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A METHODOLOGY TO RELATE GROUNDWATER SALINITY TO IRRIGATION DELIVERY SCHEDULES: A CASE STUDY IN SOUTHERN ITALY

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SUMMARY - A study was conducted on a large-scale irrigated area located in southern Italy to analyze the likely cumulative effects on aquifer due to operations of irrigation system and to delivery schedules. The area is characterized by quite high levels of groundwater salinity, likely due to intensive exploitation of the aquifer during peak water demand periods and to consequent seawater intrusion. Increase in salinity levels are noted during the first part of the irrigation season up to time of peak crop irrigation requirements. The present study aimed at assessing the impacts of different irrigation delivery schedules to groundwater quality and quantity. Two delivery schedules were simulated using a soil-water balance approach under different combinations of crop-soil-climate. The first simulation concerns the delivery schedule currently implemented by the local water management authority. The second scenario simulates the delivery schedule aiming at maximizing the crops yield. A map of the potential groundwater exploitation was generated for the periods of peak irrigation demand by comparing results from the two simulations and by using a commercial GIS software. Winter and summer salinity maps were also developed through the interpolation of groundwater samples collected during pumping periods. These maps clearly show a strong relation between the effects of aquifer exploitation on the salinity increase.

Key words: irrigation delivery schedules, groundwater pumping, aquifer salinity

RESUME - *Une étude a été entreprise sur un large secteur irrigué situé en Italie méridionale pour analyser les effets cumulatifs sur l'aquifère dus aux activités de gestion de l'irrigation. La zone est caractérisée par des niveaux assez élevés de salinité des eaux souterraines, probablement dus à l'exploitation de l'aquifère et à l'intrusion conséquente de l'eau de mer. Une augmentation de salinité a été notée à partir du début de saison de l'irrigation jusqu'aux périodes de demande maximale. La présente étude a visé à évaluer les impacts des programmes de pilotage d'irrigation adoptés dans la zone sur la qualité et la quantité des eaux souterraines. Deux types de pilotage d'irrigation ont été simulés en utilisant un modèle de bilan hydrique sous différentes combinaisons de culture – sol – climat. La première simulation concerne le programme réel d'irrigation appliqué par l'autorité locale de gestion d'eau. Le deuxième scénario simule le programme optimal d'irrigation visant à maximiser le rendement des cultures. Une carte d'exploitation des eaux souterraines a été produite pour les périodes de demande d'irrigation maximale en comparant les deux types de simulations et en employant un logiciel commerciale de SIG (Arcview). Des cartes de salinité d'hiver et d'été ont été également développées à travers l'interpolation des échantillons des eaux souterraines collectés pendant les périodes de pompage. Ces cartes montrent clairement une relation forte entre les effets de l'excès d'exploitation de l'aquifère et l'augmentation de la salinité.*

Mots clés : *pilotage d'irrigation, pompage des eaux souterraines, salinité de l'aquifère.*

INTRODUCTION

The present study was conducted on the Sinistra Bradano irrigation scheme, located in the western part of the province of Taranto (southern Italy). The scheme covers an irrigated area of about 8636 ha. Agriculture in the study area is highly market-oriented and strongly depending on irrigation, due to hot and dry climatic conditions and to a poor distribution of seasonal rainfall.

Water is distributed to farmers by means of large-scale pressurized distribution system, operated by a local water management authority, namely the "Stornara and Tara" Water Users Association. The irrigation delivery service usually starts from mid April and lasts up to the end of October. The distribution network is operated by rotation delivery schedule with a delivery interval of 10 days. The rotation is fixed for the entire duration of the irrigation season with a flow rate of 20 l s^{-1} ha^{-1} for an irrigation time of 5 hours. The cumulative volume supplied during the four months of highest irrigation demand (May to August) totals 4320 m^3 ha^{-1}. Trickle irrigation is the prevalent method (80% of the irrigated area), whereas sprinkler irrigation covers some 20% of the study area.

As reported by many farmers, the water delivery implemented by the local management authority is too restrictive and not timely matching the actual crop water requirements. Soils are mainly of alluvial type and the applied water gets drained in 2 or 3 days. Thus, the current irrigation delivery schedule results as not adequate for the prevailing farming conditions. Due to the above situations, in the last ten years a large number of farmers started developing their "private water sources" by drilling unlicensed farm wells, thanks to the fact that the aquifer in the area is relatively shallow. The easy accessibility to groundwater reduced the water withdrawals by farmers from the large-scale distribution system for a large part of the irrigation season. This led to a very large number of unlicensed irrigation wells (nearly 6000 wells are reported to be existing in the study area), which pump irrigation water from the aquifer during the peak water demand periods. As a result, seawater intrusion into the groundwater occurs during periods of intensive pumping and this also likely leads to an increasing process of salt build-up in the soils.

Through this study the drawbacks resulting from not appropriate delivery schedule will be analyzed. In detail, potential summer and winter salinity maps will be simulated and the resulting aquifer exploitation will be estimated.

BACKGROUND ON THE STUDY AREA

Climatic conditions in the study area are hot and dry, which is typical for the Mediterranean region. Precipitation is scarce and occurs only in the period between November and March. Summer droughts are frequent.

The irrigation network

The Sinistra Bradano scheme is supplied by the San Giuliano dam, located in the bordering region of Basilicata. The reservoir has a total capacity of 70 Mm^3. The overall amount of water withdrawn from the San Giuliano reservoir for irrigation purpose totals 23,6 Mm^3 but only 16,4 Mm^3 are effectively delivered to irrigation users because of the 30,5 % of water losses in the distribution system (INEA, 1999).

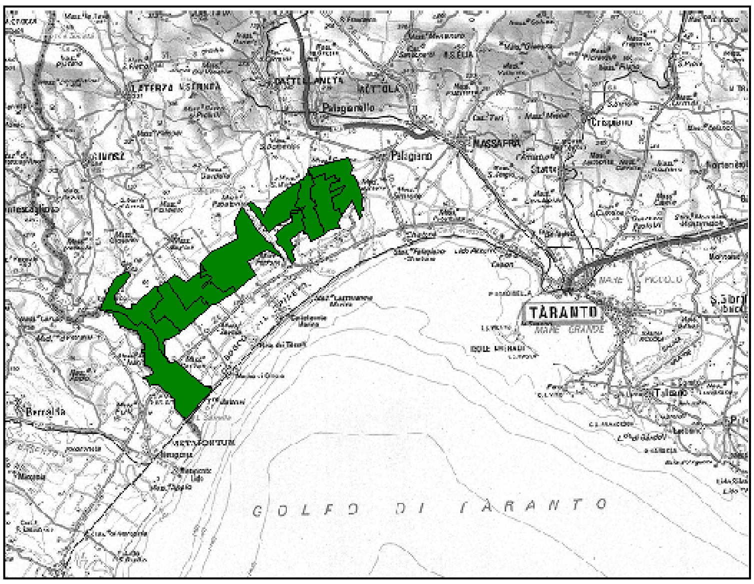

Fig. 1. Location of the irrigated area under study

Cropping pattern

The crops grown in the Sinistra Bradano irrigated area are mainly citrus, table grapes, stones fruit, olive and summer vegetables. The areal distribution of these crops is reported in the *Table 1*.

