The integrated water management approach for water saving at different scales: modelling techniques and practical solutions

Ragab R., Hamdy A.

in

Hamdy A. (ed.), El Gamal F. (ed.), Lamaddalena N. (ed.), Bogliotti C. (ed.), Guelloubi R. (ed.).
Non-conventional water use: WASAMED project

Bari : CIHEAM / EU DG Research
Options Méditerranéennes : Série B. Etudes et Recherches; n. 53

2005
pages 149-157

THE INTEGRATED WATER MANAGEMENT APPROACH FOR WATER SAVING AT DIFFERENT SCALES: MODELLING TECHNIQUES AND PRACTICAL SOLUTIONS

R. Ragab* and A. Hamdy**
* Centre for Ecology and Hydrology, CEH, Wallingford, OX10 8BB, UK. E-mail: Rag@ceh.ac.uk
** Director of Research, CIHEAM – Istituto Agronomico Mediterraneo di Bari,
9 Via Ceglie, 70010 Valenzano (BA), Italy. E-mail: hamdy@iamb.it

1. INTRODUCTION

1.1. Overview of Past and Current Climate and Water Resources

Over the last century there has been a decrease in rainfall throughout the Mediterranean region. In summer, rainfall is now 20% less than at the end of the 19th century. In Tangiers, rainfall has dropped by 100 mm in 40 years and at Ifrane, in the Moyen-Atlas Mountain in Morocco, Such changes create uncertainty. Are long term average of rainfall or river flow any longer valid as a basis for planning water resources use? The Greek hydrologists were forced to reconsider their estimates of average flows in the 220 km River Acheloos, the country's longest river and scheduled for a major diversion project to irrigate fields (Pearce, 1996). Fig. 1 illustrates the rainfall decreasing pattern over Cyprus of the last Century. The data show that a reduction of 100 mm i.e 1 mm/year has taken place.

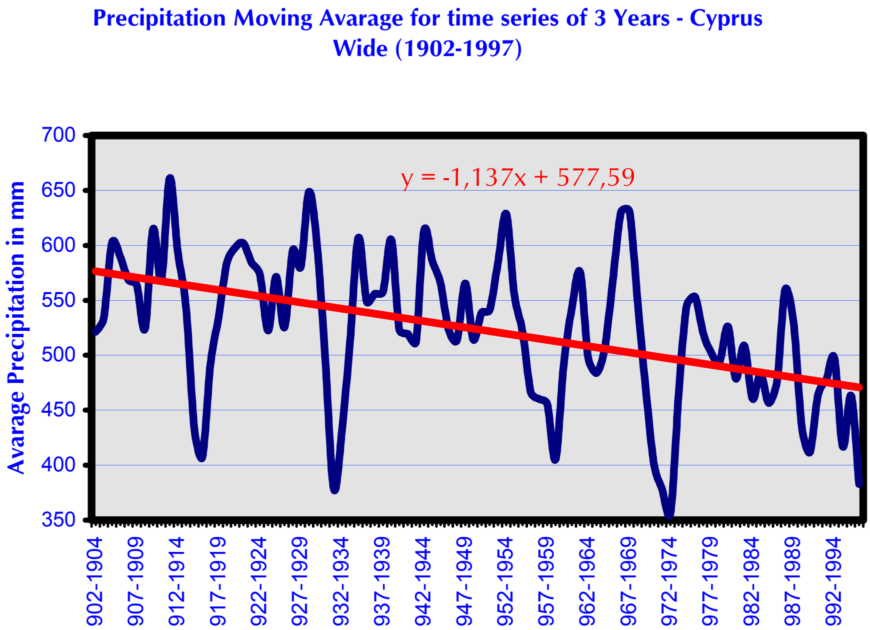


Figure1. Precipitation time series over Cyprus over the past century

According to Dragovic and Maksimovic, 2002, drought occurs occasionally in a single year or in a series of years over Yugoslavia. In some years (e.g., 1928, 1951, 1990, 2000) drought not only reduced the yields of some crops but it practically turned whole agricultural regions into a desert. In addition to precipitation amount and distribution, high temperatures, *i.e.*, the number of tropical days with maximum temperature over 30°C, can be used to define the intensity and consequences of drought. In eastern Yugoslavia, there were 31 tropical days per year on average for the period 1967 – 1996, (Fig. 2). The figure shows that this number of tropical days has been on the increase between 1976 and 1996.

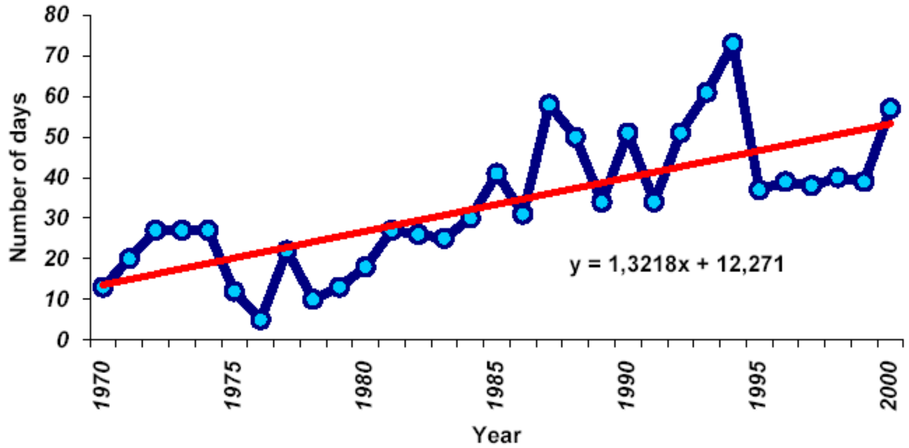


Figure 2. Number of tropical days (max. temperatures over 30°C) in Zajecar (Dragovic and Maksimovic, 2002)

Fig. 1 and 2 show clearly we have a world that is getting drier and warmer. In addition, the Mediterranean region and the Middle East seem to have already the lowest mean annual precipitation and internal renewable water resources as shown in Fig. 3 and 4 respectively.

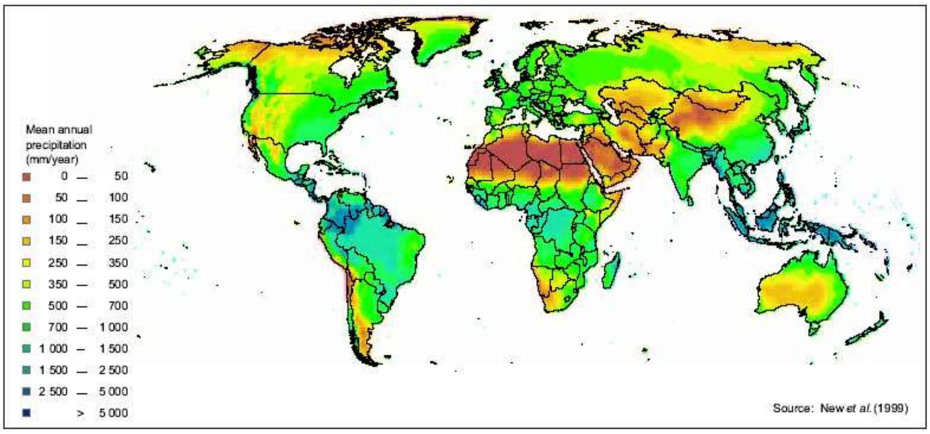


Figure 3. World map of mean annual precipitation, 1961–1990 (FAO, 2003)

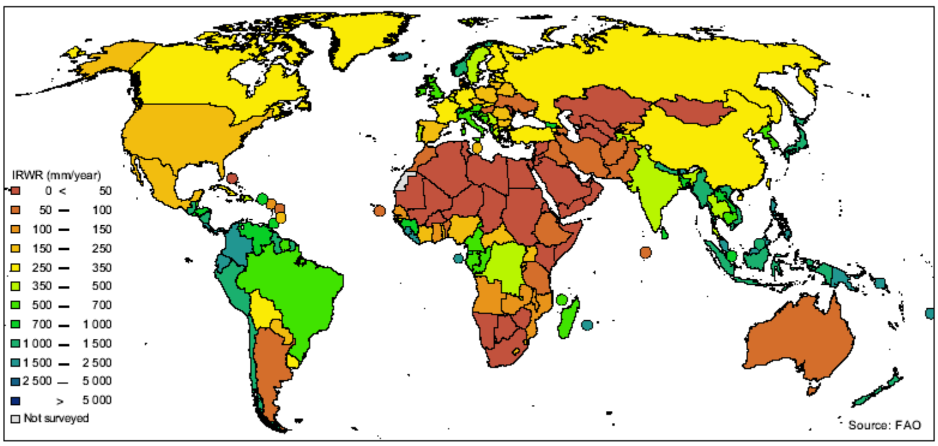


Figure 4. World map of internal renewable water resources (IRWR), per country (FAO, 2003)

The total renewable water resources (internal + external) for Africa and the Near East as well as the dependence of each country on external sources are shown in Fig. 5a and 5b. The figures show that some countries like Egypt, Sudan, Syria, Iraq, Mauritania depend largely on external waters flowing from other countries. The consequences is, any drought in source countries will be felt at the receiving end. Table 1 illustrate the wide gap between the water rich and the water poor countries. The Middle East and most of the Mediterranean countries belong to the latter which latter which could make them more vulnerable to any drought event.

