

## Monitoring of hydrological parameters related to peat oxidation in a subsiding coastal basin south of Venice, Italy

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**Abstract** The Zennare Basin is part of the southern catchment of the Lagoon of Venice, Italy, reclaimed during the 1930s for agricultural purposes. It is an area that lies almost completely below sea level and is characterized by the presence of peat deposits. Histosol drainage for agricultural practices has enhanced the loss of mass due to oxidation of organic matter leading to an increase of the land subsidence rate which is currently estimated to be roughly 2–3 cm year<sup>-1</sup>. This subsidence causes increased pumping and drainage costs and thus has an adverse effect on the sustainable development of the area. As part of a research project aimed at studying the phenomenon by an experimental and a numerical approach, a site has been selected in the area of interest for the *in situ* monitoring of basic hydrogeological and meteorological parameters controlling the process. The first few months of data acquisition have shown that vertical movement of the peat surface is strongly related to the depth of the water table, soil moisture and temperature.

**Key words** drainage conditions; hydrological parameters; land subsidence; meteorological parameters; organic soils; peat oxidation; Zennare Basin; Venice

### INTRODUCTION

Land subsidence is the most commonly observed response of histosols to drainage for agricultural purposes. Worldwide, subsidence rates in drained peaty areas vary from less than 1 cm year<sup>-1</sup> (Nieuwenhuis & Schokking, 1997) to more than 10 cm year<sup>-1</sup> (Wösten *et al.*, 1997).

Under drainage conditions, biochemical oxidation has been found to be the dominant cause of peat soil land subsidence in tropical and temperate regions (Andriess, 1988; Deverel & Rojstaczer, 1996). In a natural waterlogged environment, the soil condition is anaerobic (oxygen-poor) and organic carbon accumulates faster than it can decompose. Drainage for agricultural purposes leads to aerobic (oxygen-rich) conditions and microbial activity oxidizes the carbon in the peat soil causing carbon loss in the form of gaseous CO<sub>2</sub> flux from the soil to the atmosphere.

Experimental field (Deverel & Rojstaczer, 1996) and laboratory (Moore & Dalva, 1997) studies have demonstrated that the rate of CO<sub>2</sub> production from organic soils, and hence of related land sinking, primarily depends on peat composition and soil temperature and moisture.

In 2001, the Venice Organic Soil Subsidence (VOSS) research project was initiated to study the process in the agricultural area located in the southern part of the Venice region. The soils are characterized by high organic content and the field drainage operations, started soon after reclamation, have caused large subsidence rates of up to 2–3 cm year. During the course of the study extensive laboratory and field measurements have been carried out in a hydrologically closed basin, the Zennare Basin, selected in the area of interest (Fig. 1, left). After the hydrogeomorphic characterization of the basin a field experiment was implemented for determination of the most important hydrological and meteorological parameters and their relations with the CO<sub>2</sub> fluxes and the land subsidence rates. This paper describes the field setting and discusses the preliminary results of the experiment.

### THE STUDY SITE

The Zennare Basin (45°10'E and 12°9'N) is an area of about 23 km<sup>2</sup> located just south of the Venice Lagoon, approximately 10 km from the Adriatic Sea (Fig. 1, left). The basin, occupied in the 19th century by swamps and reclaimed approximately 70 years ago, at present lies almost entirely below mean sea level, mostly between -2 and -4 m, and is completely dedicated to corn growing.

