to agriculture irrigation growing demand. Despite water harvesting measures supported on a massive scale by government and non-government watershed development programmes, groundwater levels are declining. New programmes are being implemented to improve artificial percolation whilst the impact of former measures on groundwater recharge is still undefined. The few studies carried out so far estimate percolation fraction of artificial tanks from 35% to 50% in hard-rock aquifer context while downstream runoff is reduced by 12% to 20%. Downstream impact of upstream watershed development becomes a key question for future programmes and has to be answered by separating climate and human impacts. The present study focuses on a detailed water accounting of a typical artificial tank through intensive monitoring. During the period of observation, the total runoff generated within the catchment is stored in the tank and 35% of the stored water disappears by percolation. It appears that heavy siltation may be the main limiting factor for percolation efficacy.

# 1 INTRODUCTION

As a consequence of the “green revolution” during 1970s, groundwater resource became extensively exploited over large areas in India for irrigation water supply. The number of aquifers considered as over-exploited (groundwater draft exceeds recharge) is worryingly increasing. Over-exploitation is particularly sensitive in hard-rock and semi-arid regions, where the storage is limited by the aquifer geometry and recharge is highly variable. In Andhra Pradesh, as many other states in India, groundwater sustains a substantial cropping pattern change by increasing dry season paddy and sugarcane at the cost of traditional staples such as pulses and sorghum (Van Steenberg 2006). This results in a decline in groundwater levels exacerbated by two consecutive dry years in 2002 and 2003 (Massuel et al. 2007). In recent years, water harvesting has been promoted and funded on a massive scale as part of different government and non-government watershed development programmes for conserving and protecting sources drinking water supply, increasing or stabilising agricultural production, reducing erosion for soil conservation, and enhancing groundwater recharge to sustain groundwater levels. In Andhra Pradesh, aquifer conservation is endorsed by the Water Land and Trees Act enforced in 2004, introducing registration of the wells, licensing of drilling rig operators, and a permit for any newly constructed borehole. Watershed development programmes are being carried out at large scale whilst published relevant surveys assessing the impacts and benefits of these measures are limited (e.g. Muralidharan et al. 1995, Selvarajan et al. 1995, Sukhija et al. 1997, Gore et al. 1998, Chary & Subbarao 2003, Sudarshan 2003, Machiwal et al. 2004, Sharda et al. 2006). For instance, the State of Andhra Pradesh set the objective to increase aquifer recharge from 9% of total rainfall under natural conditions to 15% by the year 2020 (Government of Andhra Pradesh, 2003). Reaching such an objective would require the processes of local water deep percolation to be understood for optimizing artificial groundwater recharge structures.

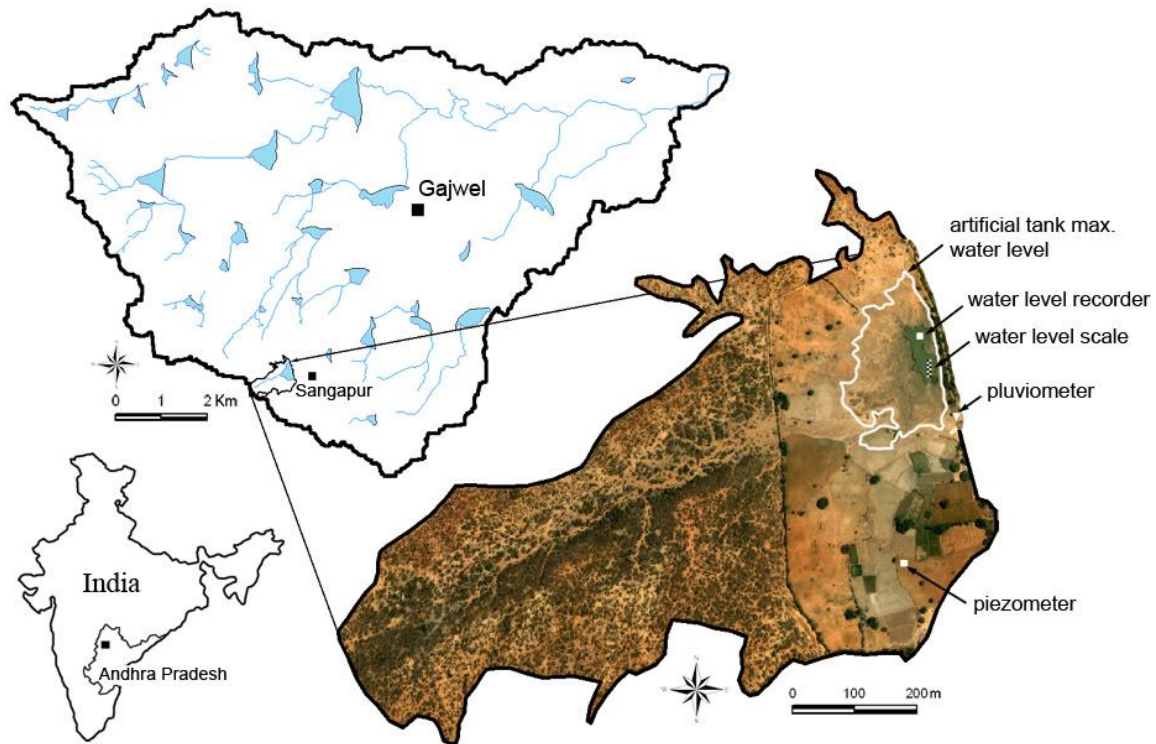
In the framework of the SUSTWATER Project (EuropeAid), the Gajwel watershed (80 km<sup>2</sup>) considered as overexploited, has been selected for implementing a Decision Support Tool that simulates the impact of changing cropping patterns and artificial recharge on groundwater levels. In the basin, 29 artificial tanks have been identified, their size ranges from 2 to 46 ha and covers approximately 3% of the total basin area (2.5km<sup>2</sup>). The present study focuses on a representative tank, for assessing the surface and ground water impact of the structure. Preliminary results concern a detailed water accounting based on reliable field measurements of which methodology is reported hereafter.