Table 1. Crops cultivated in Sinistra Bradano

Crops	Sinistra Bradano (ha)	Percentage %
Table grapes	3753.4	43
Citrus	2208.3	26
Vegetables	2184	25
Olive	431.9	5
Stone fruit	44	0.5
Almond	14.4	0.5
Total (ha)	***8636***	***100***

Source: Consorzio di Bonifica Stornara e Tara, 2001

Fig. 2. Map of crops distribution in the Sinistra Bradano irrigated area

METHODOLOGY AND APPRAOCH

Water analysis: Electrical Conductivity

Measurements of the Total Dissolved Salts (TDS) and the Electrical Conductivity (EC) were taken on samples collected from the groundwater in the Sinistra Bradano area during the irrigation season 2006. This dataset allowed the generation of winter and summer salinity maps using a geo-statistical interpolation function within the used GIS software.

The leaching requirement (LR), defined as the minimum amount of water that must pass through the root zone to prevent salt build up (Bernstein, 1974), was also calculated for the trickle irrigation method according to the following equation:

$$LR = \frac{EC_w}{2.(\max EC_e)} \quad (1)$$

where:

LR: leaching requirement ratio under trickle irrigation

EC_w : electrical conductivity of the irrigation water, dS m^{-1}

$\max EC_e$: electrical conductivity of the saturated soil extract that will reduce yield to zero, dS m^{-1}

Values for EC_e are presented by Ayers and Westcott (1985). Values of EC_e relative to crops grown in the study zone are presented in *Table 2.*

Table 2. Values of *max* EC_e for the crops grown in the study area

Crop	$\max EC_e$ (dS/m)
Almond	7
Grape	12
Olive	14
Citrus	8
Stone fruit	7.25
Vegetables	12.5

Estimating irrigation requirements

Crops, soils and climatic thematic maps were developed for previous studies. These maps were then overlapped and intersected in by using a dedicated function in the GIS software (ArcGIS, ESRI 2003). Eighty-four different unique combinations (simulation units) were obtained and identified with a specific code that characterizes each of the resulting polygons. To facilitate the codification process, each soil type (Fig. 3) was replaced by an identification number (*Table 3*). For instance, vegetables grown on a soil type 7 within the climatic zone surrounding the meteorological station of Ginosa Marina are coded as VEGS7GMA (Zaccaria and Vinukollu, 2005).

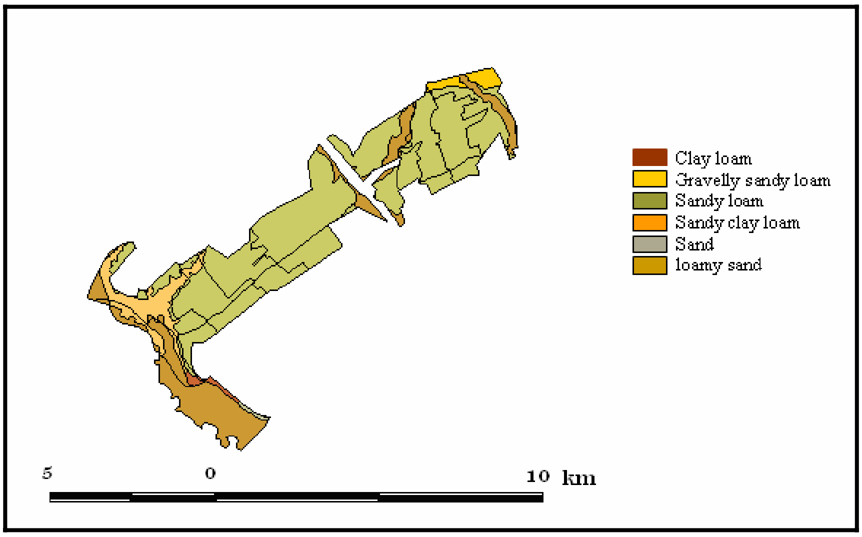

Fig. 3. Pedologic map of the Sinistra Bradano irrigated area.

Table 3. Soil codes

Code	Soil type
S7	Sandy loam
S8	Clay loam
S9	Sandy clay loam
S11	Loamy sand
S13	Sandy

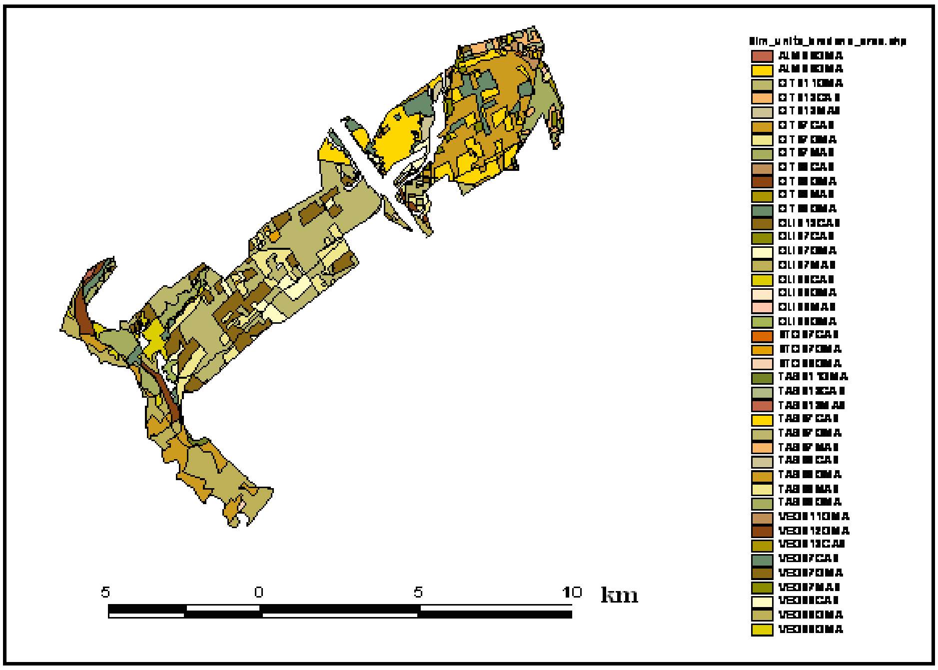

Fig. 4. Map of the simulation units identified in the Sinistra Bradano scheme

After identifying and coding the different simulation units, the irrigation schedules for each combination of crop-soil-climate were simulated by using a daily soil-water balance.

Soil water balance modeling

The ISAREG model (Teixeira, Pires And Pereira, 1999) was used to simulate the soil water balance with variable time scales and with alternative irrigation scheduling practices for a given soil – crop – climate system.

The input data for such model was organized as follow:

- Meteorological files, including data on effective precipitation and reference evapotranspiration;
- Crop files, indicating the development stages, dates, the crop coefficients (Kc), root depth evolution (z) and the depletion factor (p);
- Soil files, with the values of potential depth for root extraction (rd), field capacity (FC) and wilting point (WP), defined for each soil layer.

