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The influence of urbanization on groundwater level of the alluvial aquifer in Avignon-France

Salah Nofal[a,*], Yves Travi[b], Anne-Laure Cognard-Plancq[b], Vincent Marc[b], Michel Daniel[b], Bach Thao Nguyen[c], Gihan Mohammed[d]

[a]*University of Lille, 59655 Villeneuve d'Ascq, France*
[b]*University of Avignon, BP 21 23984 916 Avignon Cedex 09, France*
[c]*Hanoi University of Mining and Geology, Hanoi, Vietnam*
[d]*INRA, Site Agroparc, 84914 Avignon, France*

Abstract

The alluvial aquifer constitutes the main source for drinking and irrigation purposes in the city of Avignon. The occurrence of groundwater in this aquifer is controlled by surface water. In fact, Durance River could recharge the aquifer directly and indirectly by the irrigation via infiltration. Piezometric measurements show that irrigation leads to rise up locally the piezometric head during irrigation's period in summer. Different factors and processes taking place on surface of soil could impact this aquifer which is near to the surface. Especially if we know that natural and irrigated lands are progressively being reduced by an urban development. Thus, a decrease of recharge could happen in future. Temporal hydraulic head and the areal extent of the urbanized area over 50 years were compared to urban development in order to determine the influence of urbanization of groundwater level. A numerical model was built to predict future consequences.

Keywords: urbanization; irrigation; alluvial aquifer; groundwater level; Avignon

1. Introduction

The city of Avignon lies at the confluence of the Rhone and Durance in a quaternary plain. This plain has natural limits. The Rhone from the north-west, the Durance from the south and tertiary hills from the east (Fig. 1). This area is characterized by smooth landscape with an elevation ranges from 16 m in the west to 40 m in the east. The urbanized area is the dominant land use, while the agricultural lands occupy only 30% of the total surface (Nofal, 2009). This is a result of gradual urban extension (Alkhalifeh, 2008). A network of irrigation canals derived from Durance River is used by the farmers to ensure an optimal growing of corps during summer. The only source of drinking water of the city comes from municipal wells field (La Saignonne), situated 1 km away from the Durance River at the south east of the city. The daily production from this field averaging 40 000 m^3.

* Corresponding author.
E-mail address: salah.nofal@univ-lille1.fr

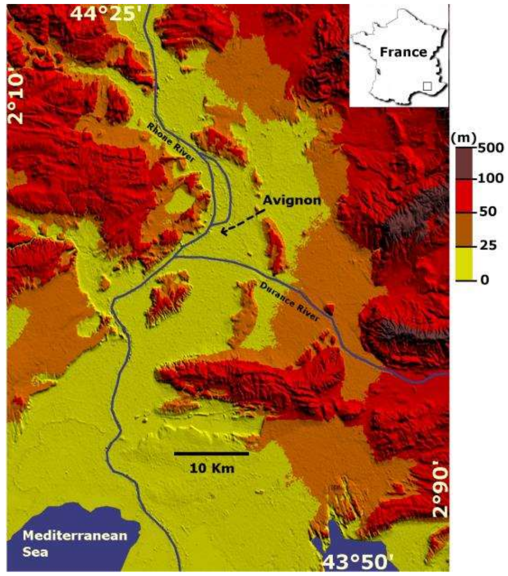

Fig. 1. Location of Avignon city and elevation in meters

2. Hydrogeological settings

The aquifer formation in the study area is made of unconsolidated sedimentary materials of quaternary age. The average thickness of the alluvial formations varies between 15 m and 23 m (Putallaz, 1972). The aquifer formation is characterized with high hydraulic conductivities comprise between 10^{-2} m/s and 10^{-3} m/s (Ciron, 1992; Durozoy et al., 1964; Garnier, 1987; Mallessard, 1983). The storage coefficient of this aquifer is about 10^{-4}, and the porosity is about 5% (Burgeap, 1995). The bedrock of the alluvium deposits, recognized by many drilling, consists essentially of Miocene marls which outcrops east (Fig. 2)