## 2 STUDY AREA

The Gajwel watershed is located in Andhra Pradesh (Figure 1). The climate is semi-arid and total annual rainfall is 750 mm on average, occurring mainly during the monsoon period from June to October. The topography of the area is mostly flat with only small granitic hills in the upstream part of the watershed. The drainage network has been largely modified by human activities, with 39 identified small dams along drainage lines, and runoff is limited to a few hours during storm events, caught by the water harvesting structures closing the catchments. The Gajwel watershed is in a rural context, half of the cultivated surfaces are devoted to rainfed crops (mainly cotton and maize), the other part being irrigated (paddy dominated) mainly by groundwater. The geology of the watershed is characterised by the predominance of orthogneissic granite (a.k.a. pink granite) and limited occurrence of leucocratic granite. A few dolerite dykes and pegmatite veins are also present. The granite is weathered with a saprolite layer thickness comprised between 10 and 30 metres with the exception of rare granite outcrops.

The hard-rock aquifer is depleted due to intense draft caused by approximately 1200 irrigation boreholes implemented in the watershed. In most places, the saprolite is totally unsaturated and groundwater is limited to the fissured layer of the aquifer. Farmers have said that a significant number of boreholes may run dry after a bad monsoon year.

In the watershed, the selected artificial tank meets two criteria: (i) it has to be located in the upstream part of a drainage line in order to collect runoff without human disturbance upstream, and (ii) its geometry should be as smooth as possible for an accurate storage capacity mapping. It is located close to Sangapur village and can reach a maximum surface of around 3 ha. The catchment of the tank is approximately 45 ha, mainly covered by shrubs and surrounded by forest (Figure 1). In the vicinity, about a hundred hectares of land are cultivated and groundwater irrigated.



*Figure 1. Gajwel basin and Sangapur tank location. Equipment features and tank extension.*

### 3 MATERIAL AND METHOD

#### 3.1 Water accounting

The volume of water percolating below the tank ( $P$ ) is estimated through an accurate determination of all the components of the water budget (equation 1).

$$P = R_f + R_r + I_{rf} - ET - L - O_f + (V_i - V_t) \quad (1)$$

Inputs
outputs
stock variation

Where:

$V_t$  is the volume of water in the tank at time  $t$   
 $V_i$  is the initial volume of water in the tank  
 $R_f$  is the incoming runoff volume  
 $R_r$  is the direct rainfall input volume  
 $I_{rf}$  is the irrigation surface return flow volume  
 $ET$  is the total evapotranspiration volume  
 $P$  is the percolation volume  
 $L$  is the livestock consumption volume  
 $O_f$  is the overflow volume

In order to estimate accurately the volume of water percolated below the tank ( $P$ ), the different variables of equation (1) are measured or approximated as detailed hereafter.