The data on rainfall and evapotranspiration are related to the year of 2003. Climatic datasets were collected and processed for three meteorological stations (Ginosa Marina, Massafra and Castellaneta) located within the province of Taranto. The area of influence of each meteorological station was identified by using the Thiessen method (Fig. 5).

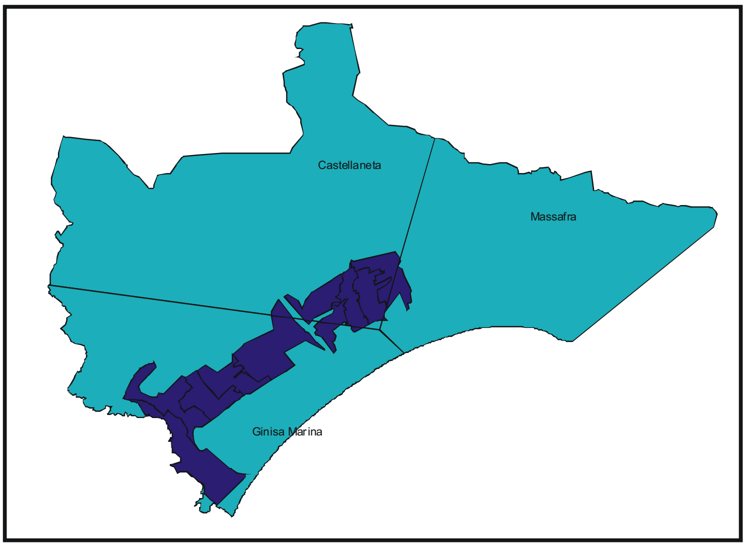

Fig. 5. Delimitation of zones of influence for the meteorological stations using Thiessen method

From the meteorological data, the reference evapotranspiration (ETo) was computed by using the Hargreaves-Samani (1985) equation. This empirical method has proven to work fairly well in many Mediterranean locations under hot and dry conditions and requires only the values of the daily temperature, according to the following equation:

$$ET_o = 0.0135*(K_T)*(Ra)*(T_D)*0.5*(T_C+17.8) \quad (2)$$

Where:

$T_D = T_{max} - T_{min}$ (°C),

T_C is the average daily temperature (°C).

K_T is a correction factor.

For each simulation unit two different irrigation schedules were generated. The first one represents the type of delivery implemented by the Water Users Association, with a fixed irrigation interval of 10 days and the irrigation depth of 36 mm. The second represents the irrigation aiming at the maximum yield.

To build the map of potential groundwater exploitation of the area, the two different irrigation schedules for each combination were compared. The applied methodology assumes that pumping from the aquifer occurs when the soil-water balance indicates that irrigation is required and that amount of water is not supplied by the distribution system because of rotation intervals. This assumption of using the groundwater for complementing volumes and timing of delivery by the large-scale distribution network involves the existence of a plan for conjunctive use in the area.

The extra amount of water resulting from computation of the leaching fraction was added to the estimated irrigation water requirement and finally, the gross irrigation requirement was computed as:

$$GIWR = \frac{IWR}{Eff} \quad (3)$$

Where:

Eff is the efficiency of the irrigation method, which is assumed to be 85 % in the study zone.

RESULTS AND DISCUSSION

Salinity maps of the groundwater in the study area

Salinity maps were obtained by the interpolation of the measurements of electric conductivity from 18 samples taken during the winter and summer of 2006 (Fig. 6).

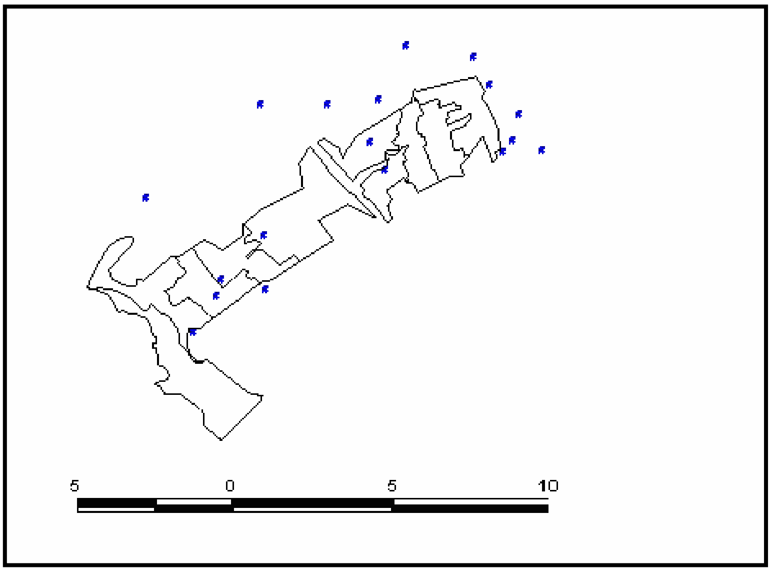

Fig. 6. Location of salinity samples collected during 2006

As it can be observed from the comparison between winter and summer salinity maps, (Figs 7 and 8), the salinity level increased during 2006 from winter (Fig. 7) to summer (Fig. 8). The groundwater salinity measured during winter for the western part of the study area ranged between 1.5 and 1.8 g l^{-1}, whereas it reached values ranging between 1.9 and 3.1 g l^{-1} in summer. The eastern part of the study area showed a non significant increment of groundwater salinity (from a range of 0.8 – 1.1 g l^{-1} to 0.8 – 1.4 g l^{-1}), apart from a small rise on its border that can reach 2.5 g l^{-1} (Fig. 8).

