Simulations of multipurpose water availability in a semi-arid catchment under different management strategies.

J. BURTE[a,b,c,d], J.Y. Jamin[b], A. COUDRAIN[c], H. FRISCHKORN[d], E.S. MARTINS[a] Corresponding author: julienburte@yahoo.fr

[a] FUNCEME, Fortaleza-CE BRAZIL, [b] CIRAD, UMR G-EAU (CIRAD, IRD, CEMAGREF, ENGREF) Montpellier, France, [c] IRD, Great Ice (UR IRD 032) University of Montpellier 2, [d] UFC, DEHA, Fortaleza, Brazil

Context

The Brazilian Northeast (750 000 km², 51 million inhabitants) is a semi-arid region (P ≤ 700 mm.yr⁻¹, ETP > 2000 mm.yr⁻¹) where the high annual rainfall deficit is accentuated by a short rainy season (3 months) and strong rainfall irregularity. Spatial and temporal heterogeneity of precipitations combined with shallow soils, crystalline basement and high evaporation, lead to intermittent rivers flow with a mean duration less than 3 months **(Cadier, 1996)**. In adaptation to this restricted water availability, the inland colonization of the Northeast, which started in the 1650's, has been guided by the river systems that constitute open paths and allow water access to the river bed itself or to the related alluvial aquifer. Indeed, during the dry season, the cattle and human water supply was provided by open dug wells **(Molle, 1994)**.

During the last decade, the exploitation of groundwater from the alluvial aquifer of Forquilha watershed has been favored by the drilling of wells. This allowed the development of irrigated crops, more attractive and lucrative than rain-fed ones. The pressure on water resources is indeed increasing (growing population, increasing domestic needs per capita, irrigation) and it is now an open question whether water availability can be sustainable.

There are many reservoirs in the Forquilha catchment. Sixty nine are annual reservoirs, filling and emptying every year; their capacities range from 0.05 hm³ to 0.3 hm³ and they are well distributed over the 17 communities (**Fig 1**). Four are over-year reservoirs, with a capacity of about 1 hm³, the biggest one is Reservoir Verde (6.7 hm³). Salinity is often less than 0.4 g/L; however, the impact of evaporation may increase strongly this value during the dry season (up to 3 g/L).

The alluvial aquifer covers about 0.6 km² (23 km by 250 m) and the alluviums have a mean depth of 6.8 m. The water table is at about 2.8 m below soil surface at the end of rainy season, the groundwater volume is about 2.3 hm³, and the main inflow originates from the intermittent river **(Burte et al., 2005).**

Objective

To evaluate water availability for different users and different uses within the whole Forquilha watershed (221 km2) for the next 30 years, according to different possible future evolutions of irrigated crops (the main water consumers).

Methods

1. **Characterization of the different water resources** (amount, salinity and variability) **and development of the related hydrological models (Fig.2)**, of **the different uses and users**, and of the main constraints (physical, socio-political and economic) on water resources management;
2. **Development of evolution scenarios** for the next 30 years, taking into account the possible increase of the population, assuming that domestic water supply needs are growing and must be secured and different assumptions on the increase, decrease or stagnation of the irrigated field area and taking into account possible transfer of water from different parts of the watershed to others (release from the upstream reservoirs to the river that may feed the downstream aquifer)
3. **Simulations, based on a 30-year rainfall series**, of the impacts of the above scenarios on the satisfaction or not of the needs of water resources availability and quality in the reservoirs (volume and salinity) and in the aquifer (volume) for main user categories, taking into account a realistic climatic variability.

Results and discussion

• Based on physical and socio-economic issues, three **main water territories have been defined** ('Aquifer', 'Reservoirs' and 'Disperse Habitat'). Considering the next 30 years with a realistic population growth, three hypothesis of irrigated area (i.e. 0, 75 (**Fig.3**) and 150 ha) and several possible water management scenarios, hydrological balance models were built and used to simulate the different impacts on the availability and the salinity of water resources.

• Results from simulations **(Table 1)** show that, in all cases, **releases from the upstream main reservoir are necessary for** keeping water salinity of the reservoir below 0.7 g/L and for **guarantying domestic needs** in the whole watershed.

• The simulations show that **the area of irrigated fields cannot grow above the present situation** (75 ha) without serious problems of availability and salinity of the water resources in the whole watershed. Otherwise, important socio-economic problems, including a high cost of palliative water supply with tank trucks from external sources, are expected. The consequence is that **free extension of irrigated crops, as currently observed, and even encouraged by authorities, is unsustainable.**

• To avoid future conflicts, irrigation extension should be restricted through negotiations between communities and irrigating farmers. As a consequence, a management taking into account the interrelations between the three territories appears necessary. **A participatory water management, integrating main related water resources would be hydrologically effective and socially desirable**; communities of both 'Reservoir' and 'Aquifer' territories would benefit from it.