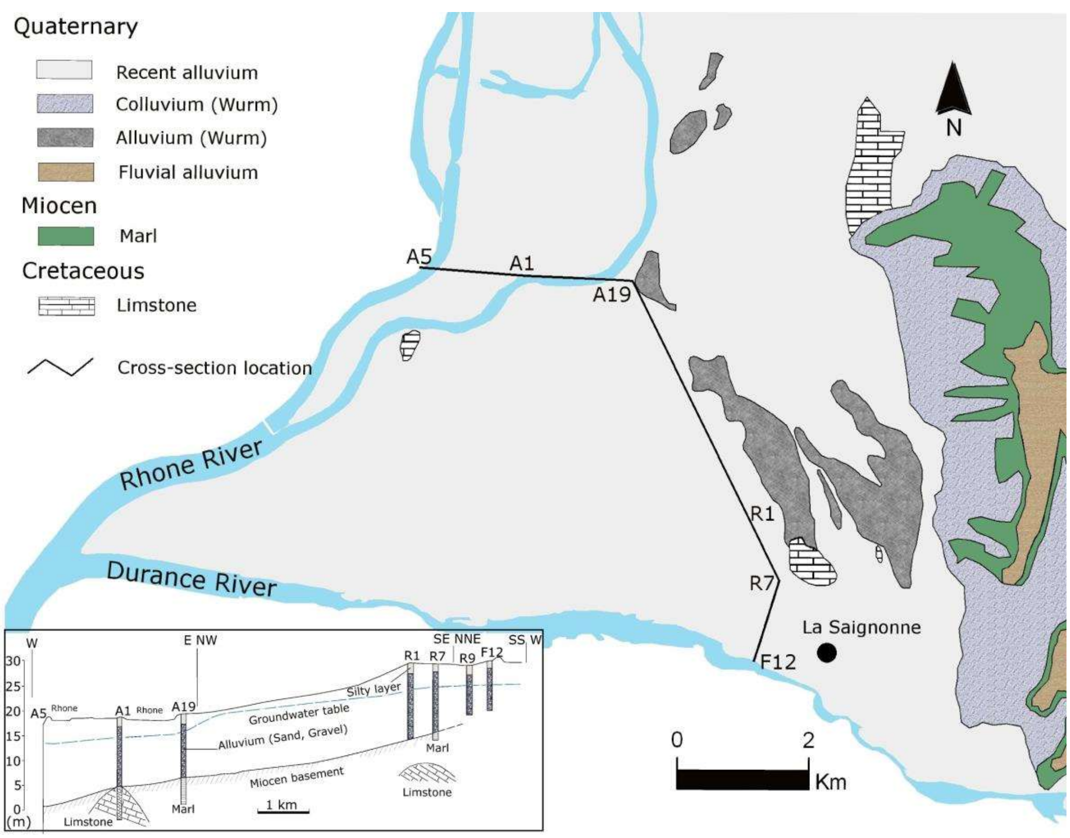

Fig. 2. Geological map and cross-section of the study area

3. Groundwater recharge

The recharge of the alluvial aquifer of Avignon by surplus of irrigation is highlighting by the piezometric measurements (Fig. 3). The piezometric variations show that the high level of groundwater is observed during summer (July) with the absence of effective rainfall when irrigation is at its maximum. While low groundwater level is observed during winter (February) when irrigation channels are unemployed.

Many studies conducted on the plain show that 25% of water brought by gravity irrigation reach the aquifer (Blavoux, 2003). This assessment was first achieved globally using natural isotopic tracing (O^{18} of water's molecule) (Lacroix, 1991). It has been confirmed and refined by water balances (Clementz, 1999). The irrigation provides an average annual volume of 19 millions m^3 which is 7 times more than annual recharge by the rainfall (Nofal, 2014).

Beside the Durance River, we should consider that the main source of recharge of the alluvial aquifer is from the Durance River (Nofal, 2014).