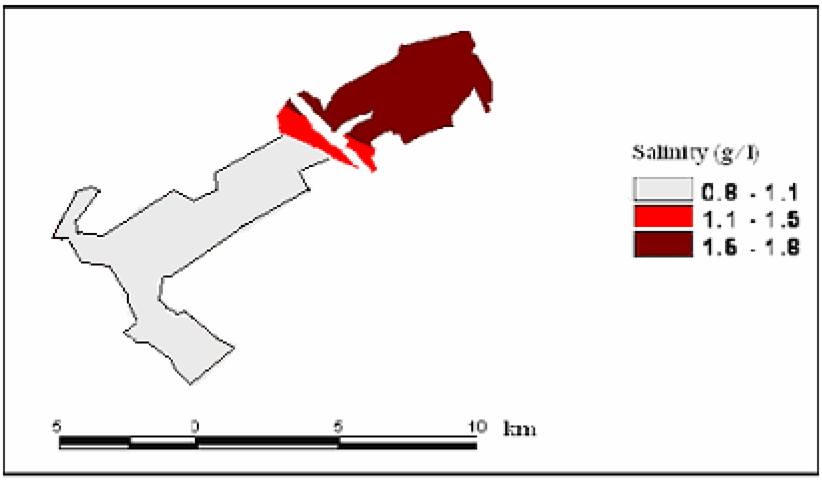

Fig. 7. Winter salinity map of the Sinistra Bradano area

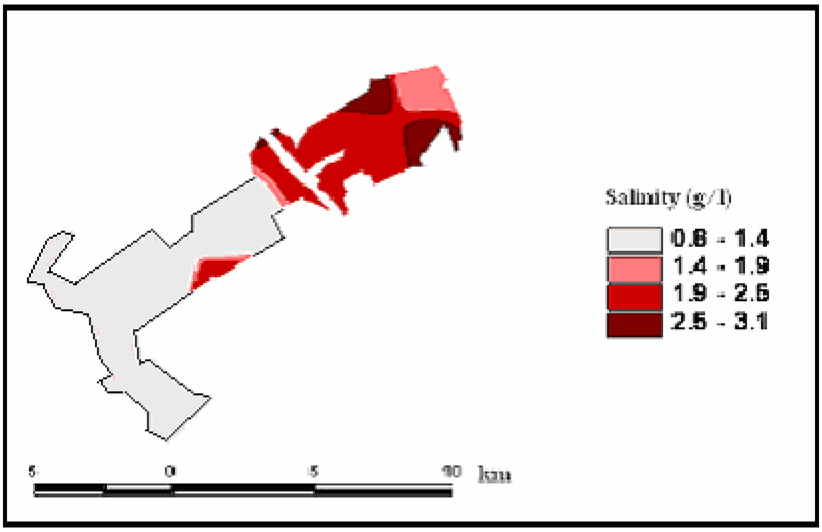

Fig. 8. Summer salinity map of the Sinistra Bradano area

This increase in salinity is likely due to the intensive pumping from the aquifer during period of peak demand and specifically from May to August. The intensive pumping is mostly a consequence of a non-adequate irrigation schedule applied by the local Water Users Association. The simulations performed by using the daily soil-water balance clearly show that pumping likely occurs when the delivery schedule by which the distribution system is currently operated does not match the estimated crop irrigation requirements, both with regard to volumes and timing of irrigation events.

Interpretation of simulation's results

The Fig. 9 presents the simulated soil water balance for vegetables grown on sandy-loam soil (soil of type 7) within the climatic zone of the Massafra meteorological station. The simulation was carried out under the hypothesis of rotational delivery schedule (10 days) with a flow rate of 20 $ls^{-1}ha^{-1}$ at the farm turnout for 5 hours of irrigation time. From the figure it can be observed that during large part of vegetative growth the crop faces water stress condition. The Soil Water Storage (SWS) goes far below the Optimum Yield Threshold (OYT).

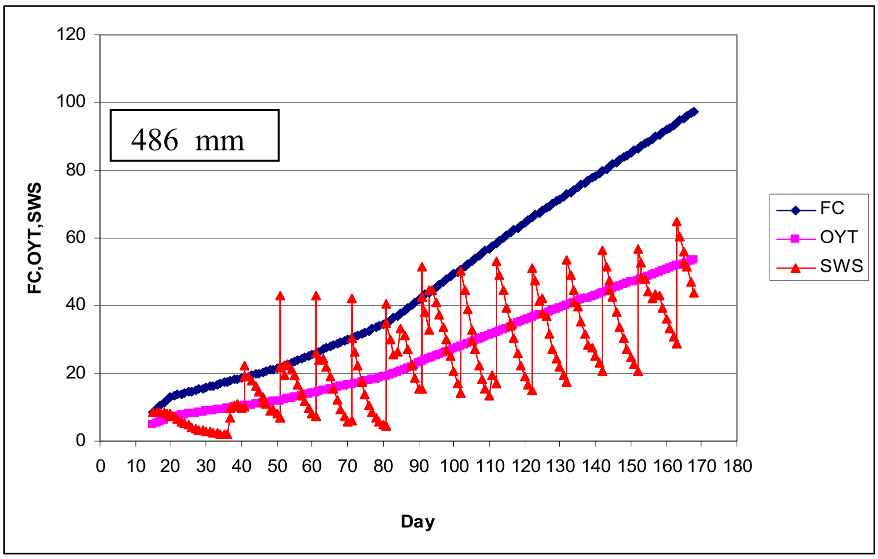

Fig. 9. Simulated soil water balance for VEGS7MAS under the schedule applied by the WUA

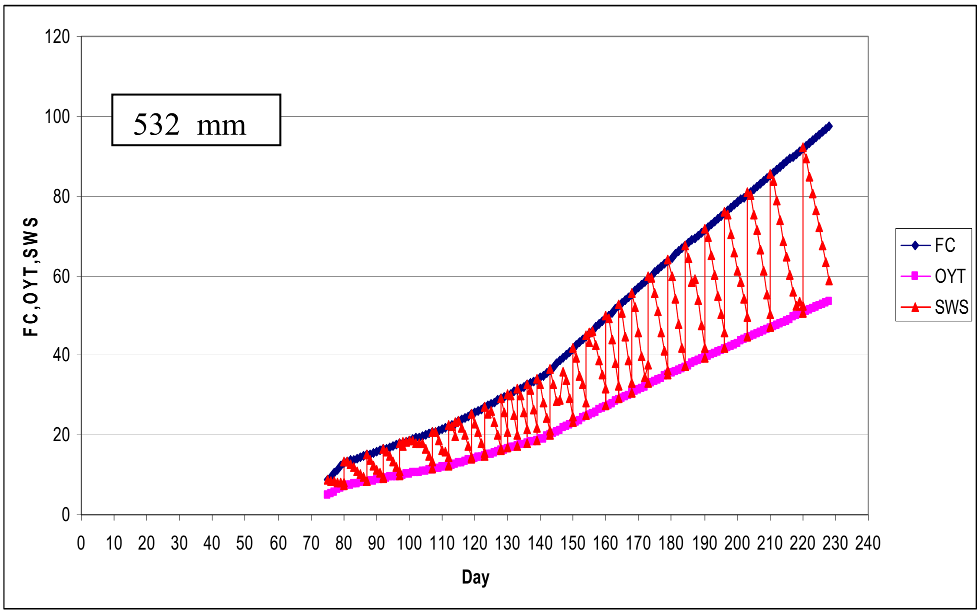

Fig. 10. Simulated soil water balance for VEGS7MAS under the maximum-yield schedule

The Fig. 10 shows the simulation results under the irrigation schedule giving the maximum crop yield. It can be observed that under this water delivery schedule the crop never gets under water deficit.

By comparing the results from the two simulations it can be inferred that the delivery schedule applied by the WUA does not allow maximizing crops yield, as water deficit conditions occur several times. This situation pushes farmers to pump water from the aquifer, at least to supply to crops complementary water with respect to what is delivered by the large-scale distribution network. The total volume of water supplied according to the rotation delivery schedule is 468 mm. When the leaching requirement (140 mm) and irrigation efficiency (85%) are considered, this total amount should be increased to 765 mm. If this is the case, the resulting irrigation deficit is estimated as 297 mm (*Table 4*). Since vegetables require frequent irrigation and cannot tolerate water deficit situation without yield reduction, farmers rely on farm wells as complementary source of irrigation. According to the simulation, the gross volume of water that would be likely pumped from the aquifer, under the above assumptions, is therefore estimated as 464 mm.