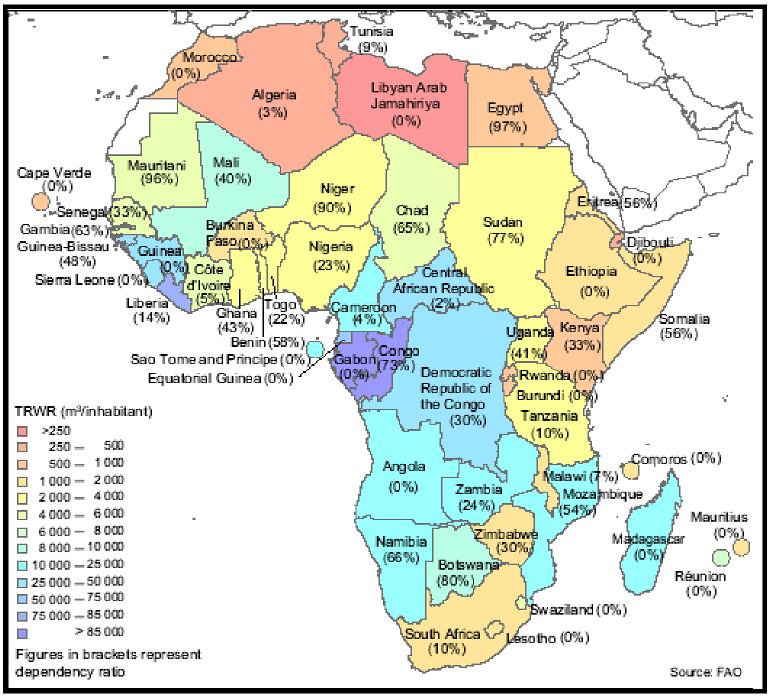


Figure 5a. Water resources in the Africa region, total renewable water resources (TRWR) and dependency Ratio (FAO, 2003)

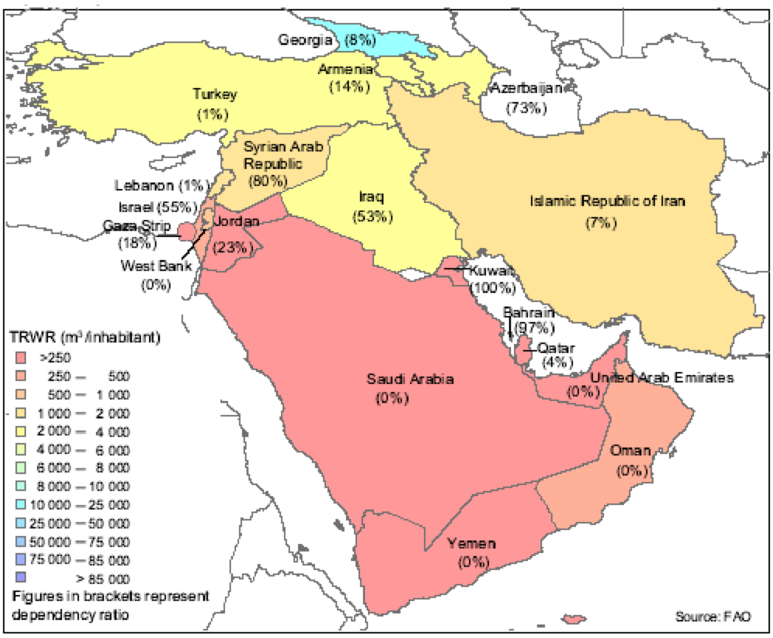


Figure 5b. Water resources in the Near East region, total renewable water resources (TRWR) and dependency ratio,(FAO, 2003)

Table 1. Water resources in the water rich and water poor countries (FAO, 2003)

FAO Code	Country	Average precipitation 1961-1990 (km^3/year)	Internal resources: surface (km^3/year)	Internal resources: groundwater (km^3/year)	Internal resources: overlap (km^3/year)	Internal resources: total (km^3/year)	External resources: natural (km^3/year)	External resources: actual (km^3/year)	Total resources: natural (km^3/year)	Total resources: actual (km^3/year)	IRWR/inhab. (m^3/year)
21	Brazil	15236	5418	1874	1874	5418	2815	2815	8233	8233	31795
185	Russian Federation	7855	4037	788	512	4313	195	195	4507	4507	29642
33	Canada	5352	2840	370	360	2850	52	52	2902	2902	92662
101	Indonesia	5147	2793	455	410	2838	0	0	2838	2838	13381
41	China, Mainland	5995	2712	829	728	2812	17	17	2830	2830	2245
44	Colombia	2975	2112	510	510	2112	20	20	2132	2132	50160
213	United States of America (Cont.)	5800	1862	1300	1162	2000	71	71	2071	2071	7153
170	Peru	1919	1616	303	303	1616	297	297	1913	1913	62973
100	India	3559	1222	419	380	1261	647	636	1908	1897	1249

Water Rich countries

FAO Code	Country	Average precipitation 1961-1990 (km^3/year)	Internal resources: surface (km^3/year)	Internal resources: groundwater (km^3/year)	Internal resources: overlap (km^3/year)	Internal resources: total (km^3/year)	External resources: natural (km^3/year)	External resources: actual (km^3/year)	Total resources: natural (km^3/year)	Total resources: actual (km^3/year)
105	Israel	9.16	0.25	0.50	0.00	0.75	0.92	0.92	1.67	1.67
112	Jordan	9.93	0.40	0.50	0.22	0.68	0.20	0.20	0.88	0.88
124	Libyan Arab Jamahiriya	98.53	0.20	0.50	0.10	0.60	0.00	0.00	0.60	0.60
136	Mauritania	94.66	0.10	0.30	0.00	0.40	11.00	11.00	11.40	11.40
35	Cape Verde	1.70	0.18	0.12	0.00	0.30	0.00	0.00	0.30	0.30
72	Djibouti	5.12	0.30	0.02	0.02	0.30	0.00	0.00	0.30	0.30
225	United Arab Emirates	6.53	0.15	0.12	0.12	0.15	0.00	0.00	0.15	0.15
179	Qatar	0.81	0.00	0.05	0.00	0.05	0.00	0.00	0.05	0.05
134	Malta	0.12	0.00	0.05	0.00	0.05	0.00	0.00	0.05	0.05
76	Gaza Strip (Palestinian Authority)	0.00	0.00	0.05	0.00	0.05	0.01	0.01	0.06	0.06
13	Bahrain	0.06	0.00	0.00	0.00	0.00	0.11	0.11	0.12	0.12
118	Kuwait	2.16	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02

Water poor countries

Water resources regions	Water resources subregions	Total area (km^2) (FAOSTAT, 1999)	Total population (inh.) (FAOSTAT, 2000)	Internal resources: total (km^3/year)	External resources: actual (km^3/year)		Total resources: actual (4) (km^3/year)	% of internal water resources of the region	IRWR/inhab. (m^3/year)	TRWR (actual/Inhab.) (m^3/year)
7 Near East	Arabian Peninsula	3003230	46958000	7.7	0.0	(1)	7.7	1.58	163.8	163.8
	Caucasus	186100	17090000	75.3	18.4	(2)	93.7	15.44	4407.0	5483.7
	Middle East	3158640	193066000	404.7	3.2	(3)	407.9	82.98	2096.3	2112.6
	Near East	6347970	257114000	487.7	3.2		490.9	100.00	1897.0	1909.2
	World	133845436	6052577900	43764.3	0.0		43764.3		7230.7	7230.7
	Near East as % of world	4.7	4.2	1.1			1.1			

Notes

(1) No external resources.
(2) From Middle East (Turkey, Islamic Republic of Iran) subregion.
(3) From Central Europe (Bulgaria) region.

Transboundary or border river	Riparian countries tied by a treaty	Other riparian countries not tied by the treaty
Arax	Turkey, Armenia and Azerbaijan	Islamic Republic of Iran

1.2. Agriculture and Water Use

In the Mediterranean region nearly 70% of the available water resources are allocated to agriculture. (Hamdy and Lacirignola, 1997). In the arid and semi-arid countries of the region agricultural water use accounts for as much as 80% of the water consumed, decreasing to 50% of the total available resources in the Northern countries (Fig. 6).

