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in

Hamdy A. (ed.), Trisorio-Liuzzi G. (ed.).
Water management for drought mitigation in the Mediterranean

Bari : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 47

2004
pages 47-112

Water Management Strategies to Combat Drought in the Semiarid Regions

Ragab Ragab[1] and Atef Hamdy[2]

Abstract

Water causes controversial and different problems in various parts of the world. Too much water causes flood and too little causes drought, poor distribution causes famine, poor quality causes health hazard and poor management creates competition and conflicts. Water is essential for life. It is needed for: the health of the environment, food security, human health, industry and energy. Water exists as surface water, soil moisture and groundwater. It differs in quantities and qualities, it varies in time and space, it has a long term trend and it leads to unexpected and unpredictable extreme events.

Drought is a normal event that takes place in almost every climate on Earth, even the rainy ones. It is the most complex of all natural hazards as it affects more people than any other hazard. Drought should not be viewed only as a physical phenomenon or natural event as it has subsequent negative impact on the economic, environment and the society. The recent drought events highlighted the vulnerability of our societies to this natural hazard. There are different types of drought. Meteorological, agricultural and hydrological droughts are the most identified types. The sequence of impacts associated with these drought types highlights their differences. When drought begins, the first to suffer is usually the agricultural sector because of it is heavily dependant on stored soil water. If no precipitation period continues, then users who rely on surface water (i.e., reservoirs and lakes) will suffer first followed by those who rely on subsurface water (i.e., ground water). Obviously, the length of the recovery period is a function of the intensity of the drought, its duration, and the quantity of precipitation received following the drought period.

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. The rainfall data show that a reduction of 100 mm i.e. 1 mm/year over Cyprus has taken place. Such changes create uncertainty and cast doubts on using the long

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term average of rainfall or river flow as a basis for planning water resources use. The Mediterranean and the Middle East regions are becoming hotter and drier. The climate change scenarios for 2050 predict a reduction in rainfall between 15 and 25% and increase in temperature between 1.5 and 2.75 °C. Subsequently, the expected negative impact would be a reduction in water resources per inhabitant both in terms of water availability and water withdrawals. Nearly 50% reduction in the available water per capita is expected in the Mediterranean region by 2025.

In order to combat drought, a management strategies for short and long term should be in place. The drought Management strategies should include: I. Climate forecasting, Design and Implementation of common monitoring system, II. Developing new water supplies (through construction of dams, reservoirs, wells and canals, controls flooding and captures water otherwise lost to the sea, use of use of non-conventional water resources such as treated wastewater, desalinated brackish and saline water, water transfers, artificial precipitation, and conjunctive use of surface and groundwater), developing innovative solutions to increase the water supply (new solutions to harvest rainwater i.e. artificial precipitation and desalinate seawater and developing salt tolerant crops that can be irrigated with saline water), III. Adopting rea - time management of supplies (i.e. reallocation of supplies among different users at crises time to ease water constraints), IV. Adopting more efficient demand management system (i.e. reducing water losses, modification of water demand at farm level, using low water consumption systems in industry and urban development, development of cropping pattern for less water consumption, developing appropriate regulations and guidelines) and reducing demand (i.e. using advanced technology to monitor flows and pressure to detect leaks and prevent water wastage, adopting price incentive to encourage savings, using more efficient irrigation systems, adopt supplementary and deficit-irrigation and reusing treated wastewater of cities and farms), V. Reducing drought impacts in Agriculture, Environment and society, coordination and organization (establishing national drought commission and subcommittee for monitoring, impact and vulnerability assessment and mitigation and responses) and strategic planning for short and long term (an effective planning process should take place before the onset of drought and implemented before drought starts until some time after it has ceases) and VI. Minimizing the drought impacts through development of early warning system, reallocation of water resources, use of drought resistant plants and development of a drought contingency plan. Simply, there is need to adopt an integrated water supply and demand management to combat drought.

Whatever the reasons for drought, the fact is it causes serious problems (economic, environmental and in extreme cases problems of human survival). Drought itself is a periodic phenomenon and may not result in permanent or irreversible changes of the environment. Drought adversely affects the economy by reducing or even eliminating agricultural production, herds of cattle, energy generation, and domestic and industrial water supply. In agriculture drought is described in terms of reduced yields resulting from insufficient soil moisture. In order to assess the degree of severity of a given drought period it is not sufficient to give a simple qualitative appraisal. A quantitative parameter or index is necessary to characterize the intensity of the event. Several indices are used to describe the features of drought and their harmful impacts on both the environment and the living organisms. They are: Standardized Precipitation Index (SPI), Palmer Drought Severity Index (The Palmer; PDSI), Crop Moisture Index (CMI), Surface Water Supply Index (SWSI), Reclamation Drought Index and Deciles

Combating drought through water saving approaches can take place in different sectors if fresh water is used more efficiently in the different sectors of the society. For example in: 1. 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. 2. Industry Sector, many industries use volumes of water that by far exceed their needs and lowering its quality. There are defects in recycling, leakage, loss and inefficient production processes. 3. Irrigation Sector: Almost one half of the volume of water supplied for irrigation through systems is not actually used in the field.

In order to combat drought, we need to shift from water policies based on water supply management to new policies that favour the management of water demand and to shift from preoccupation with development of water resources by major construction programs towards a more balanced approach that should emphasize: water demand management; water conservation and efficient use of water; water pricing and cost recovery; sustainable use of non-conventional water resources; water quality management; capacity building development and tailored

Education and Training. The desirable balance between supply and demand management measures varies over time as conditions evolve. The speed by which the shortages are emerging will inevitably make some governments to face the difficult issues associated with reallocation between users. Simply, there is am important role for the integrated water supply and demand management to play.

In this paper, three examples of solutions to combat drought were presented. First example was on how to save water for household use in residential areas. The example shows some house roofs can catch up to 90% of the rainfall (depending on roof slope and direction). The amount is quite significant to meet most of average house requirements. The second example was on the rainfall harvesting on small mountain lakes/reservoirs in the coastal areas: how to design a surface reservoir to a certain storage capacity at acceptable risk level and how to predict the runoff volume that could be generated from a given storm event. Examples from Tunisia and Syria are given as well as the usefulness of the HYDROMED model as a design and management tool was also illustrated. The third example was on the use of saline / brackish water for irrigating field crops. Example of irrigating tomato in Egypt and Syria with water salinity up to 9 dS m^{-1} was shown. The capability of the SALTMED model as a management tool was also illustrated. These three examples showed that the non-conventional water resources can be used if a proper integrated water management was adopted. These resources are valuable assets in drought prone areas and offer alternatives to fresh water when in short supply.

1. Introduction

Water causes controversial and different problems in various parts of the world. Too much water causes flood and too little causes drought, poor distribution causes famine, poor quality causes health hazard and poor management creates competition and conflicts. Water is essential for life. It is needed for: the health of the environment, food security, human health, industry and energy. Water exists as surface water, soil moisture and groundwater. It differs in quantities and qualities, it varies in time and space, it has a long term trend and it leads to unexpected and unpredictable extreme events.

Water use has increased 5-fold since 1940 with agriculture accounts for two thirds of all water used - mostly for 'irrigation'. In arid and semi arid regions such as the Mediterranean, population growth, rapid urbanization and industrialization are imposing rapidly growing demands and pressures on the water source. This growing imbalance between supply and demand has led to shortages, competition, rising pollution and other environmental pressures. The costs of responding to these pressures have significant implications for economic development.

The dilemma of having a limited water supply and steadily increasing water demand in the Mediterranean region implies that unless the decision makers act decisively now, inadequacy in the quantity and quality of water supply could very well reach crisis level within few years. In fact, the problem is not only the one related to inadequacy of water sources, but, equally, it is highly connected to inadequacies in water management, distribution facilities and institutions.

Early civilizations emerged along the Nile, Tigris and Euphrates and the struggle for water shaped life in desert communities. Water has always been the central concern to life in the southern Mediterranean and Middle East countries. The overgrowing population and the recent droughts are exerting a lot of pressure on the water resources. According to the World Bank (1993), the minimum water required to sustain human life is about 25 l day^{-1} (10 m^3 yr^{-1}) A reasonable supply to maintain health may be 100-200 l day^{-1} per capita (40-80 m^3 yr^{-1}) though in developed countries domestic use can exceed 300-400 l day^{-1} per capita (up to 150 m^3 yr^{-1}or more). By year 2025 renewable water resources in four South Mediterranean and the Middle East, (MED & ME) countries will barley cover the basic human needs in Jordan, Libya, Saudi Arabia, and Yemen.

At present, the water exploitation index taken as percentage of renewable annual water resources for Tunisia is 83%, Egypt is 92%, Gaza is 169%, Libya is 644% (because 84% come from non-renewable fossil water from beneath the Sahara), Syria is nearly 50%, Lebanon is about 25%, Algeria is 20%, and Morocco is nearly 40% (Pearce, 1996).

The Mediterranean region suffers frequently from years of low rainfall. Most of the region was hit by severe drought in 1989-1990 and some have seen poor rainfall. Tunisia suffered severe drought from 1987-1989, while Morocco has suffered continually since 1990. Because countries are using their water resources with growing intensity, poor rainfall increasingly leads to national water crises as water tables fall and reservoirs, wetlands and rivers run dry.

Generally, the climate of the Mediterranean is characterized by hot dry summer and mild wet winter. The coasts of Algeria and Libya normally have seven dry months, receive only around 200 mm of rain in an average year and have typical July temperature of 30°C. When rain does fall, it tends to arrive as heavy storms, falls of over 125 mm in a day, often with thunder, are not uncommon and records for individual sites include more severe storms such as Tripoli (130 mm) and Haifa (183 mm) (Acreman, 2000). Thus, some areas receive their total annual rainfall in a few days.

There is a growing debate about whether these droughts are simply another manifestation of the notorious variability of Mediterranean rainfall or a sign of a long term shift in rainfall patterns perhaps linked to global warming. There has been a decrease in rainfall throughout the region over the past century. 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 averages 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).

It is clear that the Mediterranean region is becoming hotter and drier. This would lead to reduction in water resources per inhabitant both in terms of water availability and water withdrawals. It is expected by the year 2025 that the available water per capita in the Mediterranean region will be reduced by nearly 50% of the present level. Over exploitation of water at a relatively high rate will cause water quality deterioration. On the other hand, excessive reduction in water withdrawals per capita will impose significant effect on the water use, creating notable competition and conflicts among users in the various sectors and could cause progressive degradation in the quality of available water resources because of increasing waste load discharged into water bodies.

2. The Drought Phenomenon

Drought is a complex phenomenon and is generally viewed as a sustainable and regionally extensive occurrence of below average natural water availability either in the form of precipitation, river runoff or groundwater. Drought is a normal, recurrent feature of climate. It can take place almost everywhere, although its manifestation varies from region to region and therefore a global definition is a difficult task (Dracup et al. 1980, Wilhite, and Glantz. 1985). For example, one might define drought in Libya as occurring when annual rainfall is less than 180 mm, but in Bali, drought might be considered to occur after a period of only 6 days without rain! In general sense, drought originates from lack of precipitation over an extended period of time, usually a season or more, resulting in a shortage of water supply for a certain activity, group, or environment. Drought is a normal part of virtually every climate on the planet, even rainy ones. It is the most complex of all natural hazards, and it affects more people than any other hazard. Analysis shows that it can be as expensive as floods and hurricanes. The major problem in drought prone areas is of course the problem of the shortage of water. The rapid development of irrigation in several of these areas, especially when groundwater is being extracted, has already in several instances resulted in the exhaustion of the resource and the requirement to stop the agricultural exploitation. It is more serious problem in the cases where fossil groundwater resources were exhausted as it will take centuries before the source is being recharged.

2.1. The Concept of drought

Aridity is a permanent feature of climate, while drought is a temporary event. Drought is viewed relative to some long-term average often considered as “normal”. It is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with drought in many parts of the world and can significantly aggravate its severity.

Drought should not be viewed only as a physical phenomenon or natural event. The recent droughts in many countries and the subsequent negative impact on the economic, environment as well as the human being hardships have highlighted the vulnerability of all societies to this "natural" hazard. There are two kinds of drought definitions: conceptual and operational.

2.1.1. Conceptual definitions of drought

Conceptual definitions help people understand the concept of drought in more simple way. For example: Drought is a period of deficient precipitation resulting in extensive damage to crops and resulting in loss of yield.

2.1.2. Operational definitions of drought

Operational Definitions are relatively more technical. They help people identify the beginning, end, and degree of severity of a drought. This is usually carried out by comparing the current situation with the historical average.

