Assessment and Management of Environmental Risks Resulting from Operation of Irrigation Delivery Systems: a Case Study in Southern Italy

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Background

The study was conducted in an irrigated agricultural area within the framework of the STRIM Project (EU-CADSES, 2006-2008)

The objectives of the study were:

1) Assessing the environmental risks resulting from the current irrigation delivery schedule on the cropped soils and on the aquifer

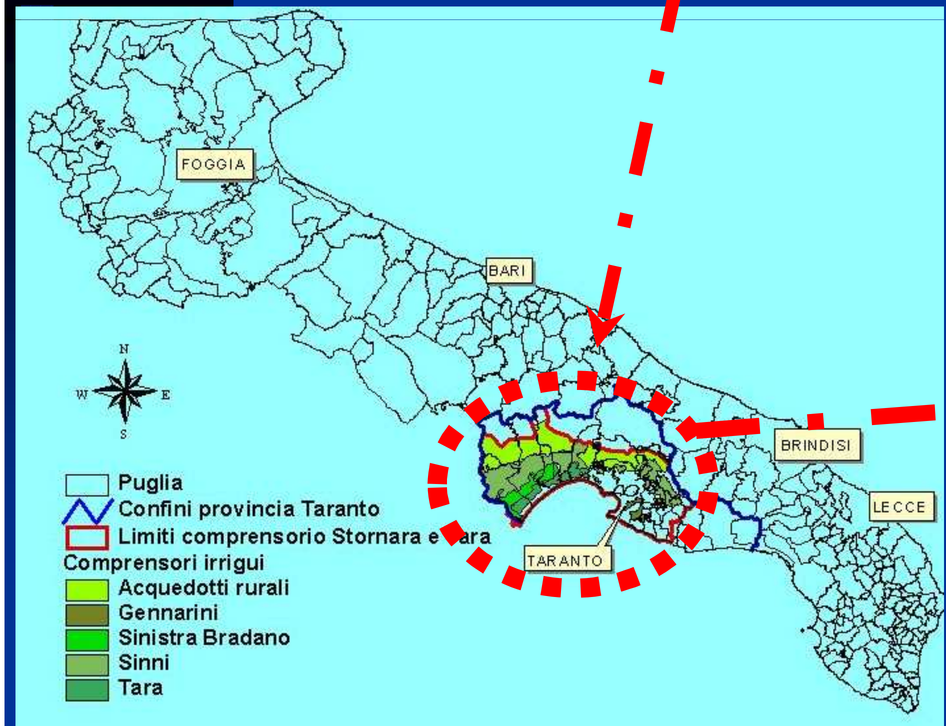
2) Identifying feasible improvements with respect to the “business-as-usual” in the study area for reducing the existing “pressure” on groundwater resources

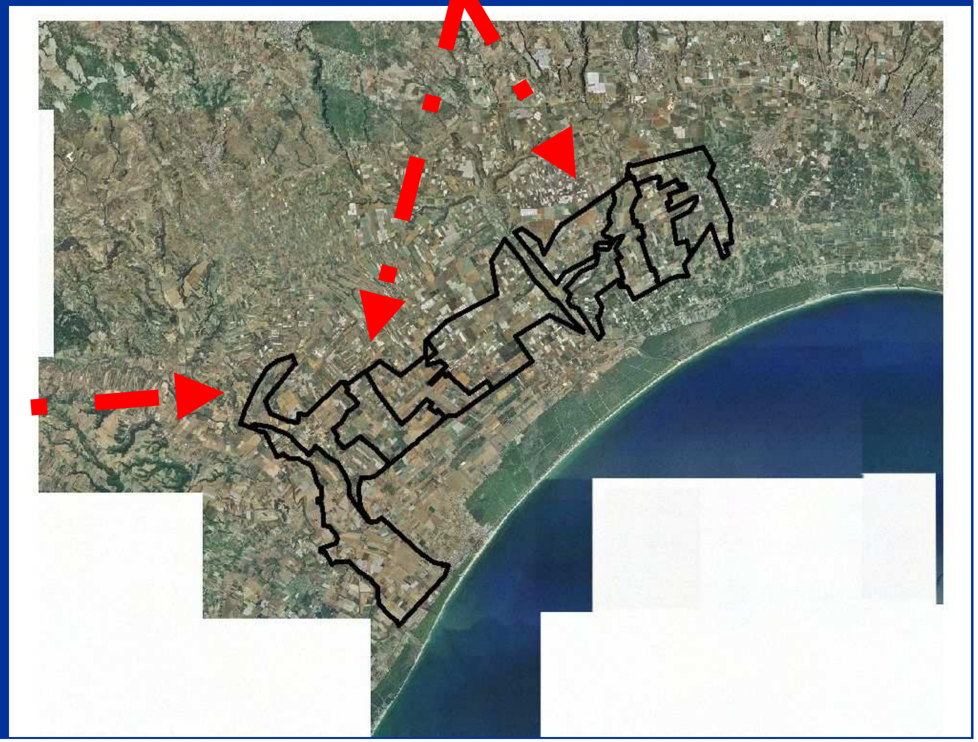
3) Testing the applicability of a DSS for ERA&ERM, which was developed within the STRIM Project (**http://www.strim.eu**)

The study area is an irrigation scheme equipped with a water distribution network operated by a local Water Users' Association

Total Area: 9,651 Ha

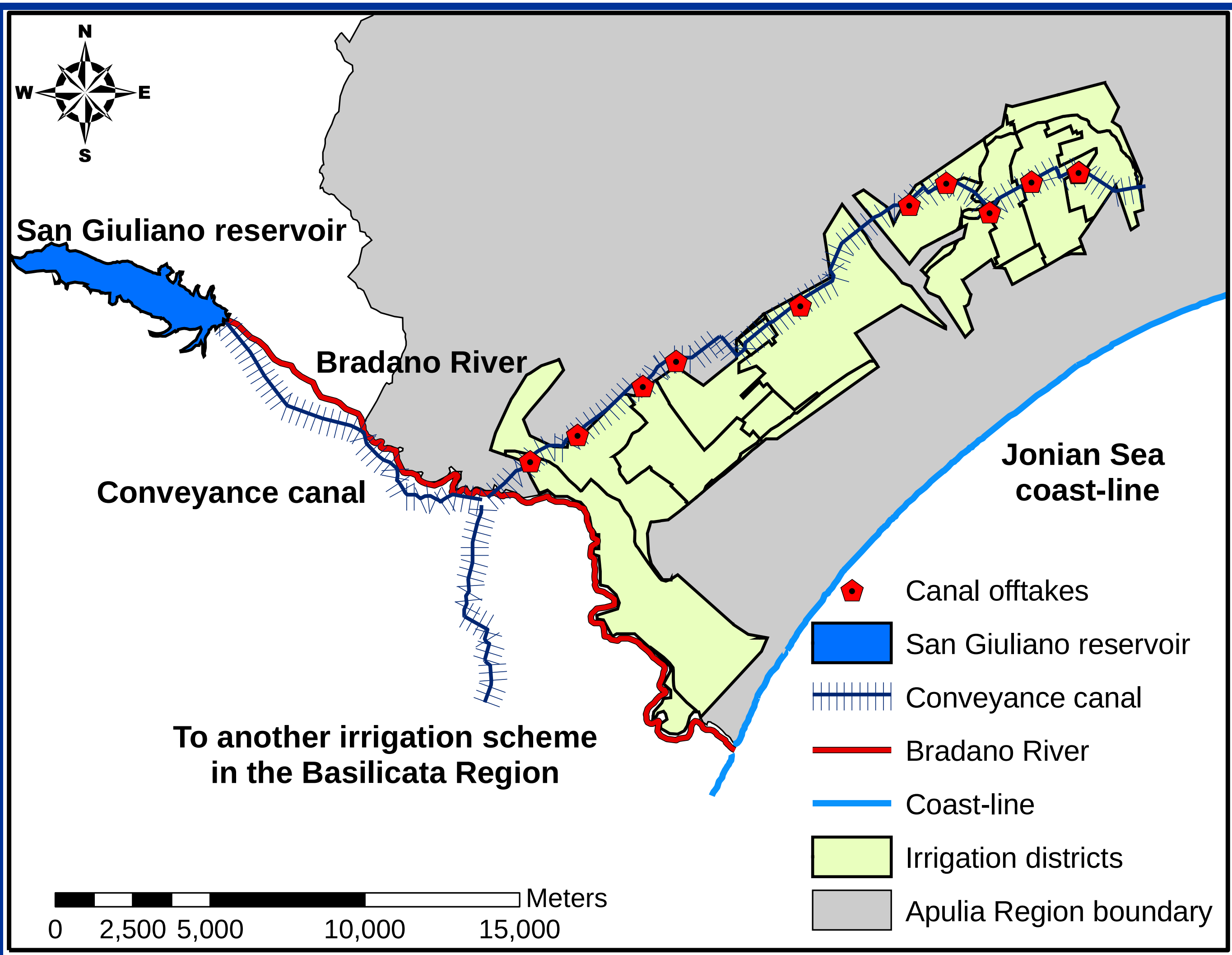
Area equipped for irrigation 8,636 Ha sub-divided in 10 irrigation districts