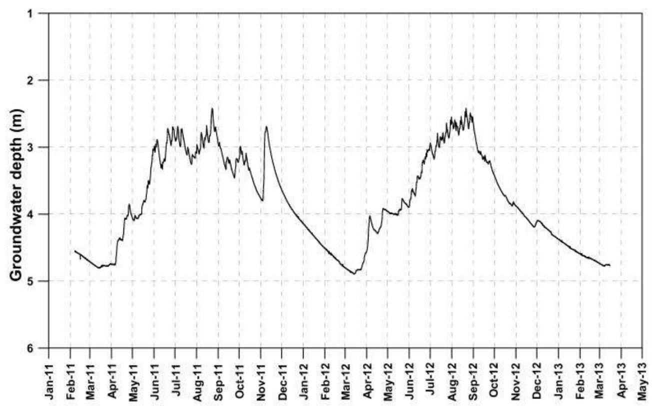

Fig. 3. Groundwater level variations in irrigated land

4. Impact of urbanization on groundwater level

The cumulative areal extent of the urbanized area for approximately 50 years is summarized in Fig. 4. The urban area blocked by the Rhone River has been quickly extended eastward. In the 1940s, urban area was limited in the western part of the city. The period between 1970-1980 has known the largest spread in terms of space consumed by the agglomeration, while from 1990s this trend has been slowed considerably. This evolution largely coincides with changing demographics of the study area (INSEE). Consequently, the morphology of the city has multiplied its surface six times during 60 years (487 ha in 1954 to 2820 ha in 2005).

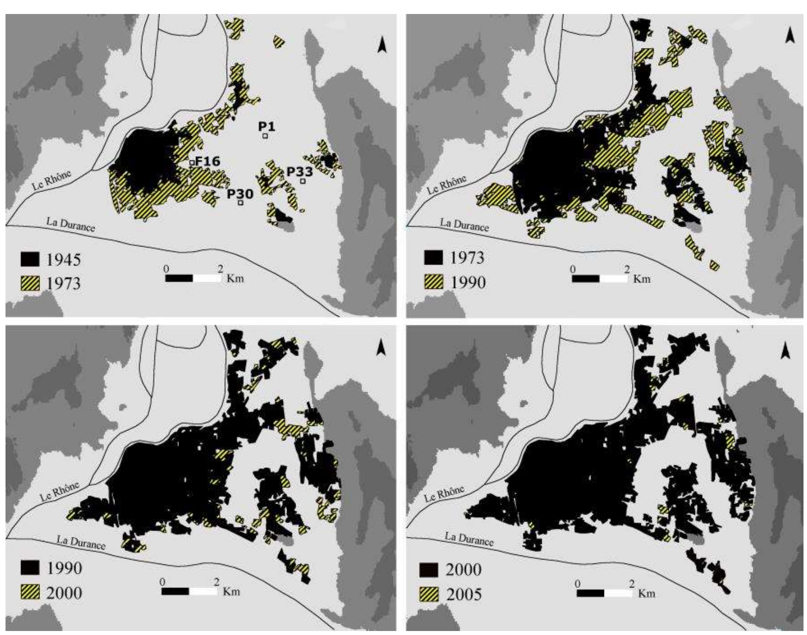

Fig. 4. The cumulative areal extent of the urbanized area (Alkhalifeh, 2008)

The urbanization led to a decrease in irrigated areas in alluvial plain of Avignon (Alkalifeh, 2008) (Fig. 5). Piezometric measurements for three piezometers (P30, P33, F16) distributed over the alluvial plain (Fig. 4), are available for about half of century (Fig. 6). These measurements show that the water table has markedly dropped. This drop was about 1.5 m in piezometer F16 and about 1 m in piezometer P30. However, water table declined mainly during 60's and seem relatively stable from the 80's.