Volumes  $V_i$  and  $V_t$  are function of the tank water level and geometry. In semi-arid climate storm events are very brief; in the tank, 85% of the flood occurs in only 45 min, so if the tank does not overflow, the other variables can be neglected during a flood event and variation of volume can be considered as the total runoff ( $R_f$ ) and direct rainfall input ( $R_r$ ).  $R_f$  and  $R_r$  are estimated flood event-wise using the relationship between water level and volume and surface. Hence, it is necessary to determine the water level in the tank at any point of time and the topography of the bottom of the tank. To do so, two water level recorders were installed in the bottom of the tank at about 30 m from each other. The automated probes (Madofil, IRIS Instruments, France) record every 15 min the water level with an accuracy of 0.05% under 2 bars (+/- 1cm). A limnometric scale was also installed for manual measurement and cross-validation with the digital data. Since the surface of water is perfectly horizontal, each level corresponds to an elevation contour line. The periphery of the lake was delineated by GPS at different levels. Resulting contour lines were interpolated to obtain an accurate Digital Elevation Model (DEM) of the tank bottom.

Irrigation surface return flow ( $I_{rf}$ ) is locally measured after an inventory of all irrigated fields of which excess water flows into the tank.

The evapotranspiration  $ET$  is determined by monitoring the daily evaporation ( $E$ ) in a Class A evaporation pan in the vicinity of the tank and adding the plant evapotranspiration  $ET_{crop}$  (see Perrin et al., 2008). According to Shaw (1994),  $ET_{crop}$  can be estimated by the water requirement of the crop, based on the crop coefficient. Plants growing over tank were assimilated to lucerne (tall grasses). The crop coefficient for lucerne is comprised between 0.57 during the germination period and 1.4 during the growth period (Singh et al. 2007). As a first approximation, a mean crop coefficient of 1.0 is taken. Geochemistry methods are planned to be implemented in the next phase of the study for estimating  $ET$  but are not presented here.

$L$  is estimated by livestock head inventory in the village and based on livestock water consumption for semi-arid area based on Peden *et al.* (2007) study.

$O_f$  cannot be measured but can be detected for each flood. It has no impact on the tank balance for average monsoons such as in 2007 as the tank did not overflow (maximum tank level about 1.5 m below overflow threshold).

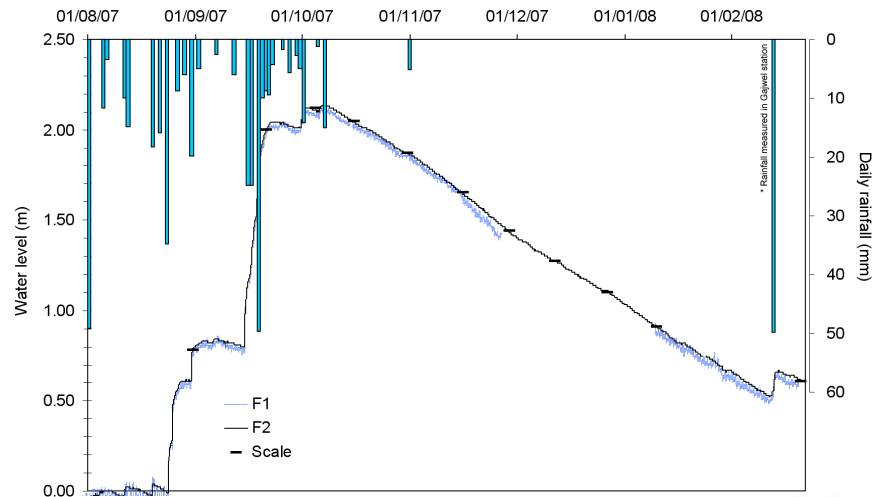
### 3.2 Impact on groundwater

An automatic water level recorder was installed in a nearby abandoned borehole to have a preliminary insight on the piezometric fluctuations in the area. A piezometric mapping of the tank surroundings was carried out monthly using abandoned irrigation wells, and currently used boreholes. Some piezometers, specific for the study, are planed to be drilled during the year 2008. All the measurement points were levelled by Differential GPS in the same frame of reference as the tank bottom elevation. In addition, groundwater conductivity is also measured in the pumping boreholes to detect any dilution effect from the tank water.

