A sub-soil fresh-water distribution system using pipes located along the main sandy pale-channel

Deliverable D_4.2.3

Contributing partners:

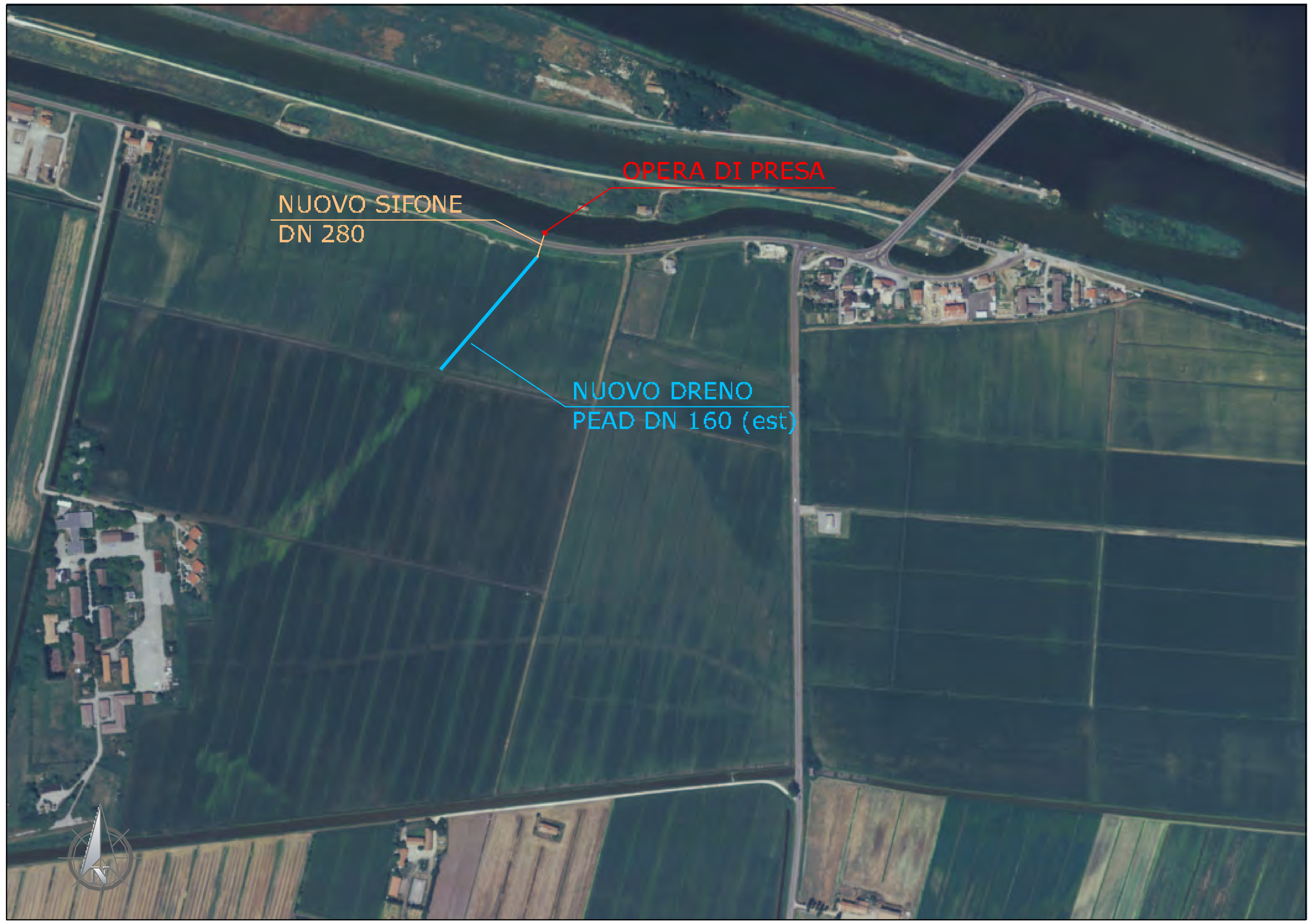
PP1 – CNR IGG

PP2 – Adige Euganeo Land Reclamation Authority

LP – UNIPD DICEA

Section 1

Graphical tables describing the draining pipe and the control valve system



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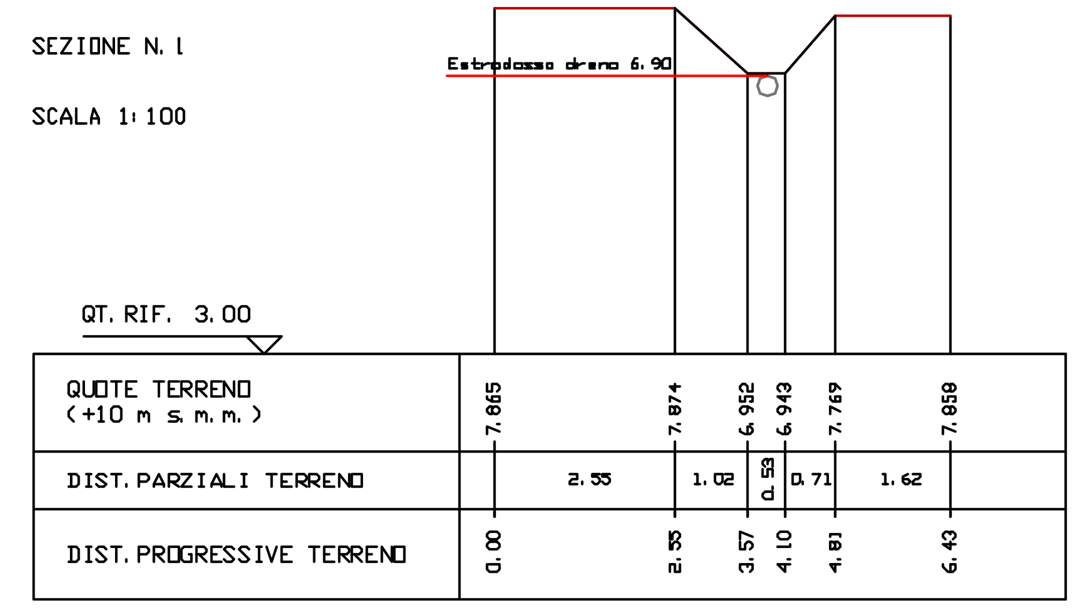

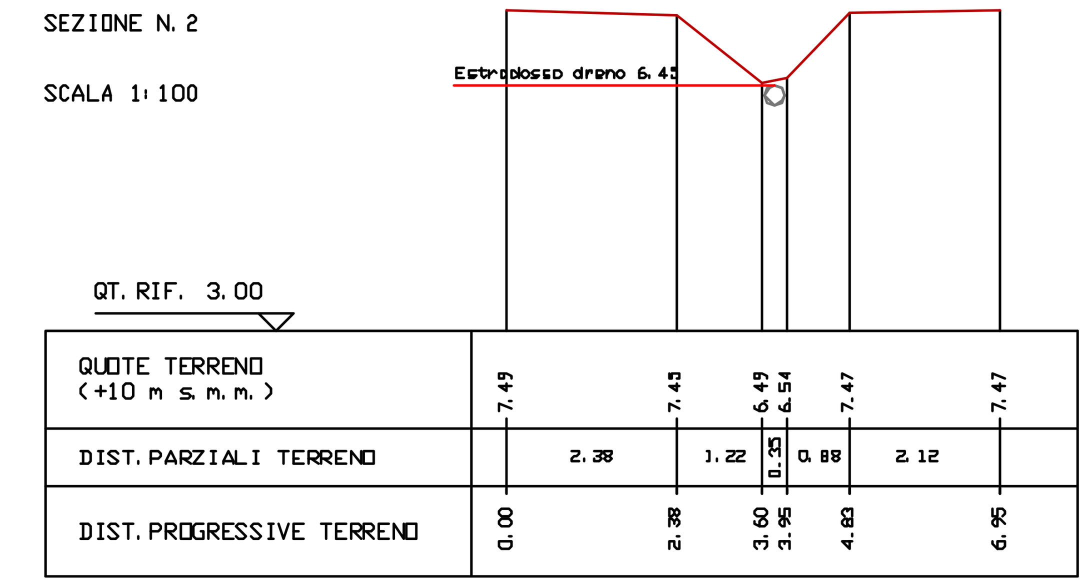

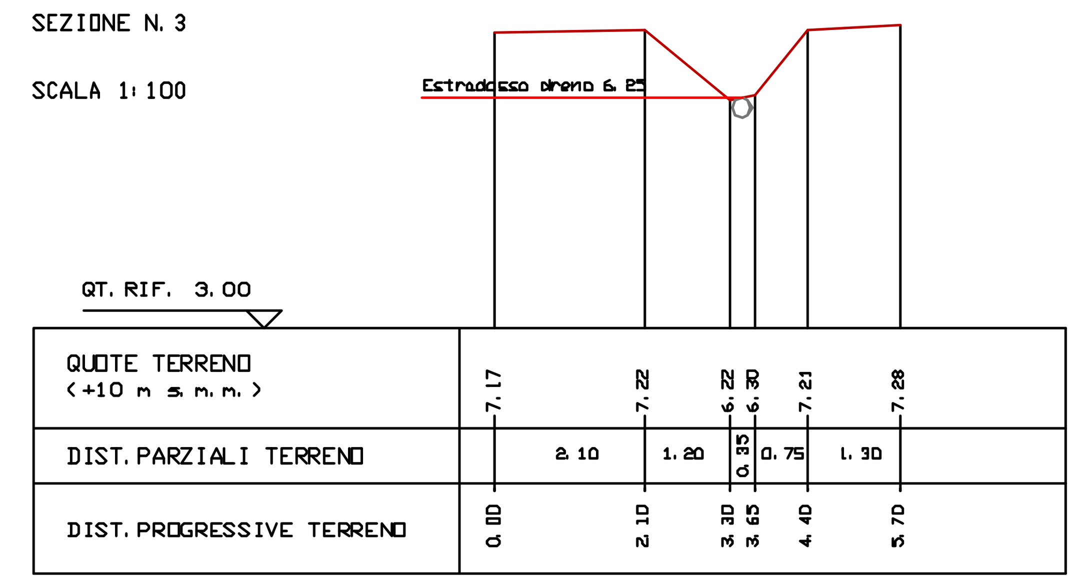

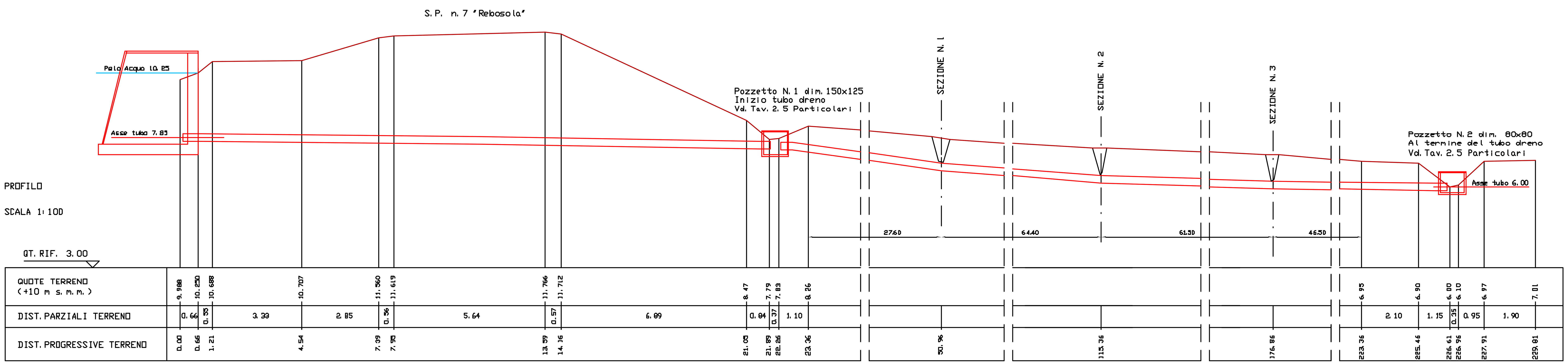

UNIVERSITA' DEGLI STUDI DI PADOVA
Dipartimento ICEA

CONSORZIO DI BONIFICA ADIGE EUGANEO

MOST - MOnitoring Sea-Water intrusion in coastal aquifer and Testing pilot projects for its mitigation

DATA		TAVOLA
30/01/2020	Planimetria e sezione longitudinale in asse del dreno	2.4
SCALA VARIE		

IL RESPONSABILE DEL PROCEDIMENTO
Dott. Ing. Giuseppe Gasparetto Stori

I PROGETTISTI
Prof. Ing. Paolo Salandin
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REV.	DATA	DESCRIZIONE DELLA REVISIONE	REDIGE	VERIFICA
1	30/01/2020	Esecutivo	Artuso	Frison