Such definitions, however, require weather data on hourly, daily, monthly, or other time scales and, possibly, impact data (e.g., crop yield), depending on the nature of the definition being applied. For more details, see the web site of the National Drought Mitigation Center University of Nebraska–Lincoln, USA http://www.drought.unl.edu

Meteorological drought is commonly based on precipitation's departure from normal average over a certain period of time and is region-specific. Examples of different drought definition are: United States (1942): less than 2.5 mm of rainfall in 48 hours, Great Britain (1936): 15 consecutive days with daily precipitation totals of less than 25 mm, Libya (1964): annual rainfall less than 180 mm, India (1960): actual seasonal rainfall deficient by more than twice the mean deviation and Bali (1964): a period of six days without rain.

Agricultural drought occurs when there isn't enough soil moisture to meet a crop water requirement at a particular time. Agricultural drought takes place after meteorological drought but before the hydrological drought. Agriculture in many parts of the world is usually the first economic sector to be negatively affected by drought.

Hydrological drought refers to deficiencies in surface and subsurface water supplies. This drought can directly be measured as stream/ river flow and as lake, reservoir, and groundwater levels. Because there is a time lag between the time of rain falling and its appearance in streams, rivers, lakes, and reservoirs, hydrological measurements are not the earliest indicators of drought.

Socioeconomic drought occurs when physical water shortage starts to affect people, individually and collectively. Most socioeconomic definitions of drought associate it with the supply and demand. Socioeconomic drought occurs when the demand exceeds the supply as a result of a weather-related shortfall in water supply. For example, in Uruguay in 1988–89, drought resulted in significantly reduced hydroelectric power production because power plants were dependent on stream flow.

In most instances, the demand on water supply is increasing as a result of increasing population and per capita consumption. Supply may also increase because of the construction of reservoirs that increase surface water storage capacity or rainfall harvesting or indirect groundwater recharge (Bradford *et al*. 2002). If both supply and demand are increasing, the critical factor would then be is the relative rate of change. If the demand is increasing more rapidly than supply this could lead to more vulnerability and the incidence of drought may increase in the future.

2.2. Time sequence of drought impacts

The sequence of impacts associated with meteorological, agricultural, and hydrological droughts highlights their differences. When drought begins, the first to suffer is usually the agricultural sector because of it is heavily dependant on stored soil water. The latter can be rapidly depleted over extended dry periods. If no precipitation period continues, then people will begin to feel the effects of the shortage. Those who rely on surface water (i.e., reservoirs and lakes) will suffer first and those who rely on subsurface water (i.e., ground water) are usually the last to be affected. Although, ground water users, often the last to be affected by drought during its onset, they are the last to experience a return to normal water supply levels. Obviously, the length of the recovery period is a function of the intensity of the drought, its duration, and the quantity of precipitation received following the drought period. Figure 1 shows the different droughts and the sequence of occurrence as well as the impacts.

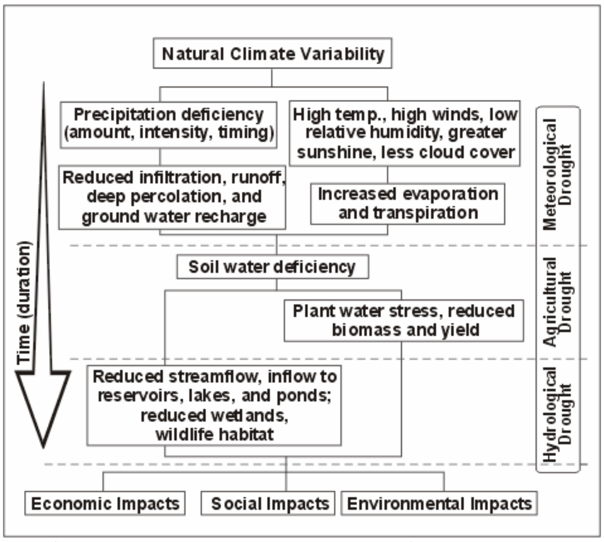


Fig. 1. The types of droughts, their sequence of occurrence and their impacts (Source: National Drought Mitigation Center University of Nebraska–Lincoln, USA, http://www.drought.unl.edu)

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

3.1. 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 averages 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). Figure 2 illustrate 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.

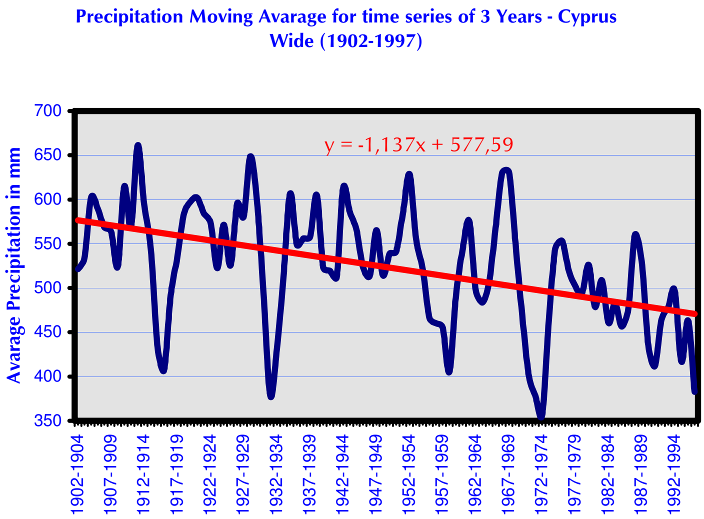


Fig. 2. Precipitation of Cyprus over the past century.

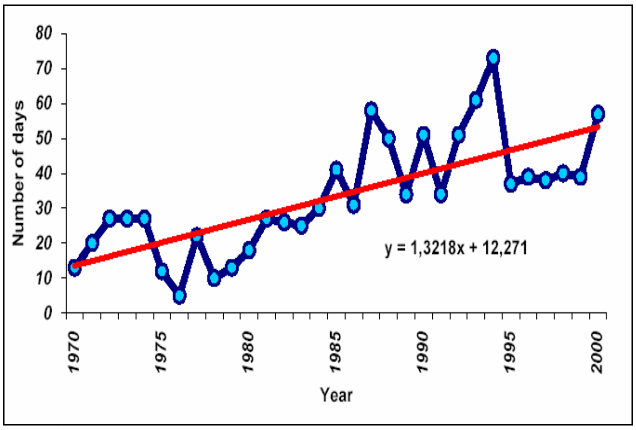


Fig. 3. Number of tropical days (max. temperatures over 30 °C) in Zajecar (source: Dragovic and Maksimovic, 2002)

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, (Figure 3). The figure shows that this number of tropical days has been on the increase between 1976 and 1996. Figure 2 and 3 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 Figure 4 and 5 respectively.

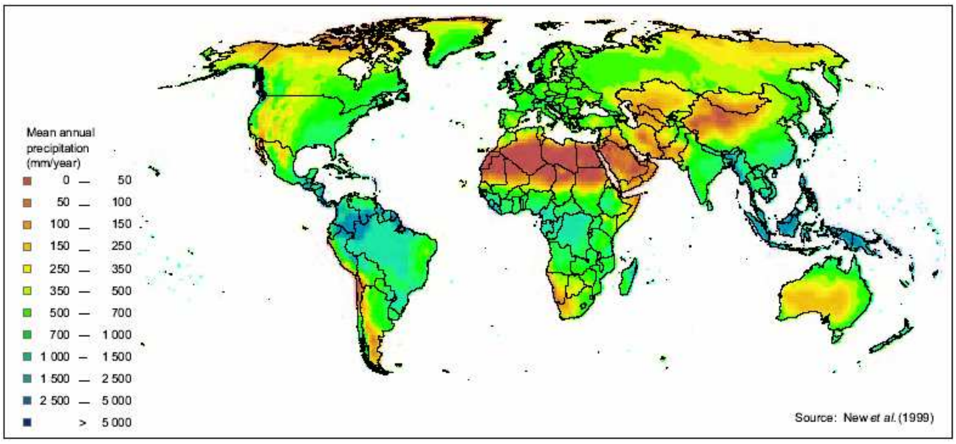


Fig. 4. World map of mean annual precipitation, 1961–1990 (source: FAO, 2003)

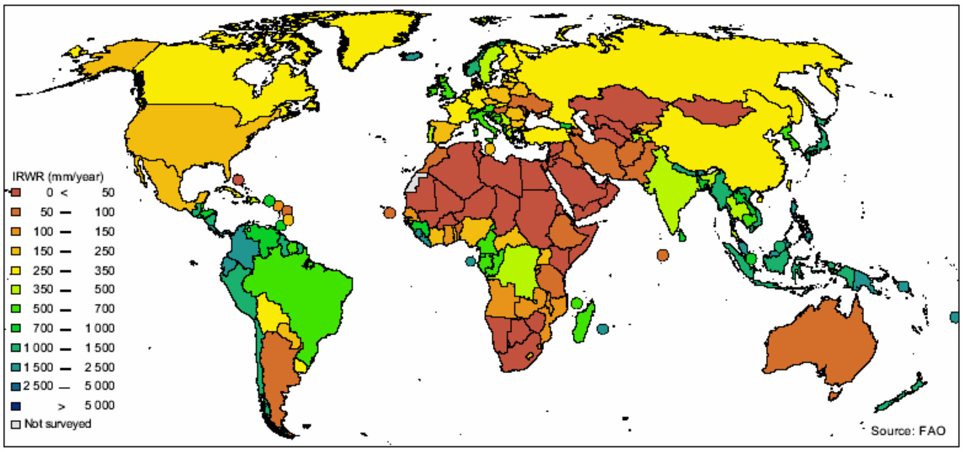


Fig. 5. World map of internal renewable water resources (IRWR), per country (source: FAO, 2003).

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 Figures 6a and Figure 6b. The figures show that some countries like Egypt, Sudan, Syria, Iraq, and Mauritania depend largely on external waters flowing from other countries. The consequences are any drought in source countries will be felt at the receiving end. Table 1 illustrates 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 and that would make them more vulnerable to any drought event.

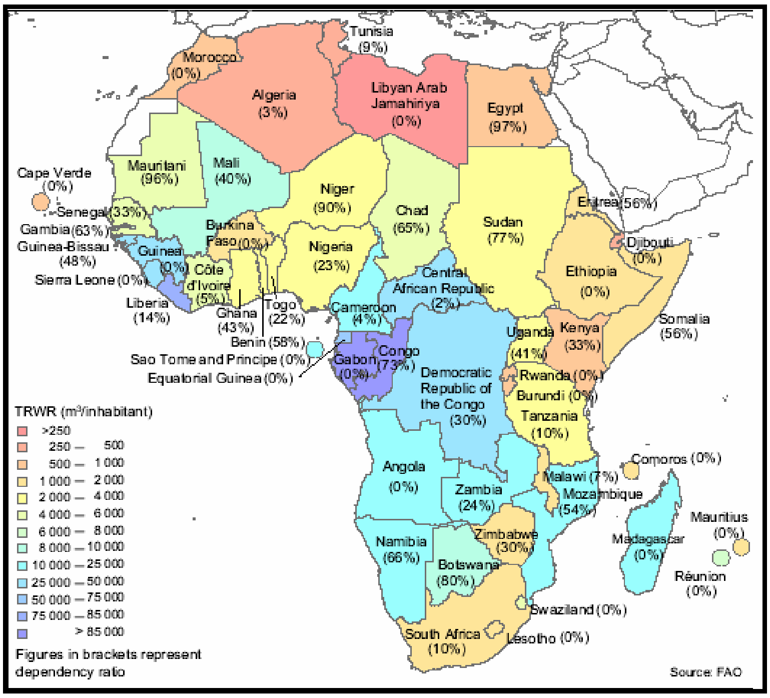


Fig. 6a. Water resources in the Africa region, total renewable water resources (TRWR) and dependency Ratio (source: FAO, 2003).

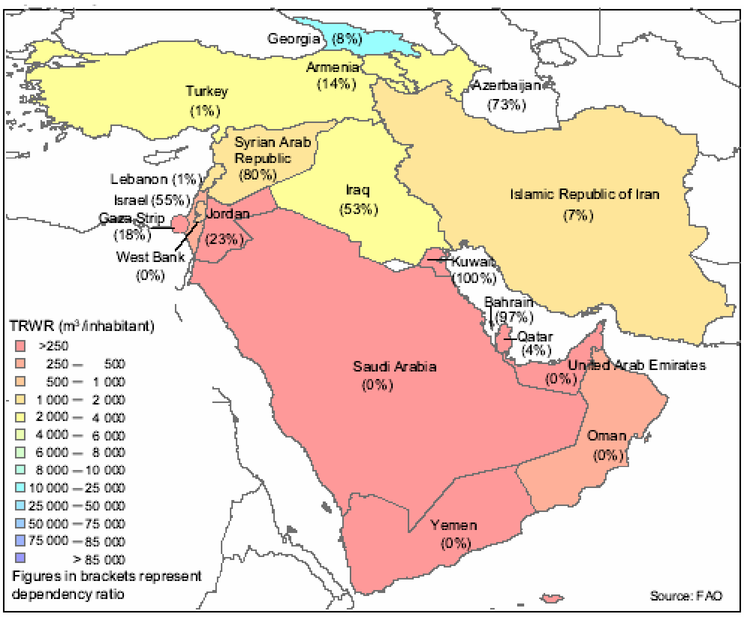


Fig. 6b. Water resources in the Near East region, total renewable water resources (TRWR) and dependency ratio (source: FAO, 2003).