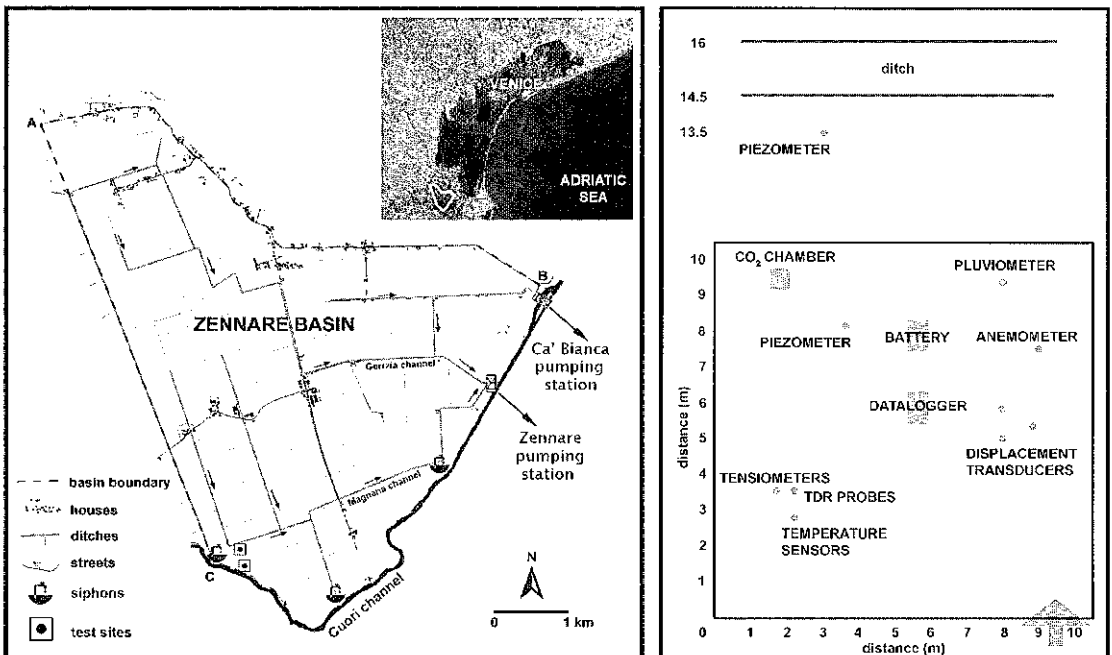


Fig. 1 Map of the Zennare Basin showing the principal drainage network (left), and schematic representation and sensor areal distribution of the field site (right).

Boreholes drilled down to 15 m from the ground surface, geophysical investigations, field surveys, and aerial photograph interpretation have allowed the identification of the main geological features of the area. A top peat layer between 1 and 1.5 m thick is nowadays uniformly present in the southern and central parts of the basin. It is underlain by alternating sandy, silty, and clayey layers that form an impermeable bottom boundary. The peat deposits are intersected by several palaeo-channels and palaeo-rivers ranging from a few metres up to 100 m in extent.

The boundaries of the hydrological catchment are: the bank of a main road on the north (A–B, Fig. 1 left); the Cuori channel embankment on the east and south (B–C); and the west boundary is a ditch directly connected to the Cuori channel through a siphon operated by the reclamation authority (C–A). The drainage network is formed by a small number of channels, approximately 5 m wide and 1.5 m deep, connected to a fine network of small ditches that subdivide the basin into rectangular fields of size 30–50 m × 200–500 m. This network is used to control the depth of the water table in the entire basin. Two major waterways, the Magnana and the Gorizia channels, convey the drained water to the Zennare pumping station.

## MATERIALS AND METHODS

Two principal test sites with an areal extent of 100 m<sup>2</sup>, 200 m apart from each other, have been established in the southern tip of the basin (Fig. 1, left). Each site is permanently equipped with (Fig. 1, right): (a) a tilting bucket raingauge with a sensitivity of 0.2 mm; (b) a non-directional anemometer with an accuracy of 0.25 m s<sup>-1</sup>; (c) two piezometers, one located within the test site and the other close to the adjacent ditch, made from 3 m long PVC pipe of 2 inch (~2.5 cm) diameter and instrumented with a pressure transducer characterized by a measuring range of 0–300 mbar (0–30 kPa) and an accuracy of ±1.5 mbar (0.15 kPa); (d) five soil temperature sensors at 1, 5, 15, 30, and 100 cm depths with a measurement range between –15°C and 50°C and accuracy of ±0.1°C; (e) five tensiometers to measure the capillary pressure, inserted at 45° and sloped so that the ceramic cups are located along the same vertical line at depth intervals of 15 cm down to 75 cm; and (f) five three-wire time domain reflectometry (TDR) probes for soil moisture content measurement, 15 cm long, and inserted horizontally along the same vertical and at the same depth of the tensiometers.

Ground surface displacement at each site is monitored by three displacement transducers having a measurement range of 0–25 mm and an accuracy of ±0.125 mm. The transducer body is attached at one end to a steel tripod anchored on three piles set into the ground to a depth of 11–12 m where an over-consolidated clay layer is located. The other end is connected to the land surface through a 0.5 cm thick, 10 × 10 cm aluminium plate resting on the soil. The triangular steel structure, with sides of approximately 2 m, has been designed to be as light as possible but with a negligible deformation with respect to the expected subsidence rate when loaded with the force exerted by the displacement transducers (2.5 kg each) and by a thermal range of 40°C.