The same approach was applied for orchards. Under the simulated rotational delivery schedule, the irrigation rates are not supplied with adequate timing with respect to the crop needs. Fig. 11 shows the simulation carried out for table grapes on soil of type 3 for the climatic zone of Massafra (TABS3MAS). An important volume of water exceeds the crop needs in certain periods, while in others the crop faces water stress. The total crop irrigation requirements in this simulation are estimated as 504 mm (*Table 4*).

When the delivery schedule aiming at maximum yield is simulated for the same crop and growing conditions (Fig. 12), no stress and no excess of water are observed. The comparison between the two simulations shows that when the rotational delivery schedule is applied, in order to avoid water deficit situation farmers would probably pump an amount of 243 mm as complementary volume to the water delivered by the distribution system.

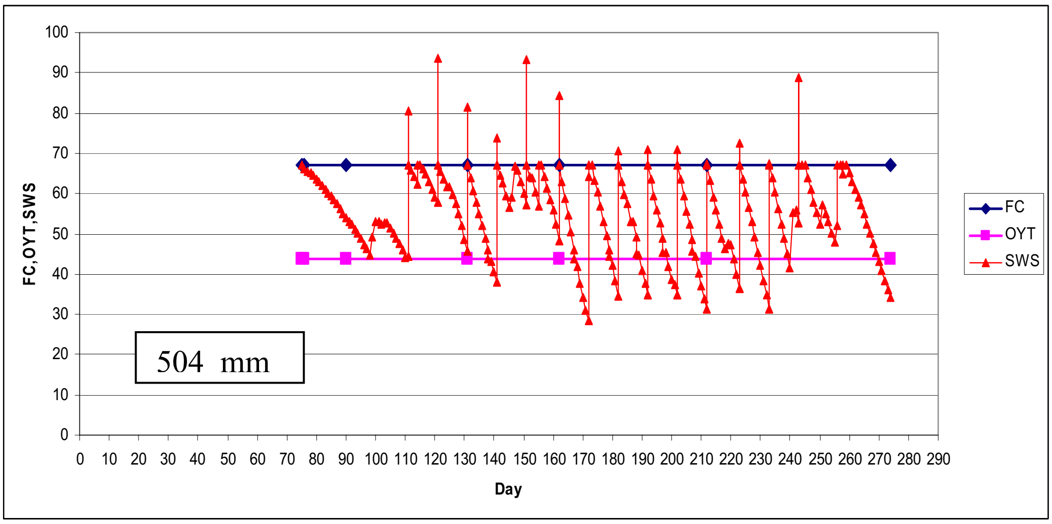

Fig. 11. Soil available water of TABS3MAS under the consortium schedule

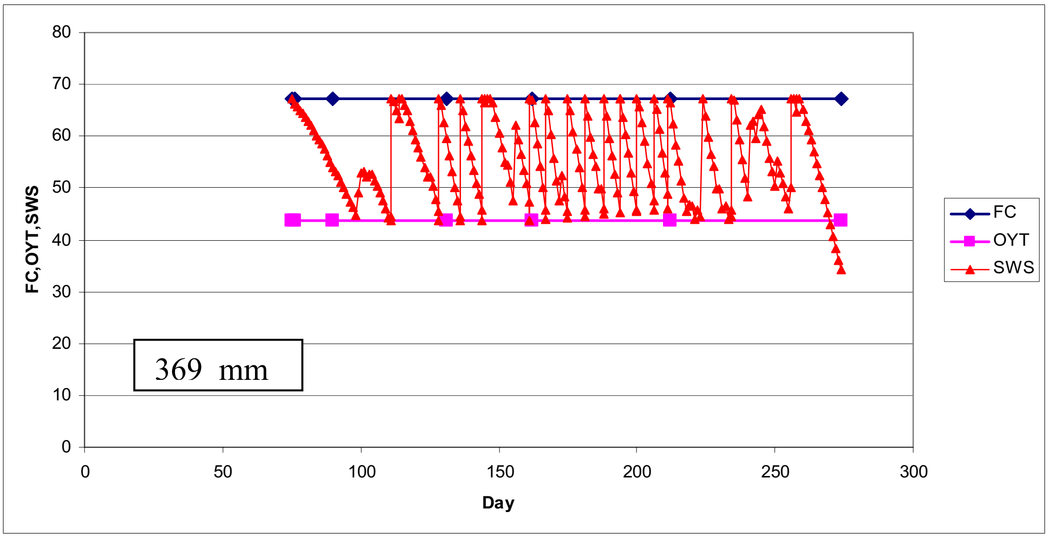

Fig. 12. Soil available water of TABS3MAS under the optimum schedule

Different results are obtained simulating the soil-water balance for citrus and almond. These results are presented in Figs 13 and 15. They show that the rotation delivery schedule leads to an excess of water application estimated as 97 mm and 123 mm respectively for CITS8GMA and ALMS8GMA (*Table 4*). By comparing the results from rotation and delivery aiming at maximum yield for the two crops it can be inferred that the rotation delivery schedule does not allow for an efficient use of the available water, as also water excess situations are to be avoided for not reducing the crop yield. In this case, farmers should reduce the application of water to the amount which is actually required and eventually store the excess amounts at the farm level in some effective ways. Alternatively, the excess volumes should be stored by the WUA in district reservoirs located at the upstream level of the distribution networks and then should be supplied in times of actual needs.

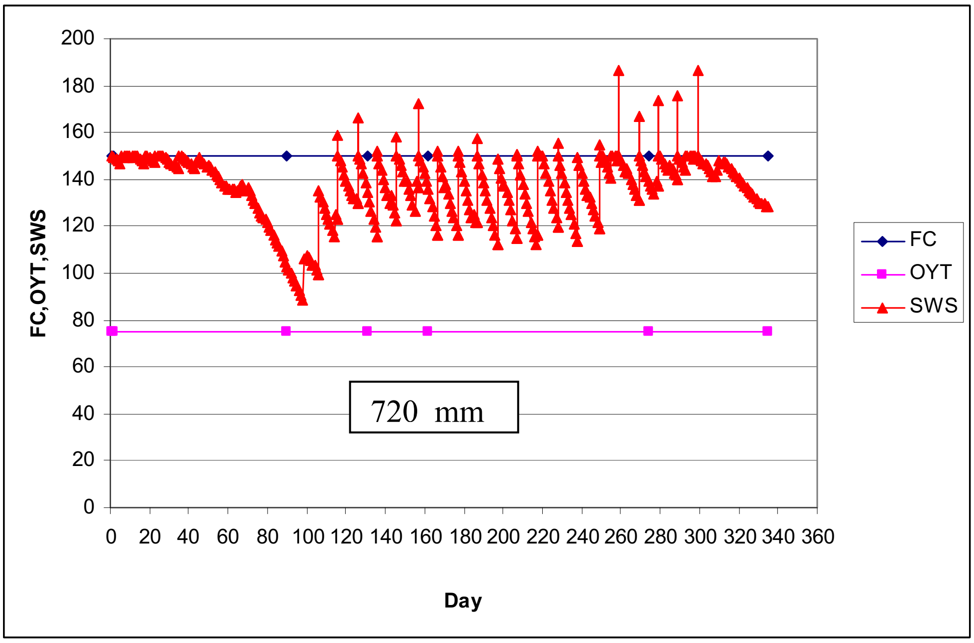

Fig. 13. Simulated soil water balance for CITS8GMA under rotation delivery schedule

