Salt Water Intrusion in The Shallow Aquifers of Venice

Fulvio Zezza and ***Eloisa Di Sipio***
Department of Architectural Construction, University IUAV of Venice, Venice, VE, Italy

ABSTRACT
This paper presents the results concerning the water circulation of the first 50 m depth of the Venice subsoil, till now not interested by hydrogeological evaluation.
This research describes the aquifers, characterized by a significant thickness and constance, recognized in the Venetian geological context and the different hydrochemical facies of perched and confined aquifers, interested by salt water intrusion and influenced by tide variations, whose effects are diminishing with depth.

INTRODUCTION
A recent research on the geological settings of the Venice city centre subsoil (Zezza 2007), focused on the lithostratigraphic reconstruction of the first 50 m from the ground level, shed new light on the circulation of shallow groundwater.

The historical centre of Venice is located on the southern threshold of the Veneto Platform. The particular depositional events (marine transgression and regression), which have affected this region over the last 2 M years (Brambati et al. 2003), creates a typical stratigraphical sequence characterized by a great deal of variability in both the horizontal and vertical directions (McLennen et al. 1997; Carbognin et al. 2004). The analysis of the upper part of the sedimentary sequence by means of the lithostratigraphic method has allowed to distinguish the *cyclothemic organization* of Late Pleistocene, typical of lagoonal area, from the *multistorey sandbody,* the sedimentary structure typical of the city centre subsoil (Zezza 2007). The *cyclothemic organization* is constituted by a rhythmical alternation of sand, silt, clay and peat deposits, while the *multistorey sandbody* is formed by a vertical recurrence of sand body, created by alluvial channel and bank and overflowing deposits, whose complexity is influenced by climatic variations of the last glaciation (Wurm) and by the fluvial condition changes over time. If we consider the distribution of permeability characteristics in the subsoil, it is easily recognizable the influence of the *multistorey sandbody* sedimentary structure: the levels with a medium permeability correspond to sand, while the sediments characterized by low permeability or practically impermeable are clayey-sandy silt and clay deposits (Fig.1). From an hydrogeological point of view, the succession of these levels in the Late Pleistocene deposits identify a multilayered aquifer systems, constituted by four confined aquifers, located respectively at depth of 12-14 m, 18.5-21.5 m, 26-30 m and >30 m from the mean sea level, while the sandy silt typical of tidal Holocene channel and the landfill deposits are able to store perched aquifers (Fig.1).

METHODS
Sixty one piezometers, disposed at different depths all over the city and realized mainly during restoration intervention to control water level variations, have been used as references for the present work (Fig.2a). The great part of these (> 50) reaches a maximum depth of 6-8 m, while the remaining are able to involve the permeable deposits located under 12 m depth. Conductivity logs, together with temperature, pH and piezometry values, have been collected in each well in different periods, and the measured data allows to verify whether significant variations take place over the time. Moreover, the influence of tidal variations, registered at Punta della Salute marigraph, on the water level have been considered. The area of San Basilio (SB) has been

selected as sampling areas, due to the existence of some still open piezometers tapping aquifers at different depth: cation and anion contents have been determined, respectively, by ICP-MS and ion chromatography, together with isotope analyses in order to determine the hydrogeochemical facies of water.