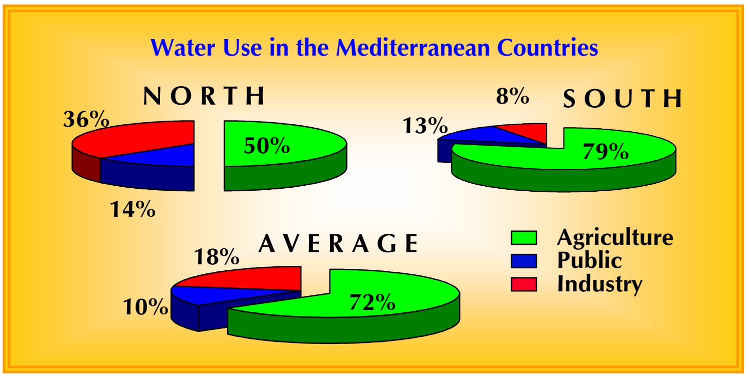


Figure 6. Water use per sector in the Mediterranean (Hamdy and Lacirignola, 1997)

Diminishing water resources in the eastern and southern Mediterranean are expected to be one of the main factors limiting agricultural development, particularly in the 2000 – 2025 period. The water needed for irrigation is even scarcer than the land itself and land suitable for irrigation is becoming harder to find. At present, the irrigated areas account for more than 16 million hectares.

Despite the high priority and massive resources invested, the performance of large public irrigation systems has fallen short of expectations in both the developing and developed countries of the Mediterranean. Crop yield and efficiency in water use are typically less than originally projected and less than reasonably achieved. In addition, the mismanaged irrigation project schemes lead to the deterioration of some of the best and most productive soils. Salinity now seriously affects productivity in the majority of the southern Mediterranean countries as well as in the coastal zones. Salt affected soils in the region amount to nearly 15% of the irrigated lands.

Given the increased costs of new irrigation developments, together with the scarcity of land and water resources, future emphasis will be more on making efficient use of water for irrigation and less on indiscriminate expansion of the irrigated area.

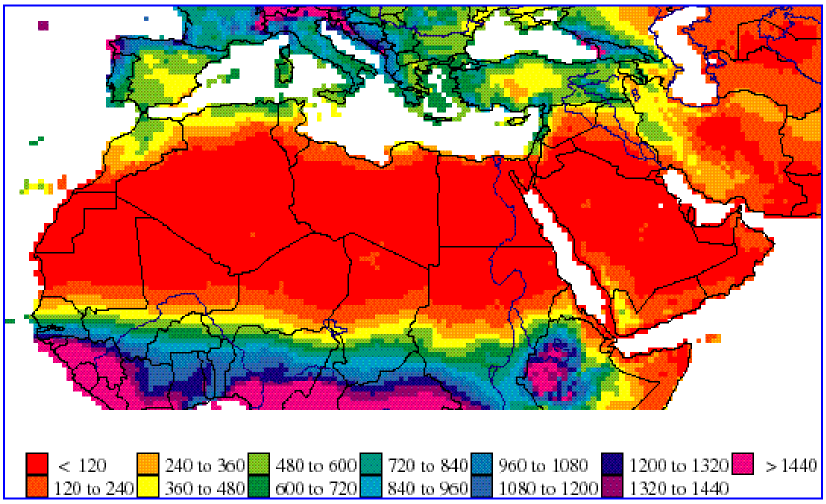
Over the next twenty five years, substantial amounts of fresh water supplies will be diverted from agriculture to industry and households in the region. Irrigated agriculture will face two challenges: water scarcity and dwindling financial resources. Despite these challenges, irrigated agriculture is expected to provide 70 to 75 percent of the additional food grain requirements to the developing countries of the region. This will not be possible without developing effective methodologies and systems for assessing and improving the performance of irrigated agriculture. Such systems have to evaluate the contribution and impact of an irrigation scheme in terms of production, self-reliance, employment, poverty alleviation, financial viability, farmers' profitability and environmental sustainability.

1.3. What the Future Holds for the Mediterranean and Middle East Countries?

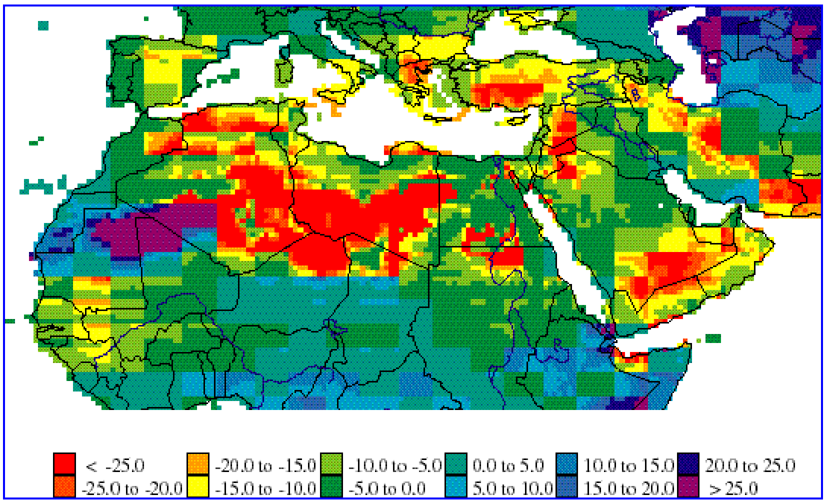
The UK Hadley Centre's global climate model has been run to study the possible future climate change. The model comprises several layers into the atmosphere and below soil surface and accounts for most of the essential/dominant hydrological processes. The model runs at spatial scale of $2.5° \times 3.75°$ grid squares for rainfall predictions and $0.5° \times 0.5°$ grid squares for temperature, (Viner and Hulme. 1997). Version two (HadCM2) of this model accounts only for CO_2 impact (does not account for the aerosols impact). All the scenarios are for the time horizon 2050. They are expressed as percentage change (rainfall) or temperature change compared to the CRU climatology corresponding to the baseline period of 1961-1990 (New *et al.* 1999). The model has been run on monthly basis to predict the % change in Rainfall with respect to mean monthly values. The model was run for the dry (April-September) and wet (October – March) periods. The annual figures which combines both dry and wet periods are shown as Fig. 7 and 8, (Ragab and Christel Prudhomme. 2002).

Fig. 7a, shows the basic annual precipitation based on 1961-1990 data while Fig. 7b shows percent (%) changes in annual precipitation for the year of 2050 according to the HadCM2 Scenario-GHGX. Fig. 8a, shows the basic annual temperature based on 1961-1990 data while Fig. 8b shows the changes in annual temperature in °C For the year of 2050 according to the HadCM2 Scenario-GHGX.

In dry period (April-September), the results showed that by the year 2050 North Africa and some parts of Egypt, Saudi Arabia, Iran, Syria, and Jordan are expected to have a reduced rainfall amounts to 20 to 25% less than the present mean values. This decrease in rainfall is accompanied by temperature rise in those areas between 2°C and 2.75°C. For the same period, the temperature in the coastal areas of the south Mediterranean and Middle East countries will rise by about 1.5°C. In winter time (October - March), the results showed that the rainfall will decrease by about 10% to 15% while, the temperature in the coastal areas will increase by only 1.5°C on average and inside the region by 1.75°C to 2.5. The decrease in rainfall during summer time has great impact on both irrigation and tourism as both activities take place in summer time and require more water supplies.