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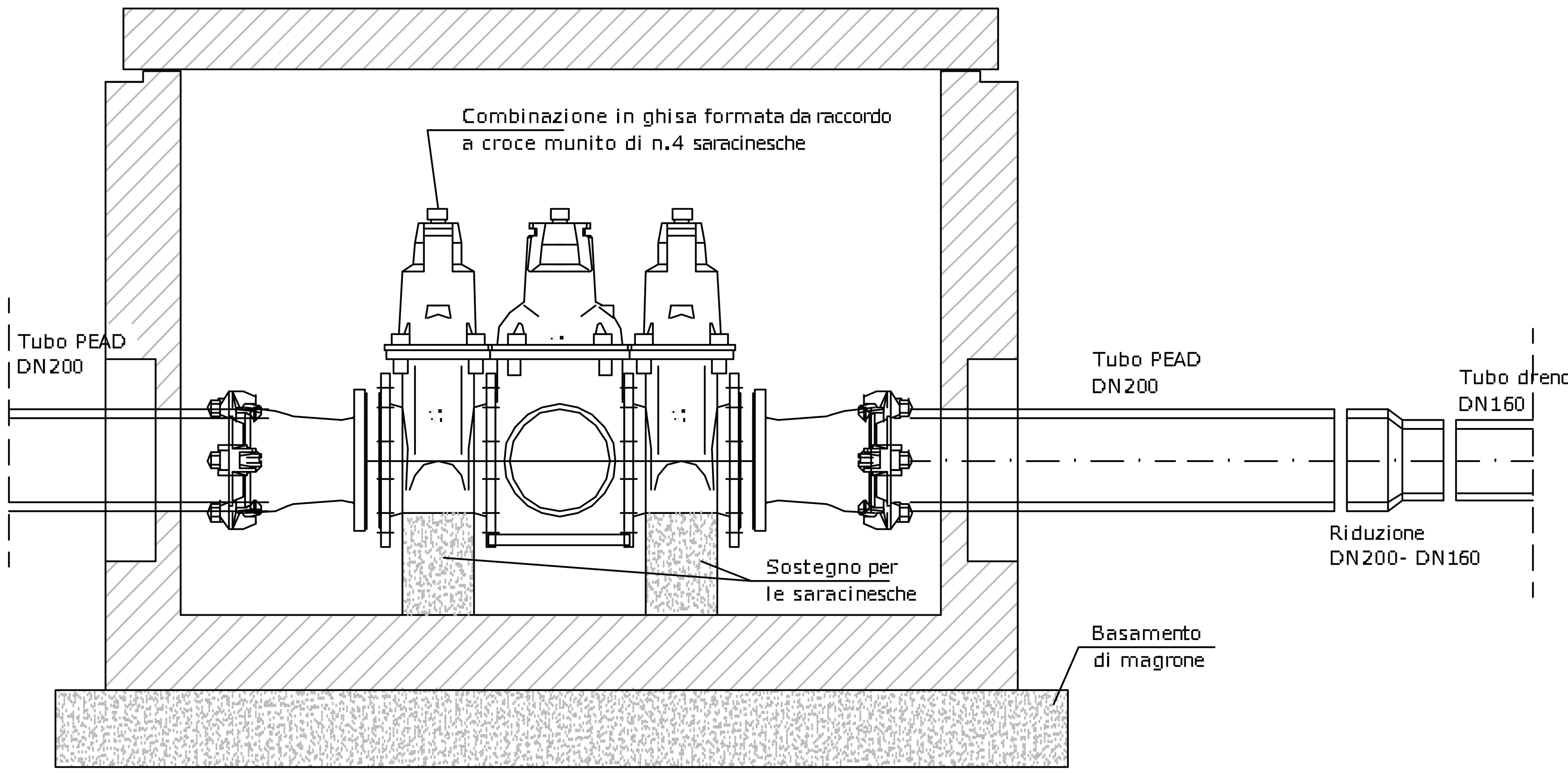
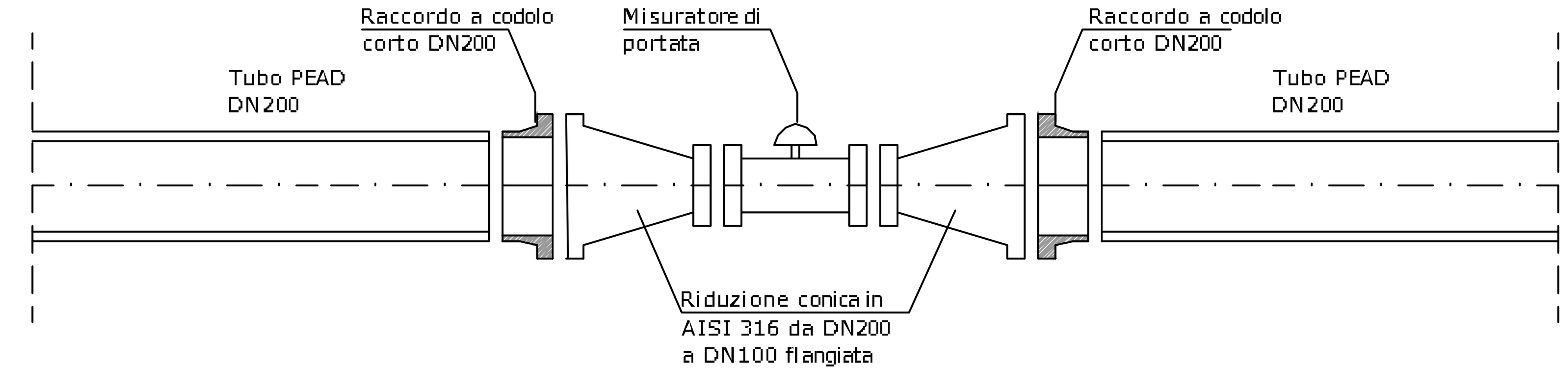
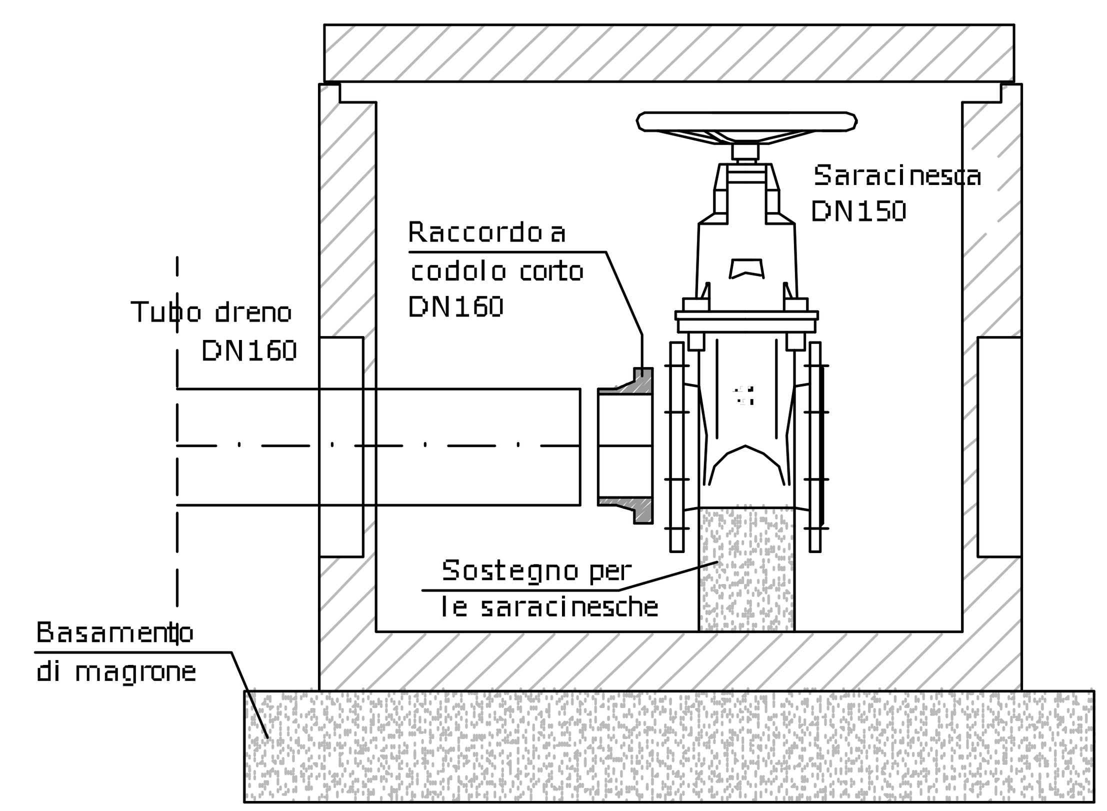


Attacco del misuratore di portata alla tubazione
Vista in sezione



Pozzetto N. 2 dim. 80x80
Vista in sezione
Fine tubo dreno



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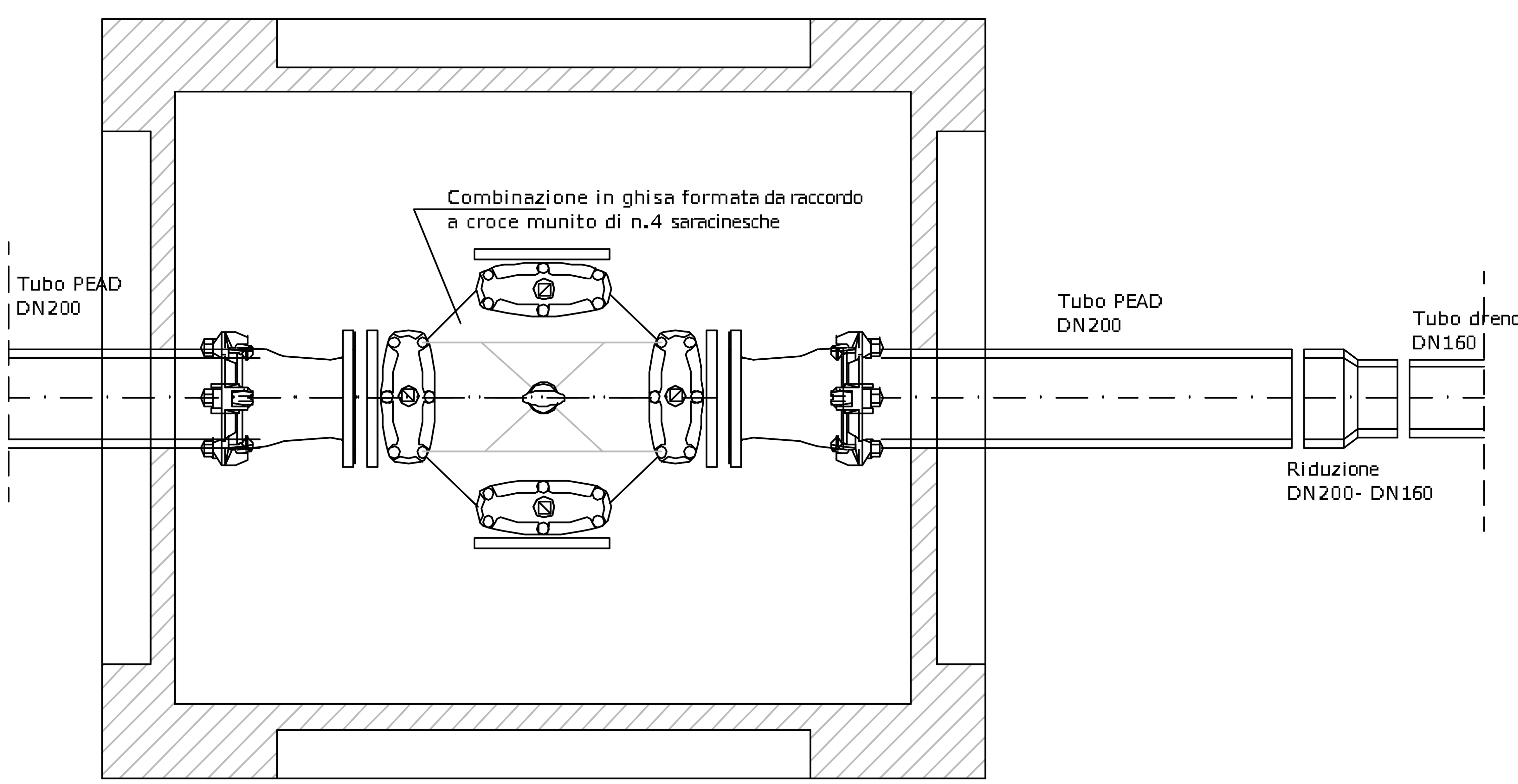