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

FAO Code	Country	Average precipitation 1961-1990 (km³/year)	Internal resources: surface (km³/year)	Internal resources: groundwater (km³/year)	Internal resources: overlap (km³/year)	Internal resources: total (km³/year)	External resources: natural (km³/year)	External resources: actual (km³/year)	Total resources: natural (km³/year)	Total resources: actual (km³/year)	IRWR/inhab. (m³/year)
21	Brazil	15 236	5 418	1 874	1 874	5 418	2 815	2 815	8 233	8 233	31 795
185	Russian Federation	7 855	4 037	788	512	4 313	195	195	4 507	4 507	29 642
33	Canada	5 352	2 840	370	360	2 850	52	52	2 902	2 902	92 662
101	Indonesia	5 147	2 793	455	410	2 838	0	0	2 838	2 838	13 381
41	China, Mainland	5 995	2 712	829	728	2 812	17	17	2 830	2 830	2 245
44	Colombia	2 975	2 112	510	510	2 112	20	20	2 132	2 132	50 160
231	United States of America (Cont.)	5 800	1 862	1 300	1 162	2 000	71	71	2 071	2 071	7 153
170	Peru	1 919	1 616	303	303	1 616	297	297	1 913	1 913	62 973
100	India	3 559	1 222	419	380	1 261	647	636	1 908	1 897	1 249

Water Rich countries

FAO Code	Country	Average precipitation 1961-1990 (km³/year)	Internal resources: surface (km³/year)	Internal resources: groundwater (km³/year)	Internal resources: overlap (km³/year)	Internal resources: total (km³/year)	External resources: natural (km³/year)	External resources: actual (km³/year)	Total resources: natural (km³/year)	Total resources: actual (km³/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 (km²) (FAOSTAT, 1999)	Total population (inh.) (FAOSTAT, 2000)	Internal resources: total (km³/year)	External resources: actual (km³/year)		Total resources: actual (4) (km³/year)	% of internal water resources of the region	IRWR/inhab. (m³/year)	TRWR (actual)/inhab. (m³/year)
7 Near East	Arabian Peninsula	3 003 230	46 958 000	7.7	0.0	(1)	7.7	1.58	163.8	163.8
	Caucasus	186 100	17 090 000	75.3	18.4	(2)	93.7	15.44	4 407.0	5 483.7
	Middle East	3 158 640	193 066 000	404.7	3.2	(3)	407.9	82.98	2 096.3	2 112.6
	Near East	**6 347 970**	**257 114 000**	**487.7**	**3.2**		**490.9**	**100.00**	**1 897.0**	**1 909.2**
	World	**133 845 436**	**6052 577 900**	**43 764.3**	**0.0**		**43 764.3**		**7 230.7**	**7 230.7**
	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.

(4)

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

3.2. Current water and land use

3.2.1. Current water use

In the Mediterranean region nearly 70% of the available water resources are allocated to agriculture, (Hamdy and Lacirignola, 1997). In the Southern Mediterranean countries the 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 (Figure 7).

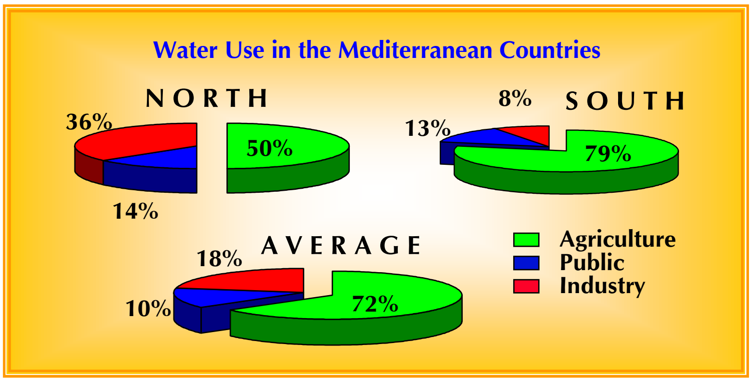


Fig. 7. Water use per sector in the Mediterranean (Source: Hamdy and Lacirignola, 1997)

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.

3.2.2. Current land use

The term "land use" is more comprehensive than the term "soil use". Land, commonly, stands for a section of the earth's surface, with all the physical, chemical and biological features that influence the use of the resource. It refers to soil, spatial variability of landscape, climate, hydrology, vegetation and fauna, and also includes improvements in land management, such as drainage schemes, terraces and other agrobiological and mechanical measures. The term "land use" encompasses not only land use for agricultural and forestry purposes, but also land use for settlements, industrial sites, roads and so on (De Wrachien *et al*., 2002 a,b).

Land use and distribution of agricultural land in the Mediterranean basin are illustrated in Figure 8. As shown also in Table 2, there are major differences in land use patterns from one country to another and between north and south of the Mediterranean.

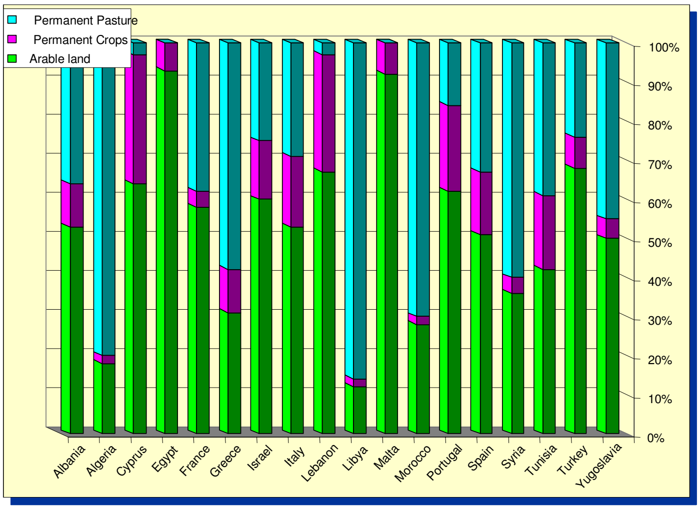


Fig. 8. Distribution of agricultural land in the Mediterranean countries (source: FAO, 1993)

Table 2. Land use as % of cultivated area in the Mediterranean. (Hamdy & Lacirignola, 1997)

Region	Annual crops %	Permanent crops %	Permanent pastures %
North	57.55	10.90	30.89
South	38.60	6.40	55.0
East	56.50	20.50	22.75
Average	50.88	12.60	36.22

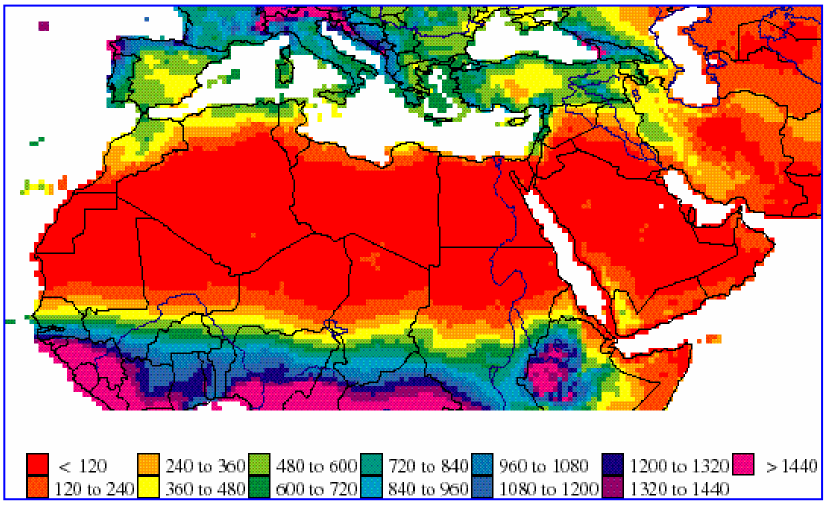
3.3. Impact of future climate change on the Mediterranean and the Middle East regions

3.3.1. The climate change predictions for the Mediterranean and the Middle East Regions

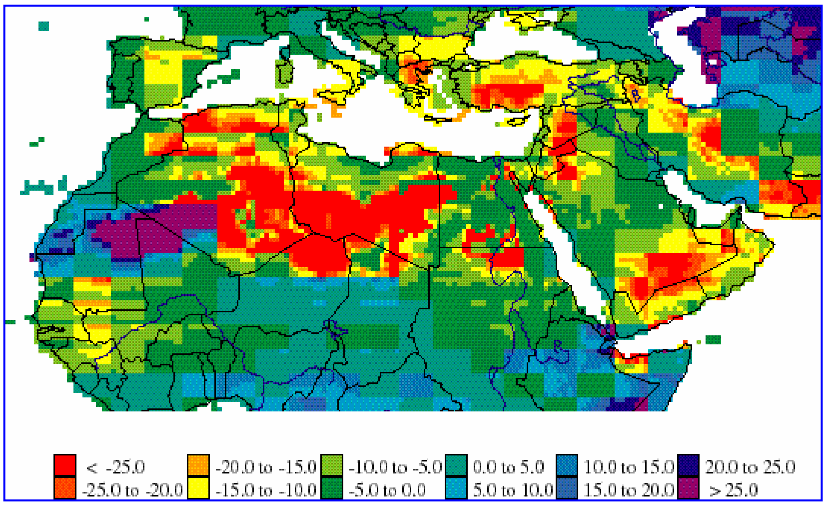
The UK Hadley Centre's global climate model has been run to study the possible future climate change. The model comprises several layers into the atmosphere and below soil surface and accounts for most of the essential/dominant hydrological processes. The model runs at spatial scale of $2.5° \times 3.75°$ 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 combine both dry and wet periods are shown as Figure 9 and 10, (Ragab and Christel Prudhomme. 2002).

Figure 9. a, shows the basic annual precipitation based on 1961-1990 data while Figure 9b shows percent (%) Changes in annual precipitation for the year of 2050 according to the HadCM2 Scenario-GHGX. Figure 10. a, shows the basic annual temperature based on 1961-1990 data while Figure 10 b 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.

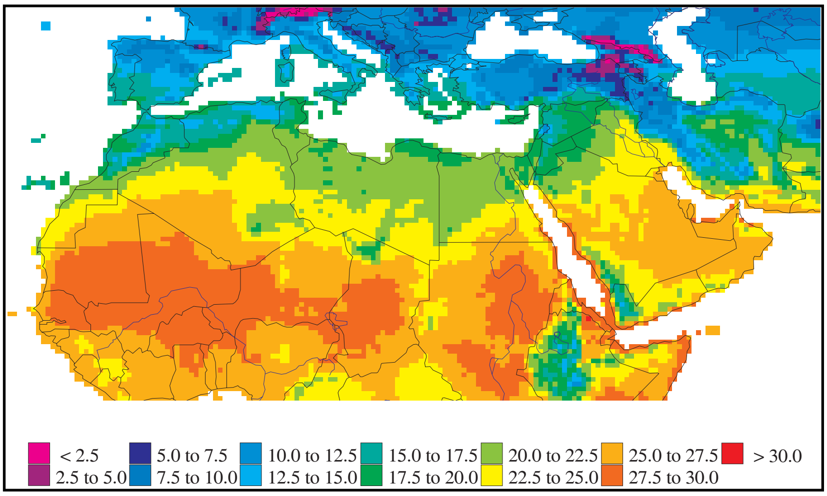


a, Basic annual precipitation

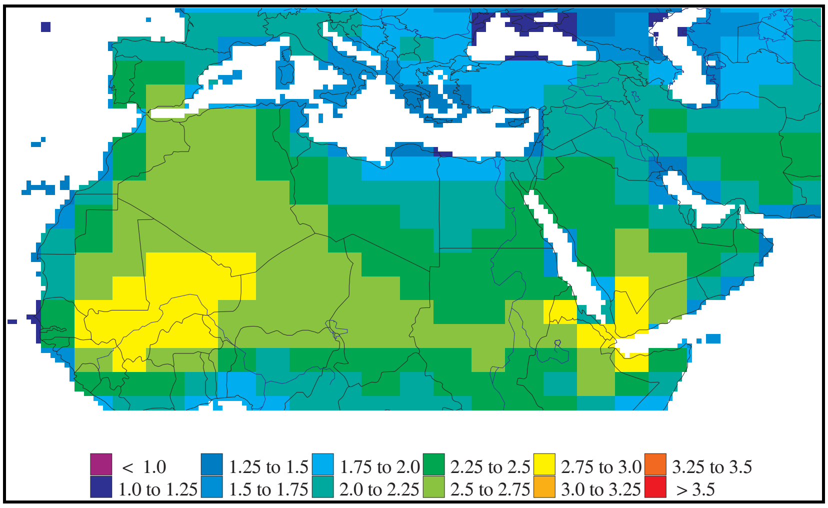


b, Predicted % changes in precipitation by 2050

Fig. 9. 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, & Christel Prudhomme, 2002).



a Basic annual temperature



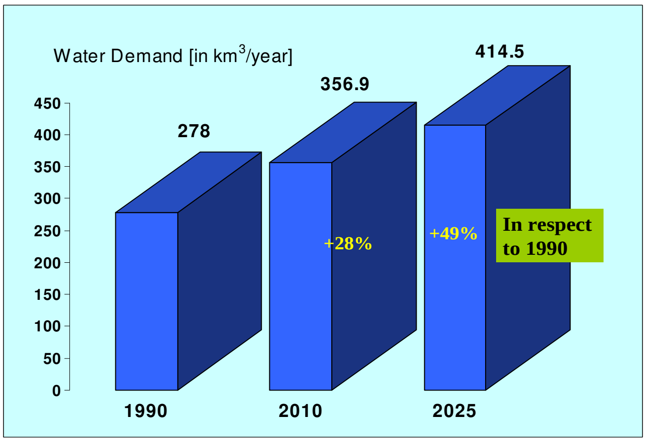
b Annual temperature 2050

Fig. 10. 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, & Christel Prudhomme, 2002).