Table 1: Results from simulations for 30 years (population increasing from 3900 to 5600 persons)

Conditions of simulations :	Results of simulations (in bold when highly beneath desired):				
Surface of irrigated fields Release from R. Verde during the dry season	Mean annual cost for tank trucks (US$ / yr)	% time of satisfaction for domestic needs (% yrs or % months)	% time of satisfaction of the irrigation needs (% yrs or % months)	% time with volume of R.Verde > 15% of its capacity (% yrs or % months)	% time with salinity of R. Verde < 0.7 g/L (% months)
Irrigated fields : 0 ha					
0 L/s		88% yrs	-	100% yrs 100% months	**40%**
30 L/s during 5 months		98% yrs	-	100% yrs 100% months	86%
Irrigated fields : 75 ha					
0 L/s	**3000**	**40% yrs 77% months**	**10% yrs 77% months**	100% yrs 100% months	**40%**
50 L/s during 5 months	**3500**	**70% yrs** 85% months	90 % yrs 96% months	70% yrs 85% months	95%
Irrigated fields : 150 ha					
80 L/s during 5 months	**17500**	**30% yrs 73% months**	**30% yrs 73% months**	**50% yrs 75% months**	99%

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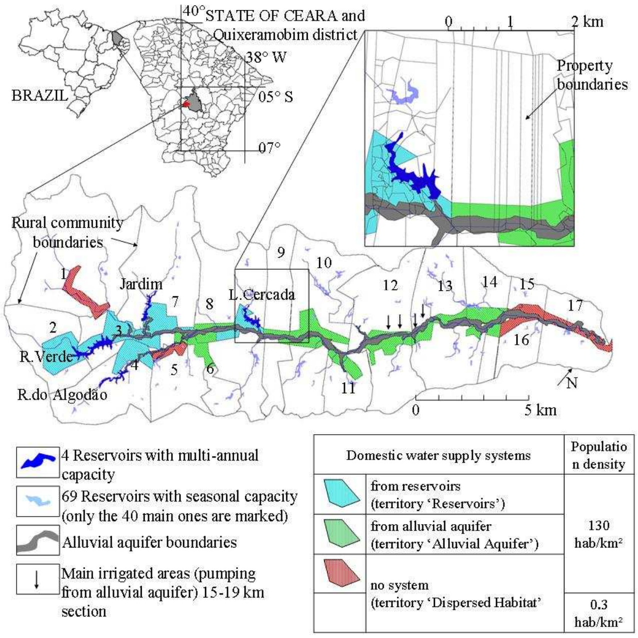

Fig.1: Forquilha Watershed (CEARÁ-BRAZIL) location and characteristics: main water resources (reservoirs and alluvial aquifer); irrigated areas, boundaries of the 17 rural communities; population density and respective type of domestic water supply system with the three water territories. Framed area shows the land structure with very narrow properties allowing water access in river.

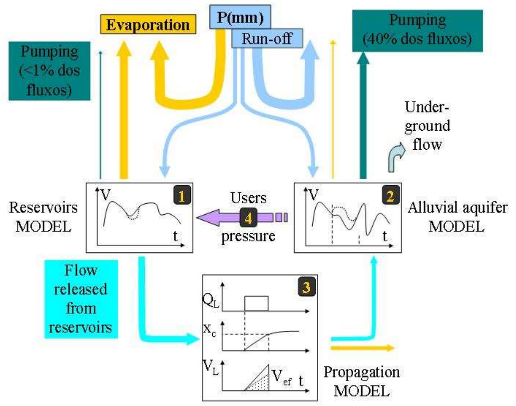

Fig.2: Hydrological models built and used in the study with monthly time-step to simulate the time evolution of the water content and water salinity (1) of the reservoirs, (2) of the alluvial aquifer and (3) of the released discharge propagation. Constraints due to social pressure are taken into account (4) in the flow released from reservoirs.

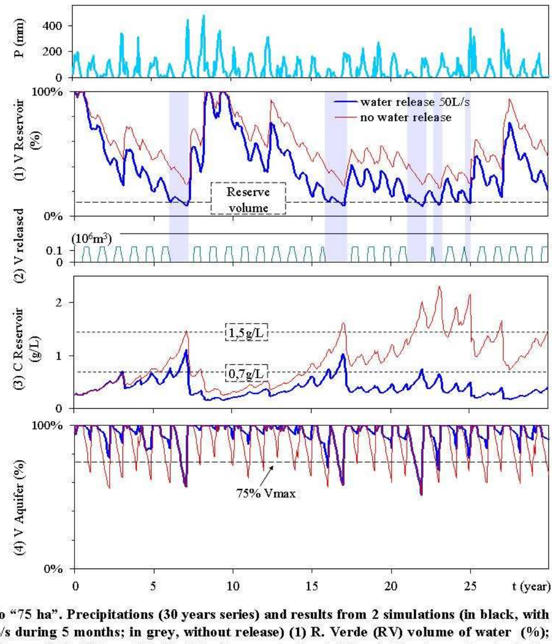

Fig.3: Scenario "75 ha". Precipitations (30 years series) and results from 2 simulations (in black, with release of 50L/s during 5 months; in grey, without release) (1) R. Verde (RV) volume of water (%); (2) released volumes (106m3) from RV; (3) RV salt concentration (g/L) and (4) volume of water in the alluvial aquifer(%). Horizontal dotted lines and outlined grey areas indicate critical values and periods.