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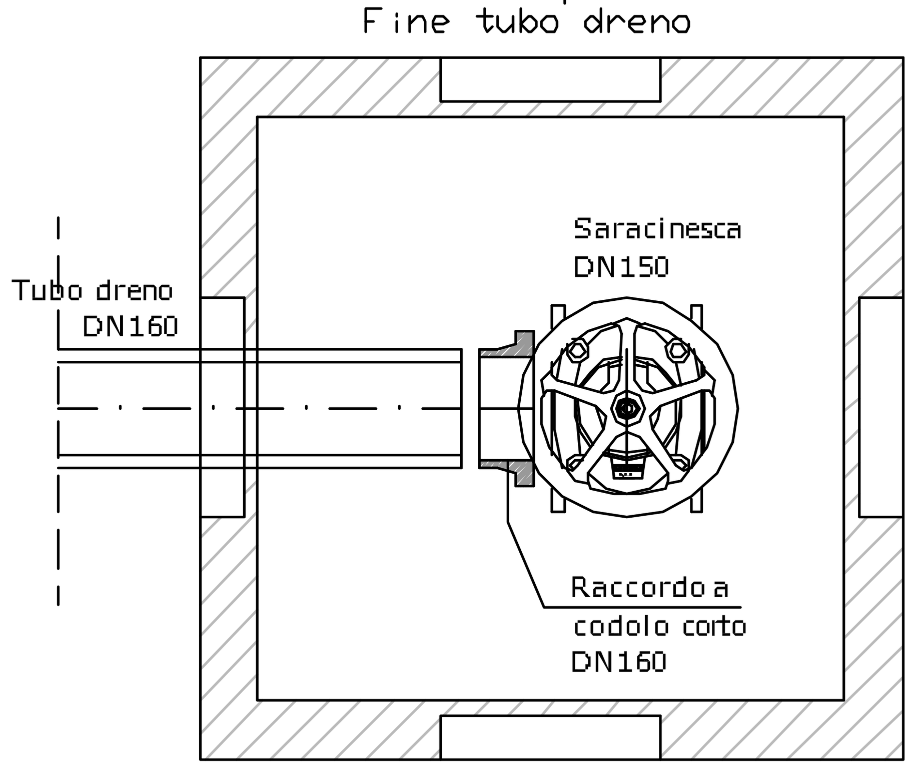
Vista in pianta
Fine tubo dreno



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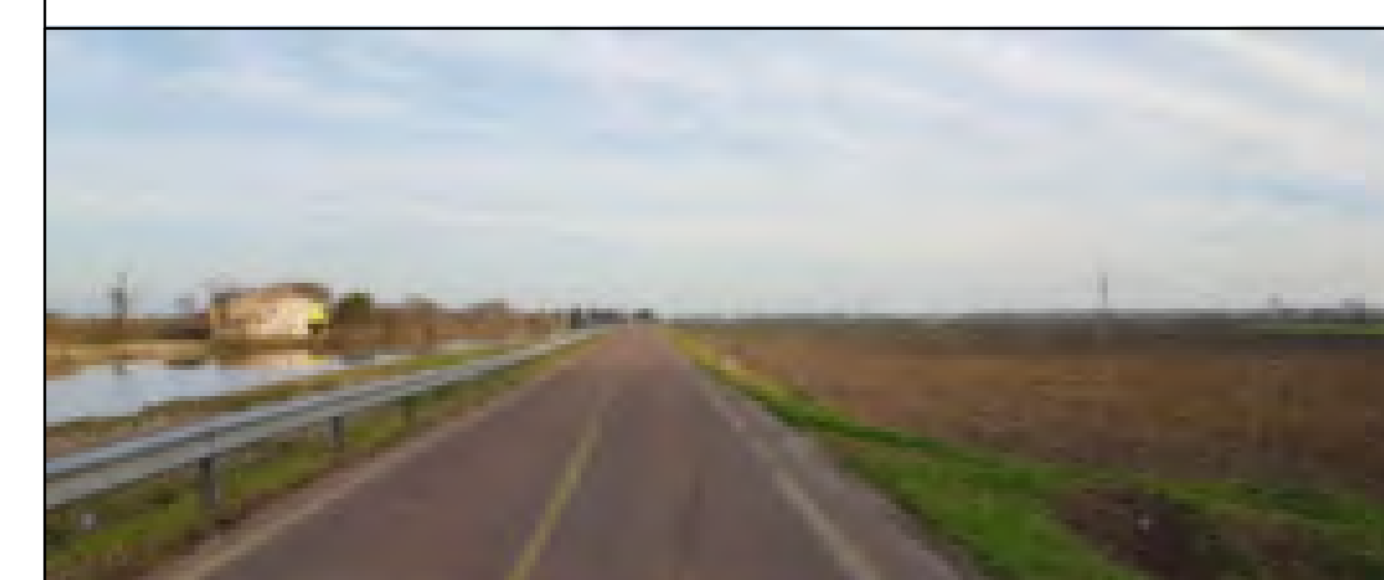
MOST - MOnitoring Sea-Water intrusion in coastal aquifer and Testing pilot projects for its mitigation



DATA 30/01/2020	Particolari costruttivi Pozzetti	TAVOLA 2.5
SCALA 1:10		

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REV.	DATA	DESCRIZIONE DELLA REVISIONE	REDIGE	VERIFICA
1	30/01/2020	Esecutivo	Artuso	Frison

Section 2

Sub-soil fresh-water distribution system planning and testing

TABLE OF CONTENTS

1 Introduction

WP4.2 Action (Venice coastal plain) aims to test the efficiency of specific adaptation measurements to counteract and/or mitigate the effects of climate changes on the process of saltwater intrusion. Specifically, a proper sub-irrigation system through drainage pipes was established along the sandy high-permeable paleo-channels crossing the farmland, in the Italian Pilot site.

2 Study area

The study area encompasses the territory between the southern Venice lagoon margin and the final stretch of the Adige River. Specifically, the pilot test area is located in a low-lying farmland just south of the Brenta and Bacchiglione rivers (Fig. 1).

Holocene deposits and the presence of ancient fluvial ridges, paleo-river beds and paleo-coastlines characterizes the study area. The different depositional environments are responsible for the various lithologies and geological features. Sandy and silty soils characterize the remnants of ancient fluvial and beach ridges, whereas clayey silts, often rich in organic matter, fill the inter-distributary lowlands; bogs with peat layers occur in the reclaimed marshy areas.

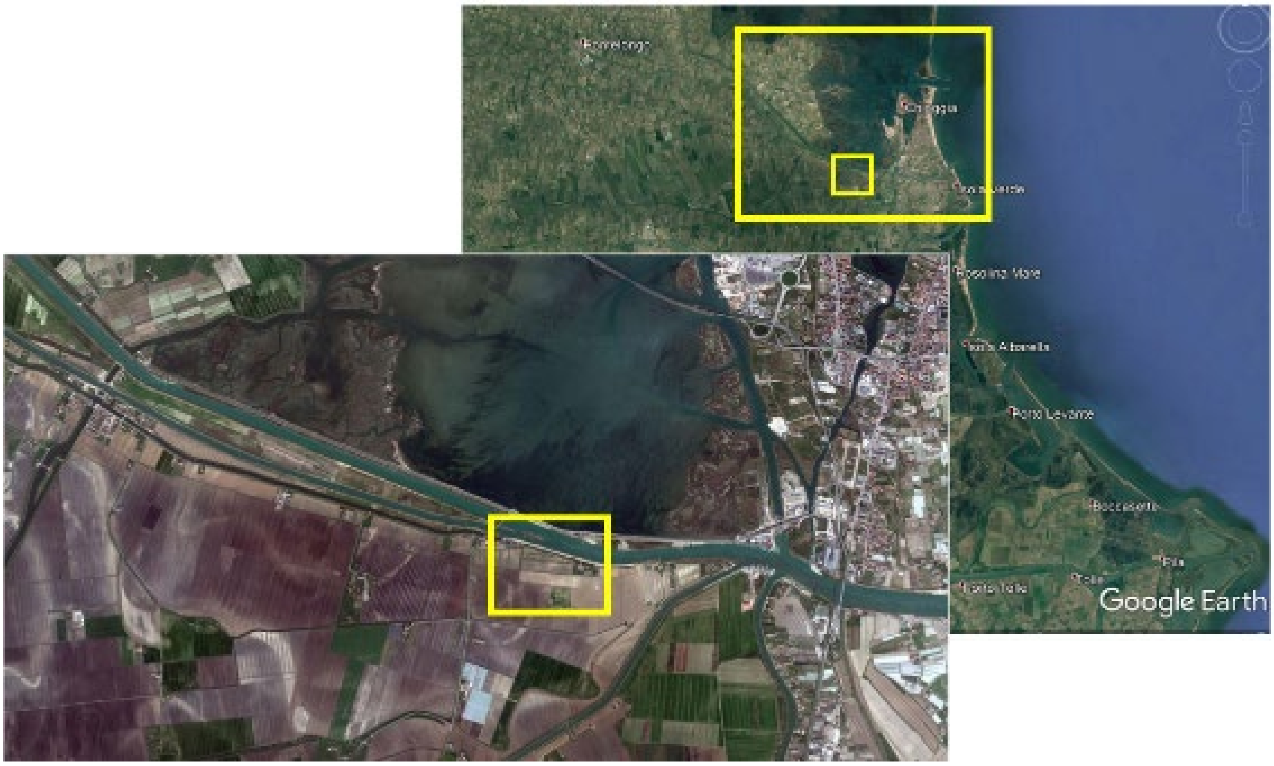


Fig. 1 - Location of the study area and the pilot test.

3 Selection of the site for the setup of the sub-irrigation system through drainage pipe

The proper site for the setup of the sub-irrigation system through a drainage pipe has been initially selected based on the result of the preliminary hydro-geomorphological investigation summarized in the following sections. The datasets used in this report as hydro-geo-morphological knowledge background are included in the reports DOC n. MoST-CNR 3.1, DOC n. MoST-CNR 3.2, DOC n. MoST-CNR 3.3, DOC n. MoST-CNR3.4.

3.1 Sediment core data

Among the above listed materials, 5 new 20m-long sediment cores and 6 new piezometers have been carried out for the specific purpose to acquire new subsoil data for the proper planning of the pipe installation. The photos of the sediment line cores 0-5m are shown in *Fig.* 2, *Fig.* 3, *Fig.* 4, *Fig.* 5.

Fig. 2 - MoST1a sediment line cores 0-5m.

Fig. 3 - MoST2 sediment line cores 0-5m.

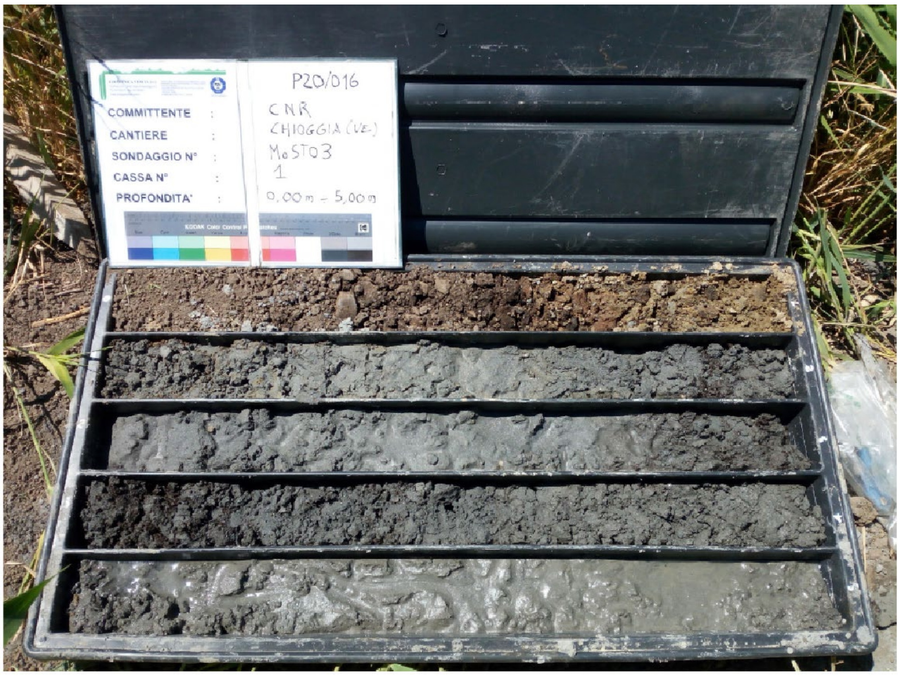


Fig. 4 - MoST3 sediment line cores 0-5m.

Fig. 5 - MoST4 sediment line cores 0-5m.

3.2 Geomorphological data

Once selected the study area, the first step was the choice of the sandy buried body along which will be established the sub-irrigation system. The study area (*Fig.* 6) is characterized by the presence of several buried sand bodies, mapped by remote sensing together with in-situ surveys and sampling. A further analysis of each single structure led to the selection of a specific paleo-channel system for more detailed investigation. The selected buried paleo-channel system is shown in *Fig.* 7.