3.3.2. Future Climate change and the expected increase in water demand

The water demand in the Mediterranean region is expected to increase by almost 50% by the 2025 as shown in Figure 11, (Hamdy *et al.* 2003). After agriculture, industry is the second major user of water in the region. Nearly one fifth of total freshwater withdrawals are 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%. Figure 12 shows that some Mediterranean countries such as Turkey, Syria, Lebanon, and Cyprus that were stress free in the 90's are expected to be water stressed by the year 2050 (Hamdy *et al*. 2003).

The Mediterranean Region:Water Demand in 1990 and Foreseen Demand for the years 2010 and 2025 *[in km^3/year]*



Source: Data refer to national level. They are collected from various sources (gathered up to September 1997).

Fig. 11. The increase in the water demand of the Mediterranean region with respect to 1990 (Source: Hamdy *et al*. 2003).

Renewable Fresh Water Availability Per Person in the Southern Mediterranean Countries, 1990 to 2050

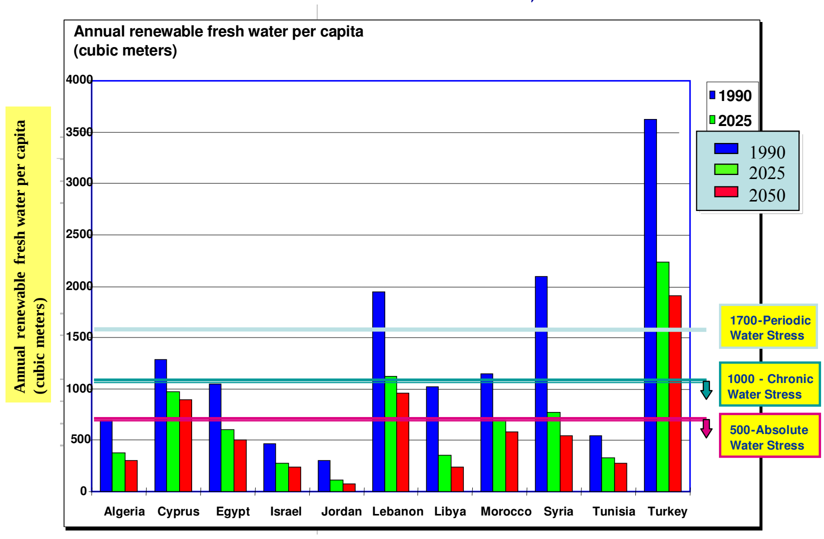


Fig. 12. Renewable fresh water availability 1990-2050 for the Mediterranean Region. (Source: Hamdy *et al*. 2003).

3.3.3. Future climate Change and the irrigation water requirements

Agriculture is a human activity that is intimately associated with climate. Modern agriculture has progressed by weakening the downside risk of some environmental factors through irrigation, the use of pesticides and fertilizers, the substitution of human labour with energy intensive devices, and the manipulation of genetic resources. A major concern in the understanding of the impacts of climate change is the extent to which agriculture will be affected. Thus, in the long term, climate change is an additional problem that agriculture has to face in meeting global and national food requirements. This recognition has prompted recent advances in the coupling of global vegetation and climate models.

In the last decade, global vegetation models have been developed that include parameterizations of physiological processes such as photosynthesis, respiration, transpiration and soil water uptake (Bergengren *et al.*, 2001). These tools have been coupled with GCMs and applied to future scenarios (Doherty *et al.*, 2000). The use of physiological parameterizations allows these models to include the direct effects of changing CO_2 levels on primary productivity and competition, along with the crop water requirements. Subsequently, the estimated crop water demands could serve as input to agro-economic models which compute the irrigation water requirements (IR), defined as the amount of water that must be applied to the crop by irrigation in order to achieve optimal crop growth. Adams *et al.* (1990) and Allen *et al.* (1991) used crop growth models for wheat, maize, soybean and alfalfa at typical sites in the USA and the output of two GCMs to compute the change of IR under double CO_2 conditions.

On the global scale, scenarios of future irrigation water use have been developed by Seckler *et al.* (1997) and Alcamo *et al.* (2000). The latter employed the raster-based Global Irrigation Model (GIM) of Döll and Siebert (2001), with a spatial resolution of 0.5^0 by 0.5^0. This model represents one of the most advanced tools today available for exploring the impact of climate change on IR at worldwide level. More recently, the GIM has been applied to explore the impact of climate change on the irrigation water requirements of those areas of the globe equipped for irrigation in 1995 (Döll, 2002). Estimates of long-term average climate change have been taken from two different GCMs:

- the Max Planck Institute for Meteorology GCM (MPI-ECHAM4), Germany

- the Hadley Centre's GCM (Had-CM3), UK

The following climatic conditions have been computed:

- present-day long-term average climatic conditions, i.e. the climate normal 1961-1990 (baseline climate);

- future long-term average climatic conditions of the 2020s and 2070s (climatic change).

For the above climatic conditions, the GIM computed both the net and gross irrigation water requirements in all 0.5^0 by 0.5^0 raster cells with irrigated areas. "Gross irrigation requirement" is the total amount of water that must be applied such that evapotranspiration may occur at the potential rate and optimum crop productivity may be achieved. Only part of the irrigated water is actually used by the plant and evapotranspirated. This amount, i.e. the difference between the potential evapotranspiration and the actual evapotranspiration that would occur between irrigations, represents the "net irrigation requirement", IRnet, (De Wrachien, 2003).

Figure 13a provides, for the Mediterranean and Middle east regions, a map of IRnet per unit irrigated area for the baseline climate, while Figures 13b and 13c present the percent changes for the 2020s time horizon as computed for the MPI-ECHAM4 (13b) and Had-CM3 (13c) climate scenarios (Döll, 2002).

The maps show that irrigation requirements (mm/yr) increase in most irrigated areas in the north (Figures 13b, 13c), which is mainly due to the decreased precipitation during the summer. In the south, the pattern becomes complex. For most of the irrigated areas of the arid northern part of Africa and the Middle East, IRnet diminishes. In Egypt, a decrease of about 50% in the southern part is accompanied by an increase of more than 30% in the central part. The decrease in IRnet depends on the fact that the cropping patterns and growing seasons of an irrigated area are strongly influenced by temperature and precipitation conditions (Döll, 2002). In GIM, temperature determines which areas are best suited for multi-cropping system and the growing seasons are identified based on optimal temperature and precipitation conditions. In Egypt, for example, the modeling of the cropping patterns for the baseline climate results in two crops per year in the southern part and only one crop per year in the central part, and vice versa for the 2020s (De Wrachien, 2003) .

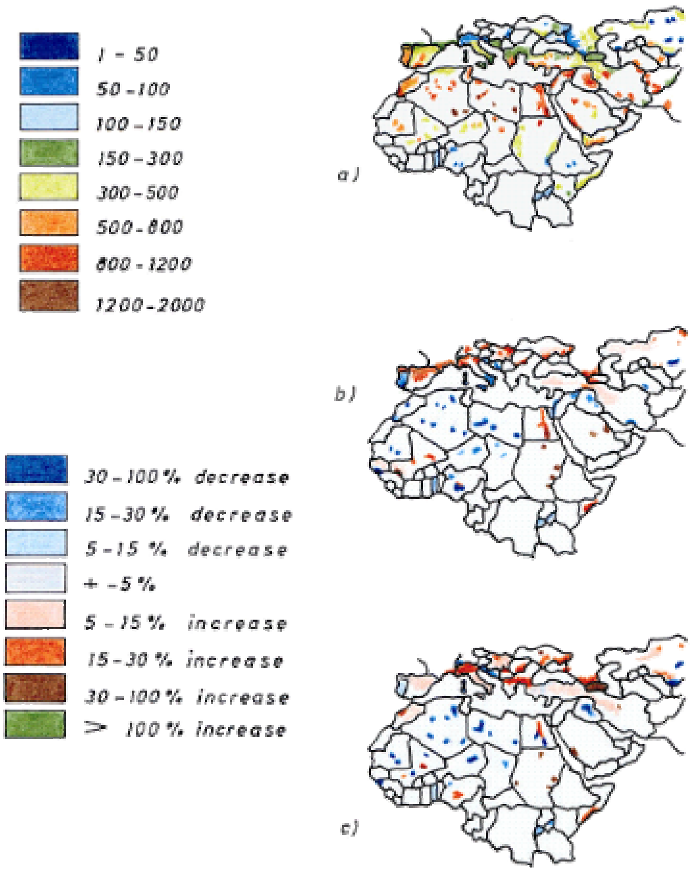


Fig. 13. Net irrigation requirement IRnet per unit irrigated area under baseline climate (1961-1990) [mm/yr]. (b) Change of IRnet between baseline climatic condition and the 2020s, due to climate change as computed by ECHAM4. (c) like (b), but due to climate change as computed by HadCM3. Only those cells are shown in which IRnet per unit cell area was more than 1 mm/yr (baseline climate, 1995 irrigated areas, (source: Döll, 2002).

4. The Drought Impact

Drought represents a significant threat to our social and economic life and causes damage to natural resources. It reduces not only the primary production of crops, grass and fodder, that is essential to maintain human health and animal production, but also jeopardizes the constant supply of good quality water. Drought, also, leads to degradation of the environment. In areas affected by prolonged drought periods, the process initiate a chain of reactions that result in soil exposure, erosion, land degradation and, finally, desertification. In some countries the risk of land degradation and desertification is already taking place under the present climatic pattern and human activity, and there is no doubt that the greenhouse effect will increase this. Drought produces a complex network of impacts that spans over many sectors of the economy and reaches well beyond the area experiencing physical drought. This complexity exists because water is integral to our ability to produce goods and provide services.

Impacts are commonly referred to as direct or indirect. Few examples of direct impacts are: reduced crop, rangeland and forest productivity; increased fire hazard; reduced water levels; increased livestock and wildlife mortality rates and damage to wildlife and fish habitat. The indirect impacts are usually the consequences of the direct impacts. For example, a reduction in crop, rangeland, and forest productivity may result in reduced income for farmers, increased prices for food and timber, unemployment, reduced tax revenues, increased crime, increased money borrowing by farmers and businesses and increased migration. The impacts of drought can be categorized as economic, environmental, or social.

- **The economic impacts** occur in agriculture and related sectors, including forestry and fisheries, because of the reliance of these sectors on surface and subsurface water supplies. In addition to obvious losses in yields in crop and livestock production, drought is associated with increases in insect infestations, plant disease, and wind erosion. Droughts also bring increased problems with insects and diseases to forests and reduce growth. The incidence of forest and range fires increases substantially during extended droughts, which in turn places both human and wildlife populations at higher levels of risk.