The water source is the San Giuliano reservoir along the Bradano river with a total storage capacity of 70 Mm^3, out of which 35 Mm^3 are available for irrigation in the study area

From the reservoir water is transported through a main conveyance canal, along which the pressurized distribution networks originate for each district



Main features of the study area

- Climate is semi-arid classified as “Maritime-Mediterranean” typical of the coastal areas
- Average annual rainfall: 550 mm, concentrated between November and March
- Average farm size: 2.5 – 3.0 ha (small land-holdings)
- Main irrigation methods: trickle irrigation (drip) and sprinkler irrigation is some residual areas
- Irrigation season: May through early November
- Irrigation Delivery Schedule: rotation, with fixed 10-day interval, flow-rate of 20 $l\ s^{-1}$ for 5 hours of delivery to each user

CROPS	Area (ha)	Percentage out of total (%)
Table-grapes	3,753.4	43
Citrus	2,208.3	26
Vegetables	2,184	25
Olive	431.9	5
Fruit Orchards	44	0.50
Almonds	14.4	0.16
TOTAL (ha)	*8,636*	*100*

The water distribution network was conceived and designed in the late 1960's for surface irrigation methods

Nowadays the majority of farmers use micro-irrigation methods (drip irrigation)

The irrigation distribution network supplies water to farmers every 10 days with 20 l/s and with low pressure (0.3 - 0.6 bar). These delivery conditions do not match farmers' and crops' needs

Although the cropped area remained nearly the same along the years, the area irrigated with water supplied by the delivery network has drastically decreased in the last decade with no changes occurred in the cropping pattern

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Area (Ha)	2128	2046	2026	2044	1815	--	1354	1183	1004	987	921
Percentage on irrigable area (%)	24.6	23.7	23.4	23.7	21.0	--	15.7	13.7	11.6	11.4	10.7

Areas irrigated with water supplied by WUO in the last 10 years in the Sinistra Bradano scheme
(Source: Consorzio di bonifica Stornara e Tara - Taranto, 2007)

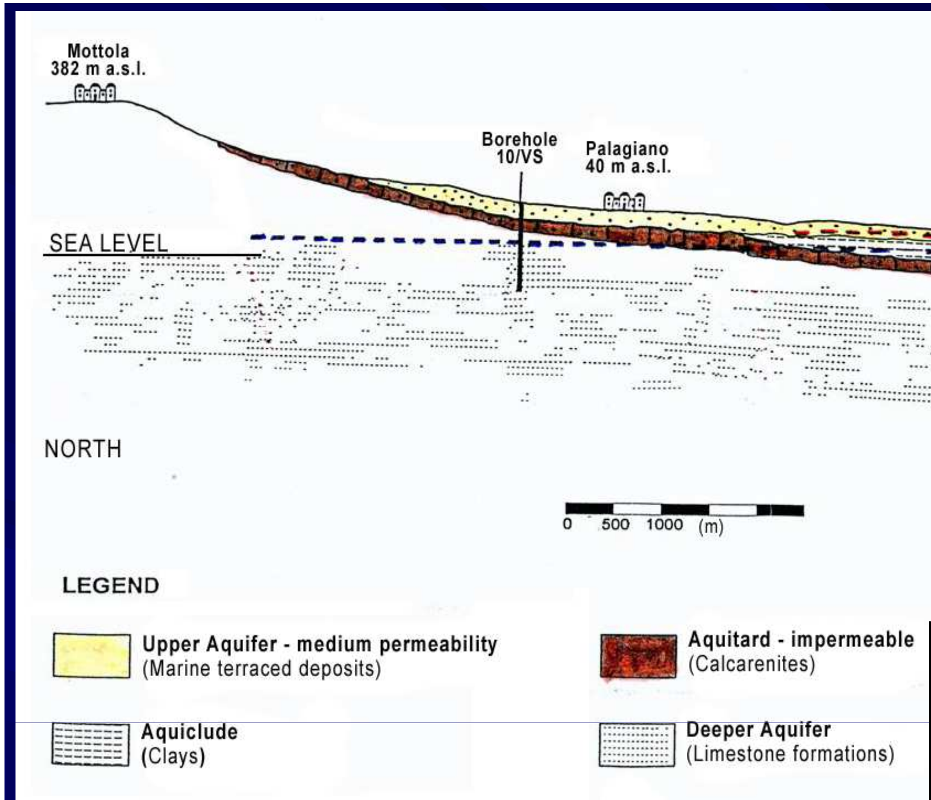
Statement of the problem

The semi-arid climatic conditions of the area make crop production tightly relying on irrigation.

An increasing number of farmers uses groundwater pumping as main water source for irrigation

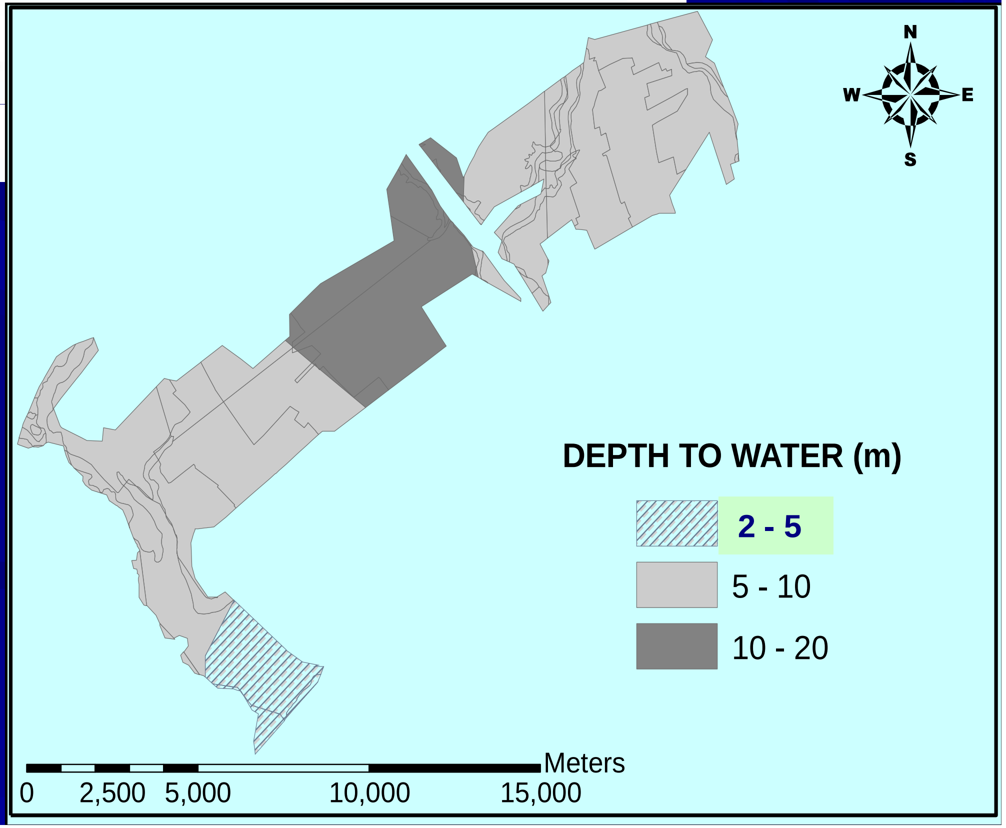
This has led to a high pressure on the aquifer, causing phenomena of soil degradation and aquifer salinization