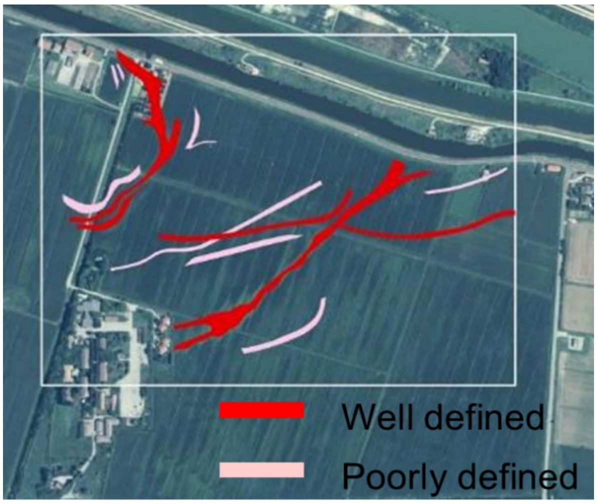


Fig. 6 - Main geomorphological structures mapped in MoST pilot site.

Fig. 7 - Geomorphological structure selected for a detailed investigation.

3.3 Texture of the shallow soil layers

The soil texture in the upper 80 cm has been characterized by the analysis of hundreds of sediment samples carried out within the GEO-RISKS Project.

Two maps have been obtained, between 15 and 45 cm and between 45 and 80 cm depths (*Fig.* 8). In the deepest layer along the selected geomorphological structure at the location where the sub-irrigation pipe will be installed, the sand content is greater than 70%.

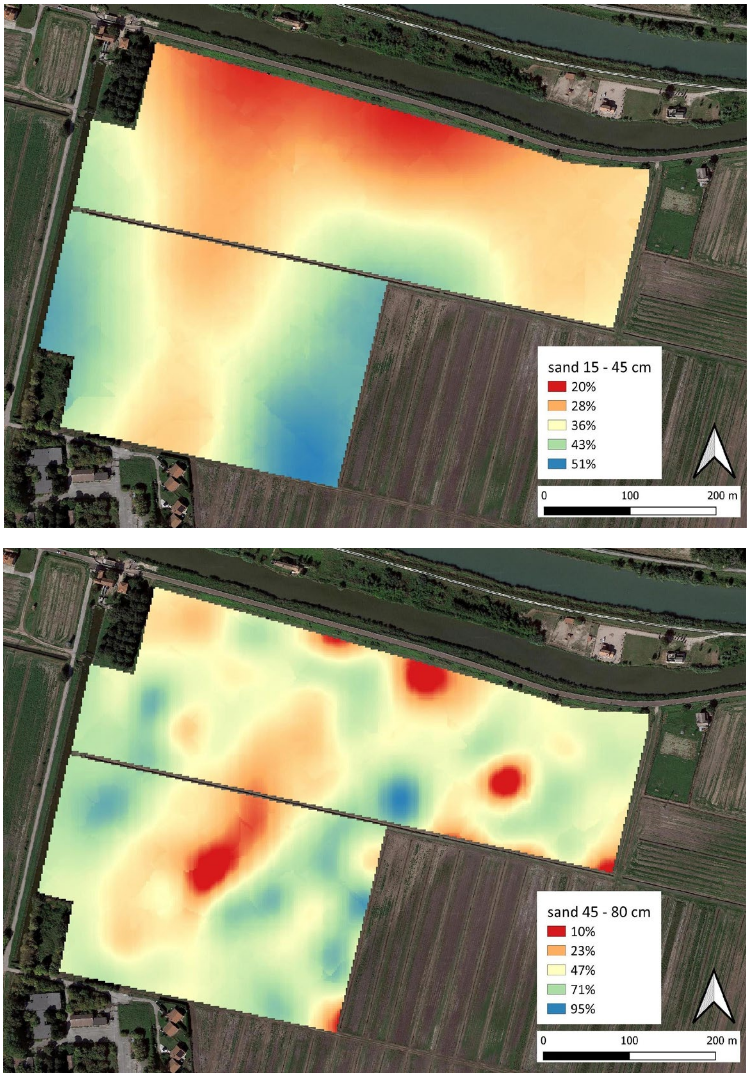


Fig. 8 - Maps of the texture of the shallow deposits.

3.4 Hydro-stratigraphic architecture

In the pilot area, the subsoil is formed by alternating sandy-silty, clayey-silty and clayey layers of sediments representing alluvial, lagoon, deltaic, and littoral units (Tosi et al., 2007).

Focusing on the shallower units, which is the target of the MoST project, a more detailed hydro-stratigraphic model, obtained by the analysis of sediment cores taken next to the pilot site is shown in *Fig.* 9.

The hydrogeological model is sketched along the same direction of the selected paleo-channel.

Along this section, the subsoil shows two main quite uniform units consisting in an upper sandy body about 10 m thick, at the top of which is located the paleo-channel, and the lower unit, mostly formed by silty sand and silty clay layers.

The over-consolidated clay known as caranto lies at about 17 m below msl. This is the uppermost Pleistocene alluvial sedimentation and above it, the Holocene units are formed by marine-lagoon and back barrier deposits.

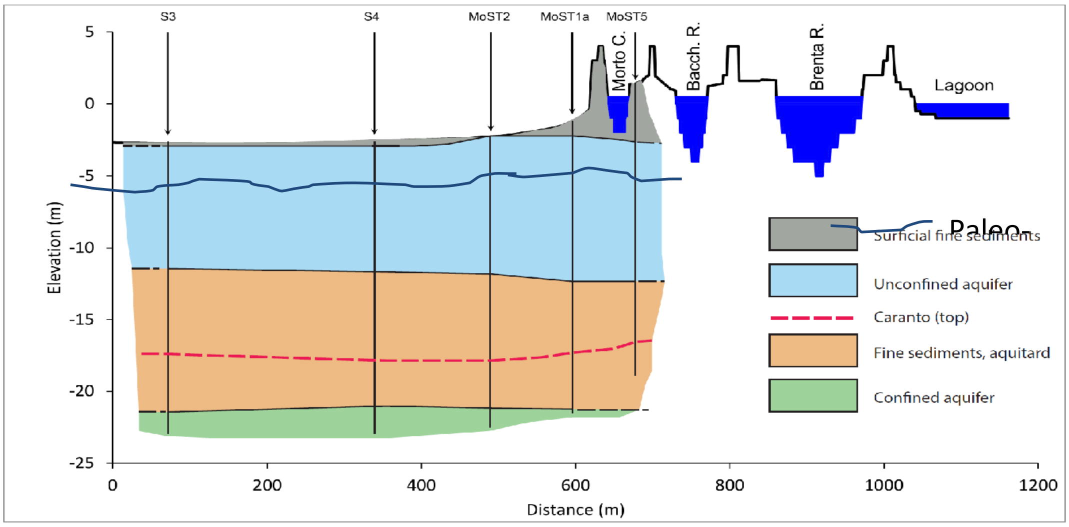


Fig. 9 - Hydrogeological model along a N-S the ground elevation profile of the pilot test site. The positions of the sediment cores are shown in Fig. 10.

3.5 EC characterization of the aquifer

Phreatic and locally confined aquifers are generally contaminated by salt, despite brackish water is present in some of them in the shallower parts. Specifically, fresh-brackish waters occur in the sandy paleo-channel systems when rainfalls and leakages from the rivers recharge them.

The EC logs, reflecting the salinity degree in aquifers A1 (0-8 m) and A2 (15-20 m) in the pilot site, are shown in *Fig.* 11and *Fig.* 12.

Fig. 10 - Pilot site with the position of the sediment cores and wells.

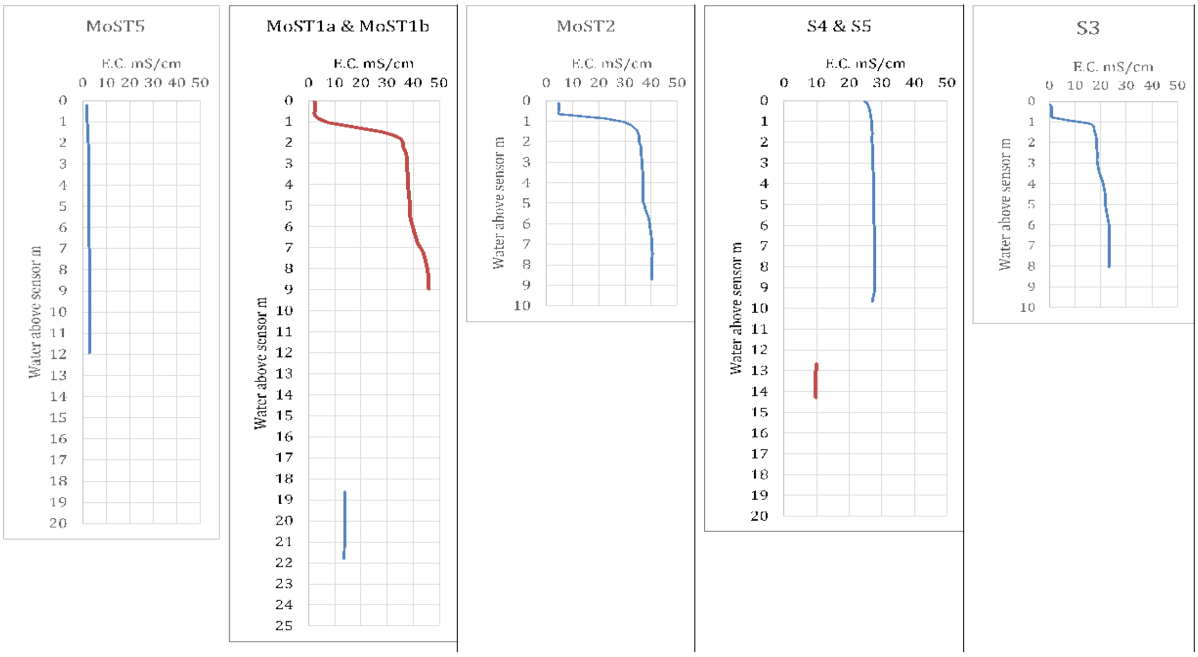


Fig. 11 - EC logs reflecting the salinity degree in aquifers A1 (0-8 m) and A2 (15-20 m) in the pilot site along the profile shown in Fig. 10.

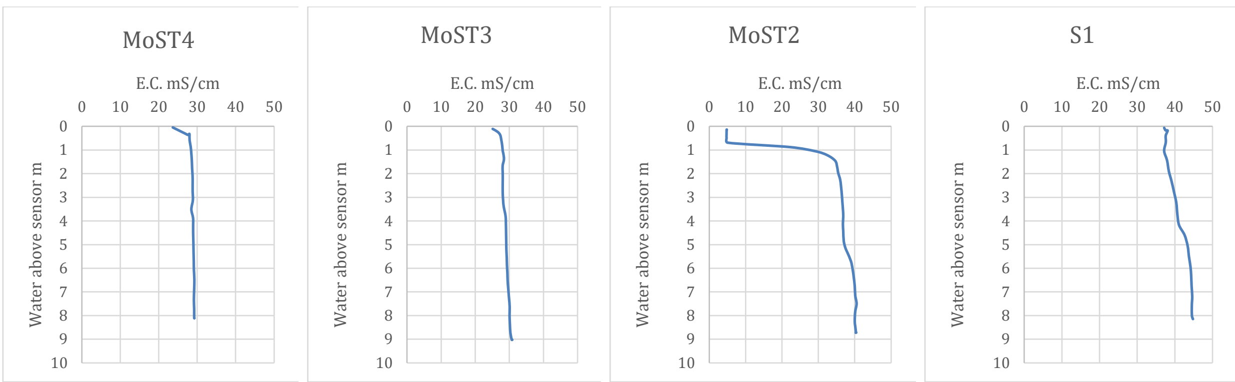


Fig. 12 - EC logs reflecting the salinity degree in aquifers A1 (0-8 m), A2 (15-20 m) in the pilot site along the profile shown in Fig. 10

4 Installation of the drainage pipe

4.1 Position of the drainage pipe

Based on the updated set of data, including in-situ measurements, the position selected for the installation of the drainage pipe is shown in *Fig.* 13, including the position of the water catchment on the Canal Morto and of the cut-off wall at the end of the pipe (see Doc.N. MoST-CNR 4.2-04).