Income loss is an important indicator used in assessing the impacts of drought because so many sectors are affected. Reduced income for farmers has a significant effect. Consequently, retailers and others who provide goods and services to farmers face reduced business and income. This leads to unemployment, increased credit risk for financial institutions, capital shortfalls, and loss of tax revenue for local, state, and federal government. Less discretionary income affects the recreation and tourism industries. Prices for food, energy, and other products increase as supplies are reduced. In some cases, local shortages of certain goods result in the need to import these goods from outside the stricken region. Reduced water supply affects the navigability of rivers and results in increased transportation costs because products must be transported by rail or truck. Hydropower production may also be stopped or reduced significantly.

- **The environmental impact:** Environmental losses are the results of damages to plant and animal species, wildlife habitat and air and water quality; forest and range fires; degradation of landscape quality; loss of biodiversity and soil erosion. Some of the effects are short-term and conditions can quickly return to normal following the end of the drought. Other environmental effects linger for some time or may even become permanent. Wildlife habitat, for example, may be degraded through the loss of wetlands, lakes, and vegetation. However, many species will eventually recover from this temporary situation. The degradation of landscape quality, including increased soil erosion, may lead to a more permanent loss of biological productivity of the landscape. Although environmental losses are difficult to quantify, growing public awareness and concern for environmental quality has forced public officials to focus greater attention and resources on these effects.

- **Social impacts** mainly involve public safety, health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief. Many of the impacts specified as economic and environmental have social components as well. Population migration is a significant problem in many countries, often stimulated by greater availability of food and water elsewhere. Migration is usually to urban areas within the stressed area or to regions outside the drought area; migration may even be to adjacent countries, creating refugee problems. However, when the drought is over, these persons seldom return home, depriving rural areas of valuable human resources necessary for economic development. For the urban area to which they have immigrated, they place ever-increasing pressure on the resources and social infrastructure, possibly leading to greater poverty and social unrest. The drought-prone northeast region of Brazil had a net loss of nearly 5.5 million people between 1950 and 1980. Although not this entire population shift was directly attributable to drought, it was a primary factor for many in their decision to relocate. This continues to be a significant problem in Brazil and many other drought-prone countries. Drought represents one of the most important natural triggers for malnutrition and famine, a significant and widespread problem in many parts of Africa and in other countries as well.

- **Drought impact on Tourism**

The Mediterranean region is the leading tourist destination in the world with 250 million domestic and foreign tourists annually. Tourism increases the demand of drinking water in the reception areas by additional 500-800 liters per day per capita in luxury hotels.

It also causes: more pressure on water distribution and sanitation facilities, lowering of groundwater level through over-pumping and intrusion of sea-water into the aquifers.

- **Conflicts as indirect impact of drought**

Conflicts at national scale

Fast-rising water demand inevitably creates conflicts especially when uses are regarded as "non-essential" or of benefiting only a few people or of being stolen by neighboring communities or countries. In Tunisia, there is a conflict between Agriculture and Tourism in Cap Bon region, where hotels containing beds for more than 100,000 tourists are competing for water from the local aquifer, which is already, seriously overexploited to meet farmers needs.

In Morocco, both tourism and industrial development are competing for water resources currently used for irrigation around Casablanca. This has not stopped the government from formulating a national plan to increase the area of irrigated land to more than one million hectares by the end of the year 2000 under programme known as the “Politique des Barrages”.

Conflicts at International scale

Political boundaries often do not follow hydrological boundaries. Instead national boundaries sometimes run down the middle of rivers as on the Danube, or rivers may flow from one country into another. Thus, the Rhone passes from Switzerland into France, and the river Jordan passes through Syria, Israel, Jordan and Palestine territory.

There is ongoing dispute between Israel and its neighbors since 1964 when Israel diverted most of the water of River Jordan to the Sea of Galilee. It passes now down a "new" River Jordan, the Israel National Water Carrier that takes water to all major cities and even to the Negev desert in the far south. The West Bank aquifer receives its water from rainfall over the West Bank hills. It extends beneath Israel and drains into the Mediterranean Sea. With a new Palestinian state in sight, how will the two states jointly manage this vital resource to provide an equitable allocation? Palestinian towns and villages currently extract water from springs and shallow wells in the hills. The Israelis extract it from deep boreholes to supply new West Bank settlements and from boreholes on Israeli territory near the coast. Israel takes more than 300 Mm^3/year from the aquifer, with Palestinian villages taking much less, though the exact amount is disputed. In any case, the resource is already over abstracted by at least 100 Mm^3/year (Pearce, 1996). This has resulted in a reduction of the size of the irrigated area from 27% before the occupation to 4% by 1990s, whereas Israeli settlers on the West Bank irrigate 70% of their crops. Israeli hydrologist admit that in some areas such in village of Jiftlik in the Jordan valley and Barada near Nablus, Israeli boreholes sunk deep into the aquifer have dried up shallow Arab wells, causing local disputes.

Today Egypt, which is using most of the Nile water, is in fear that upstream neighbors such as Ethiopia will begin to harness the water for their own use. The Nile treaty of 1929 under the British role was updated and signed only between Egypt and Sudan in 1959.

The River Jordan provides Israel with 40% of its water resources. Farmers on the east bank suffer a great shortage to irrigate their lands. Also, Syria and Jordan are suffering.

Underground aquifers also frequently cross national boundaries. If anything, the potential for conflict is even greater here because the aquifer, once emptied, might take centuries or even longer to refill. There is a greater room for dispute over the basic data of the resource: how much water it contains, what the recharge rates are, where the recharge comes from, etc.

Conflicts can be especially acute over the exploitation by one country of non-renewable "fossil" reserves that extends beneath the neighbour. By pumping water out from the aquifer beneath its own territory, it could begin to drain forever the water beneath its neighbor's territory. The great fossil-water filled aquifers beneath the Sahara desert are a major potential cause of future water conflict. The Eastern Erg artesian aquifer, south of the Atlas Mountains, extends from Algeria into Tunisia. The Nubian aquifer underlies Libya, Egypt and Sudan and contains an estimated 6,000km^3 of water. Only Libya is tapping it so far – but on a massive scale, with the "Great Man-made River" project. The World Bank says there is a study on the region indicating that there is a fear that this may reduce substantially the groundwater reserves in Egypt and Sudan. There are already claims that the Libyan pumping is drying up Egyptian oases.

5. The Drought Risk Management

5.1. Principles of the drought risk management

In order to define the risk, one needs first to define the components of the risk (Nirizi, 2003).

Hazard: Is a physical event, phenomena or a substance with potential to causes harm. Including losses of life, injuries, financial losses and social environmental negative impacts.

Vulnerability: Is a multitude of conditions and processes based on physical, social technological and management factors which reflects the sensitivity of a society to a hazard.

Capability: Is the way by which people and institutes will react upon the occurrence of hazard or disaster and using their available resources efficiently and effectively.

Risk: Risk expresses the likelihood that the harm from a particular hazard is realized. It is the product of the extend hazard and vulnerability relative to the capability of the society and community to control the damage.

$$Risk = \frac{\text{Hazard x Vulnerabilty}}{\text{Capability}}$$

Risk, therefore, reflects both the likelihood that harm will occur and its severity.

5.2. Risk management versus crises management

Risk management: Is a proactive approach to mitigate the potential damage of a disaster prior and after its occurrence. It involves risk identifications, risk evaluation and risk control.

Crises management: Is a reactive approach to control and mitigate the negative impacts of a hazard or natural disaster after its occurrence.

It is usually ineffective, because response is untimely, poorly coordinated, and poorly targeted to disaster stricken group or areas.

5.3. Risk management process

Risk identification: Risk identification is achieved through inspection and analysis of historical events. It may involve multiplicity of techniques and safety audits and analysis.

Risk evaluation: Risk evaluation may be based on economic, social; or legal consideration. In this respect, vulnerability and potential impact assessment of all division of systems should be considered.

Risk control: Risk control strategies may be classified into four main areas:

- **Risk avoidance:** Risk avoidance involves a conscious decision on the part the organization to avoid completely a particular risk by discontinuing the operation producing the risk and it presupposes that the risk has been identified and evaluated.

- **Risk retention:** The risk is retained in the organization or region where any consequent loss can be covered by company, organization or local government. Risk retention can be with or without knowledge of organization.

- **Risk transfer:** Risk transfer refers to the legal assignment of the costs of certain potential losses from one party to another. The most common way of affecting such transfer is by insurance.

- **Risk reduction:** The principles of risk reduction rely on the reduction of risk within the organization by the implementation of a loss control program or effective remedial action.

5.4. Risk management program implementation

The abovementioned risk control strategies should be linked to a program as part of a general decision framework for implementation under continuous monitoring.

6. The Drought Management Strategies

Drought management involves several action programs.

6.1. Assessing and forecasting the drought events.

This includes: I Climate forecasting which involves detail analysis of climatic parameters, development of appropriate drought intensity indices, drawing a regional or continental drought sensitivity map and establishing a monitoring system to assess the harmful effect of drought. II. Design and Implementation of common monitoring system which involves establishing a continuous service of drought, forecast to help farmers, water management experts and other stakeholders and use of all different audio and visual media for disseminating knowledge (Nirizi, 2003). Examples of forecast are shown in figures 14, 15, and 16. Figure 14 shows the forecast of daily stream flow, Figure 15 shows the forecast of daily soil moisture, Figure 16 shows the daily forecast of the drought and Figure 17 shows the forecast of seasonal drought levels. Stream flow forecast can be found at the following web site: http://water.USGS.gov/waterwatch.

6.2. Adoption of preventive measures

This is based on:

Developing more water supplies: that involves development of new supplies i.e. construction of dams, reservoirs, wells and canals, controls flooding and captures water otherwise lost to the sea and other sinks, more efficient use of existing water recourses and use of non-conventional water resources (treated wastewater, desalination of brackish and saline water, wastewater treatment and reuse), water transfers, artificial precipitation, and conjunctive use of surface and groundwater. The alternative supplies such as reclaimed wastewater is increasingly used. There has been a significant increase in the availability and the use of treated wastewater in meeting the industrial and agricultural needs. Desalination can offer limitless fresh water as salty water represents 97% of the global water resources. In 1997 the global desalination capacity reached 18 Mm^3 /day Most of these in the Middle East and the Persian Gulf region where water is scarce but money is not. Table 3 shows the use of non-conventional water resources in some Mediterranean countries.

Developing innovative solutions to increase the water supply: that involves new solutions to harvest rainwater. These could be based on old techniques used in the past especially in the deserts. Desalination of seawater by reverse osmosis (is electricity consuming), evaporation using solar /wind energy (less expensive). The cost of desalination is three to five times the cost of tapping groundwater. Brackish water could be desalinated but a cheaper is to develop salt tolerant crops that can be irrigated with this water either mixed with fresh (to dilute) or alone. The use of treated waste water for irrigation and other purposes is another significant water supply that is always available.

Adopting real- time management of water supplies*:* improved real time management is alternative to investment in new supplies. Improved joint operation of basin wide facilities and reallocation of supplies among different users is a key factor to ease water constraints. In order to combat drought, there are major challenges ahead that would require: to shift from water policies based on water supply management to new policies that favour the management of water demand; to shift from preoccupation with development of water resources by major construction programs towards a more balanced approach that should emphasize: water demand management; water conservation and efficient use of water; water pricing and cost recovery; sustainable use of non-conventional water resources; water quality management; capacity building development; and tailored education and training.

Table 3. Use of non-conventional water resources in some Mediterranean countries (FAO, 2000).