## 4 PRELIMINARY RESULTS

### 4.1 Tank depletion

The tank water level variations from July to March 2007 are presented in **Figure 2** with daily total rainfall data. Water levels recorded in the tank are highly accurate as they match the scale readings (uncertainty within 1 cm). Almost 160 mm of total rainfall are required before generating the first significant flood in the tank. Then the maximum water level (2.14 m) is reached only one month later, after four flood events.



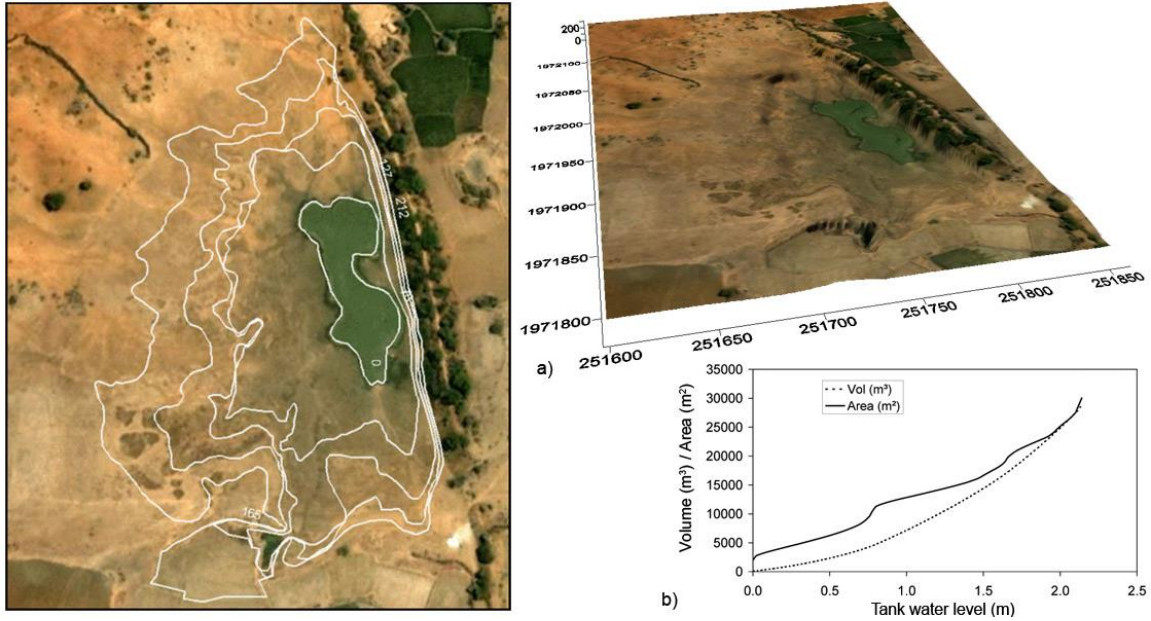
**Figure 2.** Sangapur tank water level and total daily rainfall.

The water levels are converted into volume and surface using the DEM presented in **Figure 3a** and the resulting relationship in **Figure 3b**. According to this, the maximum water level in 2007 corresponds to a volume of 29,866 m<sup>3</sup> and an area of 30,062 m<sup>2</sup>. Focusing on the depletion phase of the tank, the mean daily depleted volume over the period October-March is 187 m<sup>3</sup>.d<sup>-1</sup> (400 m<sup>3</sup>.d<sup>-1</sup> to 100 m<sup>3</sup>.d<sup>-1</sup>) which means around 12.6 mm.d<sup>-1</sup> (**Figure 4**).

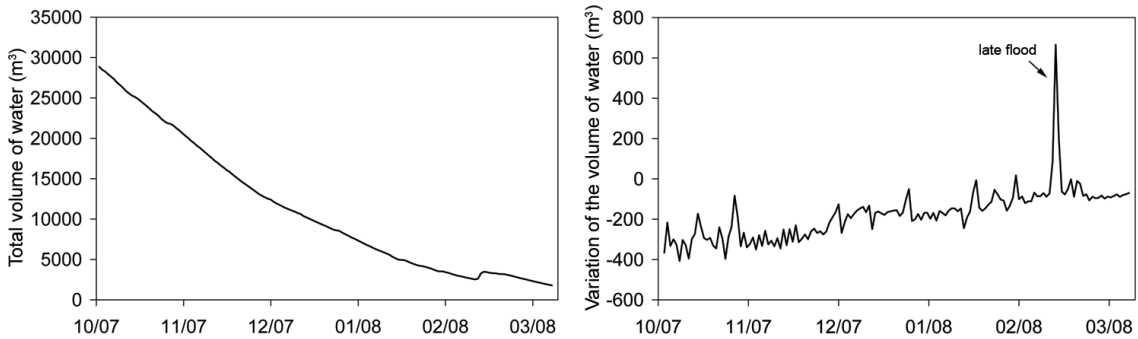
Three irrigation bore wells located on the southern side of the tank may contribute to irrigation return flow ( $I_{rf}$ ). Their mean daily pumping rate over the period October-March is 96 m<sup>3</sup>.d<sup>-1</sup> and the surface return flow to the tank is estimated around 11 m<sup>3</sup>.d<sup>-1</sup>.