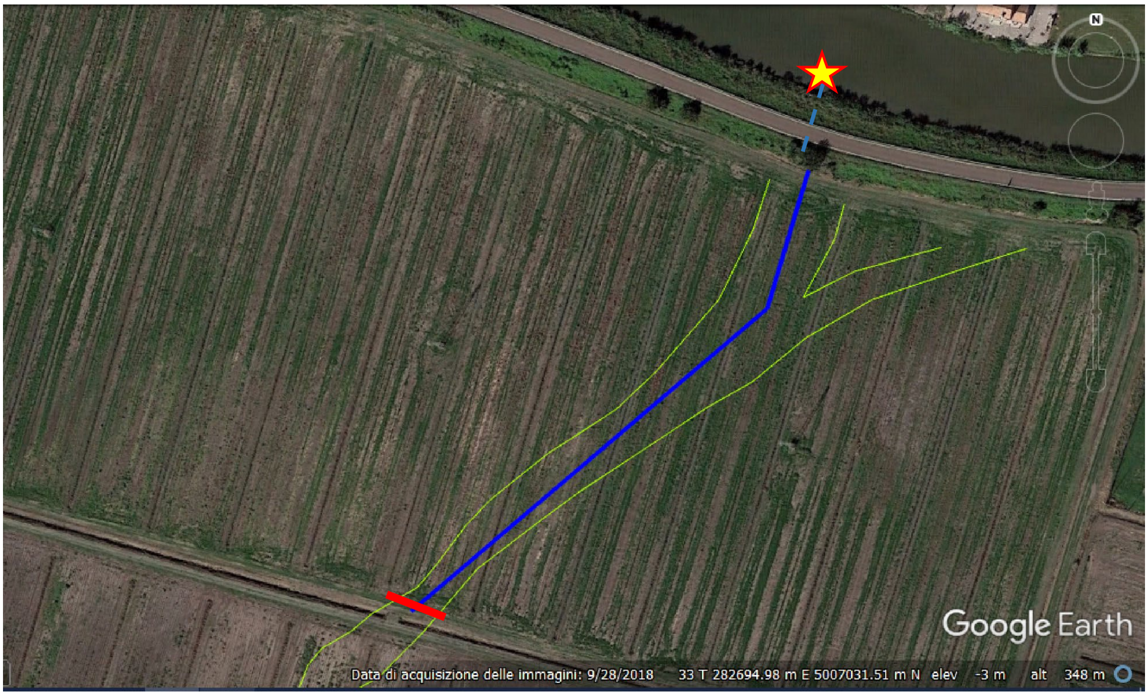


Fig. 13 - Position of the drainage pipe (blue line), water catchment on the Canal Morto (yellow star) and cut-off wall at the end of the pipe (Red line).

4.2 Setup of the pipe

The works for the installation of the drainage pipe started in October 2020 and finished at the beginning of November 2020 (*Fig.* 14, *Fig.* 15).

A trench around 2 m deep has been excavated along the selected path, around 220 m long. The pipe has been located at a depth of 1.7 m from the ground level.

Fig. 14 - Excavator working for the excavation of the trench and positioning of the pipe.

Fig. 15 - Detail of the drainage pipe.

During the excavation of the trench for the installation of the drainage pipe further stratigraphic investigations were made (*Fig.* 16), for further information see DOC n. MoST-CNR 3.2-004.

The general sketch of subsoil of the first 1.5 meters is reported in *Fig.* 17.

Fig. 16 - Geologists taking stratigraphic measurements inside the trench.

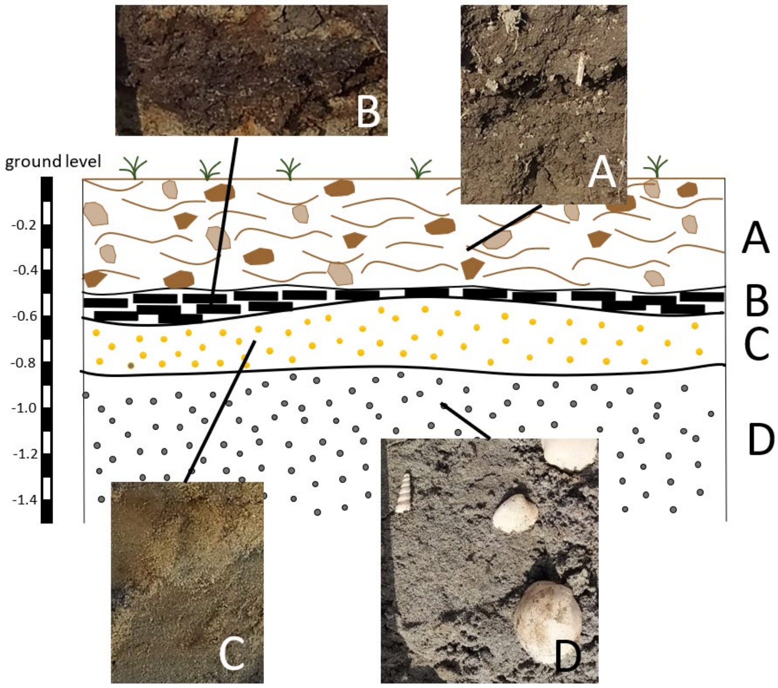


Fig. 17 - Sketch of the sub-soil realized during the excavation of the trench.

4.3 Preliminary test of the sub-soil fresh water distribution system

In November 2020 was carried out a first experiment to verify the correct functioning of the pipe and its mitigation effect on the aquifer.

The sub-irrigation system started on November 3rd and stopped on November 5th (Fig. 18). Temperature, pressure and electrical conductivity in the aquifer have been monitored before, during, and after the functioning of the drainage pipe, using logging sensors equipped in the piezometers installed in the test area (see DOC n. MoST-CNR 3.1-007). In Fig. 19 and Fig. 20 we show the EC data, collected in MoST1b and MoST2 wells, located both along the path of the pipe (Fig. 21), respectively, MoST1b next to the initial part and MoST2 next to the central part of the sub-irrigation pipe. The data collected highlight the progressive development of a fresh-water lens during the functioning of the system, (up to six meters deep, around 24h after the system started), in the

MoST1b piezometer, while they do not show significant variations in the EC of the MoST2 piezometer.

Fig. 18 - Worker opening the valve at the water catchment of the pipe.

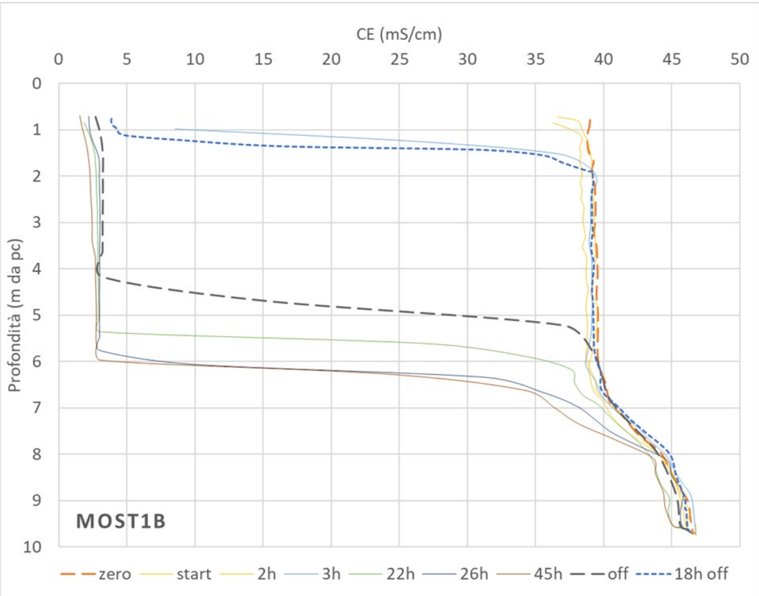


Fig. 19 - Electrical Conductivity (EC) recorded in MoST1b piezometer before, during and after the

functioning of the pipe.

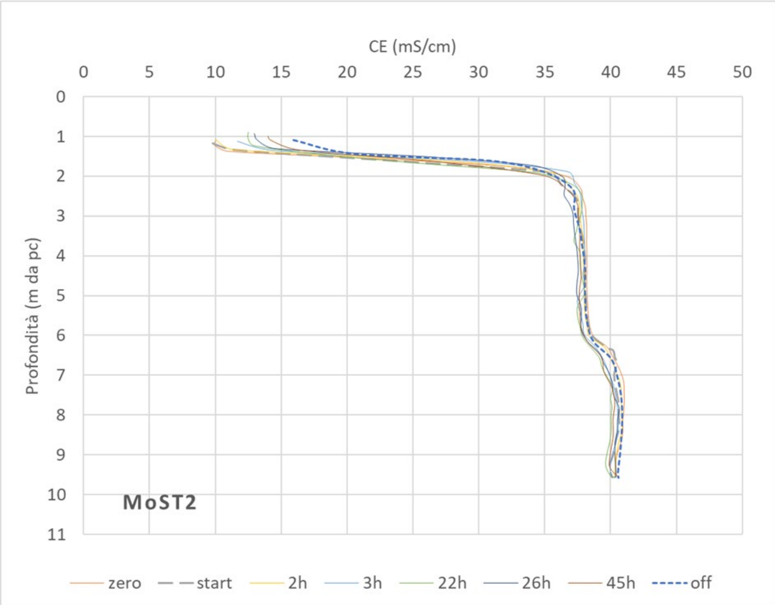


Fig. 20 - Electrical Conductivity (EC) recorded in MoST2 piezometer before, during and after the functioning of the pipe.

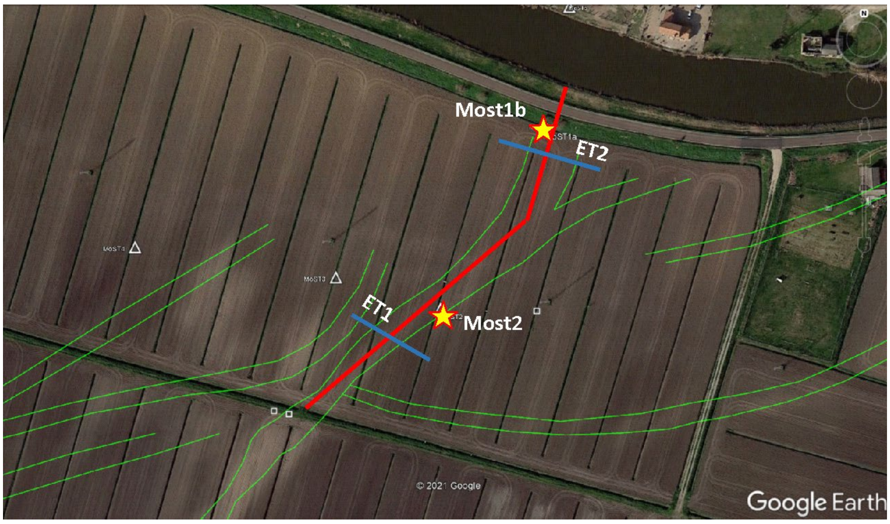


Fig. 21 - Map of the test area showing the location of the sub-irrigation pipe (red line), the piezometers MoST1b and MoST2 and the location of the electrical resistivity tomography (ERT) measurements (ET1 and ET2).

At the same time the electro resistivity of the sub-soil has been monitored with an electrical resistivity tomography (ERT) (Fig. 21) along the section ET1 (Fig. 21), located next to the final part of the drainage pipe, 20 m southwest from the MoST2 piezometer. The geophysical data do not show in this section significant changes in the sub-soil electrical resistivity (Fig. 22), meaning no significant variations in the salinity of the aquifer. From 24h after the system started, the electro-resistivity has been acquired in other sections on the field. We show here the tomography results along the ET2 section (Fig. 22 and Fig. 23), a few meters south from the MoST1b well. This second section shows the presence of a fresh to brackish water lens, up to 4 m deep.

The electrical conductivity (EC) measured in the MoST1b and MoST2 piezometers and the electrical resistivity measured in sections ET1 and ET2, are quite consistent, showing good mitigation effect of the salt water only in the first part of the pipe, at the northernmost part of the site and suggesting a malfunction of the system.

In fact, a hole was found in the initial part of the pipe, which prevented the fresh water from flowing southward and caused flooding in the northernmost part of the site (Fig. 24).

In order to fix the hole discovered in the initial part of the drainage pipe, the trench was dug again and the damaged sections of the pipe had been replaced with new ones.

Fig. 22 – Electrical resistivity tomography (ERT) (ERT).

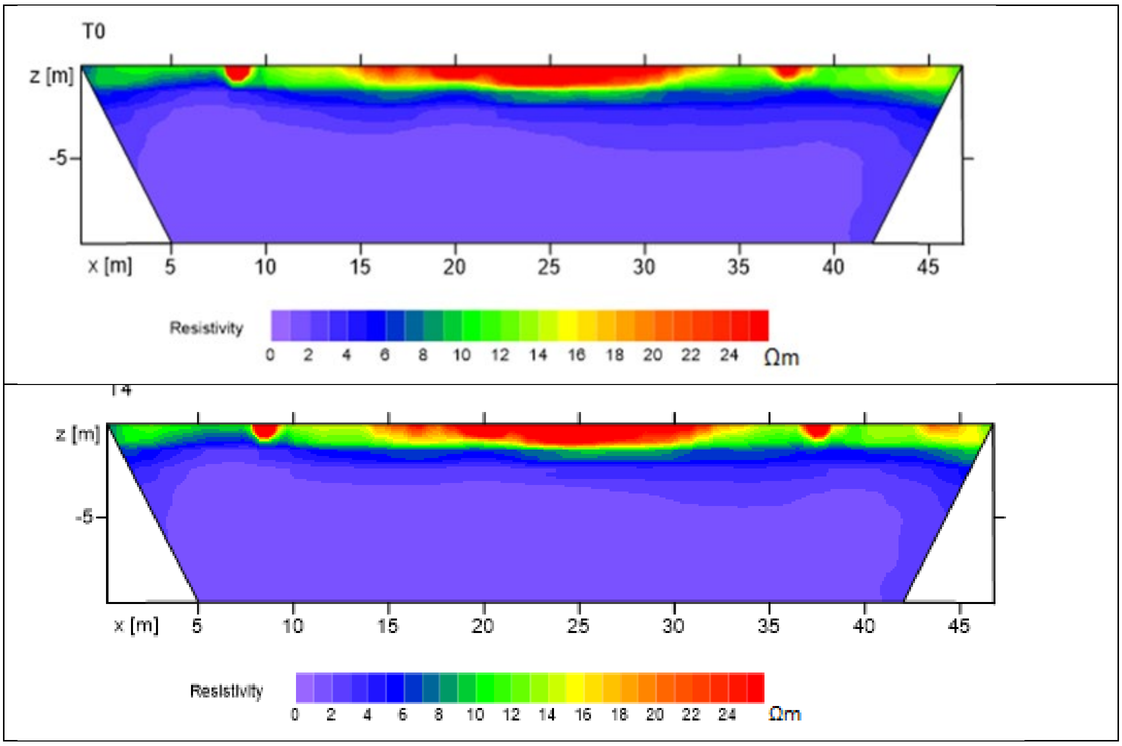


Fig. 22 - Electrical resistivity tomography (ERT) acquired in the ET1 section: before the opening of the sub-irrigation system (T0) and after 24h of operation (T4).