COUNTRY	Total water withdrawal		Desalinated water		Reused treated wastewater		Use of desalinated water and treated wastewater	
	Year	million m^3/year *(1)*	Year	million m^3/year *(2)*	Year	million m^3/year *(3)*	million m^3/year *(4)=(2)+(3)*	as % of total per year *100*(4)/(1)*
ALGERIA	1990	4 500,0	1990	64,00		-	64,00	1,422
BAHRAIN	1991	239,2	1991	44,10	1991	8,03	52,13	21,793
CYPRUS *	1993	211,0		-	1995	11,00	11,00	5,213
EGYPT	1993	55 100,0	1990	25,00	1993	200,00	225,00	0,408
IRAN	1993	70 034,0	1991	2,90		-	2,90	0,004
IRAQ	1990	42 800,0		-		-	-	-
JORDAN	1993	984,0	1993	2,00	1991	50,30	52,30	5,315
KUWAIT	1994	538,0	1993	231,00	1994	52,00	283,00	52,602
LEBANON	1994	1 293,0		-	1991	2,00	2,00	0,155
LIBYA	1994	4 600,0	1994	70,00	1990	100,00	170,00	3,696
MALTA	1995	55,7	1995	31,40	1993	1,56	32,96	59,174
MOROCCO	1991	11 045,0	1992	3,40		-	3,40	0,031
OMAN	1991	1 223,0	1995	34,00	1991	26,00	60,00	4,906
QATAR	1994	284,9	1995	98,60	1994	25,20	123,80	43,454
SAUDI ARABIA	1992	17 018,0	1995	714,00	1992	217,00	931,00	5,471
SYRIA	1993	14 410,0		-	1993	370,00	370,00	2,568
TUNISIA	1990	3 075,0	1990	8,30	1993	20,00	28,30	0,920
TURKEY	1992	31 600,0	1990	0,50		-	0,50	0,002
UNITED ARAB EM.	1995	2 108,0	1995	385,00	1995	108,00	493,00	23,387

* ***Cyprus*: total water withdrawal refers to the government controlled area**

Adopting more efficient demand management system: that involves conserving resources that are rare and/or costly to produce; to minimize the cost and effort of providing water; to limit disputes over use, to make the best use of water, to reduce demand or, at least, slowdown its increase; to safeguard the rights of access to water for future generations; to ensure equitable water distribution, to alter the factors governing water requirements and adapt the sectoral structure of water use, promoting the most effective, to maximize the socio-economic output of a unit volume of water and hence to increase efficiency of water use and to coordinate and maximize multiple uses of the limited quantity of water. Methods can take different forms, from direct measures to control water use, to indirect measures that affect voluntary behaviour (market mechanisms, financial incentives, public awareness programs). Methods include reducing water losses, modification of water demand at farm level, using low water consumption systems in industry and urban development, development of cropping pattern for less water consumption, development of non-structural approaches for reduction of water demand and developing appropriate regulations and guidelines. Measures include pprohibiting car wash, garden watering during droughts, rotational delivery of water for surface irrigation, controlling cropping patterns and rotation and regulation of groundwater abstractions to prevent over-abstractions using the administrative capacity for direct controls. Regulation can also be through indirect measures such as regulating the spaces between wells or the number of drilling rigs.

The desirable balance between supply and demand management measures varies over time as conditions evolve. The speed by which the shortages are emerging will inevitably make some governments to face the difficult issues associated with reallocation between uses.

Reducing demand on fresh water: Directing water policies toward cutting the demand using the advanced technology is a key factor. Present computer systems can monitor flows and pressure, can detect leaks and can prevent water wastage, whether in industrial or urban water-distribution networks. Market-oriented approach to water should be adopted using price incentive to encourage savings. Leaks and evaporation should be reduced; these could amount to 60% in urban areas. It is 30% in Damascus, Malta 65% and Greece cities 45%. An evaporation rate in North Africa is 2 m per year and losses from surface waters and reservoirs can be great. For Example, evaporation losses from Lake Nasser are 14%.

Increasing irrigation system efficiency: the overall global average of agricultural water use efficiency is 40%, meaning that more than half of the water allocated for agriculture never produces food. There is no doubt that improving the irrigation efficiency using new technologies such as new sprinkler design with low- energy application can increase efficiency from 60%-70% to 90% as high as the drip irrigation. Another way of increasing the use efficiency is to adopt supplementary and deficit-irrigation. Sensors linked to computer system can control flow of water in pipes and irrigation can be applied at night to reduce evaporation losses. The capital costs are high but the saving in water is substantial (between 30% to 50%). Drip irrigation is highly efficient system and should be widely used. Leak detection and repair programs, low water use devices and small supply pipes, canal lining and improved conveyance technologies can save significant amount of water. Surface irrigation can be improved through land levelling or replaced by sprinkler or drip irrigation systems. The latter in particular saves more water and allowing fewer losses by evaporation and deep percolation. It could also be rewarding if careful users were given incentives to invest in water saving technology, water recycling and dual distribution networks (fresh and poor quality water / irrigation and drainage water)

Water resources recycling: Treated wastewater of cities and farms can be recycled or reused for irrigation. This is already taking place in Cyprus, Morocco, Egypt, Libya, and Tunisia.

6.3. Developing instruments and tools to reduce the drought damage

*In Agricultural***:** This includes optimum choice of land use, reasonable selection of crop varieties, soil physical properties and fertility improvement and crop yield insurance and damage compensation. II. *In Environment:* This includes: environmental impact assessment and introducing remedial actions, groundwater quality and quantity monitoring and action plan, and wild life preservation program under drought conditions. III. *In Economical and social aspects:* This includes: drought impact assessment on different societies and groups, elaboration of government and local authority capacities for drought mitigation including, investment, available funds and subsidies, diversification of trade activities and investment out side of the affected region and improvement of insurance systems and relief funds. IV. *Risk assessment***:** This includes risk assessment to determine the branches of the economy and society damaged by drought. V. *Organization and coordination: t*his could include establishing national drought commission consisting of government, regional authority and related NGOs, involving different specialists in formulation of the national drought strategies and task allocation in an action program for all parties involved should be defined, and their duties could be categorized in three subcommittees: monitoring, impact and vulnerability assessment and mitigation and responses. VI. *Strategic planning of water resources for drought conditions:* At present, there is more awareness among decision-makers about the urgent need to take proactive approach in drought management. In advance measures are the key factors in the proactive approach (Bazza, 2003). These measures are planning strategies to prepare for drought and to mitigate its effects when it happens. An effective planning process should take place before the onset of drought and implemented before drought starts until some time after it has ceases. The planning process is a continuous process and should never end in drought prone countries. It should be subjected to evaluation and amendments to cope with ever changing climatic conditions.

The strategic planning of water resources management for drought consists of long-term and short term actions. The long term action aims at reducing the vulnerability of water supply systems to drought, i.e. to improve the reliability of each system to meet future demands under drought conditions by a set of appropriate structural and institutional measures. The short-term actions are to deal with a specific incoming drought event within the existing framework of infrastructures and management policies.

The main objective of the long-term actions as a proactive approach is to make adjustment to drought as well as to the normal conditions. Examples are: the increase of water storage capacity (building new reservoirs, dams, lakes, etc.), the adoption of water saving technology, the indirect recharge of groundwater aquifers, etc. Depending largely on the severity of drought, the long-term actions may or may not eliminate completely the drought risks. These long term actions are better supported by a supplement of short-term actions taken during what is so called a drought contingency plan. The plan is implemented during drought but the shift to it is usually gradual reflecting the progressive onset of drought. An effective water resources plan is one that has an optimal combination of both long and short term measures.

The measures contained in long and short term actions can also be regrouped into three types I. water-supply oriented measures; II. water-demand oriented measures and III. drought impact minimization measures (Bazza, 2003). The measures associated with supply management aim at increasing the available water supplies, whereas those associated with demand management aim at improving the efficient use of the available resources. These two categories of measures aiming at reducing the risk of water shortage due to a drought event, while the drought impact minimization measures is geared towards minimization of the environmental, economic and social impacts of drought. In reality, these measures are interrelated and sometimes overlap but such interrelationships could be necessary to meet the objectives

6.4. Minimizing the drought impacts

This includes development of early warning system, reallocation of water resources on the basis of water quality requirements, use of drought resistant plants, development of a drought contingency plan, mitigation of economic and social impacts through voluntary insurance, pricing and economic incentives, education activities for improving preparedness to drought and elaborate set-aside regulations

7. The Drought Mitigating

Mitigating drought by taking actions in advance of drought to reduce its long-term risk can involve a wide range of tools. These tools include policies, activities, plans, and programs.

7.1. Drought mitigation tools: examples from the USA

Wilhite (1993) and Najarian (2000) surveyed U.S. states to report on actions taken in response to recent droughts. Wilhite (1993) divided the mitigation strategies into 9 categories: assessment programs, legislation/public policy, water supply augmentation, public awareness/education programs, technical assistance, demand reduction/water conservation programs, emergency response programs, water use conflict resolution and drought contingency plans.

Drought contingency plans form the core of these strategies, although mitigative actions are not restricted to states with plans. The strategies are diverse, reflecting regional differences in impacts, legal and institutional constraints, and characteristics of contingency plans. Najarian (2000) categorized mitigation actions according to 11 impact sectors (Water Availability, Municipal Water, Water Shortage/Conservation Activities, Agricultural Industry, Public Information and Education, Fish/Wildlife Preservation, Health, Commerce and Tourism/Economy, Wildfire Protection/Forestry/Public Lands, Energy, and Social), based on survey results from the mid to late 1990s.

Assessment Programs

Specific actions taken by states are developed criteria or triggers for drought-related actions, developed early warning system, monitoring program, conducted inventories of data availability, established new data collection networks and monitored vulnerable public water suppliers.

Legislation/Public Policy

Specific actions taken by states are prepared position papers for legislature on public policy issues, examined statutes governing water rights for possible modification during water shortages, passed legislation to protect in-stream flows, passed legislation providing guaranteed low-interest loans to farmers and imposed limits on urban development.

Water Supply Augmentation

Specific actions taken by states are issued emergency permits for water use, provided pumps and pipes for distribution, proposed and implemented program to rehabilitate reservoirs to operate at design capacity, undertook water supply vulnerability assessments, inventoried self-supplied industrial water users for possible use of their supplies for emergency public water supplies and inventoried and reviewed reservoir operation plans.

Public Awareness/Education Programs

Specific actions taken by states are organized drought information meetings for the public and the media, implemented water conservation awareness programs, published and distributed pamphlets on water conservation techniques and agricultural drought management strategies, organized workshops on special drought-related topics, prepared sample ordinances on water conservation and established a drought information center.

Technical Assistance

Specific actions taken by states are provided advice on potential new sources of water, evaluated water quantity and quality from new sources, advised water suppliers on assessing vulnerability of existing supply systems and recommended that suppliers adopt water conservation measures.

Demand Reduction/Water Conservation Programs

Specific actions taken by states are established stronger economic incentives for private investment in water conservation encouraged voluntary water conservation, improved water use and conveyance efficiencies and implemented water metering and leak detection programs.

Emergency Response Programs

Specific actions taken by states are established alert procedures for water quality problems, stockpiled pumps, pipes, water filters, and other equipment, established water hauling programs for livestock, listed livestock watering locations, established hay hotline, funded water system improvements, new systems, and new wells, funded drought recovery programs, lowered well intakes on reservoirs for rural water supplies, extended boat ramps and docks in recreational areas, issued emergency irrigation permits for using state waters for irrigation, created low-interest loan and aid programs for agricultural sector, created drought property tax credit program for farmers and established a tuition assistance program for farmers to enroll in farm management classes.

Water Use Conflict Resolution

Specific actions taken by states are resolved emerging water use conflicts, negotiated with irrigators to gain voluntary restrictions on irrigation in areas where domestic wells were likely to be affected, clarified state law regarding sale of water, clarified state law on changes in water rights, suspended water use permits in watersheds with low water levels and investigated complaints of irrigation wells interfering with domestic wells.

Drought Contingency Plans

Specific actions taken by states are established statewide contingency plan, recommended that water suppliers develop drought plans, evaluated worst-case drought scenarios for possible further actions and established natural hazard mitigation council.

Continuous monitoring

All the above steps should be continuously monitored in order to be sure about the stage of preparedness for any hazard occurrence.