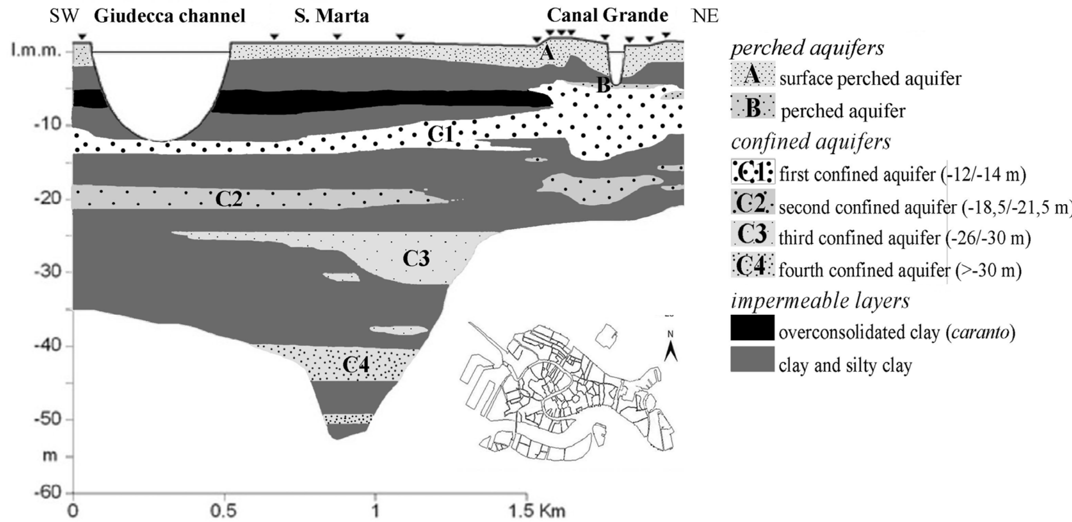

Figure 1. Groundwater circulation in the Late Pleistocene – Holocene deposits of Venice historical centre (from Zezza 2007, modified)

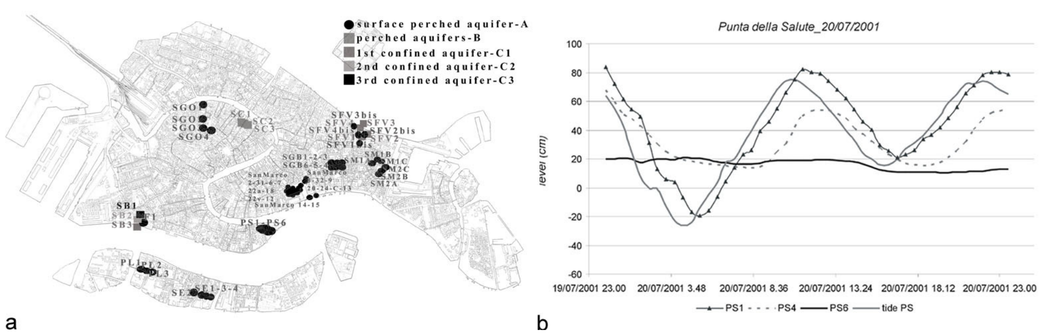

Figure 2. Relationship between water level and tide variations. a) Location of piezometers interesting different aquifers; b) in the perched aquifer of Punta della Salute, the piezometer more distant from the bank channel (PS6) shows the lower influence of tide

RESULTS

The first perched aquifer (A, Fig.1), located in the landfill deposits, has a thickness of 3.5-4 m, is characterized by high permeability values ($k=10^{-1}$-10^{-3} cm/s) and it is limited by clay and silty clay sediments of lagoonal origin. It is widespread all over the urban settlement and shows an homogeneous behaviour: the water level is included between 0.70 and 0.05 m on m.s.l. Due to its high hydraulic conductivity, this landfill soil is directly connected with the lagoon and therefore, the perched aquifer is immediately affected by the hydrostatic pressure variation driven by tides. The tide fluctuations determines water level variations that diminish gradually from 10-15 cm near the channel bank (PS1) to 2-3 cm at a distance of 8-9 m (PS6, Fig.2b). Other perched aquifers (B) are stored in semipermeable sediments (silty sand or sandy silt), located at a depth of 6-8 m from the ground level. These aquifers are irregularly distributed, have a limited extension and thickness (about 2 m) and locally their behaviour is typical of an aquiclude; the water table trend (between 0.70 and -0.80 m from the ground level) is influenced by tide variations only during low tide. The confined aquifers recognized at different depth in the alluvial sequence of the Late Pleistocene are related to the sand bodies identified by the lithostratigraphic correlation method (Zezza 2007, Fig.1). The data collected all over the piezometers interesting the Pleistocene sediments show that these three aquifers (C1-C2-C3) are not influenced by rainfall and that the piezometric levels variation due to tide fluctuations diminishes progressively with depth.

From the physical chemical analyses, the water of the first perched aquifer is slightly basic ($7.1<pH<8$) and T values range from 21.9 to 15.6 ° C. The electrical conductivity (EC) measurements reveals the presence of saline water all over the year ($2.9<EC<28.9$ mS/cm), while the Cl content is close to that of salt water ($Cl \geq 10{,}000$ mg/l). Moreover, all the three confined aquifers are characterized by slightly basic water ($7.1<pH<7.8$), with T means values of 17.8, increasing with depth. The EC ($3.8<EC<21.2$ mS/cm) and the Cl contents, typical of brackish water (300- 10000 mg/l), highlight the existence of the salt water intrusion phenomena. Therefore, following the Piper classification, the Venice shallow waters, both of perched and confined aquifers, can be defined as chloride-sulphate-alkaline waters (Fig.3a). Moreover, the anion ternary diagram focuses the existence of a mixing process between fresh and salt water related to the increasing of Cl content.