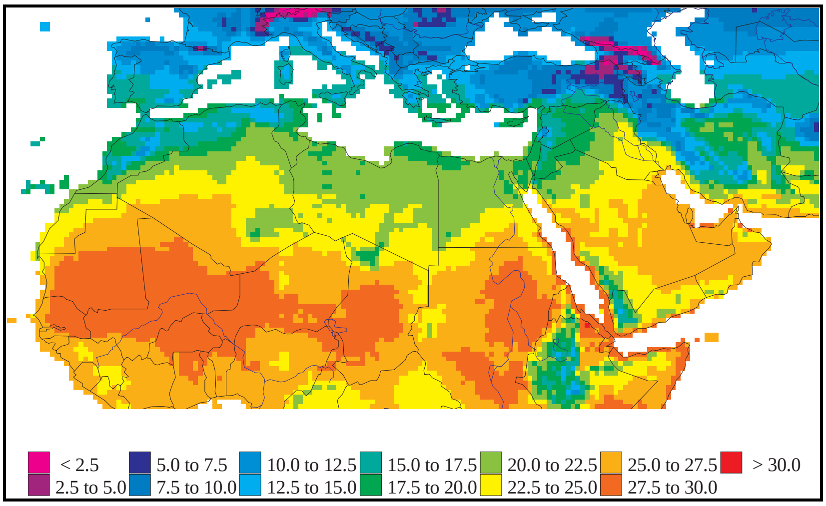


a

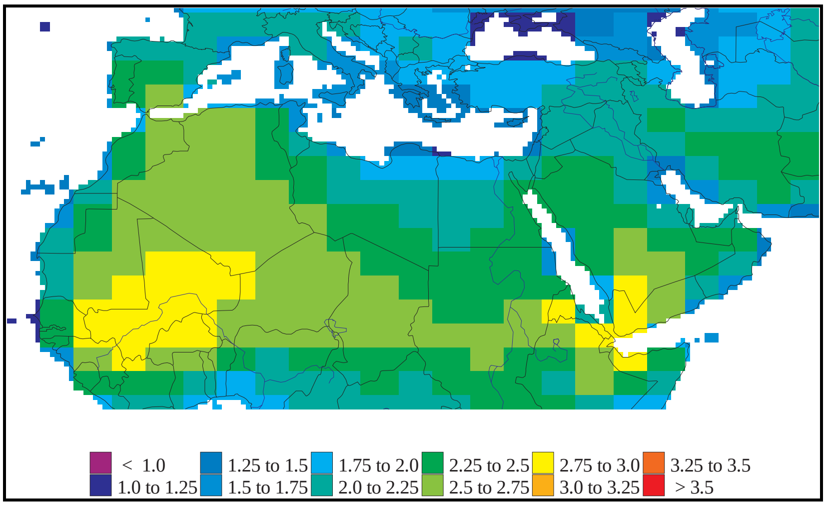


b

Figure 7. a, Basic annual precipitation based on 1961-1990 data and b, percent (%) Changes in annual precipitation for the year of 2050 according to the HadCM2 Scenario-GHGX (Ragab, and Christel Prudhomme, 2002)



a: Basic annual temperature



b: Annual temperature 2050

Figure 8. a, Basic annual temperature based on 1961-1990 data and b, changes in annual temperature °C For the year of 2050 according to the HadCM2 Scenario-GHGX (Ragab and Christel Prudhomme, 2002)

1.4. Expected Future Increase in Water Demand

The water demand is expected to increase by almost 50% by the 2025, (Fig. 9). After agriculture, industry is the second major user of water in the region. Nearly one fifth of total freshwater withdrawals is allocated to the industry development in the region. However, there are notable differences in water consumption in industrial sectors among countries of the region.

Generally, in the developed industrialized countries, the water allocated for industry represents nearly 37% of the whole water use; four-fold greater than that of developing countries which is as low as 8 %. Fig. 10 shows that some Mediterranean countries such as Turkey, Syria, Lebanon, and Cyprus which were water stress free in the 90’s will be water stressed by the year 2050.

The Mediterranean Region: Water Demand in 1990 and Foreseen Demand for the years 2010 and 2025 *[in km³/year]*

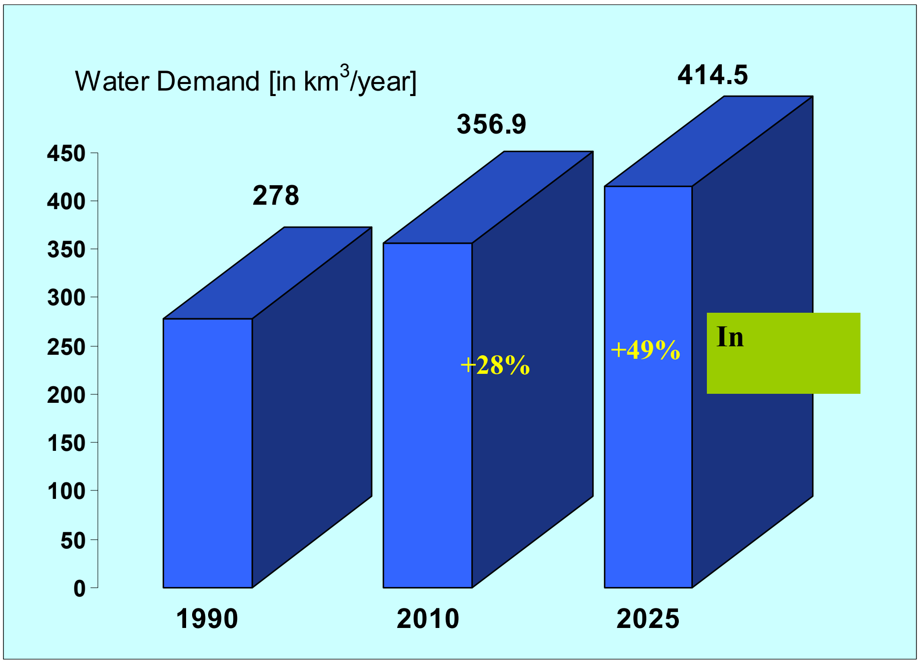


Figure 9. The increase in the water demand of the Mediterranean region with respect to 1990

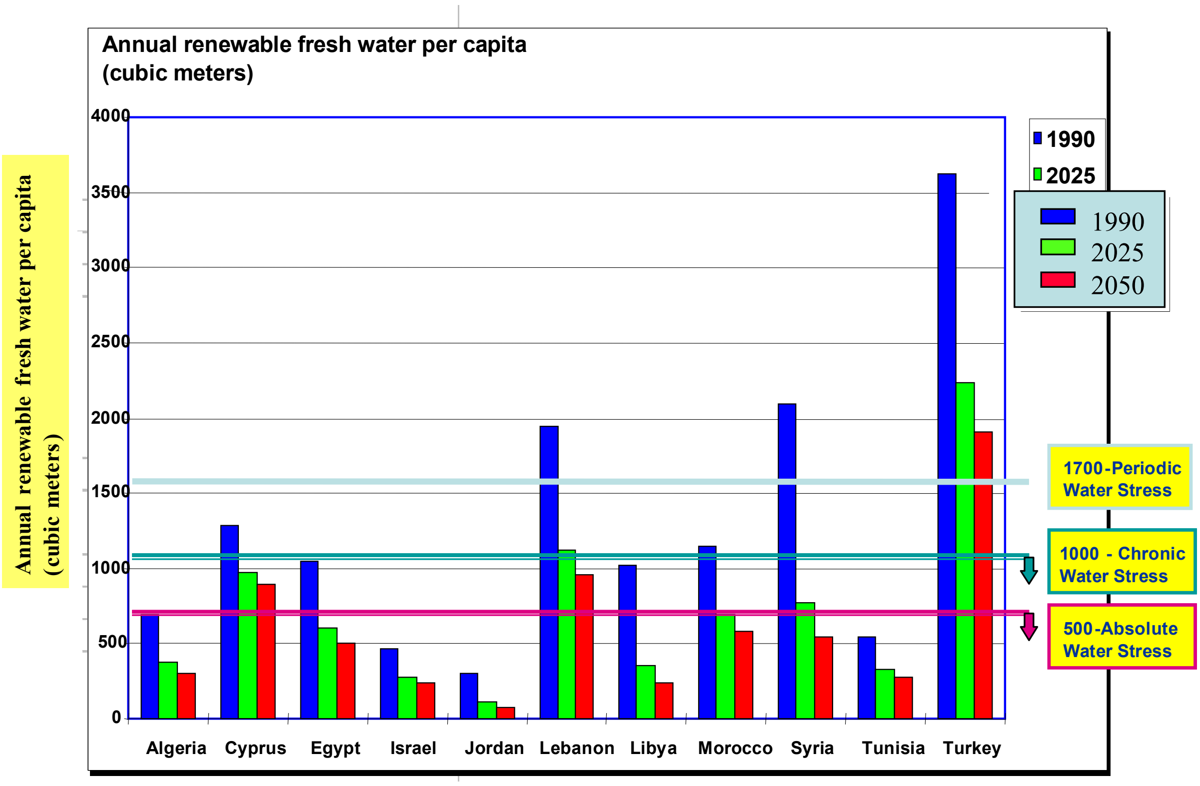


Figure 10. Renewable fresh water availability 1990-2050 for the Mediterranean Region

1.5. Possible Saving in Fresh Water Resources in Different Sectors

Fresh water can be used more efficiently in the different sectors of the society. For example:

- Drinking water sector

At least one third of the volume of water produced and distributed as drinking water in towns and villages leaks out through the network or is wasted by misuse, thus, huge sums of money are wasted each year on producing and supplying water that is not used.

- Industry sector

Many industries use volumes of water that by far exceed their needs, lowering its quality. Here again there are defects in recycling, leakage, loss and inefficient production processes.

- Irrigation sector

Almost one half of the volume of water supplied for irrigation through systems is not actually used in the field. FAO stated that water drawn and pumped for irrigation can be wasted in a proportion up to 60%. The actual losses in the irrigation sector are nearly 115 km^3/year which correspond to nearly 88% of the total water losses.