The mean pan evaporation rate measured over the period October-March is 4.5 mm.d<sup>-1</sup>. This results in a crop water requirement of 3.2 mm.d<sup>-1</sup> and the term  $ET$  of equation (1) becomes in first approximation 7.2 mm.d<sup>-1</sup> (108 m<sup>3</sup>.d<sup>-1</sup>).

According to Peden et al. (2007), in the wet season daily intake for cattle and goat is respectively 10 L and 2 L. During the dry season, daily intakes increase to 27 L and 5 L respectively. Assuming a maximum number of heads of 150 for cattle and 200 for goats, based on village wise census, the daily mean maximum livestock consumption over the period October-March is around 3.7 m<sup>3</sup>.d<sup>-1</sup>. According to equation (1), 64 m<sup>3</sup> of water percolate daily under the tank on average, that is to say 35% of the daily discharged volume. This represents a total cumulated volume of 9450 m<sup>3</sup> out of the total discharged volume of 27,061 m<sup>3</sup>.



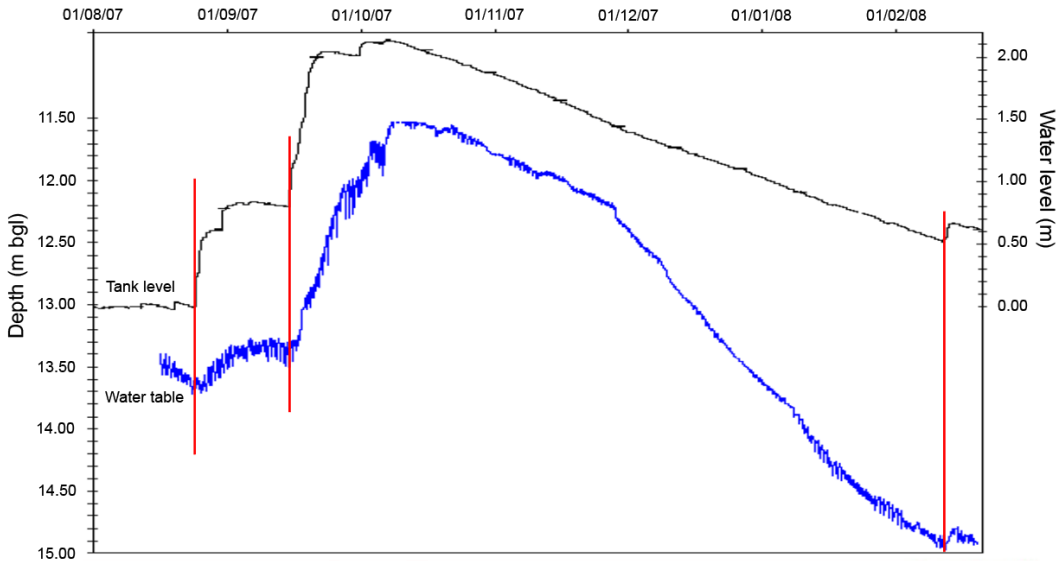
**Figure 3. a) Contour lines and DEM of the tank; b) volume and area of the tank versus water level.**