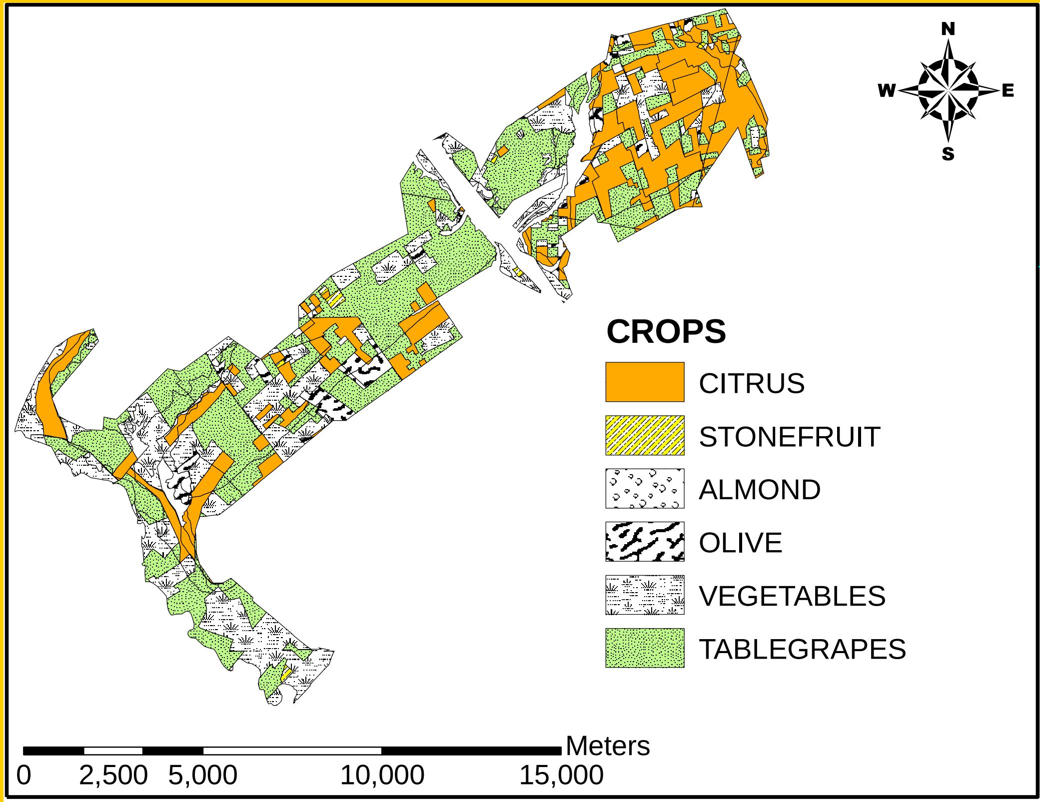
The inadequate water distribution by the management body causes hazards of degradation of the soils and aquifer far beyond their natural recovery capability



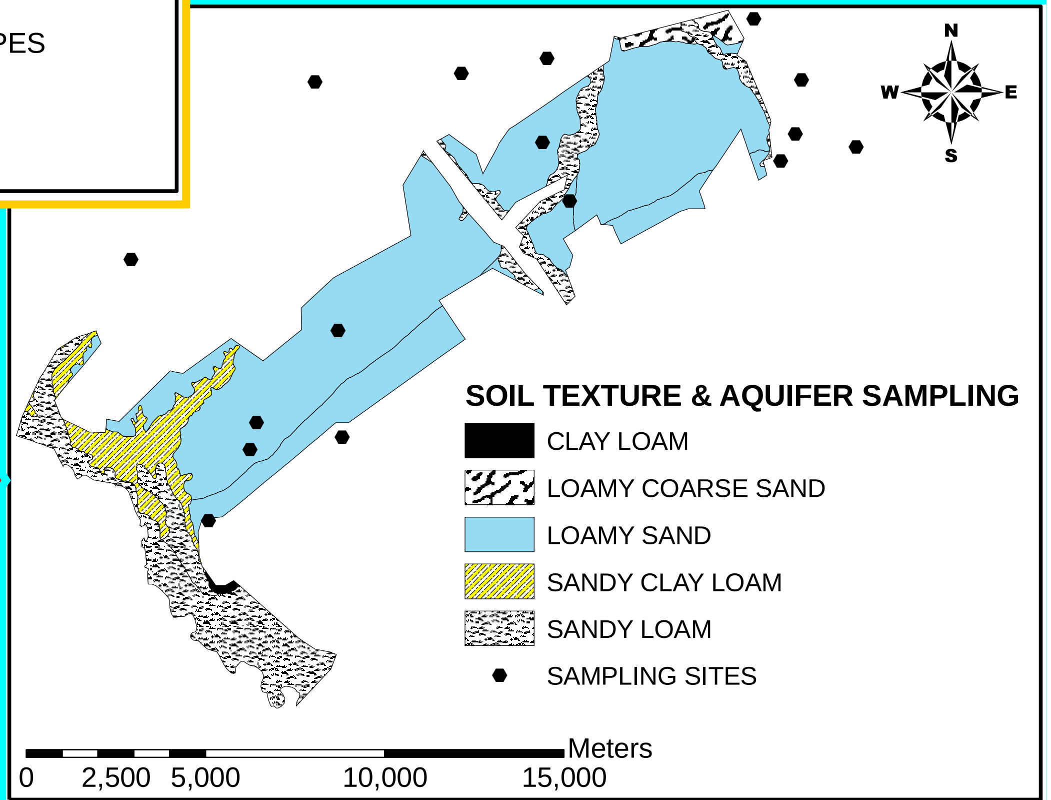
Water is available from 2 aquifers: the shallow one is located onto sands and marine terraced deposits, the deep one is confined between 2 calcarenite formations