2. APPROACHES TO SOLVE THE IMBALANCE BETWEEN SUPPLY AND DEMAND

2.1. The Integrated Water Supply and Demand Management

In order to meet the water demands in the next century, some dams and water infrastructure will be built in some countries and a new paradigm by rethinking the water use with the aim of increasing the productive use of water will have to be adopted. Two approaches are needed:

1) Increasing efficiency with which current needs are met and increasing the efficiency with which water is allocated among different uses.
2) In addition, non-conventional sources of water supply such as reclaimed wastewater, recycled water and desalinated brackish water or seawater is expected to play an important role. A more successful water management would require integration of supply and demand management. In principal the integration should account for the supply (surface, ground water and non-conventional water resources) and the demand (domestic, agriculture, industry, hydropower, creation, etc.) as shown in Fig. 11. A comprehensive integration between natural resources and human resources is crucial for a successful water and land resources Management. strictly manage the demand for that precious resources, preserve and augment the supply or more preferably to combine the previous two options in an integrated management plane aiming ultimately towards sustainable development; effective water saving programmes and strategies in all water uses sectors and, particularly, the agriculture; increasing water productivity; the re-use and recycling of non-conventional water sources as additional ones. Fig. 12 shows the principals of the comprehensive integration between natural resources and human resources.

Integrated Water Resources Management (IWRM) is an alternate approach. Moving from fragmented sectoral water management to a holistic integrated management approach (Hamdy *et al.,* 2003).

Reallocation of irrigation water supply to lower water consuming and high value crops, use of marginal quality water, wastewater recycling and use, wastewater recycling and use, conjunctive use of surface and groundwater resources, increasing water productivity, how can water productivity be improved in agriculture –the largest water user? more crop per drop, reducing non-beneficial evaporation and flows to sinks, pollution control controlling pollution can increase the amount of water available for reuse by: reducing flows through saline soils or through saline groundwater to reduce mobilisation of salts into irrigation return flows; shunting saline or otherwise polluted water directly to a sink and avoiding the need to dilute it with freshwater; utilising a basin-wide irrigation strategy that controls reuse of return flows; reducing pollution entering irrigation water supplies through return flows of municipal and industrial users; reducing pollutants originating from rainfed and irrigated agriculture.

Integrating water resources management through*:* promotion of conservation and improvement in sectoral allotments, investigation of resource utilization and water audits, institutional support, preparation of a national water conservation strategy including water law and water pricing, preparation of plans for decentralization and turnover.

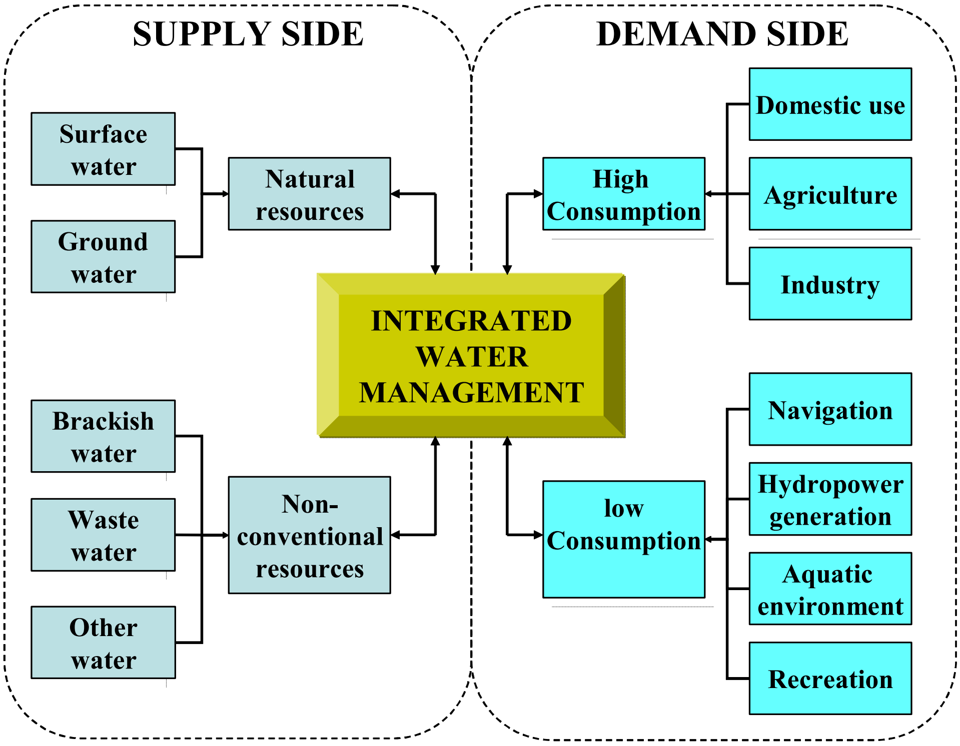


Figure 11. The water management approach based on integration of water demand and supply

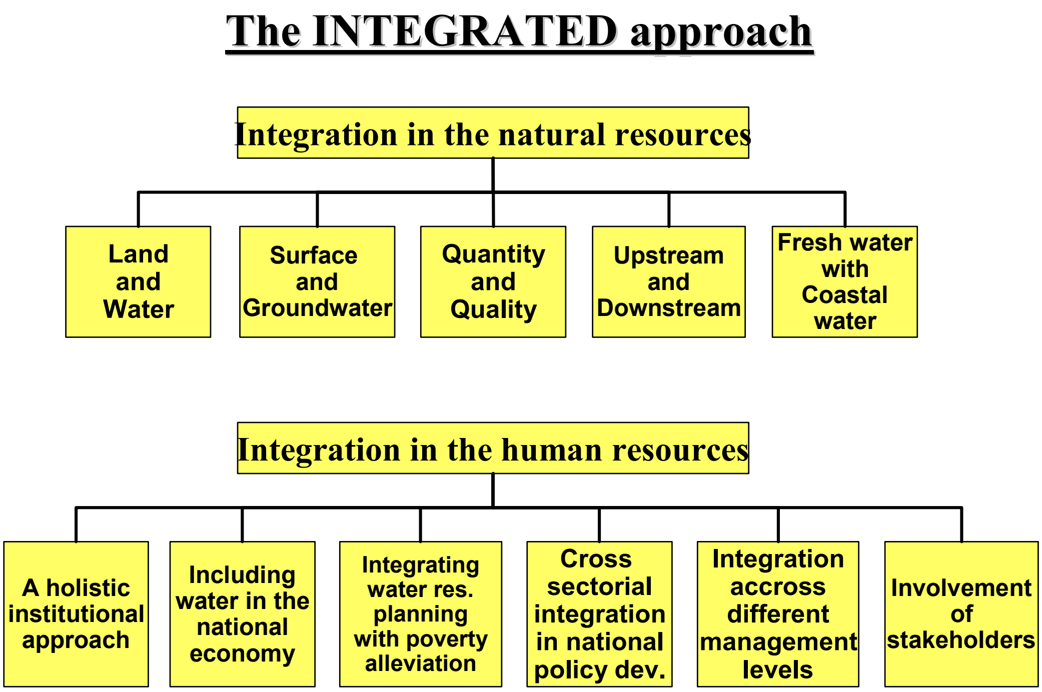


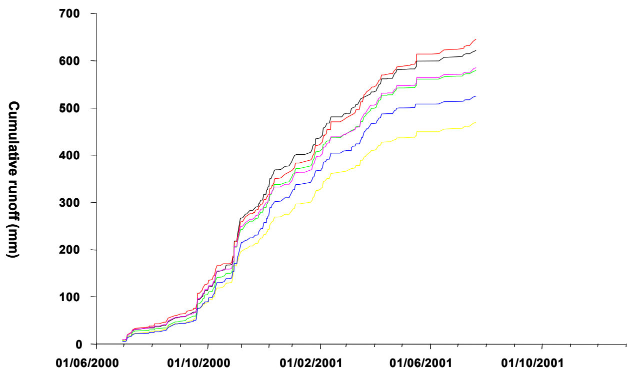
Figure 12. The water management approach based on integration of natural and human resources

3. EXAMPLES AND STUDY CASES FOR WATER SUPPLY AND DEMAND MANAGEMENT

3.1. Water Saving in Residential Areas: Rainfall Harvesting from House Roofs

This resource could be significant. In an urban hydrology study in Wallingford, UK (Ragab *et al.,* 2003a,b), it was found that depending on the slope of the roof and the aspect with respect to the prevailing wind direction, houses can catch up to 90% of the rainfall. As shown in Table 2 and Fig. 13, the amount of runoff collected is sufficient to supply an average household with its annual indoor and outdoor water requirements (i.e.WCs flush, urinals (for schools, organizations etc.), washing machines, car washing and watering gardens). The use of this water not only represents a financial gain for house owners but also will help protecting our environment through reducing demand on water resources (i.e. over abstraction of groundwater) and the need for new or large supply reservoirs as well as reducing the flood risk as its *in situ* use is considered a preventive measure known as a source control.

a



b

Figure 13. a: Increasing water supply and reducing the demand on fresh water by harvesting rainfall from house roofs for domestic use & b: amount of rainfall harvested over house roofs

Table 2. Rainfall harvested over house roofs in a residential area near Wallingford, UK