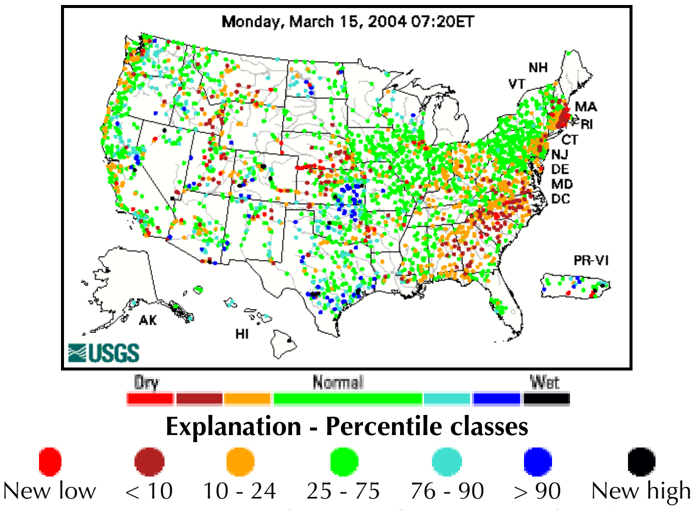


Fig. 14. Continuous monitoring of stream flow. Map of real-time stream flow compared to historical stream flow for the day of the year in USA (source:http://water.USGS.gov/waterwatch)

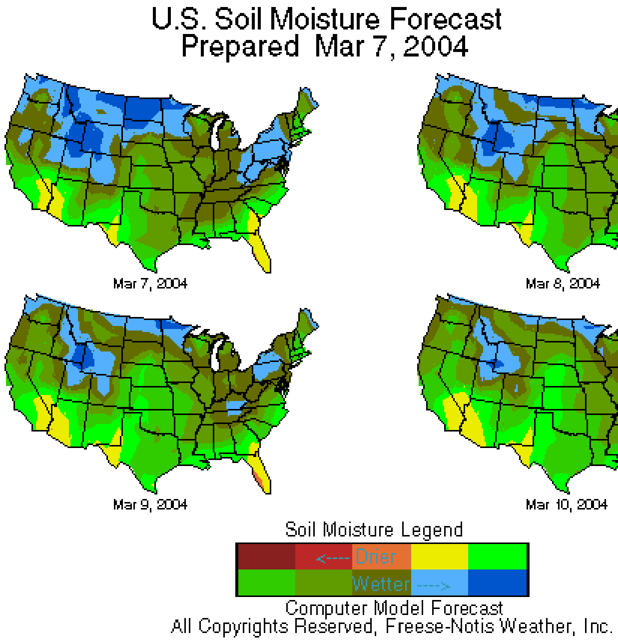


Fig. 15. Soil moisture forecast (source: Frees-Notis Weather, Inc)

Note on Soil Moisture maps:

Full Field:	unit is mm and the maximum is set to be 760 mm in the model. With a porosity of 0.47 this corresponds to a model depth of about to 1.6 meters
Wetness:	ratio of calculated soil moisture (mm) to the maximum (760 mm)
Anomaly:	departure from 1971-2000 Climatology (unit: mm)
Ranking Percentile:	from 1932-2000 period

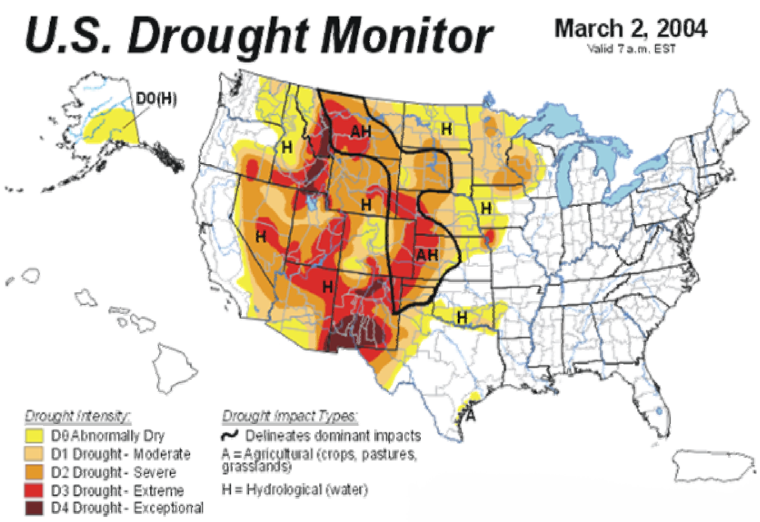


Fig. 16. USA daily drought monitoring, (source: Richard Tinker, NOAA).

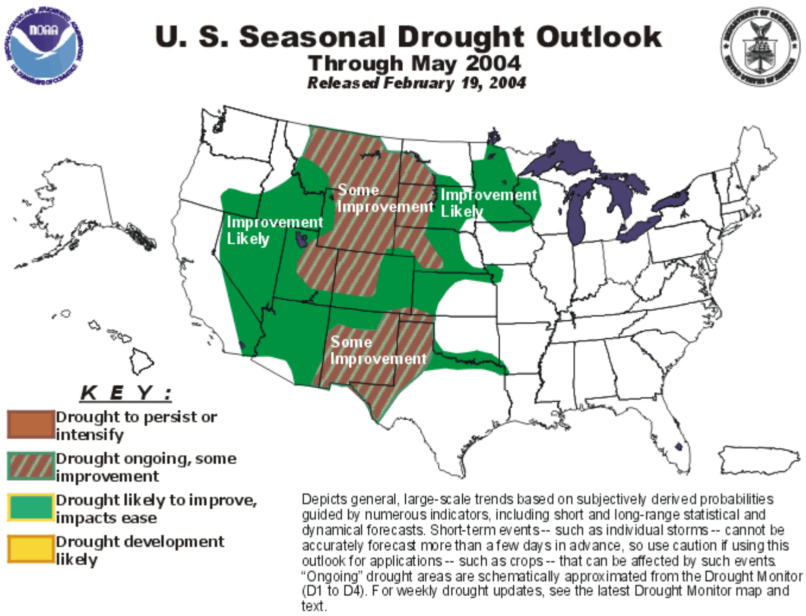


Fig. 17. Seasonal forecast of drought (Source: NOAA).

8. Monitoring the Drought

Whatever the reasons for drought appearance, the fact remains that it causes serious problems(economic, environmental and in extreme cases problems of human survival). Drought itself as a periodic phenomenon does not result in permanent or irreversible changes of the environment.

Drought adversely affects the economy by reducing, or even eliminating, agricultural production, herds of cattle, energy generation, and domestic and industrial water supply. In agriculture drought is described in terms of reduced yields resulting from insufficient soil moisture.

In order to assess the degree of severity of a given drought period it is not sufficient to give a simple qualitative appraisal. A quantitative parameter or index is necessary to characterize the intensity of the event. Several indices are used to describe the features of drought and their harmful impacts on both the environment and the living organisms.

Because there is no single definition for drought, its onset and termination are difficult to determine. One can, however, identify various indicators of drought to provide crucial means of monitoring drought. Determining which indicators to use poses more difficulties for planners: should they rely on data collected for specific parameters (such as stream flow?), or should they select one or more indices, which incorporate and weigh various types of data in various combinations? Equally important in choosing these indicators is a consideration of the type or types of water shortage facing the planner—an index or parameters well suited to agricultural concerns are of limited use to urban planners.

Drought indices assimilate large number of data on rainfall, snow pack, stream flow, and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, far more useful than raw data for decision making.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. For example, the Palmer Drought Severity Index has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance, but the Palmer is better when working with large areas of uniform topography. Western states, with mountainous terrain and the resulting complex regional microclimates, find it useful to supplement Palmer values with other indices such as the Surface Water Supply Index, which takes snow pack and other unique conditions into account.

The National Drought Mitigation Center is using a newer index, the Standardized Precipitation Index, to monitor moisture supply conditions. Distinguishing traits of this index are that it identifies emerging droughts months sooner than the Palmer Index and that it is computed on various time scales. Most water supply planners find it useful to consult one or more indices before making a decision as the case in the United States and in Australia.

8.1. The drought indices

8.1.1. Standardized Precipitation Index (SPI). Developed by McKee *et al*. 1993.

Based on the understanding that a deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snow-pack, and stream-flow. The SPI is an index based on precipitation only. It can be used on a variety of time scales, which allows it to be useful for both short-term agricultural and long-term hydrological applications. The SPI is an index based on the probability of precipitation for any time scale. Many drought planners appreciate the SPI's versatility. The SPI can be computed for different time scales, can provide early warning of drought and help assess drought severity, and is less complex than the Palmer. Values based on preliminary data may change.

SPI Values

2.0 +	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using the SPI.

McKee *et al.* (1993) used the classification system shown in the SPI values table to define drought intensities resulting from the SPI. McKee *et al.* (1993) also defined the criteria for a drought event for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude". More information can be found at the following web site: http://www.wrcc.dri.edu/spi/spi.html.

8.1.2. Palmer Drought Severity Index (The Palmer; PDSI): Developed by Palmer, 1965.

The Palmer index is a soil moisture algorithm calibrated for relatively homogeneous regions. Many U.S. government agencies and states rely on the Palmer to trigger drought relief programs. It is the first comprehensive drought index developed in the United States.

Palmer values may lag emerging droughts by several months; less well suited for mountainous land or areas of frequent climatic extremes; complex and has an unspecified and built-in time scale that can be misleading.

Palmer is an index developed to measure the departure of the moisture supply. Palmer based his index on the supply-and-demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific locations. The objective of the Palmer Drought Severity Index (PDSI), as this index is now called, was to provide measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between months. A procedure of a step by step calculation of the palmer Index is given in the following web site:

http://nadss.unl.edu/info/pdsi_doc/steps.html. Weekly maps can also be obtained from the following web site: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif.

Palmer Classifications

4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderately wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to -0.49	near normal
-0.5 to -0.99	incipient dry spell
-1.0 to -1.99	mild drought
-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
-4.0 or less	extreme drought

The PDSI is a meteorological drought index, and it responds to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking into account stream flow, lake and reservoir levels, and other longer-term hydrologic impacts.

The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil.

From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. Human impacts on the water balance, such as irrigation, are not considered. Complete descriptions of the equations can be found in the original study by Palmer (1965) and in the more recent analysis by Alley (1984).

Palmer developed the PDSI to include the duration of a drought (or wet spell). The motivation was as follows: an abnormally wet month in the middle of a long-term drought should not have a major impact on the index, or a series of months with near-normal precipitation following a serious drought does not mean that the drought is over. Therefore, Palmer developed criteria for determining when a drought or a wet spell begins and ends, which adjust the PDSI accordingly. In near-real time, Palmer's index is no longer a meteorological index but becomes a hydrological index referred to as the Palmer Hydrological Drought Index (PHDI) because it is based on moisture inflow (precipitation), outflow, and storage, and does not take into account the long-term trend (Karl and Knight, 1985).

In 1989, a modified method to compute the PDSI operationally took place (Heddinghaus and Sabol, 1991). This modified PDSI differs from the PDSI during transition periods between dry and wet spells. Because of the similarities between these Palmer indices, the terms *Palmer Index* and *Palmer Drought Index* have been used to describe general characteristics of the indices.

The Palmer Index varies roughly between -6.0 and +6.0. The Palmer Index has typically been calculated on a monthly basis. In addition, weekly Palmer Index values (actually modified PDSI values) are calculated for the climate divisions during every growing season and are also calculated. Figure 18 shows the distributed values of the Palmer Drought Index on March, 2004 for the whole USA.

The Palmer Index is popular and has been widely used for a variety of applications across the United States. It is most effective measuring impacts sensitive to soil moisture conditions, such as agriculture (Willeke *et al.*, 1994). There are considerable limitations when using the Palmer Index, and these are described in detail by Alley (1984) and Karl and Knight (1985). Drawbacks of the Palmer Index include:

1. The values quantifying the intensity of drought and signaling the beginning and end of a drought or wet spell were arbitrarily

selected based on Palmer's study of central Iowa and western Kansas and have little scientific meaning.

2. The Palmer Index is sensitive to the AWC of a soil type. Thus, applying the index for a climate division may be too general.

3. The two soil layers within the water balance computations are simplified and may not be accurately representative of a location.

4. Snowfall, snow cover, and frozen ground are not included in the index. All precipitation is treated as rain, so that the timing of PDSI or PHDI values may be inaccurate in the winter and spring months in regions where snow occurs.

5. The natural lag between when precipitation falls and the resulting runoff is not considered. In addition, no runoff is allowed to take place in the model until the water capacity of the surface and subsurface soil layers is full, leading to an underestimation of runoff.

6. Potential evapotranspiration is estimated using the Thornthwaite method. This technique has wide acceptance, but it is still only an approximation.

Several other researchers have presented additional limitations of the Palmer Index. McKee *et al.* (1995) suggested that the PDSI is designed for agriculture but does not accurately represent the hydrological impacts resulting from longer droughts. Also, the Palmer Index is applied within the United States but has little acceptance elsewhere (Kogan, 1995). One explanation for this is provided by Smith *et al.* (1993), who suggested that it does not do well in regions where there are extremes in the variability of rainfall or runoff. Examples in Australia and South Africa were given. Another weakness in the Palmer Index is that the "extreme" and "severe" classifications of drought occur with a greater frequency in some parts of the country than in others (Willeke et *al.*, 1994). "Extreme" droughts in the Great Plains occur with a frequency greater than 10%. This limits the accuracy of comparing the intensity of droughts between two regions and makes planning response actions based on certain intensity more difficult.