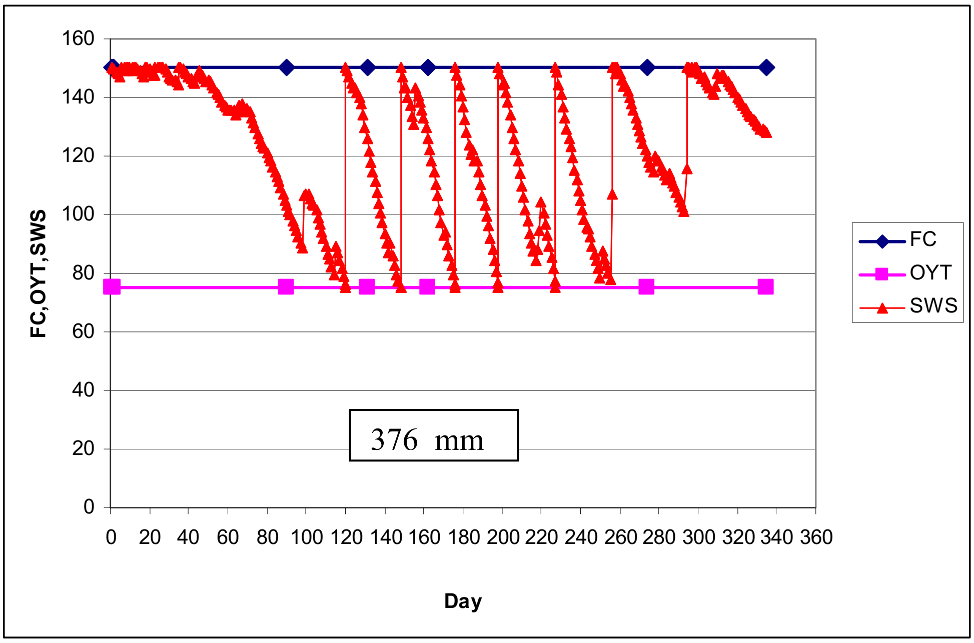

Fig. 14. Simulated soil water balance for CITS8GMA under maximum-yield schedule

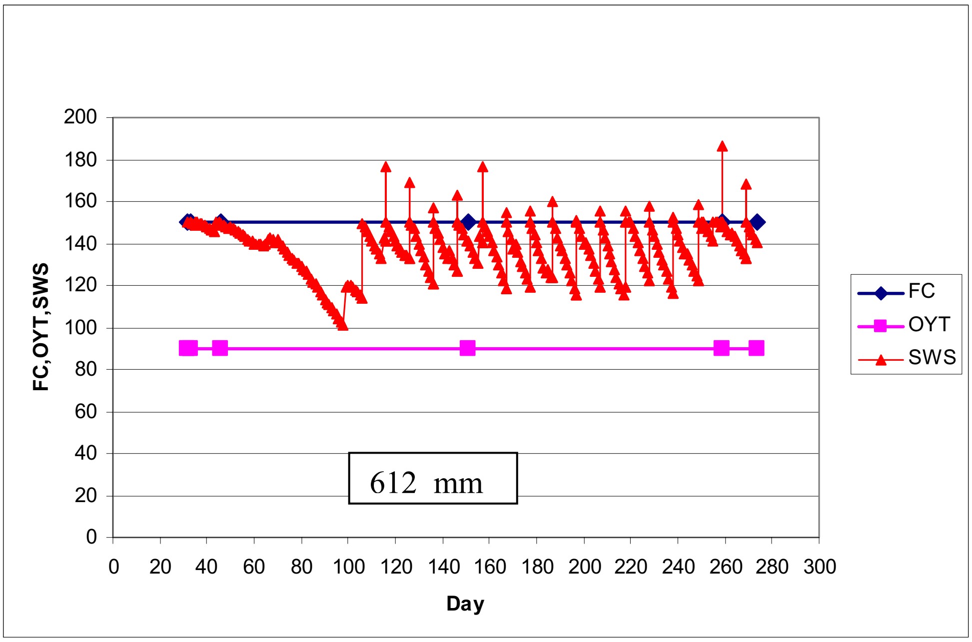

Fig. 15. Simulated soil water balance for ALMS8GMA under rotation delivery schedule

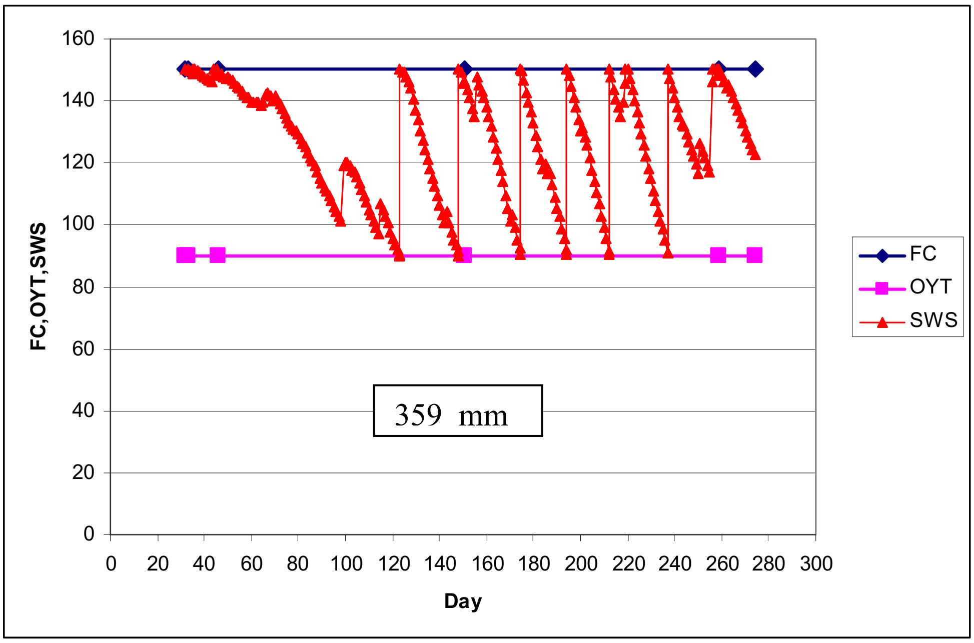

Fig. 16. Simulated soil water balance for ALMS8GMA under maximum-yield schedule

Table 4. Irrigation requirement under the rotational delivery schedule

Combination	TV_{ND} (mm)	NIWR (mm)	LN (mm)	Gross IWR (mm)	Deficit/Excess (mm)
VEGS7MAS	468	532	140	765	-297
TABS3MAS	504	369	57	492	12
CITS8GMA	720	376	181	623	97
ALMS8GMA	612	359	67	489	123

According to the simulations and to the presented results, some tentative conclusions can be drawn: the rotation delivery schedule applied for the distribution system serving the irrigated area under study does not match the crop water requirements, both with regard to the applied volumes and timing of deliveries. The rotation delivery does not allow an effective use of the available water, as water is delivered to farmers by the large-scale distribution system not in full compliance with the estimated crop requirements. As a result, some important water deficit and water excess situations may occur in the different cropped areas of the irrigation scheme. The water deficits would encourage farmers in pumping water from the aquifer, whereas excess situations would lead to poor efficiency of water use, to crop yield reduction and to leaching of nutrients.