Site	JB	GP	AJ	IT	HA	CEH	Met Site
Measurement Period				29th June 2000 to 30th June 2001			
				Litres			
Rainfall	25634.2	24454.4	44682.4	14267.6	22612.5	54688.8	N/A
Runoff	19317.7	21658.8	29773.3	14392.4	15939.3	33626.3	N/A
Evaporation	6332.0	2795.6	14909.1	2102.3	6673.2	21094.0	N/A
				Millimetres			
Rainfall	806.9	704.3	851.0	509.1	809.6	741.7	818.1
Runoff	608.1	623.8	566.5	513.5	570.7	456.1	N/A
Evaporation	199.3	95.7	284.5	286.1	75.0	238.9	540.6*
Mean value of runoff/rainfall ratio	0.711	0.856	0.610	0.905	0.667	0.581	

3.2. Water Saving in Rural Areas: Rainfall Harvesting into Mountain Reservoirs

Rainfall harvesting in coastal areas of the Mediterranean region is very essential practice to meet the growing demand on fresh water. Farmers in the region have applied several techniques to harvest rainfall water. One of the common methods in this region is to harvest water in small lakes /reservoirs as shown in Fig. 14. Subsequently, water is pumped out at a given rate to irrigate the surrounding farms around the lake. Examples of these lakes exist in Morocco, Algeria, Tunisia, Egypt, Syria and Lebanon. Quantifying this amount is essential for planning and management of the water resources. As the cost of digging and creation of reservoirs are quite high, the HYDROMED model has been proved to be a useful tool to help design the reservoirs to a ceratin storage capacity (Fig. 15) and predict the runoff volume as shown in Fig. 16. More details can be found in Ragab *et al.* (2002 a, b, c) as well as in the following web site: http://www.nerc-wallingford.ac.uk/research/cairoworkshop. The HYDROMED Model can also be downloaded free from the web site.

Figure 14. Example for rainfall harvest into mountain lakes/reservoirs, Tunisia

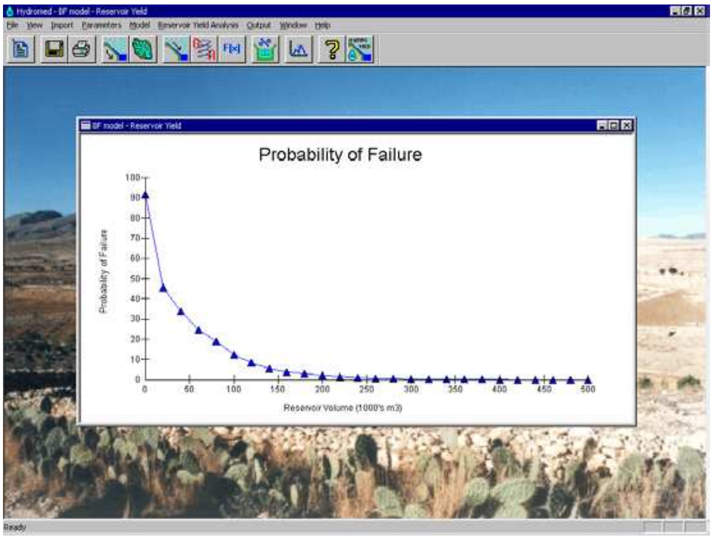


Figure 15. Reservoir storage capacity using the HYDROMED model

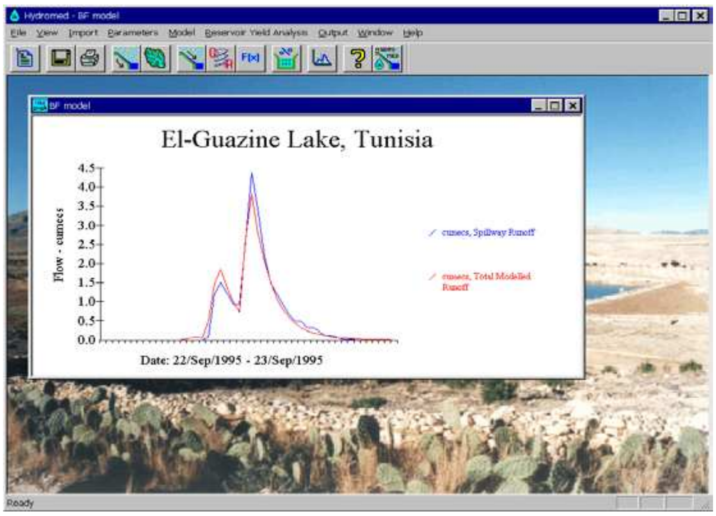


Figure 16. Prediction of runoff volume to reservoir using the HYDROMED model

3.3. Water Saving by Using Saline/Brackish Water for Irrigation

Semi-arid regions frequently suffer from years of below-average rainfall and severe drought. Studies and field practices by farmers in many regions of the world have shown that water normally classified as too saline for conventional agricultural use can in fact be used to irrigate a wide variety of annual and perennial crops. Plants (trees, crops, fodder, halophytes, etc.) of moderate to high salt tolerance can be irrigated with saline water especially at later growth stages.

Saline water could be used to irrigate salt tolerant crops under a proper management system, (Ragab *et al*., 2001). SALTMED EU funded project was carried out in a number of Mediterranean countries. Saline water up to 9 dS/m was used to irrigate tomato crop. SALTMED model (Ragab, 2002) was developed to predict yield, salinity and soil moisture profile, leaching requirements and water uptake. Fig. 17 shows the experimental fields of tomato irrigated with saline water in Egypt and Syria. The model input data are shown in Fig. 18 to 22. These are Meteorological, irrigation, crop, soil data and initial values of soil moisture and salinity respectively.

The SALTMED model outputs are shown in Fig. 24 to 29. They are 2-dimensional soil moisture distribution, 2-dimensional soil salinity distribution, soil moisture profiles, soil salinity profiles, evapotranspiration, leaching requirements and crop yield respectively. More about SALTMED model document, test results using five seasons' field experiments data of Egypt and Syria, free downloading the SALTMED software and Guidelines on the use of saline water can be found at the following web site: http://www.nerc-wallingford.ac.uk/research/cairoworkshop.

Figure 17. Using saline/brackish water to grow crops reduces the demand on fresh water