**Figure 4. Evolution of the total volume of water in the tank (left) and daily variations (right).**

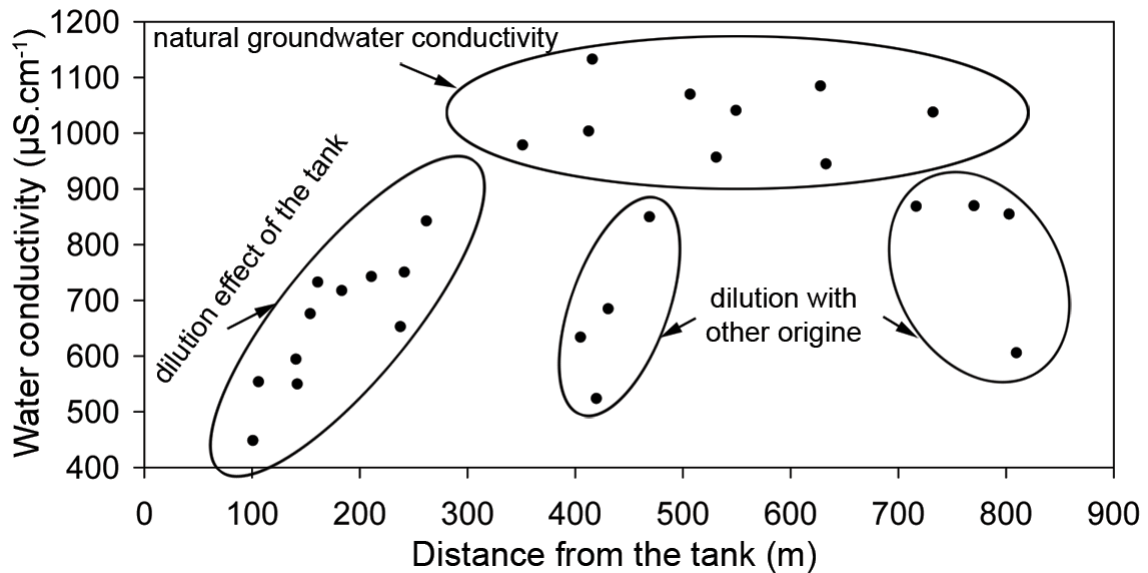
#### 4.2 Tank impact on groundwater

According to the piezometer records (figure 5), the percolation under the tank seems to have no significant influence on groundwater, 320 m away from the tank centre. The July rainfall neither contributes to the onset of the tank filling nor to the aquifer recharge. The water is mostly retained as soil moisture in the vadose zone. The water table starts rising after 170 to 260 mm of cumulated rainfall. Time lag between flood and rise of the water table is very short (40 min), which means that direct recharge is probably predominant near the piezometer. The tank depletion is not followed by a water table rise in the piezometer which confirms that the infiltration dome is much smaller than 600 m across. It underlines the necessity to drill observation piezometers closer to the tank.



**Figure 5. Water table fluctuation compared with tank water level.**

Influence of the percolation in the tanks is evidenced by water conductivity measurements. Percolated water from the tank has low conductivity ( $\sim 200\mu\text{S}\cdot\text{cm}^{-1}$ ), when mixed with groundwater with higher water conductivity (900 to  $1100\mu\text{S}\cdot\text{cm}^{-1}$ ) a dilution effect can be evidenced up to 300 m distance from the tank (Figure 6). The distance of influence can be roughly estimated at 300 m which is in agreement with piezometric measurements.



**Figure 6. Water conductivity versus distance from the tank.**

## 5 DISCUSSION AND OUTLOOKS

These preliminary results indicate that a significant volume of water stored in the tank percolates into the unsaturated zone (35%). However, the real impact on groundwater recharge is not assessed yet. To answer this question, a hydrodynamic modelling will be carried out after

monitoring the complete hydrological year. Future work will include a better characterisation of the aquifer in the vicinity of the tank based on the implementation of several piezometers and regular piezometric campaigns. Effort will be made in characterising in detail the geology of the site (geophysics and drilling) and the hydraulic properties of the aquifer (hydraulic tests).

Since the beginning of the monitoring period, water samples (tank, rain and reference sample without percolation) have been taken for further analysis. Stable isotopes ( $O^{18}$ , D) and chloride (Sukhija et al. 1997) will be analysed in order to improve the accuracy of the evaporation fraction estimation and indirectly on the percolation rate estimation. Preliminary results present a mean water budget over the hydrologic season, but in the light of the variability of the volume evolution, a daily water budget is required for better percolation rate estimation.

Infiltration tests have recently been carried out in the dried up areas of the tank. Results show a large heterogeneity of the infiltration capacity of the first centimetres of the soil (<1 to 170 mm.h<sup>-1</sup>). Shallow drill-logs show up to 80 cm of pure grey clay in the zone with the lowest infiltration capacity. It is therefore planned to realise a desilting of the tank in order to compare results before and after desiltation.

### **Acknowledgment**

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