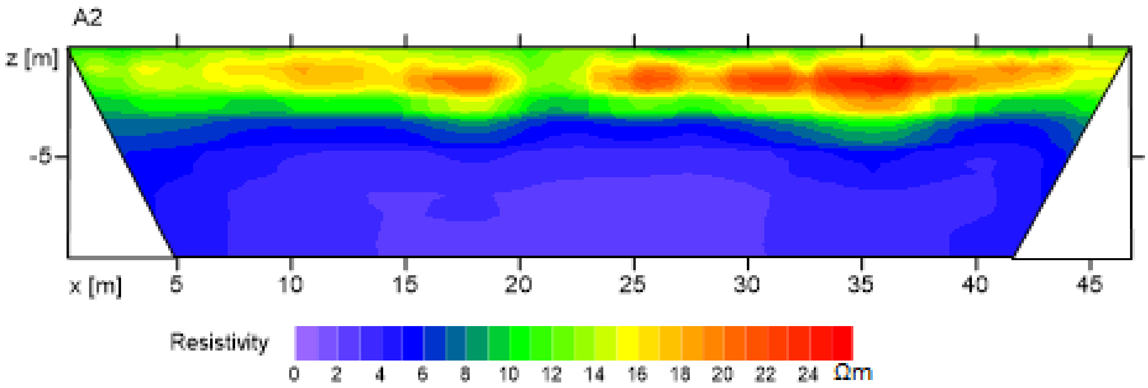


Fig. 23 - Electrical resistivity tomography (ERT) acquired along the ET2 section after 24h hours of operation of the sub-irrigation system.

Fig. 24 - The northernmost part of the test area flooded during the operation of the pipe, due to a breakage of the sub-irrigation-pipe.

4.4 Second test of the sub-soil fresh water distribution system

A second test of the sub-soil fresh water distribution system was carried out in March. This time the system started on the 2nd of March with a flow of around 200l/s and stopped on 11th of March. Even if the pipe has bee repaired, the mitigation results do not show significant changes in respect to the first test.

ET2 and MoST1b (*Fig.* 25; *Fig.* 26) show a weak mitigation after 24h of functioning (B5-B6) and the presence of a brackish water lens up to 5 m depth, respectively. The resulted weaker mitigation in this area of the aquifer in respect of the stronger one of the first experiment is due to the reparation of the pipe: during the first experiment, the presence of holes in the first portion of the pipe, all the fresh water flowed around this area.

In ET2 and MoST2 the mitigation is still negligible (*Fig.* 27, *Fig.* 28).

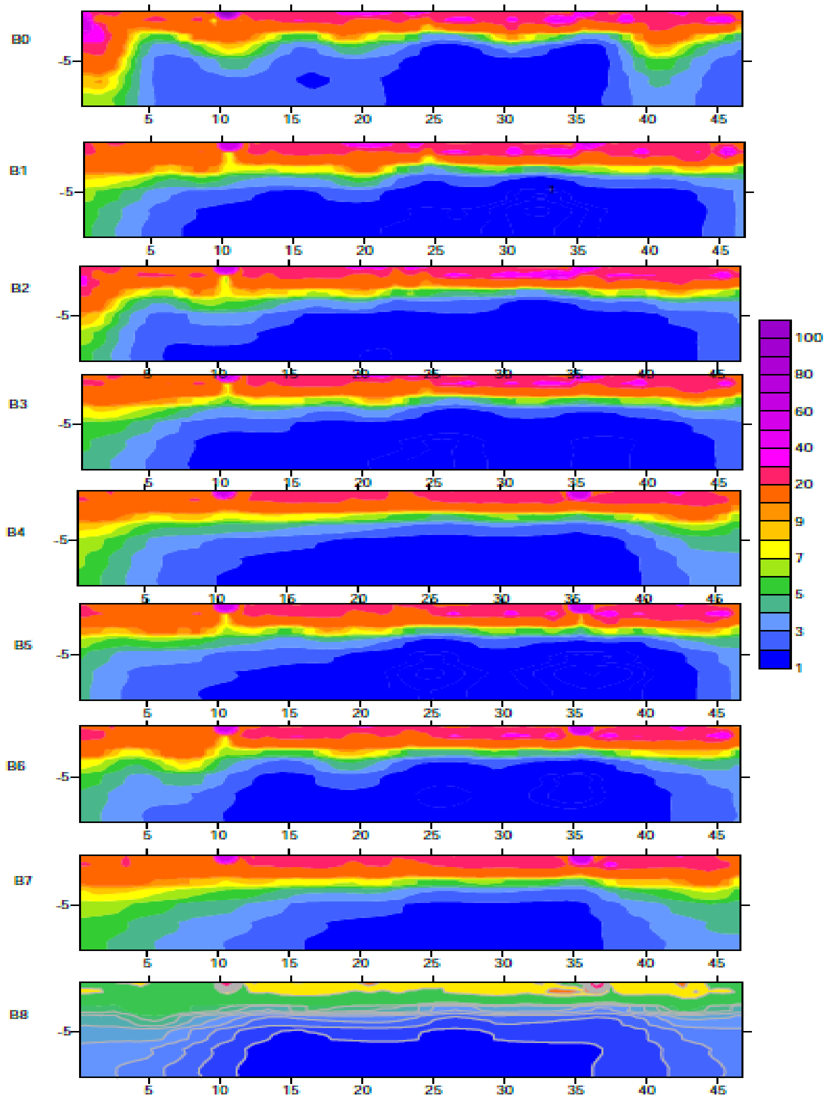


Fig. 25 - Time Lapse of the ERT ET2. BO: system off. B1: 1h of functioning. B2: 4h. B3: 5h. B4: 22h. B5: 24h. B6: 25h. B7: 48h. B8: system shut down for a week.

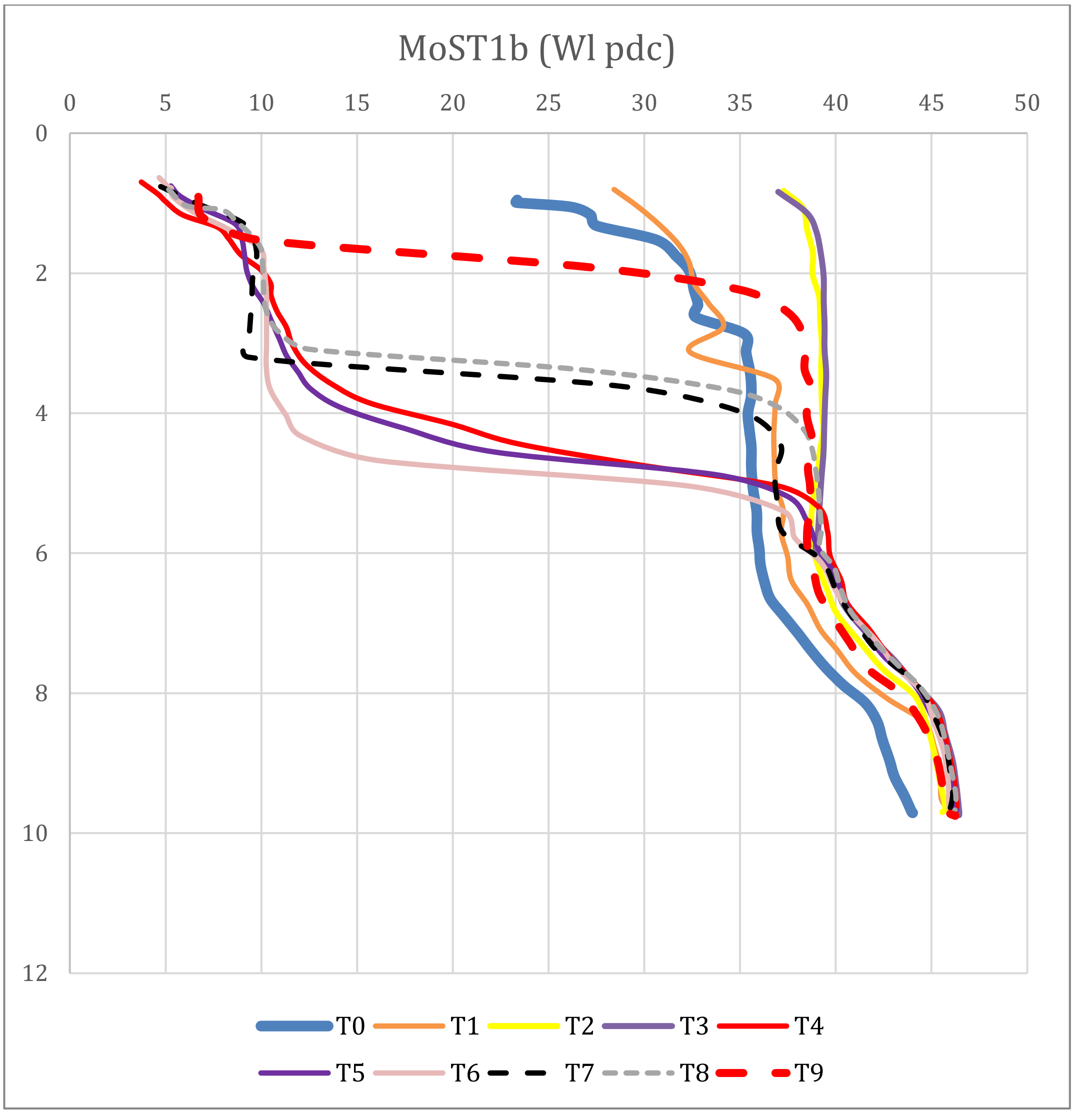


Fig. 26 - Vertical EC profiles in MoST1b during the functioning of the sub-irrigation system. T0: system off. T1: system starting. T2: 4h. T3: 5h. T4: 23h. T5: 25h. T6: 28h. T7: 46h. T8: 48h. T9: system shut down.

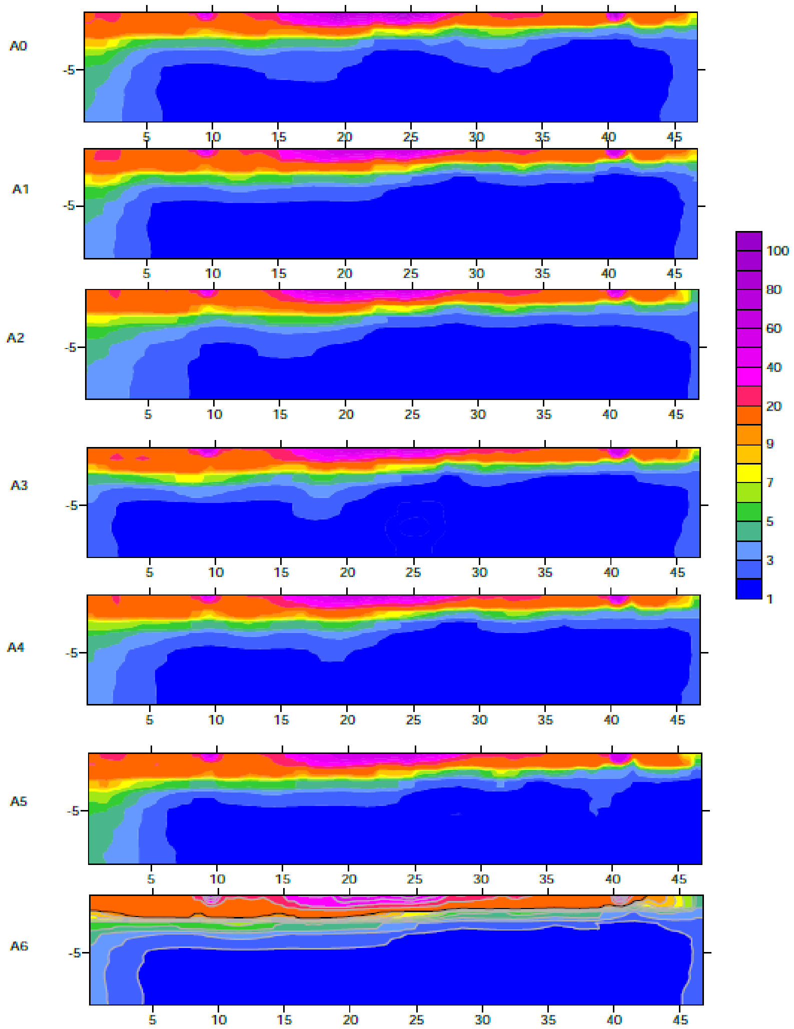


Fig. 27 - Time Lapse of the ERT ET1. BO: system off. B1: 1h of functioning. B2: 4h. B3: 5h. B4: 22h. B5: 24h. B6: 25h. B7: 48h. B8: system shut down for a week.