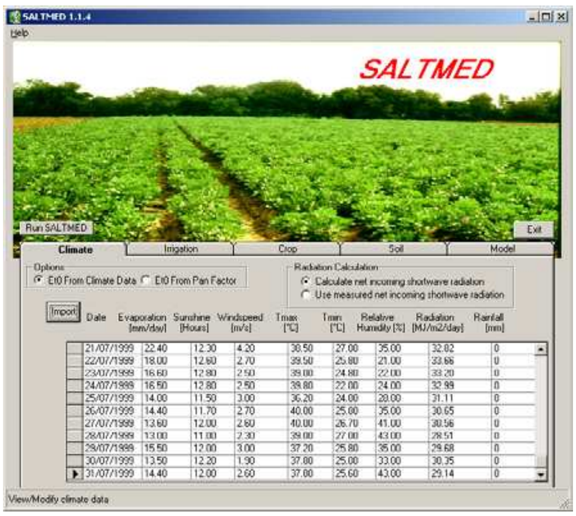


Figure 18. Example of the meteorological data input file

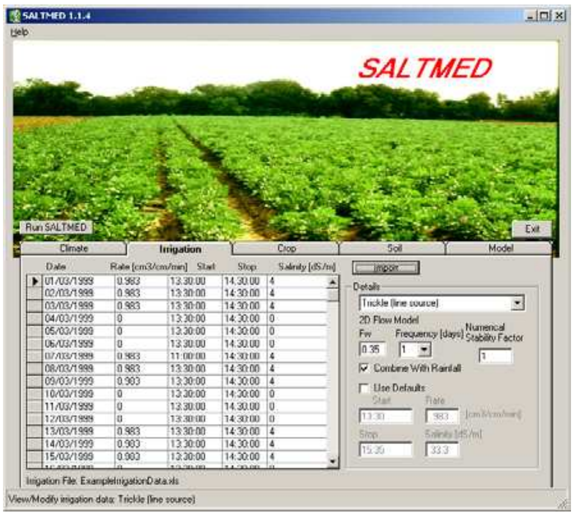


Figure 19. Example of the irrigation data input file

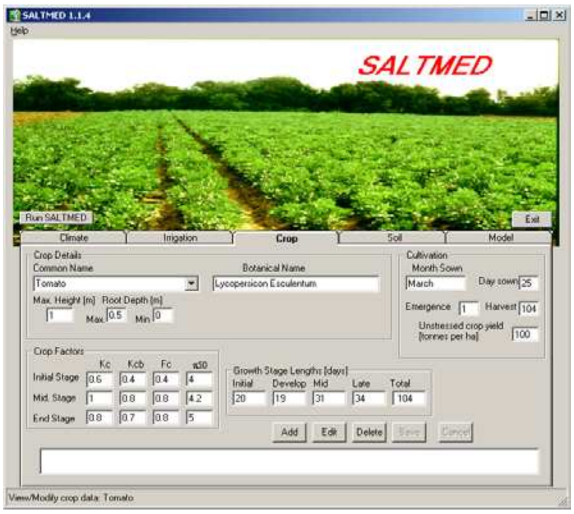


Figure20. Example of the crop parameters input menu

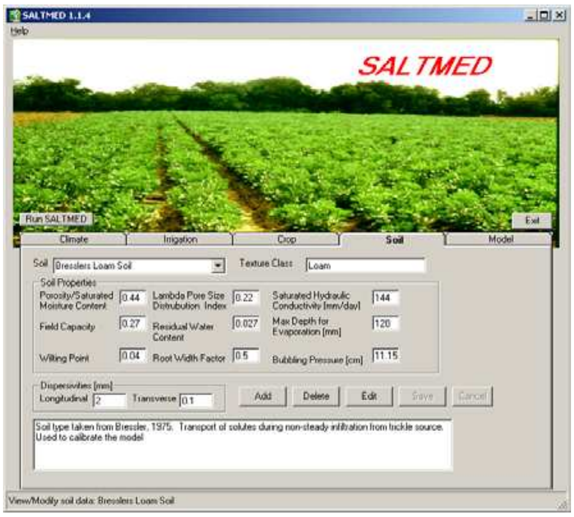


Figure 21. Example of the soil parameters input menu

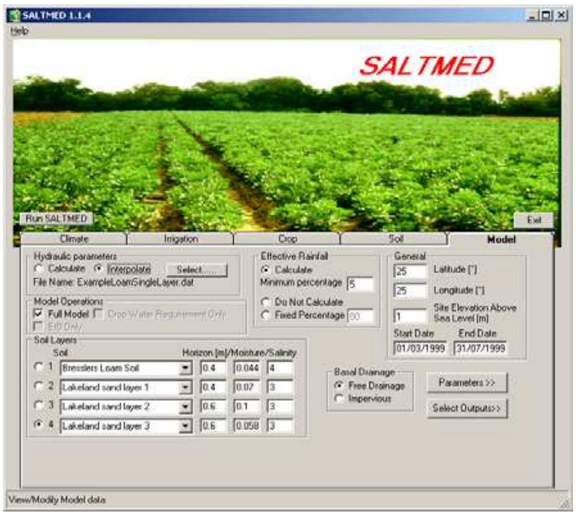


Figure 22.The soil input data file, run, drainage and effective rainfall options

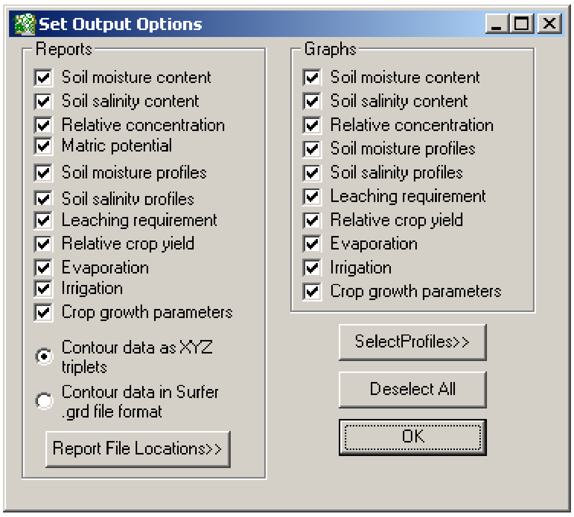


Figure 23. The output option menu

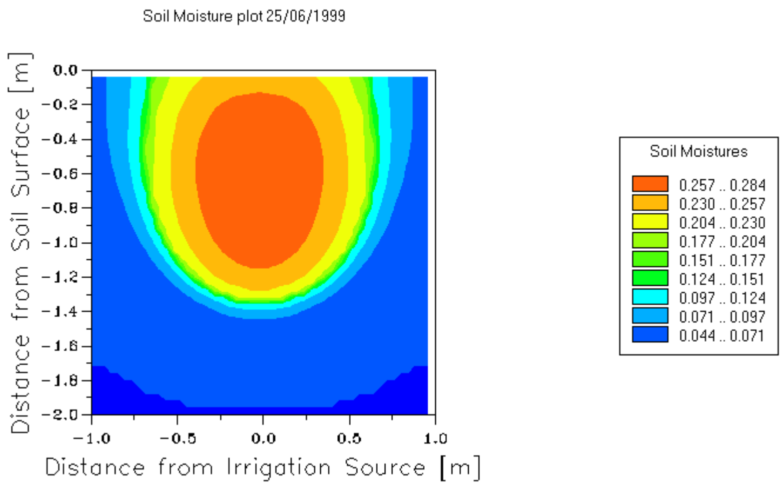


Figure 24. Example of evolution of soil moisture profile over time under trickle line source

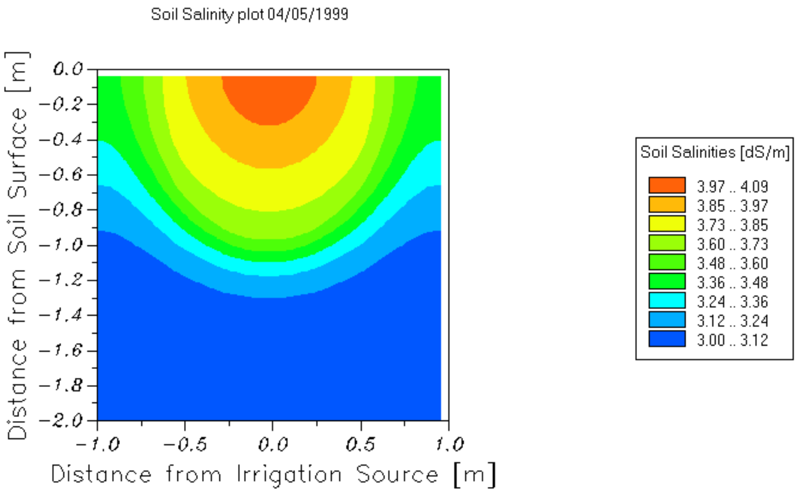


Figure 25. Example of evolution of soil salinity profile over time under trickle line source

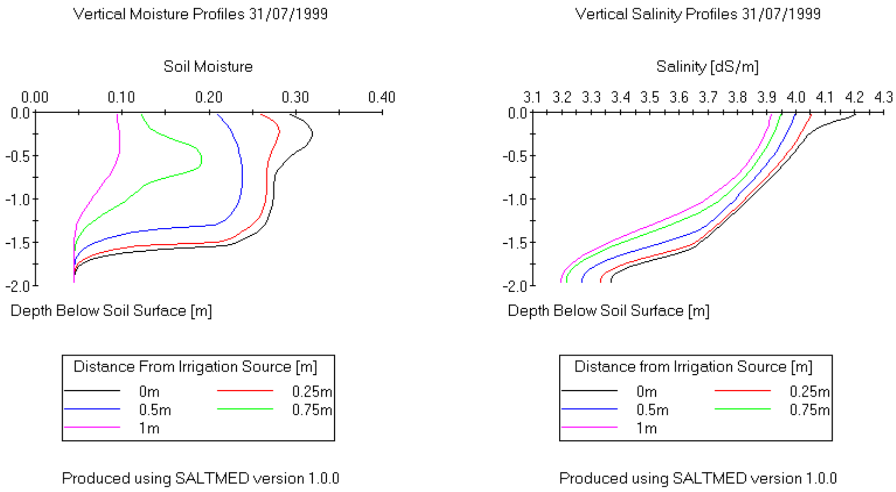


Figure 26. Example of distribution of moisture and salinity under trickle line source

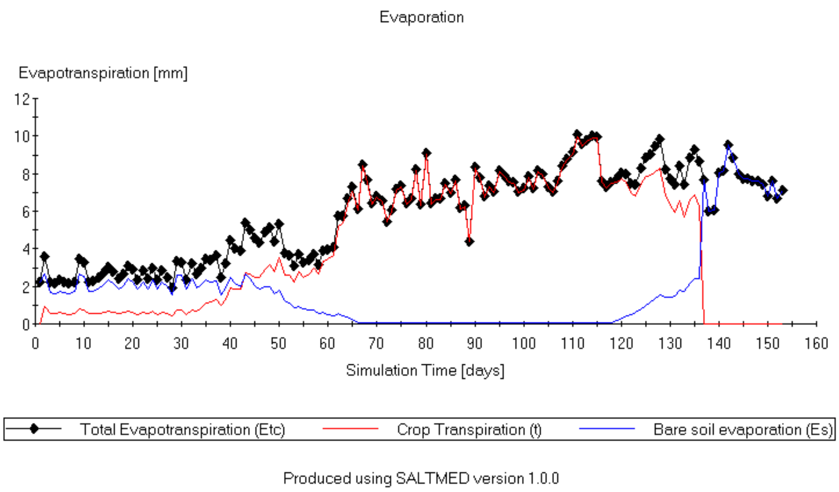


Figure 27. Example of evolution of total crop evapotranspiration, transpiration and bare soil evaporation