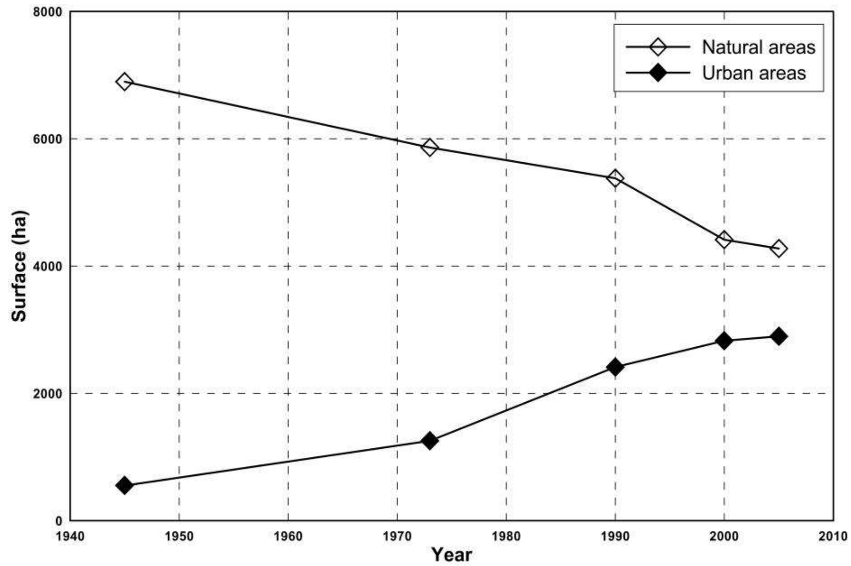

Fig. 5. Evolution of urban and natural surfaces in Avignon (1945-2005)

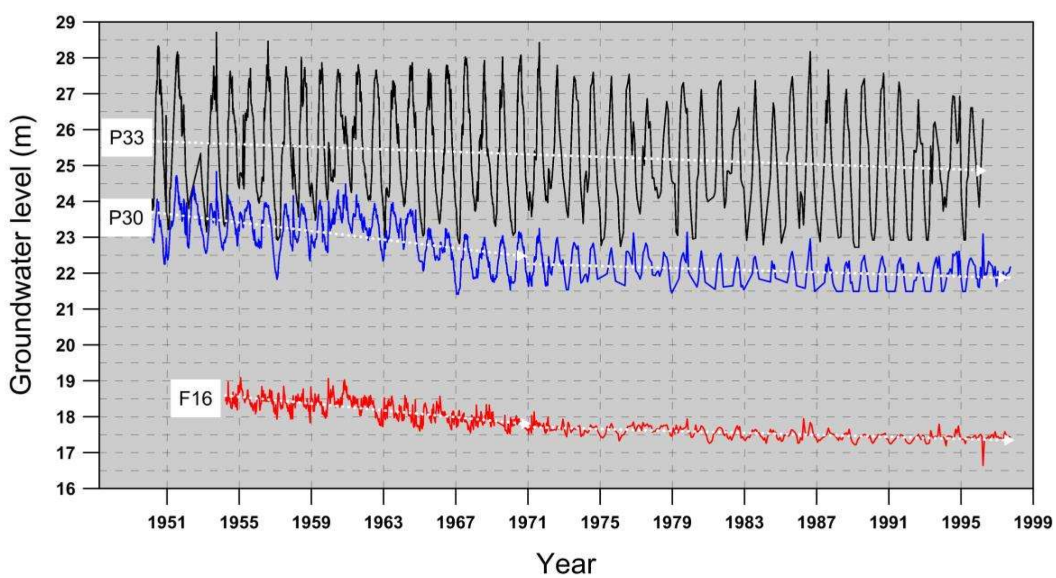

Fig. 6. Groundwater level evolution (1950-1999)

The decline of water table can be explained by various factors. The increase of water needs associated with population growth could affect the groundwater level. But this still a minor effect since the only source of pumping for drinking water is the municipal well fields (La Saignonne) and the aquifer in this area is recharged mostly by the Durance River (Nofal, 2014). Durance River's regime also could play on the groundwater level especially near the river's bank. The main reason behind the groundwater level drop seems to be the decrease in the surface of irrigated lands around. In fact, ground water level shows a good relationship with the total natural surface's evolution (R^2 = 78 % and 91 %) (Fig. 7). While in piezometer P33 situated in irrigated lands, the piezometric measurements show that the water table is more or less stable.