Map of the potential groundwater exploitation

The results from simulations allowed a preliminary estimation of the potential water pumping from the aquifer, according to the assumptions considered for the present study. The estimated potential water volumes that farmers would pump from the aquifer for the different crop-soil-climate conditions were manually attributed to each simulation unit. A map of the potential groundwater exploitation was developed as main result of the applied approach (Oueslati, 2006). This map is reported in the Fig. 17, where three exploitation classes were identified:

- 1000 – 2000 m^3/ha/year
- 2000 – 3000 m^3/ha/year
- 3000 – 4000 m^3/ha/year

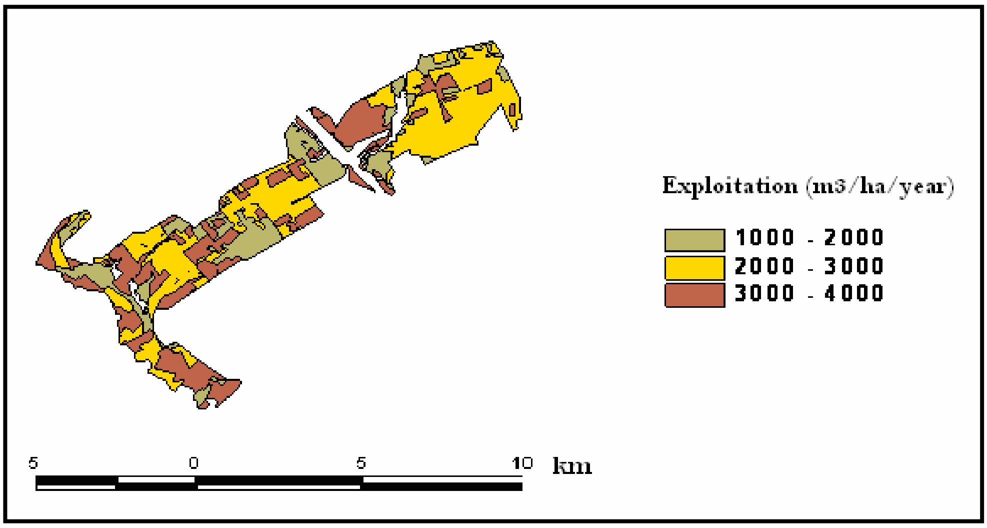

Fig. 17. Map of the potential groundwater exploitation

Comparison between groundwater exploitation and salinity results

By comparing the map of groundwater salinity with the map of potential groundwater exploitation it can be observed that in the western part of the Sinistra Bradano area the salinity ranges between 0.8 and 1.4 g l^{-1} although the aquifer exploitation would be relevant and varying between 1000 and 4000 m^3 ha^{-1}. In this part of the study area the average seasonal amount of water likely pumped would range between 2000 and 3000 m^3 ha^{-1}. For the eastern part of the study area the groundwater salinity varies between 1.9 and 3.1 g l^{-1}, with almost the same level of pressure that would be exerted on the aquifer. The important conclusion that can be drawn is that the high level of salinity would be most likely due to intensive pumping from the aquifer, which would in turn create the conditions for seawater intrusion.

For the western part of the study area, the lower increase in salinity might be due to the following reasons:

- An hydraulic pressure exerted by the Bradano river that flows to the Ionian sea and borders the most western part of the study area
- The nature of soil types and the geologic layers that work as physical barriers and decrease the potential for the seawater intrusion.

The influence of these two factors was supported by the following comparisons:

<u>Comparison 1</u>

As reported in the *Table 5* and shown in Fig. 18, the permeability (hydraulic conductivity) of soils in the eastern part of the study area is about half of that of the soil of western part. This basically makes seawater intrusion more difficult to occur in the western part, also because of the hydraulic pressure exerted by the Bradano River.

Table 5. Hydraulic conductivity of the soils of the study area

Side	Western part	Eastern part
Geology	Sand, agglomerated sand and gravel	Agglomerations, gravel, sand and alluvial limestone
Hydraulic Conductivity	≥ 81 m/d	41 – 81 m/d

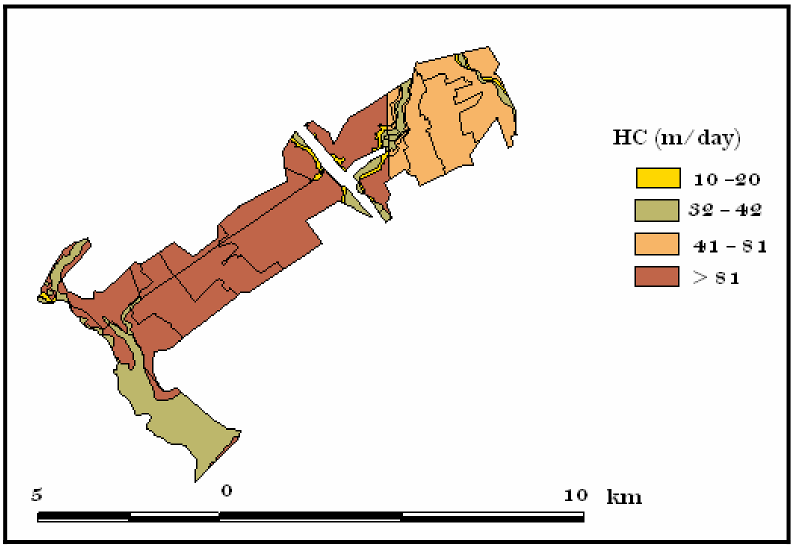

Fig. 18. Map of hydraulic conductivity for the soil of the Sinistra Bradano area

Comparison 2

By observing the geologic map, the border of the study area is characterized by three different layers identified as A1, A2 and QD (Fig. 19).