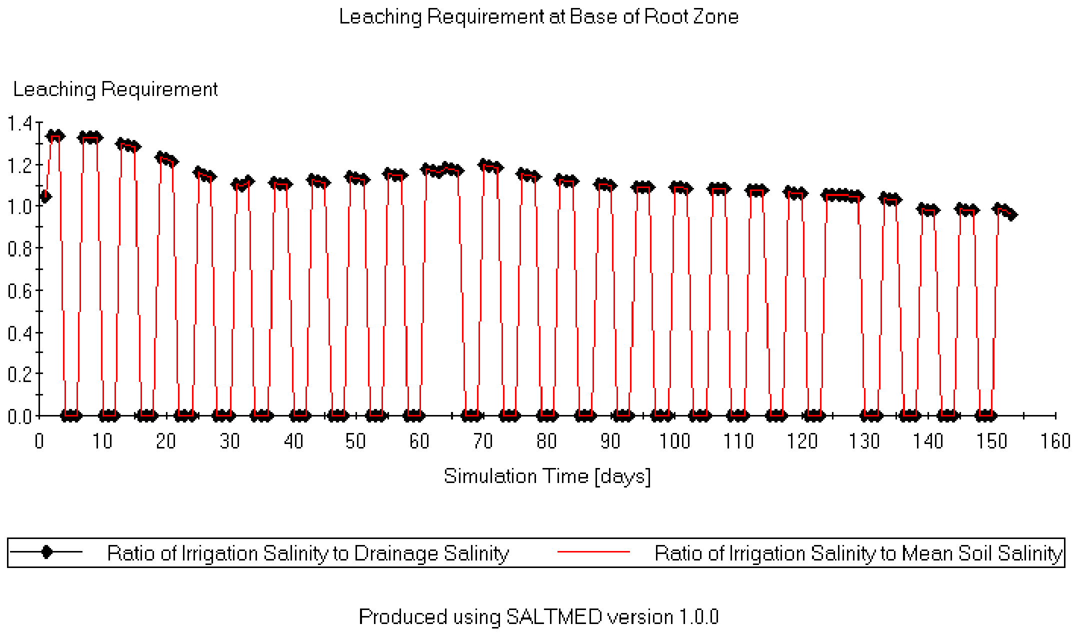


Figure 28. Example of the leaching requirement over time

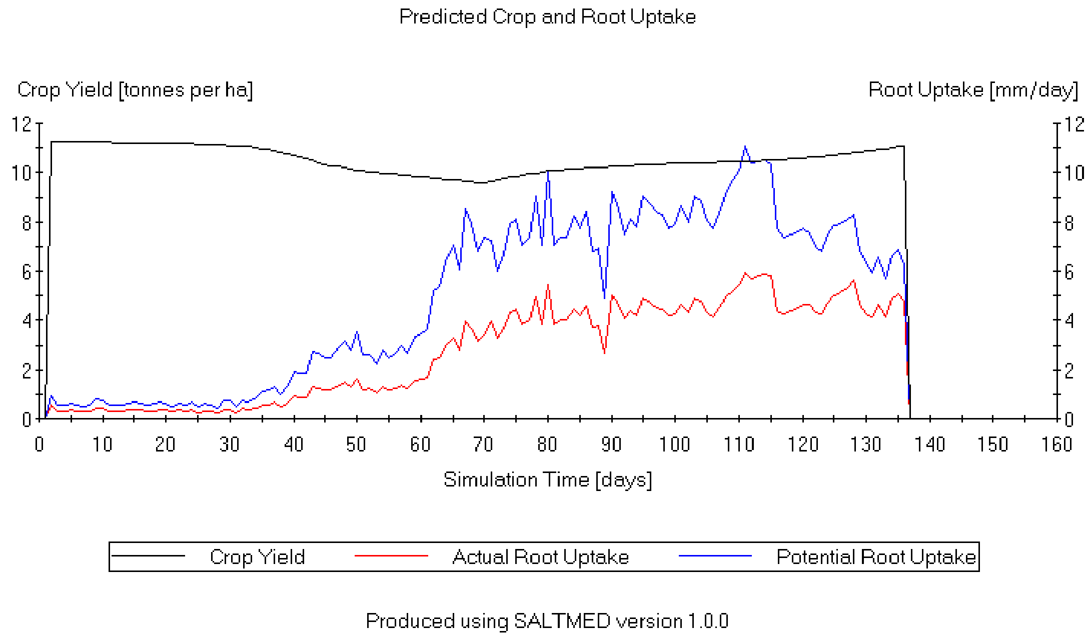


Figure 29. Example of crop potential and actual water uptake and yield

REFERENCES

Dragovic, S. and Maksimovic, L. 2002. Intensity and impact of drought and possibilities for its mitigation in Yugoslavia. International conference on drought mitigation and prevention of land desertification. The International Commission on Irrigation and Drainage (ICID), Slovenian National Committee on Irrigation and Drainage (SINCID-SDNO), Bled, Slovenia, April 21 - 25, 2002. http://www.drustvo-sdno.si

Hamdy, A. and Lacirignola, C. 1997. Use of water in the Mediterranean. Sectorial distribution and prospects. Séminaires Mèditerraneenes, Série A n. 31, Valenzano, Italy.

Hamdy, A., Ragab, R. and Scarascia, M.E. 2003. Coping with water scarcity: Water Saving and increasing water productivity. J. of Irrigation and Drainage 52:3-20
New, M., Hulme, M. and Jones, P. 1999. Representing Twentieth-Century Space-Time Climate Variability. Part I: Development of a 1961-90 Mean Monthly Terrestrial Climatology. J. of Climate:12, 829-856.
Pearce, F. (1996). Wetlands and Water Resources. Conservation of Mediterranean Wetlands (MedWet) - Number 5. (Series Editors: J. Skinner and A.J. Crivelli), Tour du Valet, Arles (France), pp82.
Ragab, R., b. Austin and D. Moidinis. 2001 a. The HYDROMED model and its application to semi-arid Mediterranean catchments with hill reservoirs. 1- The rainfall-runoff model using a genetic algorithm for optimisation. Journal of Hydrology and Earth System Sciences, 5(4): 543-553.
Ragab, R. , D. Moidinis, AlbergeL, J, Khouri, J, Drubi, A and Nasri, S. 2001 b. The Hydromed model and its application to semi-arid Mediterranean catchments with hill reservoirs. 2- rainfall-runoff model application to three Mediterranean hill reservoirs. Journal of Hydrology and Earth System Sciences, 5(4): 554-562.
Ragab, R., B. Austin and D. Moidinis. 2001 c. The HYDROMED model and its application to semi-arid Mediterranean catchments with hill reservoirs. 3- reservoir storage capacity and probability of failure model. Journal of Hydrology and Earth System Sciences, 5(4): 563-568.
Ragab, R. and Christel Prudhomme. 2002. climate change and water resources management in arid and semi arid regions: prospective and challenges for the 21st century. J. of Biosystems Engineering . 81: 3-34.
Ragab, R. 2002. A Holistic Generic Integrated Approach for Irrigation, Crop and Field Management: The SALTMED Model. J. of Environmental Modelling & Software. 17(4):345-361.
Ragab, R., Pearce, G., Kim, J., Nairizi, S. and Hamdy, A. 2001. Proceedings of the International workshop on the Wastewater Reuse Management. Seoul, Korea, September 19-20. 2001. International Commission on Irrigation and Drainage, ICID.
Ragab, R. 2002. An Integrated modelling approach for irrigation water management using saline and non-saline water: The SALTMED model. Acta Horticulturae, No. 573, International Society for Horticultural Sciences, ISHS publication, Leuven, Belgium. pp129-138.
Ragab, R., Bromley, J, Rosier, P., Cooper, J.D. and Gash, J. H.C. 2003a . Experimental Study on Water Fluxes in a Residential Area: 1- Rainfall, Roof Runoff and Evaporation: The effect of slope and aspect. Hydrological Processes :17(2), 2409-2422.
Ragab, R., Rosier, P., Dixon, A., Bromley, J. and Cooper, J.D. 2003b. Experimental Study on Water Fluxes in a Residential Area: 2- Road Infiltration, Runoff and evaporation. Hydrological Processes :17(12), 2423-2437.
Viner D. and M. Hulme. 1997. The climate impacts LINK project. Applying results from the Hadley Centre's climate change experiments for climate change impacts assessment. Climatic Research Unit, Norwich, UK, 17pp.
World water resources: Review of world water resources by country, 2003. Water Reports 23. FAO, Rome.