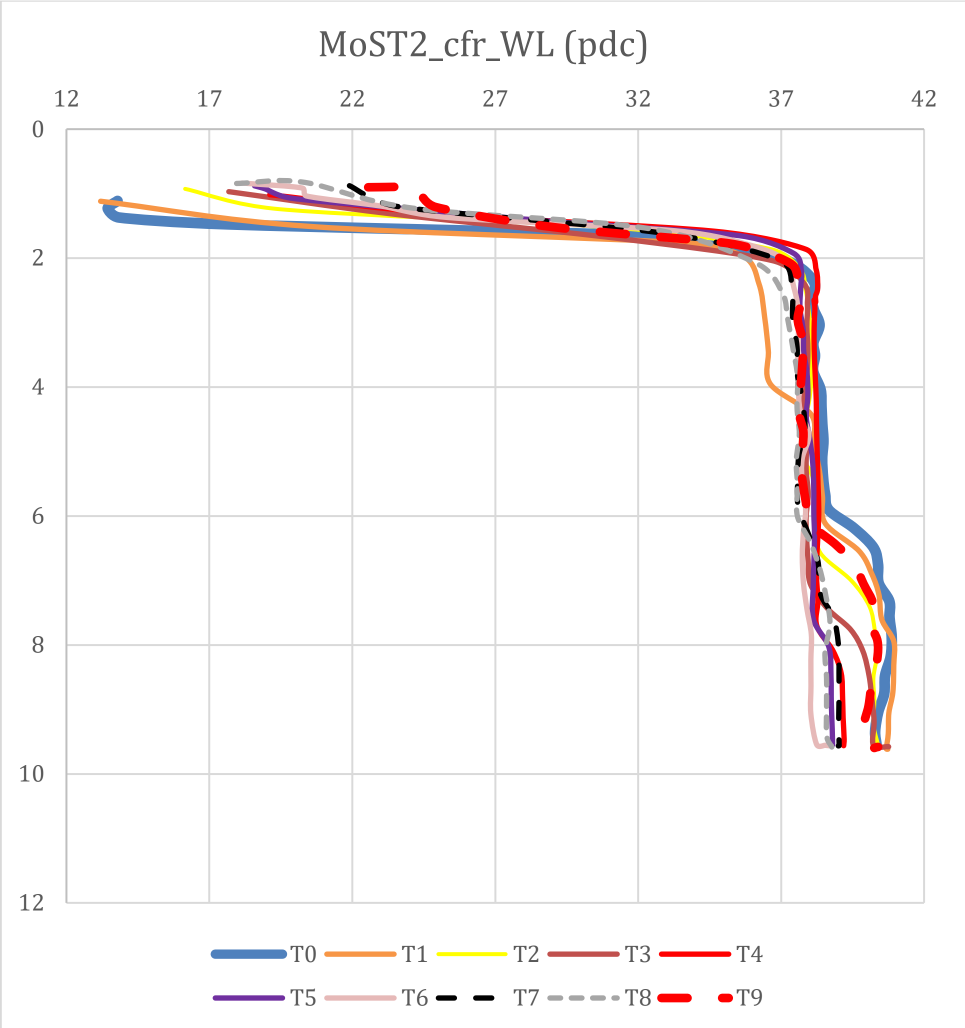


Fig. 28 - Vertical EC profiles in MoST2 during the functioning of the sub-irrigation system. T0: system off. T1: system starting. T2: 4h. T3: 5h. T4: 23h. T5: 25h. T6: 28h. T7: 46h. T8: 48h. T9: system shut down.

5 Sub-irrigation in operation

5.1 August 2021-mid September

This section reports the results of the groundwater monitoring in the Pilot site during the first operative sub-irrigation period carried out during August 2021 - mid September.

The location of the wells used for groundwater monitoring is shown in Fig. 29. Geomorphological, stratigraphical and hydrogeological settings are detailed described in Doc MoST-CNR 3.1-008, DOC n. MoST - CNR 3.2-005, and Doc MoST-CNR 3.1-010, and in particular to Doc.N. MoST-CNR 3.1-011, which reports the final hydrogeological conditions after the realization of the mitigation interventions.

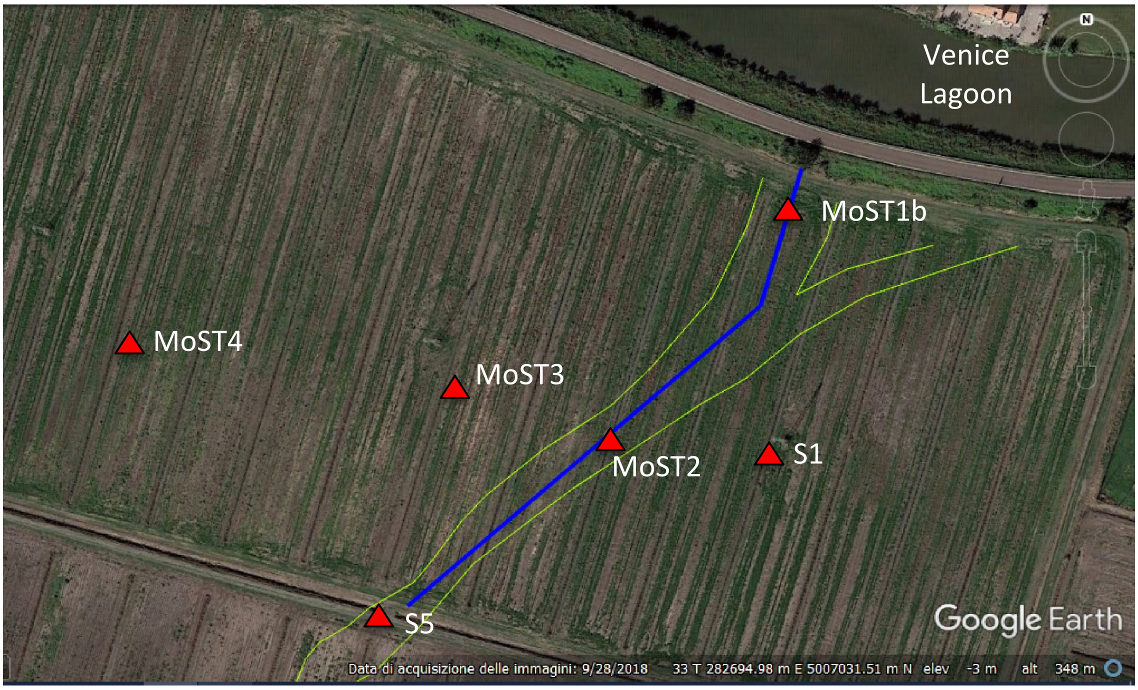


Fig. 29 - Position of the wells (red triangles) used for monitoring the effect of the sub-irrigation pipe (blue line) established into the geomorphological structure (green lines).

The results of the groundwater monitoring are shown in Fig. 30 - Fig. 33. They consist in the time series of water level (WL) and electrical conductivity (EC) recorded in MoST1b, MoST2, MoST3, MoST4, S1, and S5, i.e. the Pilot site monitoring wells located in the vicinity of the sub-irrigation pipe.

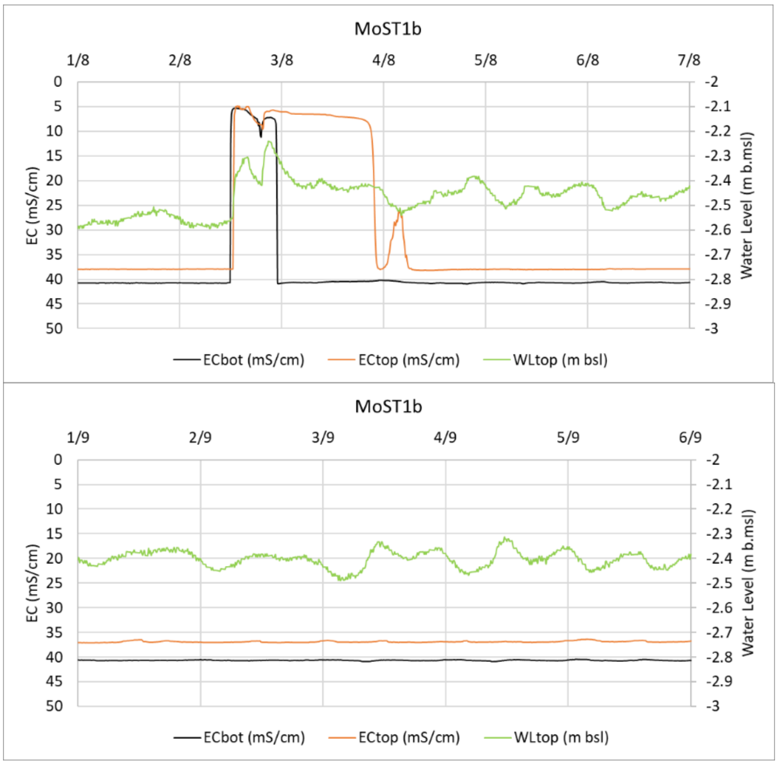
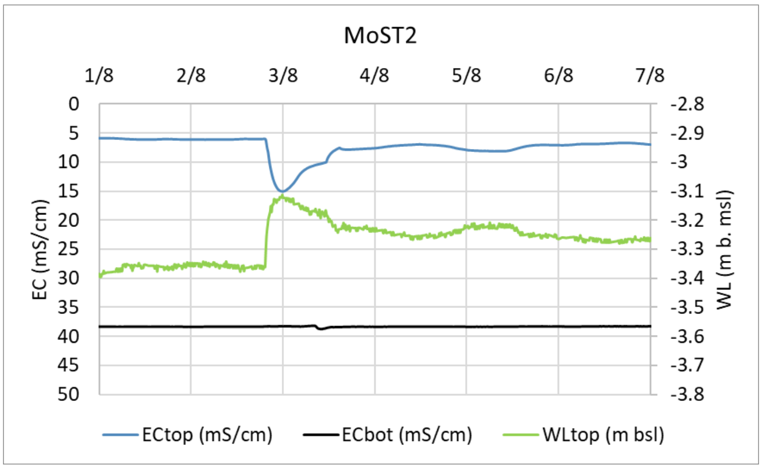


Fig. 30 - Water level and EC recorded in well MoST1b.



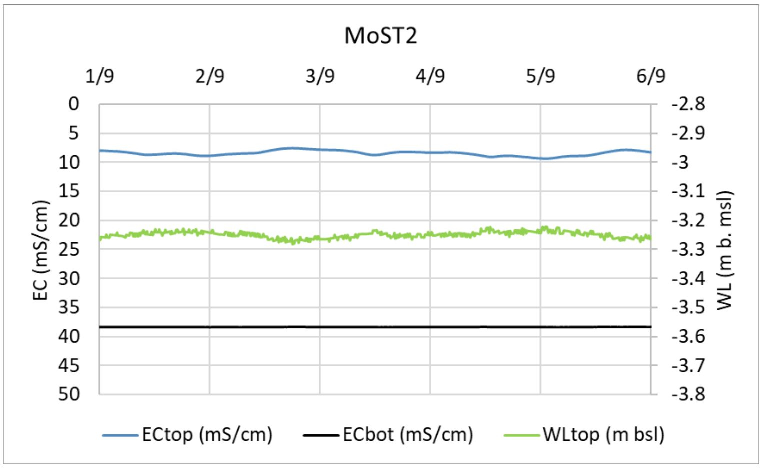


Fig. 31 - Water level and EC recorded in well MoST2.