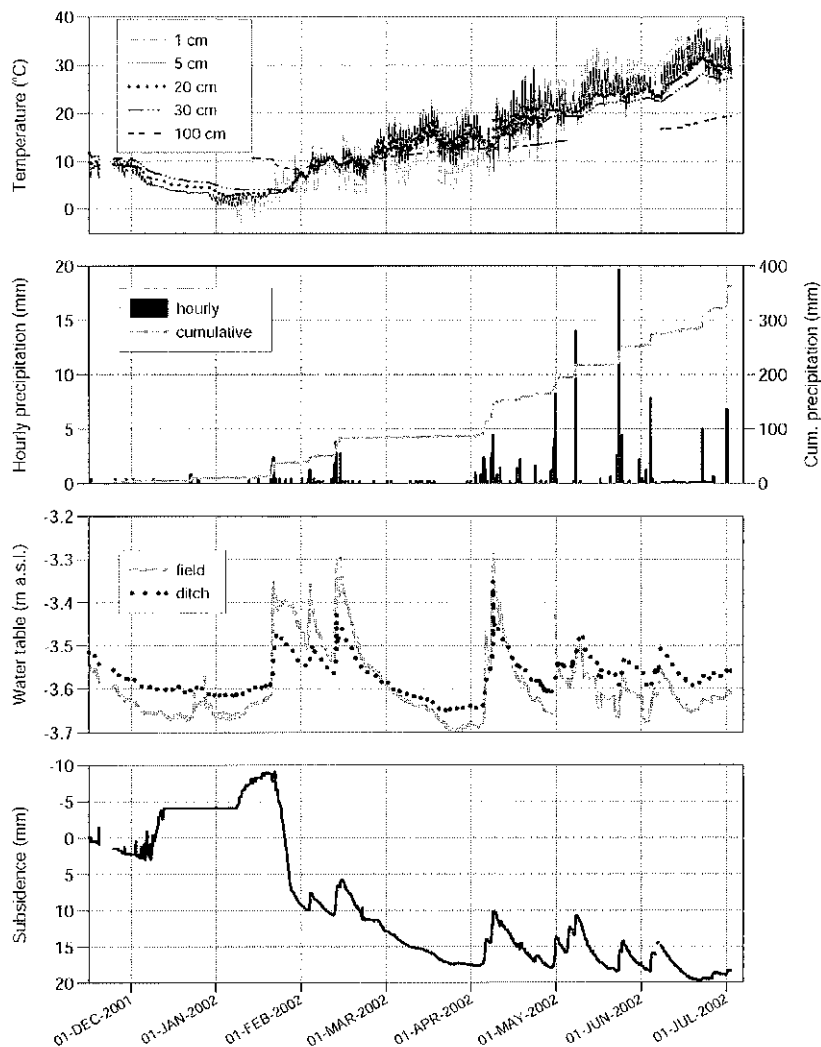
Since cultivation practices affect the peat structure and its characteristics in relation to the water-oxygen fluxes, the soil around the displacement transducers, the tensiometers and the TDR probes is managed so as to reproduce the actual conditions of the cultivated fields.

All the sensors are connected to a data logger and a 12 V, 260 Ah battery ensuring approximately one month of continuous functioning at an hourly data sampling rate.

Carbon dioxide fluxes from the peat soil to the atmosphere will be estimated using the non steady state chamber method. The results will be reported elsewhere.

## DATA ANALYSIS

The data collected so far are shown in Fig. 2, where temperature at different depths, rainfall and rainfall intensity, water table depth at the two piezometers and subsidence are plotted. The effects of rainfall on both ground displacement and water table depth



**Fig. 2** Soil temperature, hourly and cumulative precipitation, water table and land subsidence measured between November 2001 and July 2002 at the Zennare Basin field site.

are clearly visible. Daily temperature variations are very small below 20 cm depth, but are large for the surface-most probes. Note that between the end of December 2001 and the end of January 2002 the surface soil was frozen, and the extensimeter shows a net upwelling of the ground. The large downward movement that occurs during and just after the ice melting period is due to both soil volume decrease and surface mud deformation. It is also interesting to note that the ground surface is subject to significant vertical uplift at every rainfall event.

Figure 3 compares the measured soil subsidence and that predicted by the formula developed by Stephens *et al.* (1984) for the Florida Everglades:

$$S = (0.0169D - 0.1035) \cdot 2^{(T-5)/10} \quad (1)$$

where  $S$  [cm] is the subsidence,  $D$  is the water table depth [cm], and  $T$  the soil temperature [ $^{\circ}\text{C}$ ] at 10 cm depth. The dynamics of the phenomenon are not captured as the model considers only irreversible subsidence, while the peaks are due to reversible shrinkage of the peat component of the soil. In general the subsidence is evaluated with reasonable accuracy. Future studies will be aimed at a better tuning of this type of formula introducing other soil parameters, e.g. soil moisture,  $\text{CO}_2$  fluxes, etc.

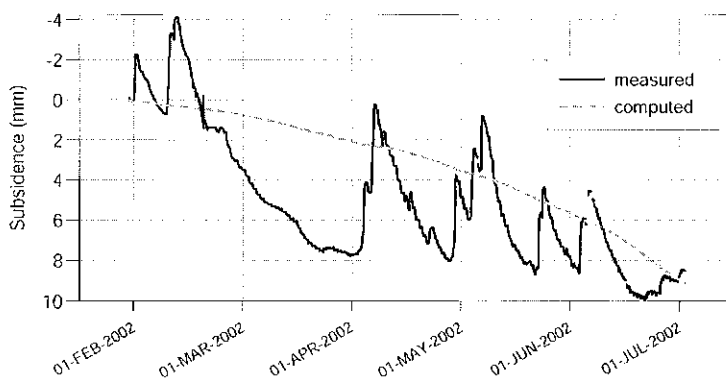


Fig. 3 Comparison between measured and calculated land displacements in the period after ice melting.

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