Depth-to-water map

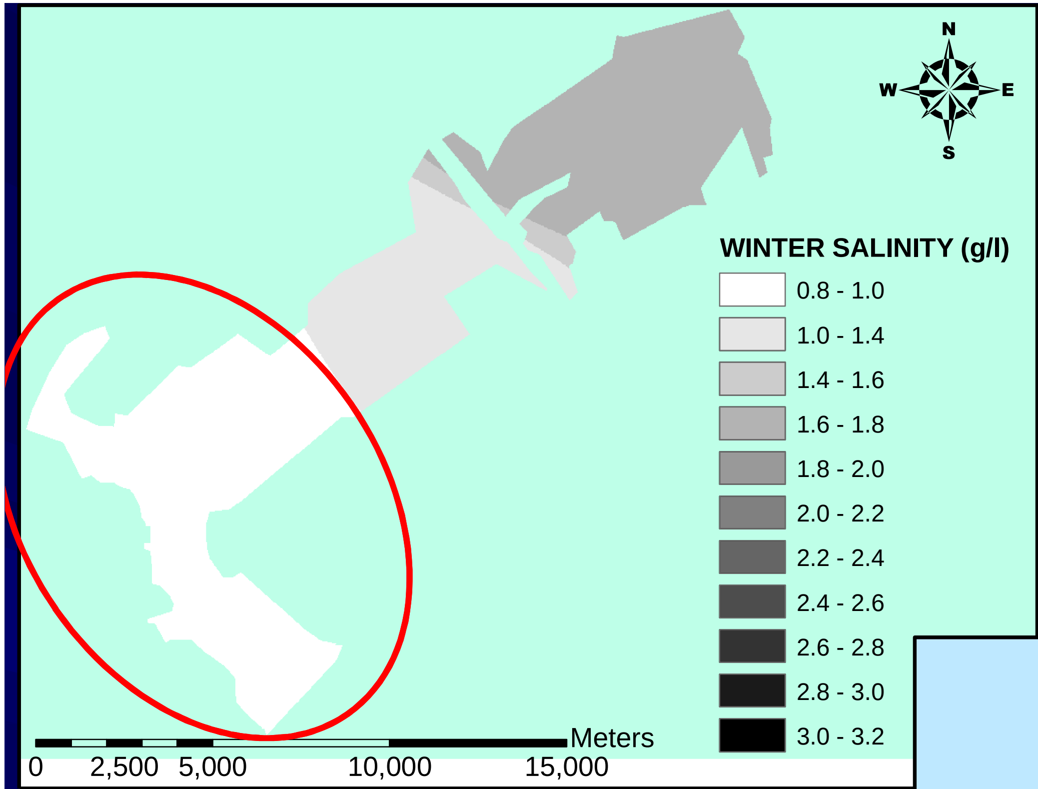




Map of cropping distribution

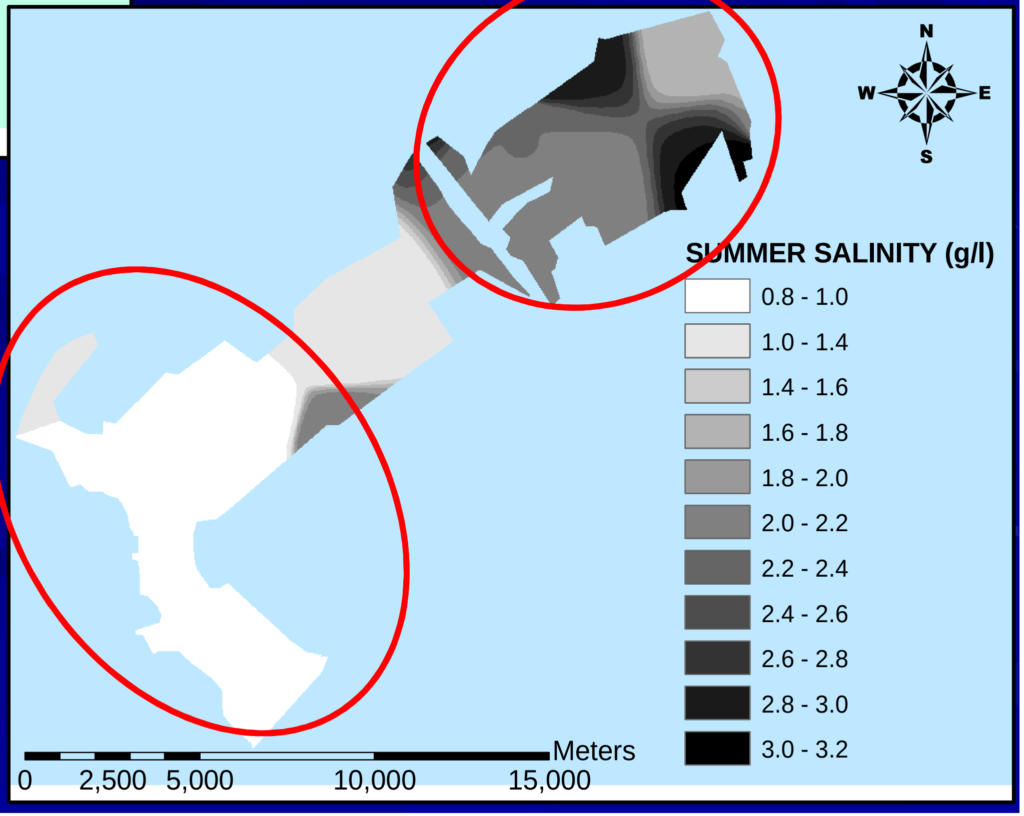


Soil textural map with the sites of aquifer sampling

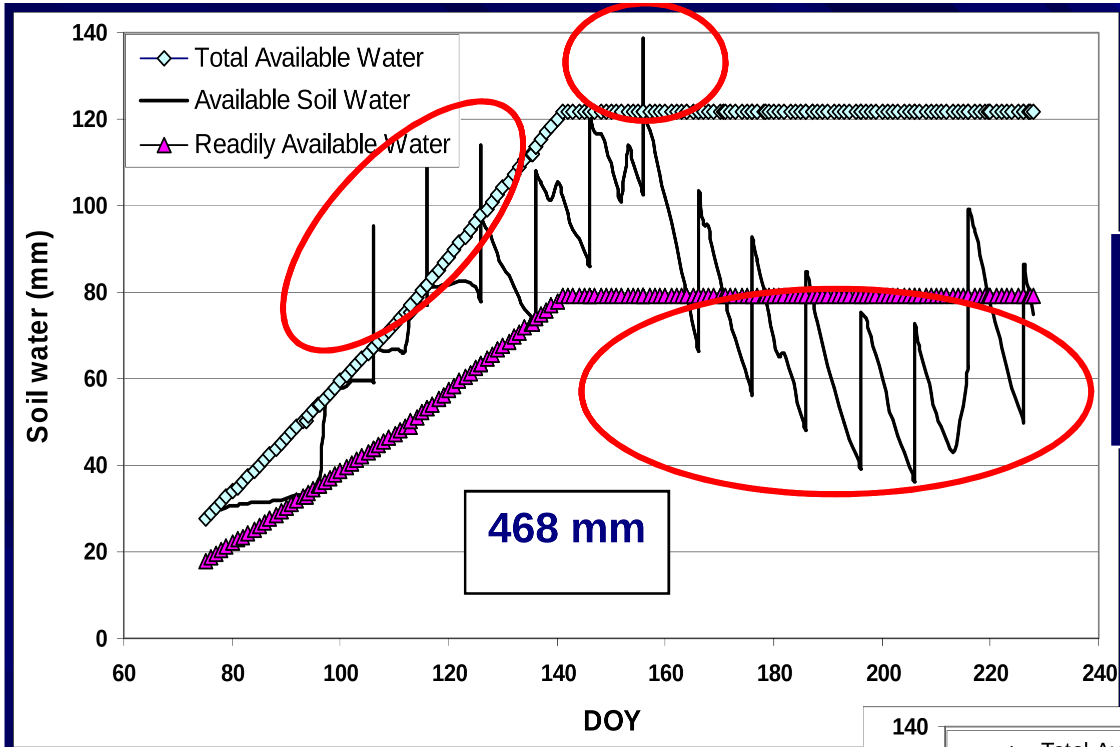


Winter salinity map (March 2006)

Summer salinity map (August 2006)



Spring-summer vegetables grown on sandy-loam soil



RDS – Fixed irrigation dates and volumes

(rotation = 10 gg, q = 20 l s^{-1} ha^{-1} , t = 5 hr)

Irrigation Volume = 36 mm/irrig.

Water excess = 93 mm

ETc_P – ETc_A = 74 mm

FDS – variable irrigation dates and volumes (rotation = 2-3 gg, Irr. Vol. = 20-25 mm/irrig.)