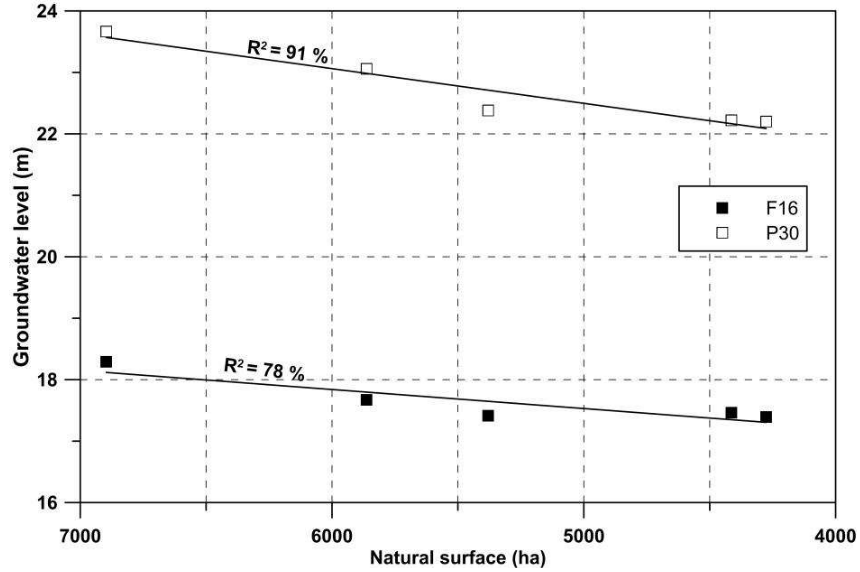

Fig. 7. Relationship between the evolution of natural surface groundwater level in F16 and P30 (1950-1999)

The results of the numerical model built for Avignon aquifer (Nofal, 2014), showed that in case of irrigated lands had to be disappeared and replaced by urban areas, water table would drop about 3 m in the irrigated areas (Fig. 8).

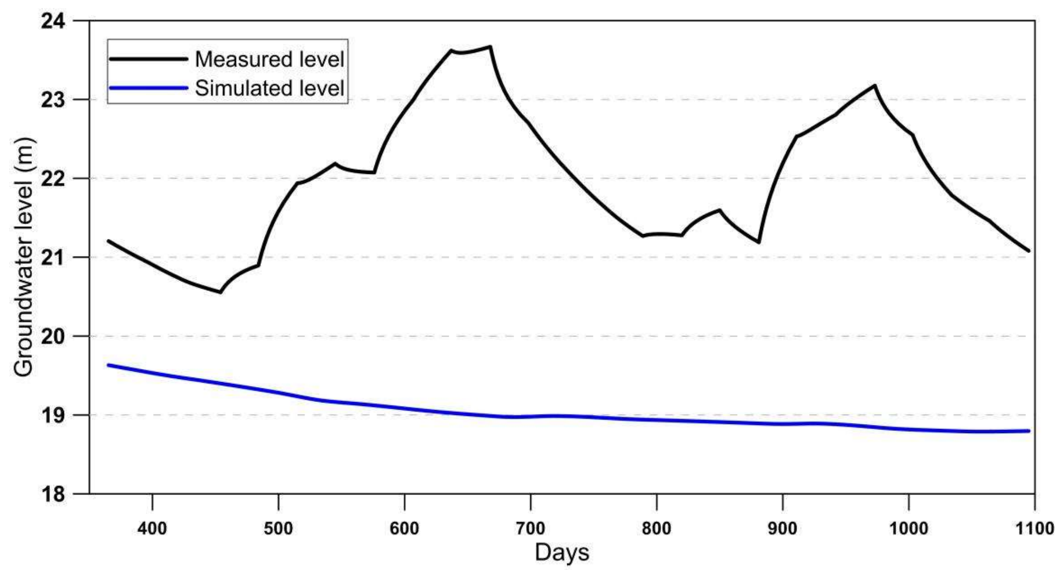

Fig. 8. Comparison between measured level and simulated (P1)

5. Conclusions

The groundwater system of the alluvial plain of Avignon, located between the Rhone and the Durance rivers, is characterized by an expanded agricultural area, whose surface is rapidly shrinking due to urban sprawl and economic development. This shallow aquifer is directly under the influence of surface water. In particular, the Durance water is heavily involved in the recharge process either directly or indirectly via irrigation. Land use, particularly urbanization, plays an important role on the hydrodynamic occurrence. The loss of agricultural land would reduce the irrigation volumes and tend to reduce the groundwater recharge.

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