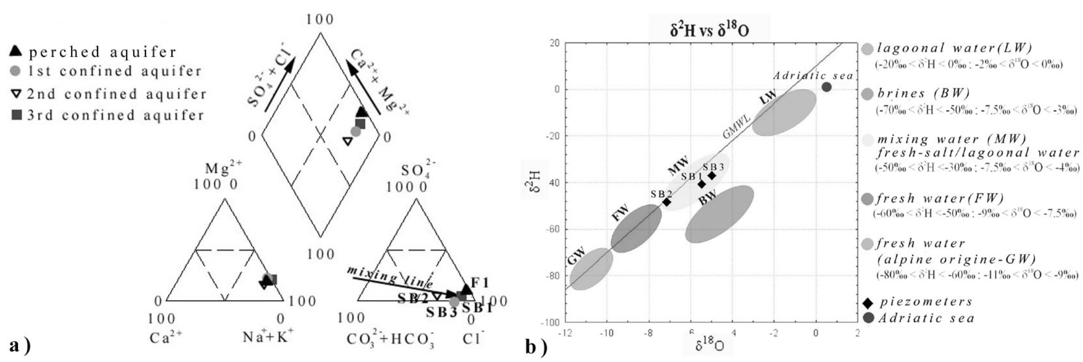

Figure 3. a) Geochemical classification of Venice water samples with Piper diagram (meq/l). b) Isotopic analyses of the confined aquifers

DISCUSSION AND CONCLUSIONS

The perched and confined aquifers waters have the same hydrochemical characterization, present typical salt water values (Cl) and can be considered as recent waters. The sea water presence in the shallow groundwater is confirmed by the (Ca+Mg)/(Na+K) ratio, ranging between 0.27 (sea water value) and 0.31, and by the Na/Cl and K/Na ratios, that exceed the sea water value (respectively of 0.86 and 0.02) only in the C2 aquifer. Moreover, in this aquifer, the negative chloride-alkaline ratio (Cl-Na+K)/Cl registered can be explained by the local presence of semipermeable layer that slow down the salinization process. The relationship between SO_4 and Cl ions confirms the presence of brackhish water within both the perched and confined aquifers, and reveals a redox environment in the first aquifer (C1), due to the presence of organic matter and peat.

The mixing phenomena is confirmed also by the isotopic analyses conducted on samples collected in the San Basilio area (Fig.3b). In particular, for the confined aquifers, the salinization process is decreasing with the distance from the lagoonal margins (from C1 to C3) or it is conditioned by the permeability variations within the subsoil: the first and the third aquifers presents a similar behaviour, while the second seems more protected by the semipermeable lithofacies bordering it.

To conclude, the hydrogeological characterization of the first 50 m of the Venice subsoil highlights the existence of different aquifers, perched or confined, all interested by salt water intrusion, characterized by the same geochemical water facies and whose behaviour is strictly connected with the sedimentation processes, that is the interbedding of permeable and impermeable deposits. Moreover, the evolution process of the fresh water towards the composition of seawater has been identified.

REFERENCES

Brambati A., Carbognin L., Quaia T., Teatini P., Tosi L. 2003. The Lagoon of Venice: geological setting, evolution and land subsidence. Episodes, vol. 26 (3): 264-268

Carbognin L., Teatini P., Tosi L. 2004. Eustacy and land subsidence in the Venice Lagoon at the beginning of the new millennium. Journal of Marine System , vol.51: 345-353

McClennen C.E., Ammerman A.J., Shock S.G. 1997. Framework stratigraphy for the Lagoon of Venice, Italy: revealed in new seismic- reflection profiles and cores. Journal of Coastal Research, vol. 13 (3): 745-760

Zezza F. 2007. Geologia, proprietà e deformazione dei terreni del centro storico di Venezia. Estratto Quaderni IUAV, Secondo Convegno “La Riqualificazione delle città e dei territori - Geologia e Progettazione nel centro storico di Venezia”, Venezia 7 dicembre 2007, Ed. Il Poligrafo

Contact Information: Eloisa Di Sipio, University IUAV of Venice, Architectural Construction Department, Terese – Dorsoduro 2206, I-30123 Venice, Italy, Phone: ++39-041-257-1291 or ++39-349-1942566,
Fax: ++39-041-522-3627, Email: disipio@iuav.it