Water excess = 0 mm

ETc_P – ETc_A = 0 mm

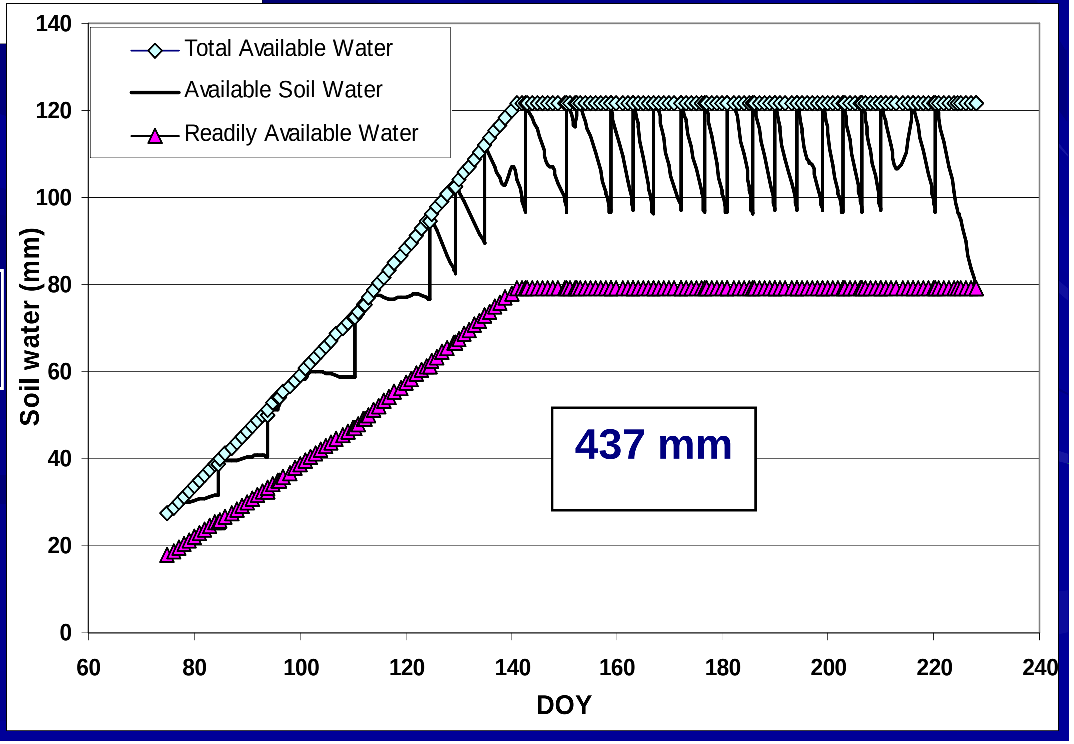
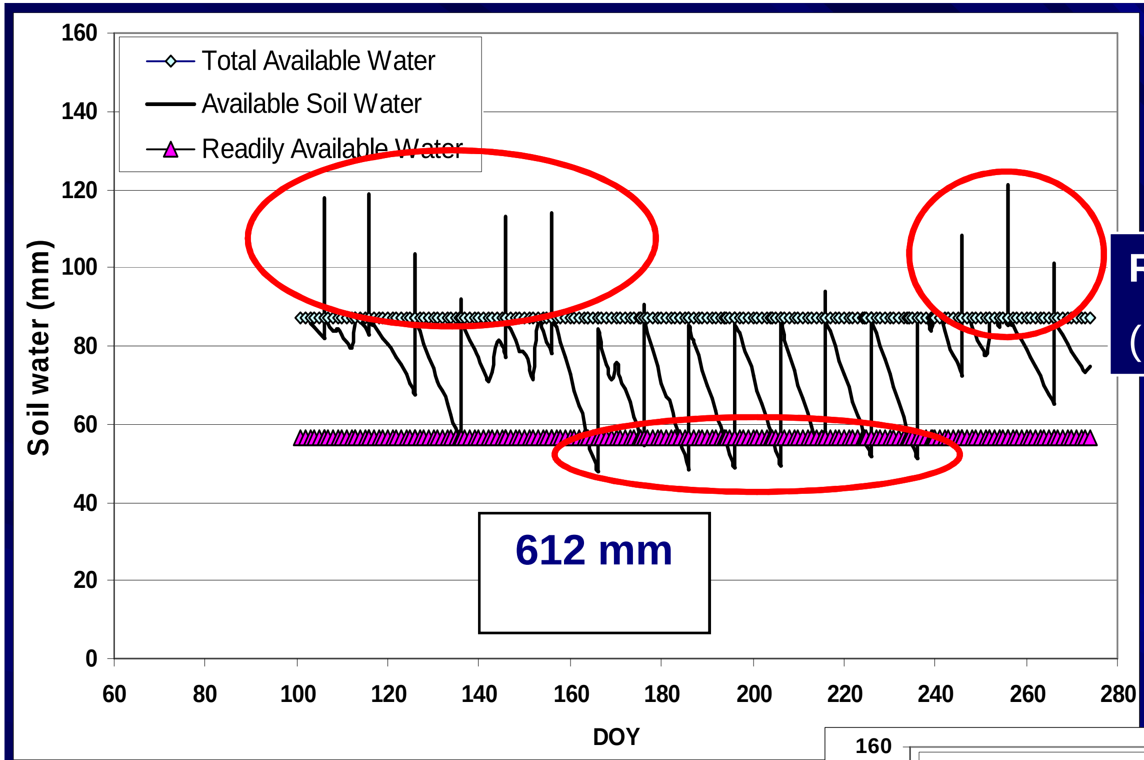


Table-grapes grown on loamy-sand soil



RDS – Fixed irrigation dates and volumes (rotation = 10 gg, q = 20 l s^{-1} ha^{-1} , t = 5 hr)