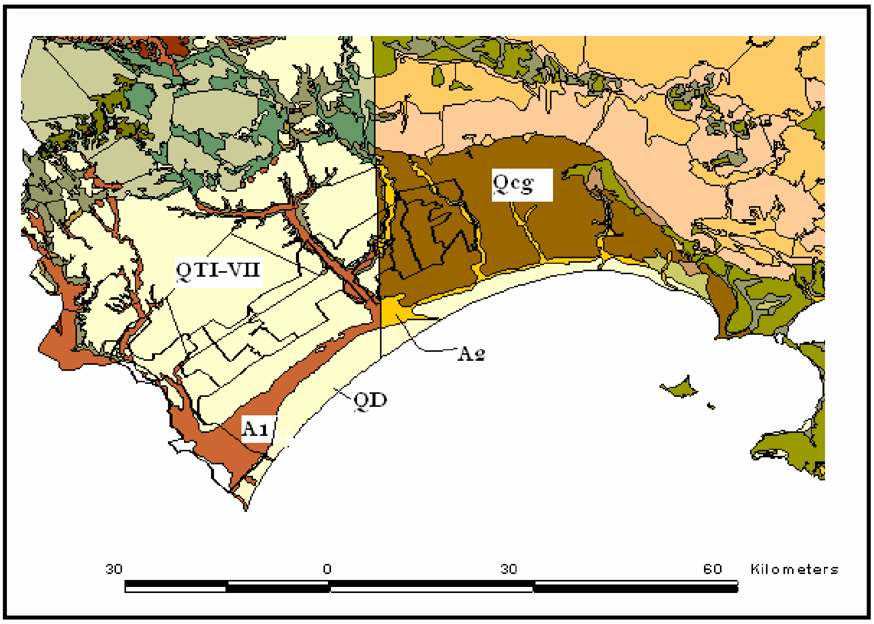

Fig. 19. Geologic map of the province of Taranto

As explained in the *Table 6*, the layer A1, which is mostly present in the western part of the study area, is composed of clay, and therefore it would block the intrusion of seawater as it was predicted. The layer A2 is composed of sand and gravel and thus might facilitate the seawater intrusion for the eastern part of the study area.

Table 6. Presentation of A1, A2 and QD layers

Geologic layer	Western part	Eastern part
A1	Recent alluvial deposit composed in a great part of clay and has15 m thickness	**X**
A2	X	Recent sand and gravel with a thickness of few meters
QD: Recent coastal dune with an elevation of 16 m on the sea water level	**X**	**X**

Furthermore, by observing the pedologic map of the study area the layer A1 correspond to the clay-loam soil type (Fig. 20), and this horizon decrease in thickness toward the eastern part of the Sinistra Bradano area.

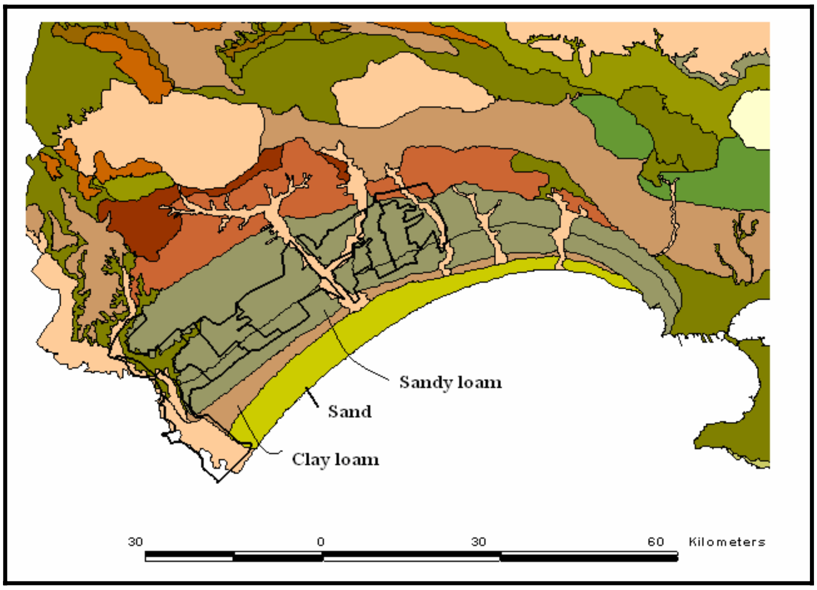

Fig. 20. Pedologic map of the province of Taranto

Consequently, it can be concluded that the layer A1 may have a notable influence on reducing the seawater intrusion even though the aquifer exploitation in the western part of the study area could be relevant.

CONCLUSIONS

According to the simulations carried out and to the assumptions considered in the present study, important water withdrawals from the groundwater may be carried out by farmers as a consequence of the inappropriate water deliveries by the large-scale distribution system. This would lead to increase the groundwater salinity, as water pumping might go beyond the safe yield of the aquifer in some periods of the irrigation season.

According to the preliminary assessment conducted for the present work, in order to reduce the salinity problem, some recommendations are suggested:

1. At the level of distribution network:

- Improve the distribution efficiency by increasing maintenance activities.
- Control water consumption by installing flow meters at the delivery points (hydrants).
- Shift the delivery schedule from the current fixed rotation to some more effective types of delivery. For instance, a differentiated rotation able to deliver water according to the actual crop irrigation needs and to the required timing for irrigation would improve the overall efficiency of water use. Alternatively, a plan for conjunctive use of surface and groundwater would increase the economic and environmental sustainability of irrigation in the area. In the best-case scenario, a delivery on-demand would enable a great enhancement of the quality of irrigation services provided by the WUA and strongly reduce the pumping from the aquifer.

2. At the farm level:

- Developing small farm storage reservoirs, which would enable farmers to store the volume of water received every 10 days and to distribute water according to actual crop water requirements, both in timing and volume.

The above recommendations would allow for a better use of the available water supply and, consequently to save the quantity and the quality of the groundwater resource.

REFERENCES

Ayers, R.S. and Westcot D.W., (1985). Water quality for agriculture *irrigation and drainage*. Paper 29, Rev. 1. FAO, Rome. 174 pp.

Bernstein, L. (1974). Crop growth and salinity. In: Drainage for Agriculture. (3. Van Schilfgaarde, (ed.) 1. Am. Soc. Argon., Madison, Wisconsin, USA. 17: 39-54.

Clement, R. (1966). Calcul des débits dans les réseaux d'irrigation fonctionnant à la demande. La houille blanche, 5, 553 – 575.

Hargreaves, G.H., Samani, Z.A., (1985). *Reference crop evapotranspiration from temperature.* Appl. Engnr. Agr. 1, 96-99

INEA, (1999). Quadro di riferimento per lo studio è il monitoraggio dello stato dell'irrigazione in Pulia: Consorzio di Bonifica Stornara e Tara, Bari.

Oueslati, (2006)._Assessment of zones vulnerable to pollution caused by nitrate and seawater intrusion: an example of Apulia region. Master thesis, Agronomic Mediterranean Institute of Bari, Italy.

Teixeira, J.L., Pires,G. And Pereira, L.S. (1999). User's guide of ISAREG: An irrigation scheduling simulation model. Rural Engineering Department, Lisboan.

Zaccaria, D. and Vinukollu R. (2005). Determination of spatially distributed irrigation water requirements at scheme level using soil water balance model and *GIS*. In: Proceedings of the ASAE 2005 Pacific Northwest Section Meeting, Lethbridge, Alberta (Canada), September 22-24, 2005.