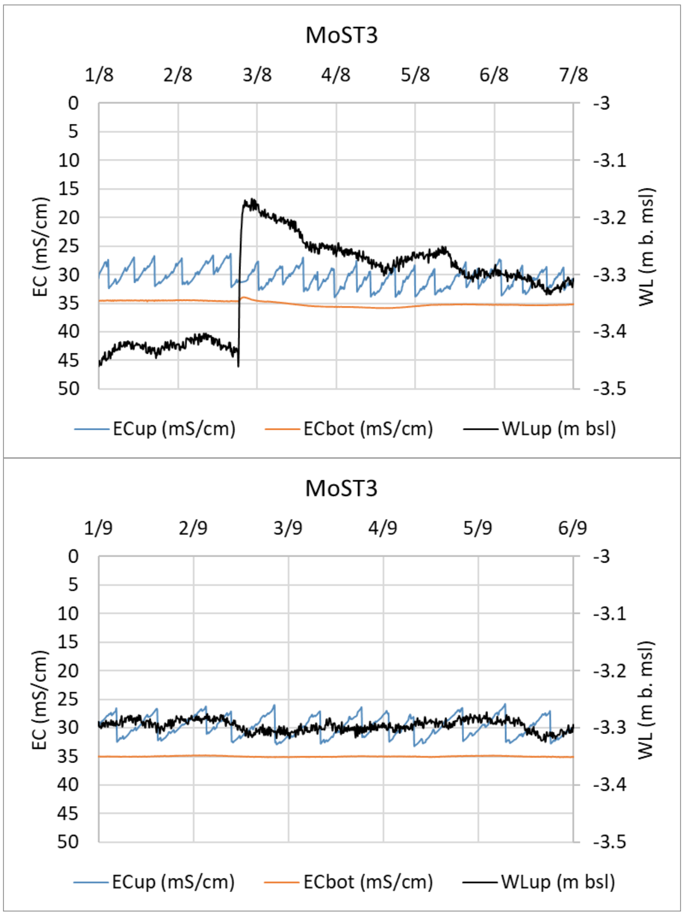


Fig. 32 - Water level and EC recorded in well MoST3.

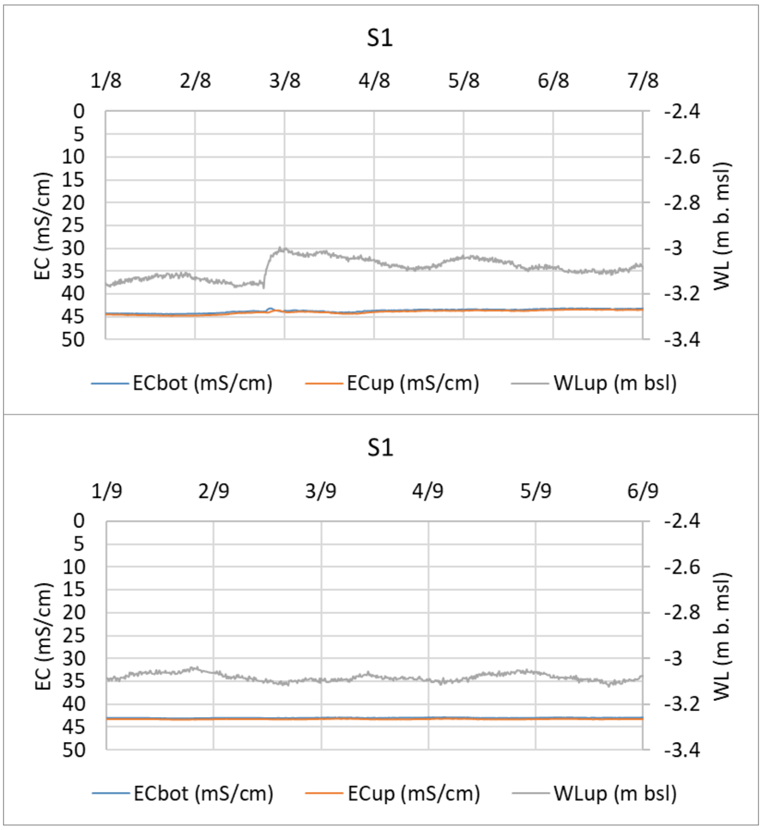
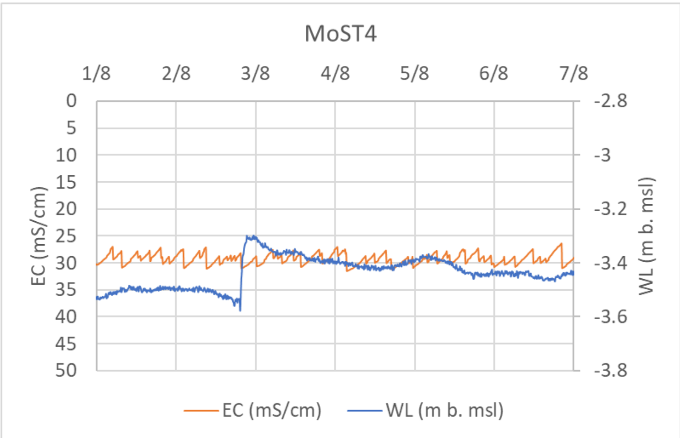


Fig. 33 - Water level and EC recorded in well S1.



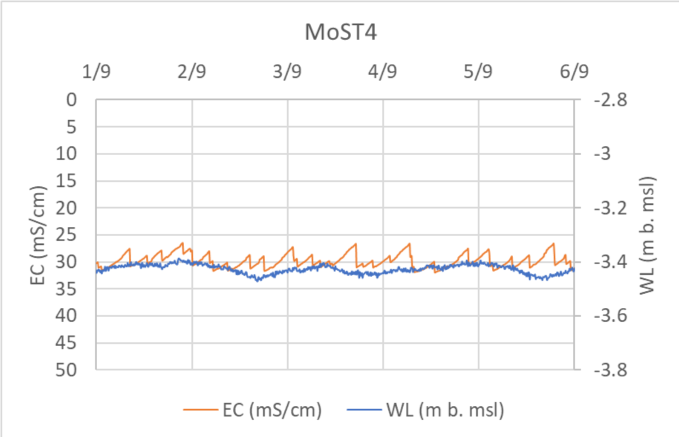


Fig. 34 - Water level and EC recorded in well MoST4.

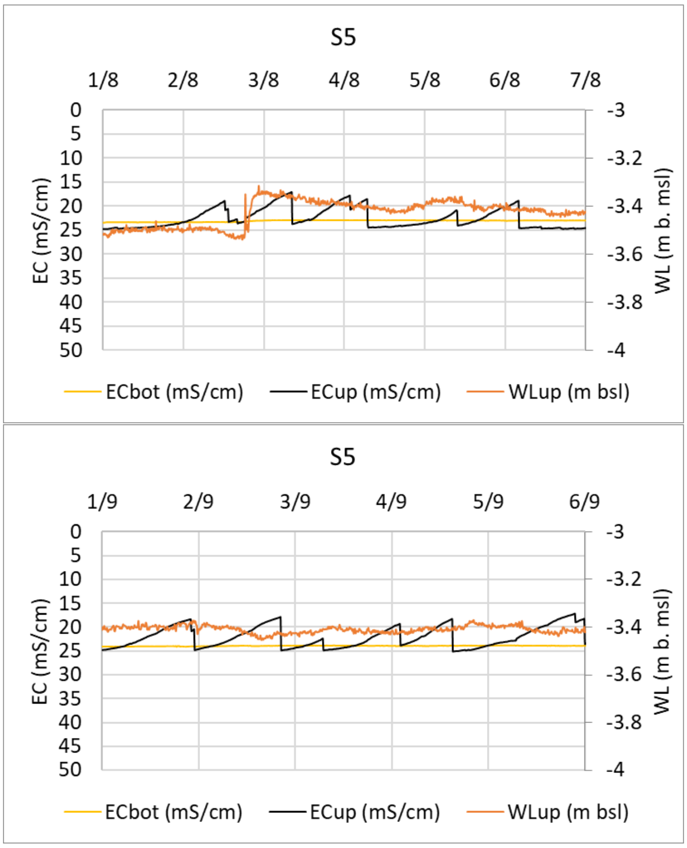


Fig. 35 - Water level and EC recorded in well S5.

5.2 June 2022

In June 2022 the sub-irrigation was activated. Fig. 36 shows the variation of EC and WL detected in MoST1b by the upper sensor. A slight decrease in EC was detected from 8 June. However, the values remained very high. The WL also shows a decrease attributable to the severe drought in this period that compromises the initial phase of salinity mitigation in the phreatic aquifer.

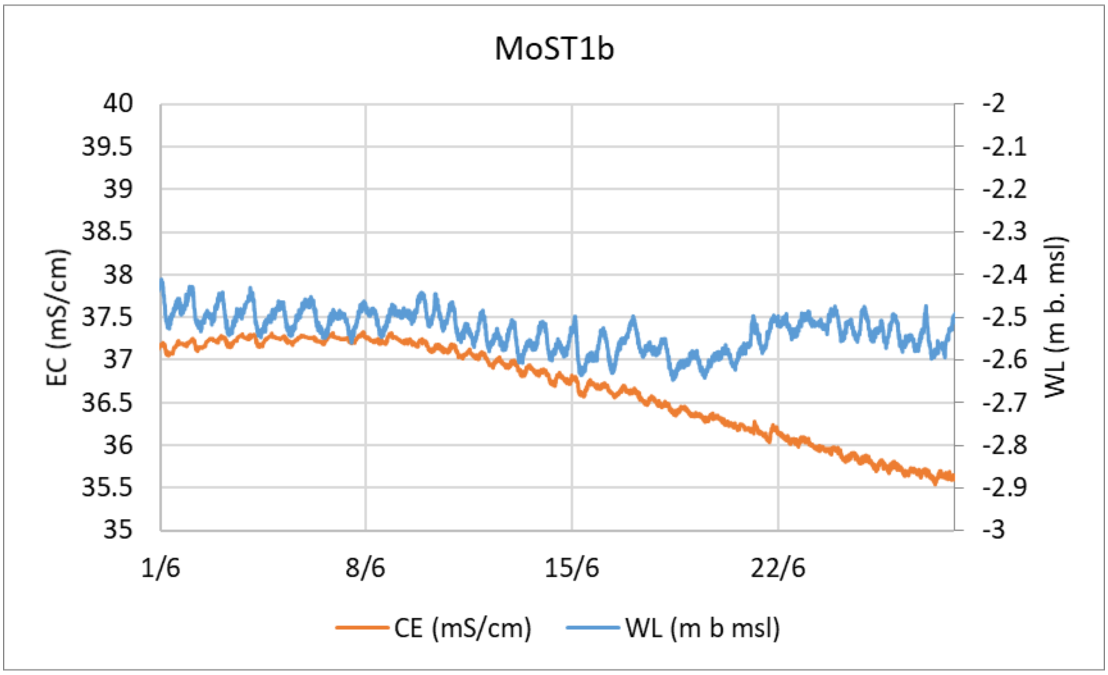


Fig. 36 - Water level and EC recorded in well MoST1b up.

6 Remarks

The observations and remarks on the groundwater monitoring are summarized in the following.

- Firstly, it is important to highlight that the fresh water injection practice thought the pipe began in August, despite of May-June, as it was previously planned. This was because of a problem with the setup and the calibration of the flow meter system.
- The sub-irrigation intervention was active from 2 August to about mid-September. Only one month of freshwater injection into the aquifer is not sufficient to fully evaluate the effectiveness of the mitigation.

- The amount of water supplied to the shallow part of the aquifer through the buried pipe was initially excessive. The partial flooding of the farmland due to the too rapid rise of the water table forced the reduction of the input flow rate.
- During the initial phase of sub-irrigation, the water table response was immediate. The groundwater level rose instantaneously in all wells installed in the vicinity of the sub-irrigation pipe and also in MoST4, which is relatively far from the pipe. Different behaviors of the EC were observed in the aquifer. At site MoST1b, a rapid reduction in salinity was detected throughout the thickness of the phreatic aquifer. A decrease in salinization was also recorded at Site S1, although this change was very low. In contrast, at the MoST2 site there was a rapid increase in salinization in the shallowest part, while the deepest part remained unchanged. An increase in salinization was observed also in at MoST3, both in the upper and bottom part of the aquifer. At well S5 and well MoST4, which are located behind the cutoff wall and at the furthest monitoring location from the pipe location, respectively, the EC showed no significant change related to freshwater input from sub-irrigation.
- After the reduction in sub-irrigation flow rate, groundwater levels decreased in all wells, instantaneously at MoST1b and gradually at the other sites, remaining slightly higher than before the freshwater injection. With respect to EC, the groundwater quickly returned to be very salt at site MoST1b. At MoST2 and MosT3, the peak salinity declined toward initial conditions. A permanent very slight reduction in EC was measured only in S1 even though the salt content in this area of the aquifer is extremely high.
- In Summer 2022 the sub-irrigation pipe was activated at the beginning of June. Unfortunately the exceptional drought period caused the lowering of the water level in the Canal Morto and its salinization up to 3-4 mS/cm.

In conclusion, it is important to emphasize that only one month of operation of the sub-irrigation pipe was not enough to fully evaluate the effectiveness of this measure adopted to mitigate the saltwater intrusion into the phreatic aquifer.