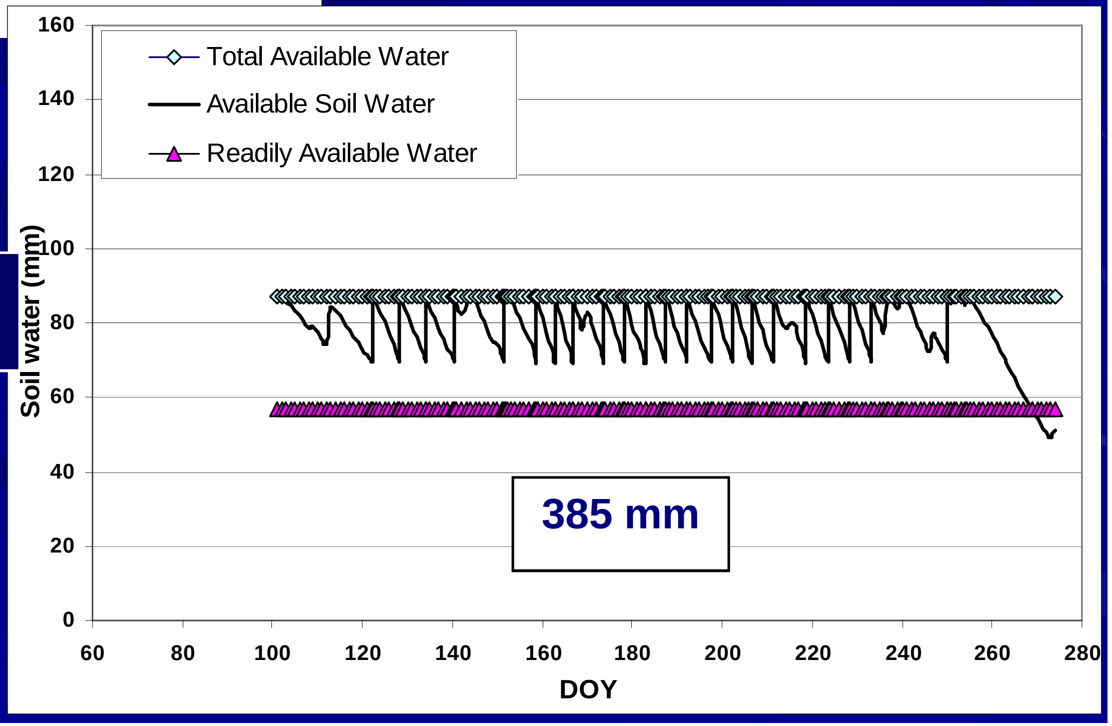
Water Excess = 227 mm

ETc_P – ETc_A = 4 mm

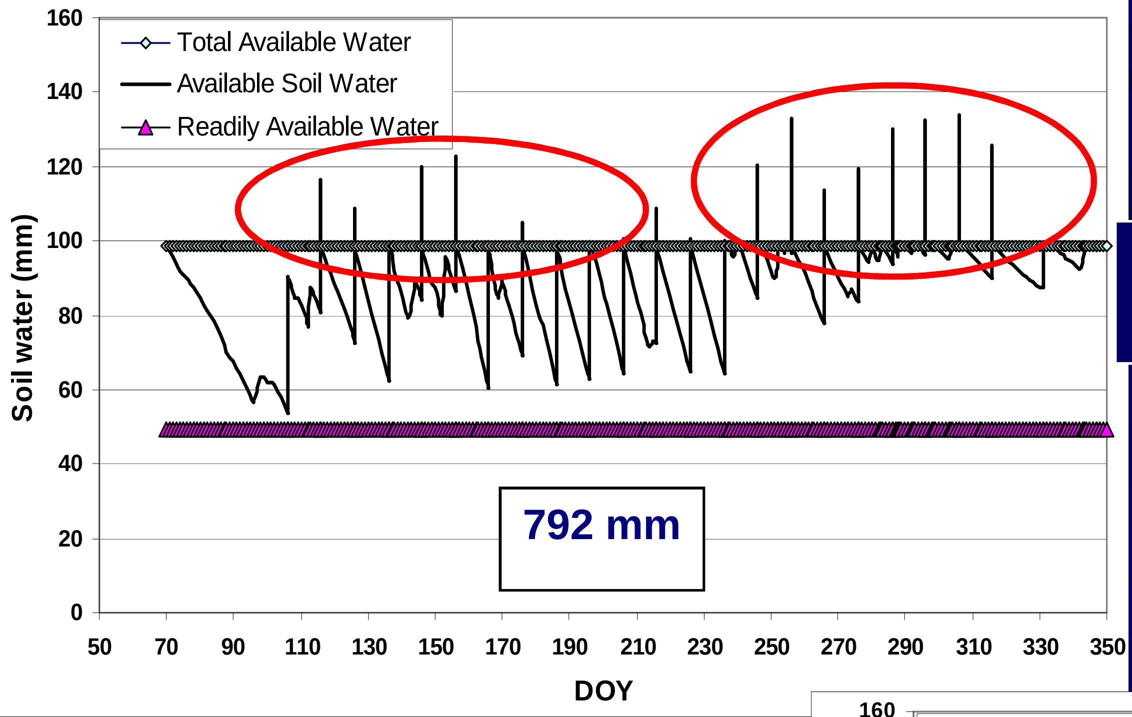
FDS – variable irrigation dates and volumes (rotation = 2-3 gg, Irr. Vol. = 20-25 mm/irrig.)

Water excess = 0 mm

ETc_P – ETc_A = 0 mm



Citrus grown on sandy-loam soil



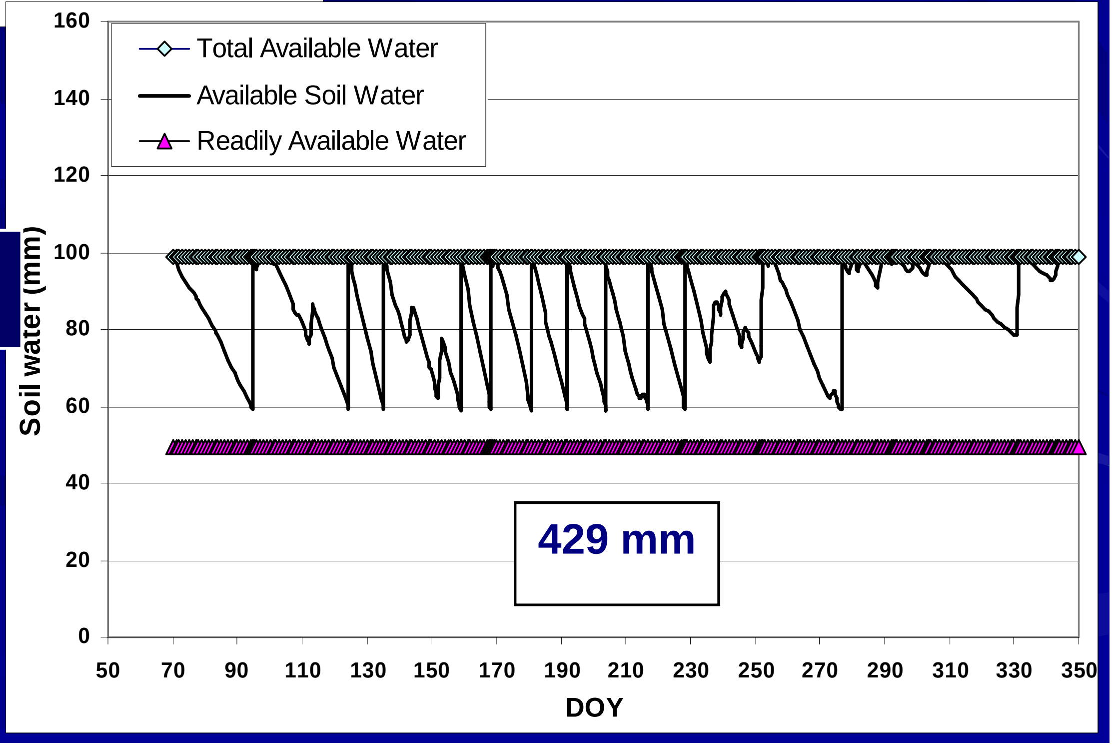
RDS – Fixed irrigation dates and volumes

(rotation = 10 gg, q = 20 l s^{-1} ha^{-1}, t = 5 hr)

Water Excess = 363 mm

$ETc_P - ETc_A$ = 0 mm

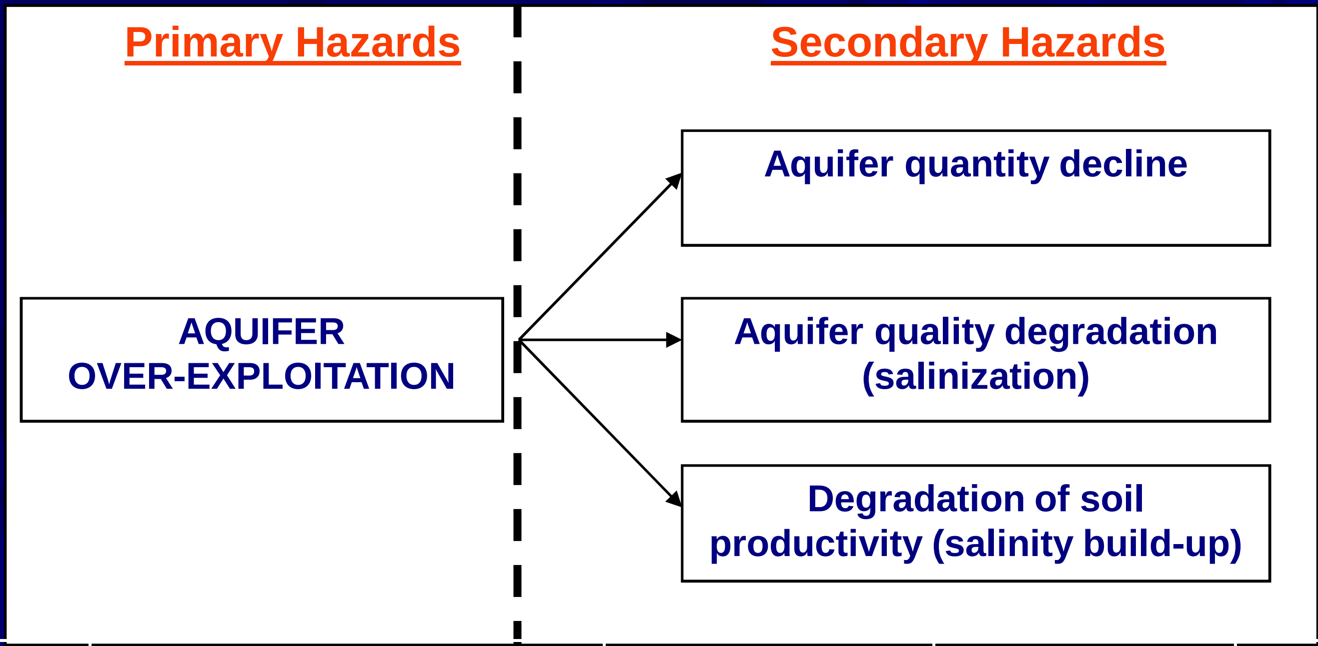
FDS – variable irrigation dates and volumes (rotation = 8-10 gg, Irr. Vol. = 35-40 mm)



Water excess = 0 mm

$ETc_P - ETc_A$ = 0 mm

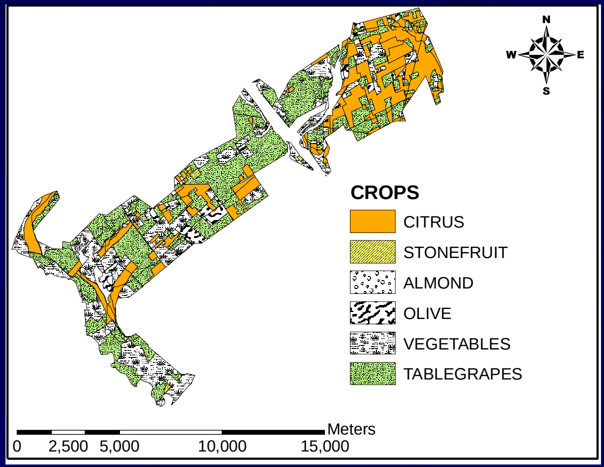
Hazards identification (primary and secondary)

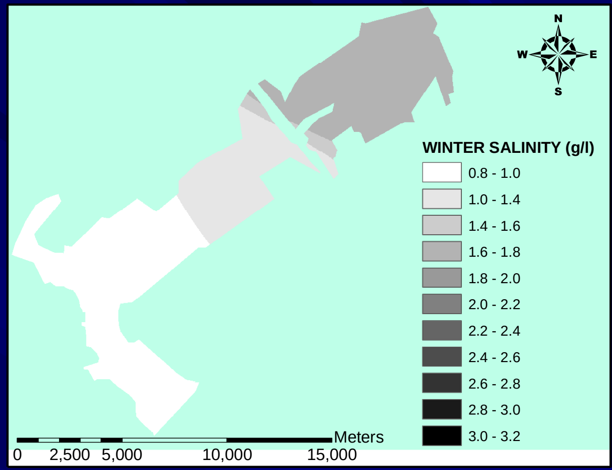


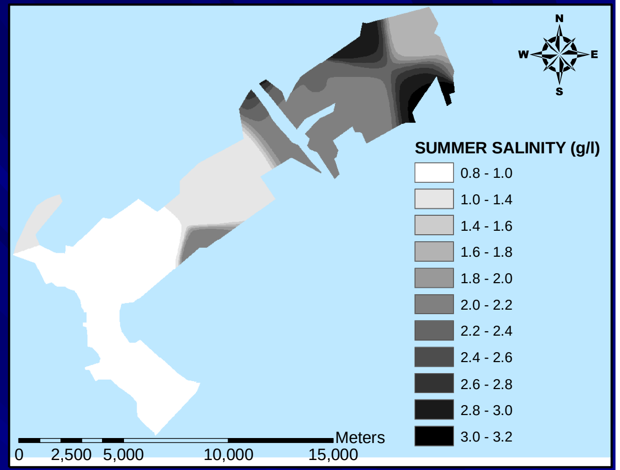
HAZARD	SOURCE	PATHWAY	RECEPTOR	IMPACT
H1 Aquifer over-exploitation during peak-demand periods	S1 – Intensive pumping by farmers during peak demand periods (July and August)	P1-Aquifer	R1- Aquifer	I1.1 - Aquifer quantity decline
				I1.2 – Aquifer quality degradation due to sea-water intrusion
	S2 – Poor water distribution through the irrigation networks	P2- water withdrawal from the aquifer and irrigation with groundwater	R2– agricultural soils irrigated with groundwater	I 2.1 – Salt build-up in cropped soil irrigated with groundwater

Identification of the risk-generating processes

1. Concentration of groundwater pumping during peak-demand periods (July and August)
2. Aquifer exploitation beyond the natural recovery capability (Overall seasonal volume withdrawn >> “Safe Yield”)
3. Reduced natural groundwater recharge of the aquifer (high-intensity and short duration rains during summer period)
4. Aquifer de-pressurization and development of sea-water intrusion cones, with breakage of the equilibrium between freshwater (aquifer) and sea-water
5. Irrigation with saline water (groundwater) and poor salt leaching







Estimated extension of the impacts

I1.1 Aquifer quantity decline: whole cropped area

I1.2 Aquifer salinization due to sea-water intrusion: estimated to be effecting the whole aquifer, given the isotropic diffusion of the sea-water into the aquifer.

I2.1 Salt build-up in cropped soils: it is assumed to be occurring throughout the whole cropped area (but with different intensities in the different areas)

Identification of controlling factors

The aquifer over-exploitation is affected by the following factors (over which some actions could be undertaken to reduce groundwater pumping)

Crop water requirements →

- Crops grown
- Climatic trends
- Soil characteristics
- Farming practices
- Irrigation practices
- Effective rainfall

Water delivery schedules by WUA →

- Available flowrate
- Irrigation demand
- Capacity of the network
- Network operation
- Management skills by the water authority

Identification of the controlling factors

Irrigation practices implemented →

- Crop management
- Production targets
- Crop sensitivity to water deficit
- Farmers' skills in crop water management

Natural aquifer recharge and salt leaching →

- Rainfall (intensity & distribution)
- Canopy cover
- Soil hydraulic properties
- Slope and topography

Magnitude of impacts

Magnitude of impacts was determined based on 3 criteria:

1. The spatial distribution of impacts
2. The duration of impacts over time
3. Time for on-set of impacts

Each criteria was then attributed a partial score ranging from 1 to 4.

For instance, in the case of ***the spatial distribution of impacts, the following scale was used***:

- Impact noticeable nowhere (0%): score = 0;
- Localized impact (< 5%): score = 1;
- Scattered impact (5-15%): score = 2;
- Highly scattered impact (15-50%): score = 3;
- Impact noticeable everywhere (> 50%): score = 4.

Magnitude of impacts

Hazard	Receptor	Impact	Spatial scale	Temporal scale	Time of onset to impact	Overall magnitude
H1 Aquifer over-exploitation	R1 Aquifer	I1.1.1 Aquifer depletion	Throughout (> 50%) **4**	Medium term (5-20 years) **2**	Medium (1-10 years) **3**	Moderate **24**
		I1.1.2 Salinization by sea-water intrusion	Throughout (> 50%) **4**	Medium term (5-20 years) **2**	Medium (1-10 years) **3**	Moderate **24**
	R2 Agricultural soils	I1.2.1 Salts build-up	Throughout (> 50%) **4**	Medium term (5-20 years) **2**	Immediate (0-1 year) **4**	Moderate **32**

The final magnitude of impacts was obtained by multiplying the partial scores attributed to the 3 criteria and then evaluated in a range of scores ranging between 0 and 64, classified as follows:

- **"negligible"** (score 0)
- **"low"** (score 1-22)
- **"moderate"** (score 23-43)
- **"serious"** (score 44-64)

Estimation of probabilities (of hazards and of their consequences)

The overall probability of hazards depends on 3 factors:

1. The probability of the hazard to occur
2. The probability of receptors (soil & aquifer) to be exposed to the hazard
3. The probability of occurrence of damages or degradations to receptors

For each criteria, the probability is assessed and classified in a scale from 0 (Negligible) to 3 (High).

		H1	
Probability of hazard occurring	receptor independent	High (3)	
Probability of receptors being exposed	R1	High (3)	
	R2	High (3)	
Probability of harm occurring to receptor	R1	High (3)	
	R2	High (3)	
Overall probability		**H1.R1=27 (high)**	**H1.R2=27 (high)**

The overall probability is calculated by multiplying the partial scores attributed to each criteria and by classifying the resulting score as follows:

- Negligible (score ~ 0)
- Low (score = 1-9)
- Medium (score = 10-18)
- High (score 19-27)

Overall relevance of the Risk

Risk = [Probability * Magnitude]

The overall risk relevance is evaluated considering both ***Magnitude*** and ***Probability*** of the consequences to occur, by means of a 2-way matrix

Increasing Acceptability →	Magnitude of consequences/impacts			
	Severe	Moderate	Mild	Negligible
Probability				
High	high	high	medium/low	near zero
Medium	high	medium	low	near zero
Low	high/medium	medium/low	low	near zero
Negligible	high/medium/low	medium/low	low	near zero

Overall risk relevance

For the 3 analyzed impacts, the estimated risk relevance is reported in the following table

Risk	Risk relevance
Aquifer quantity decline (H1.R1.I1.1)	Moderate x High = **High**
Aquifer salinization due to sea-water intrusion (H1.R1.I1.2)	Moderate x High = **High**
Salt build-up in agricultural soils (H1.R2.I1.2)	Moderate x High = **High**

Appraisal of Alternative Management Options

The evaluation of the options for managing the 3 risks was based on the following criteria:

1. Timeliness (time for generating results)
2. Social acceptability
3. Technical feasibility
4. Effectiveness in reducing the risk
5. Duration of results
6. Cost required for implementing the option

Qualitative judgments were thus attributed to the different options for each of the above criteria.

The MCA analysis was then conducted for ranking the alternative management options, on the basis of these judgments and of the weight of each single evaluation criteria.

Risk N. 1. Quantitative aquifer depletion

Risk 1 **Aquifer depletion**	**Timing** Instant result to progressive	**Social acceptability** (-- to ++)	**Feasibility** (-- to ++)	**Effectiveness in risk alleviation** (-- to ++)	**Duration**	**Cost** Low to high
Business as usual (zero option)	Never - -	Acceptable +	Very feasible ++	Very ineffective - -	Never - -	Very affordable ++
Limit water pumping from Groundwater	Immediate +	Unacceptable -	Feasible +	Very effective ++	Short term -	Unaffordable -
Improved rotation in water delivery	Medium +/-	Acceptable +	Feasible +	Effective +	Medium term +/-	Very affordable ++
Decrease water tariffs by WUO to compensate for pumping costs	Long term -	Very Acceptable ++	Feasible +	Effective +	Short term -	Unaffordable _
Water delivery on-demand	Medium +/-	Acceptable +	Feasible +	Very Effective ++	Medium term +/-	Affordable +

<u>Best management option resulting from the MCA</u>:

Network operation with a better rotation delivery schedule, *allowing to supply water to farmers in a way so as to match irrigation requirements (especially in terms of timing of irrigation delivery)*

This requires an accurate estimation of the irrigation requirements of the different districts for the different periods of the irrigation season, and the enforcement of an effective irrigation advisory service to farmers

Risk N. 2. Salinization of aquifer due to sea-water intrusion

Risk II Aquifer salinization	Timing Short term to permanent solution	Social acceptability (-- to ++)	Feasibility (-- to ++)	Effectiveness in risk alleviation (-- to ++)	Duration Instant result to progressive	Cost Low to high
Business as usual (zero option)	Never - -	Acceptable +	Very feasible ++	Very ineffective - -	Never - -	Very affordable ++
Stop groundwater pumping	Medium +/-	Very unacceptable - -	Feasible +	Very effective ++	Medium +/-	Unaffordable -
Limit groundwater pumping to safe yield of aquifer	Medium +/-	Unacceptable -	Feasible +	Effective +	Medium +/-	Unaffordable -
Rotation irrigation delivery + conjunctive use	Medium +/-	Acceptable +/-	Feasible +	Effective +	Medium +/-	Affordable +
Irrigation delivery on-demand	Medium +/-	Acceptable +	Feasible +	Effective +	Medium +/-	Affordable +
Artificial aquifer recharge	Immediate ++	Neither unacceptable nor acceptable +/-	Feasible +	Very effective ++	Medium +/-	Affrodable +

Best management option resulting from the MCA :

Artificial recharge of the aquifer in conjunction with reduction of groundwater pumping to a maximum limit (safe yield), so as to reduce the pressure exerted over the aquifer during the peak months of the irrigation season and restore the balance between freshwater and sea water

Also these measures would require an effective monitoring and control by the management body

Risk N. 3. Sal build-up in agricultural soils

Risk III **Salts build-up in the agricultural soils**	**Timing** Instant result to progressive	**Social acceptability** (-- to ++)	**Feasibility** (-- to ++)	**Effectiveness in risk alleviation** (-- to ++)	**Duration**	**Cost** Low to high
Business as usual (zero option)	Never - -	Acceptable +	Very feasible ++	Very ineffective - -	Never - -	Very affordable ++
Improved rotation delivery	Long term -	Acceptable ++	Very feasible ++	Effective +	Medium Term +	Affordable +
Improved rotation delivery + conjunctive use	Medium +/-	Very acceptable ++	Feasible +	Effective +	Medium Term +	Affordable +
Irrigation delivery on-demand	Medium +/-	Very acceptable ++	Feasible +	Very effective ++	Long term ++	Affordable +
Improved on-farm irrigation practices (leaching)	Medium +/-	Neither unacceptable nor acceptable +/-	Feasible +	Very effective ++	Long term +	Very affordable ++
On-demand delivery + leaching	Immediate +	Acceptable +	Feasible +	Very effective ++	Long term +	Affordable +

Best management option resulting from the MCA :

Irrigation delivery on-demand in conjunction with salt leaching at farm level.

The irrigation delivery on-demand requires modernization of the distribution network, as well as the irrigation advisory service to farmers for adequate crop irrigation management and for improved salt balance in the soils.

Conclusions

Selecting the best absolute option for managing the 3 risks at once may require to consider conflicting objectives for the different stake-holders:

- **Farmers**, have only interest getting good water whenever they need and in mitigating the risk of salt build-up in their soils
- ***The planners and decision-makers*** of the area would pursue more general objectives, such as reduction of aquifer quantity decline and of aquifer salinization

Aknowledgements:

- “Stornara & Tara” Water Users Association - Taranto
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THANKS FOR YOUR ATTENTION!