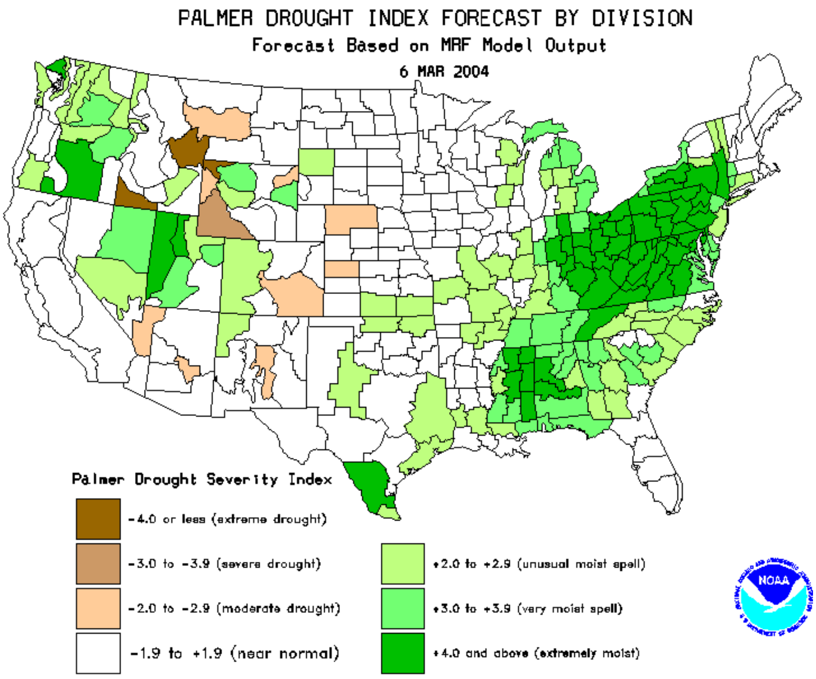


Fig. 18. Palmer Drought Index over USA on March 6, 2004 (Source: Climate Prediction Centre, NOAA).

8.1.3. Crop Moisture Index (CMI): Developed by Palmer, 1968.

A Palmer derivative, the CMI reflects moisture supply in the short term across major crop-producing regions and is not intended to assess long-term droughts. It identifies potential agricultural droughts. The Crop Moisture Index (CMI) uses a meteorological approach to monitor week-to-week crop conditions. It was developed from procedures within the calculation of the PDSI. Whereas the PDSI monitors long-term meteorological wet and dry spells, the CMI was designed to evaluate short-term moisture conditions across major crop-producing regions. It is based on the mean temperature and total precipitation for each week within a climate division, as well as the CMI value from the previous week. The CMI responds rapidly to changing conditions, and it is weighted by location and time so that maps, which commonly display the weekly CMI across the United States, can be used to compare moisture conditions at different locations. Because it is designed to monitor short-term moisture conditions affecting a developing crop, the CMI is not a good long-term drought monitoring tool. The CMI's rapid response to changing short-term conditions may provide misleading information about long-term conditions. For example, a beneficial rainfall during a drought may allow the CMI value to indicate adequate moisture conditions, while the long-term drought at that location persists. Another characteristic of the CMI that limits its use as a long-term drought monitoring tool is that the CMI typically begins and ends each growing season near zero. This limitation prevents the CMI from being used to monitor moisture conditions outside the general growing season, especially in droughts that extend over several years. The CMI also may not be applicable during seed germination at the beginning of a specific crop's growing season. Weekly maps can be obtained at the following web site:

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/cmi.gif.

Weekly maps of the CMI are also available as part of the USDA/JAWF Weekly Weather and Crop Bulletin (http://www.usda.gov/oce/waob/jawf/wwcb.html).

8.1.4. Surface Water Supply Index (SWSI): Developed by Shafer and Dezman, 1982.

The SWSI was designed to complement the Palmer in the state of Colorado, where mountain snow-pack is a key element of water supply; calculated by river basin, based on snow-pack, stream-flow, precipitation, and reservoir storage. SWSI represents water supply conditions unique to each basin. Changing a data collection station or water management requires that new algorithms be calculated, and the index is unique to each basin, which limits inter-basin comparisons.

The Palmer Index is basically a soil moisture algorithm calibrated for relatively homogeneous regions, but it is not designed for large topographic variations across a region and it does not account for snow accumulation and subsequent runoff. The authors designed the SWSI to be an indicator of surface water conditions and described the index as "mountain water dependent", in which mountain snow-pack is a major component.

The objective of the SWSI was to incorporate both hydrological and climatological features into a single index value resembling the Palmer Index for each major river basin in the state of Colorado (Shafer and Dezman 1982). These values would be standardized to allow comparisons between basins. Four inputs are required within the SWSI: snow pack, stream flow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI is computed with only snow-pack, precipitation, and reservoir storage in the winter. During the summer months, stream-flow replaces snow-pack as a component within the SWSI equation.

The procedure to determine the SWSI for a particular basin is as follows: monthly data are collected and summed for all the precipitation stations, reservoirs, and snow-pack/stream-flow measuring stations over the basin. Each summed component is normalized using a frequency analysis gathered from a long-term data set. The probability of non-exceedence: the probability that subsequent sums of that component will not be greater than the current sum is determined for each component based on the frequency analysis. This allows comparisons of the probabilities to be made between the components. Each component has a weight assigned to it depending on its typical contribution to the surface water within that basin, and these weighted components are summed to determine a SWSI value representing the entire basin. Like the Palmer Index, the SWSI is centered on zero and has a range between -4.2 and +4.2.

The SWSI has been used, along with the Palmer Index, to trigger the activation and deactivation of the Colorado Drought Plan. One of its advantages is that it is simple to calculate and gives a representative measurement of surface water supplies across the state.

Several characteristics of the SWSI limit its application. Because the SWSI calculation is unique to each basin or region, it is difficult to compare SWSI values between basins or regions (Doesken *et al.*, 1991). Within a particular basin or region, discontinuing any station means that new stations need to be added to the system and new frequency distributions need to be determined for that component. Additional changes in the water management within a basin, such as flow diversions or new reservoirs, mean that the entire SWSI algorithm for that basin needs to be redeveloped to account for changes in the weight of each component. Thus, it is difficult to maintain a homogeneous time series of the index (Heddinghaus and Sabol, 1991). Extreme events also cause a problem if the events are beyond the historical time series, and the index will need to be reevaluated to include these events within the frequency distribution of a basin component. Monthly SWSI maps for Montana are available from the Montana Natural Resource Information System (http://nris.state.mt.us/wis/SWSInteractive/).

8.1.5. Reclamation Drought Index

Developed by the Bureau of Reclamation in USA as a trigger to release drought emergency relief funds. Like the SWSI, the RDI is calculated at the river basin level, incorporating temperature as well as precipitation, snow-pack, stream-flow, and reservoir levels as input. By including a temperature component, it also accounts for evaporation. Because the index is unique to each river basin, inter-basin comparisons are limited.

RDI Classifications

4.0 or more	extremely wet
1.5 to 4.0	moderately wet
1 to 1.5	normal to mild wetness
0 to -1.5	normal to mild drought
-1.5 to -4.0	moderate drought
-4.0 or less	extreme drought

The Reclamation Drought Index (RDI) was developed as a tool for defining drought severity and duration, and for predicting the onset and end of periods of drought. Like the SWSI, the RDI is calculated at a river basin level, and it incorporates the supply components of precipitation, snow-pack, stream-flow, and reservoir levels. The RDI differs from the SWSI in that it builds a temperature-based demand component and duration into the index. The RDI is adaptable to each particular region and its main strength is its ability to account for both climate and water supply factors. The RDI values and severity designations are similar to the SPI, PDSI, and SWSI.

8.1.6. Deciles, developed by Gibbs and Maher, 1967.

The idea is to group monthly precipitation occurrences into deciles so that, by definition, "much lower than normal" weather cannot occur more often than 20% of the time. It is widely used in Australia and provides an accurate statistical measurement of precipitation. Accurate calculations require a long climatic data record.

Arranging monthly precipitation data into deciles is another drought-monitoring technique. It was developed to avoid some of the weaknesses within the "percent of normal" approach. The technique divides the distribution of occurrences over a long-term precipitation record into tenths of the distribution. They called each of these categories a decile. The first decile is the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications. The decile method was selected as the meteorological measurement of drought within the Australian Drought Watch System because it is relatively simple to calculate and requires less data and fewer assumptions than the Palmer Drought Severity Index (Smith *et al.*, 1993). In this system, farmers and ranchers can only request government assistance if the drought is shown to be an event that occurs only once in 20–25 years (deciles 1 and 2 over a 100-year record) and has lasted longer than 12 months (White and O'Meagher, 1995). This uniformity in drought classifications, unlike a system based on the percent of normal precipitation, has assisted Australian authorities in determining appropriate drought responses. One disadvantage of the decile system is that a long climatological record is needed to calculate the deciles accurately.

Decile Classifications

deciles 1-2: lowest 20%	much below normal
deciles 3-4: next lowest 20%	below normal
deciles 5-6: middle 20%	near normal
deciles 7-8: next highest 20%	above normal
deciles 9-10: highest 20%	much above normal

9. Combating Drought Through Water Saving Approaches

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.

10. 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 Figure 19. 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. Figure 20 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 mobilization 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; utilizing 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.

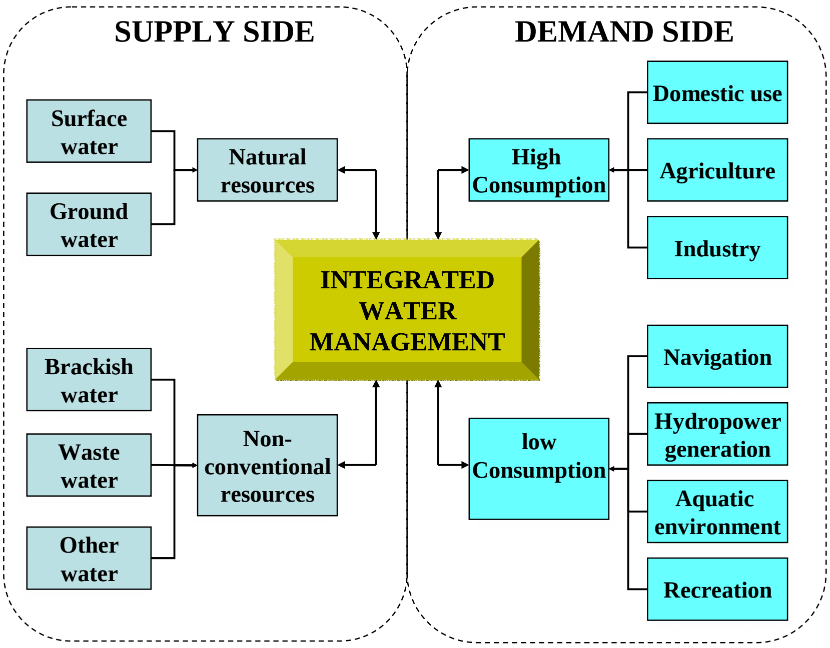


Fig. 19. The water management approach based on integration of water demand and supply.

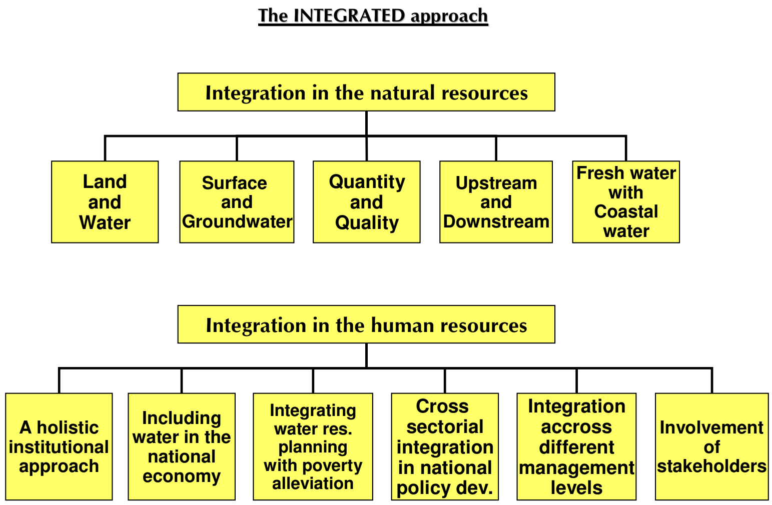


Fig. 20. The water management approach based on integration of natural and human resources.

11. Examples and Study Cases for Water Supply and Demand Management

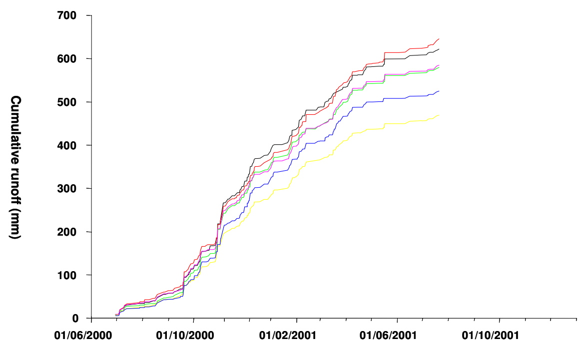
11.1. Rainfall harvesting from house roofs.

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 4 and Figure 21, 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.

Table 4. Rainfall harvested over house roofs in a residential area near Wallingford, UK

Site	JB	GP	AJ	IT	HA	CEH	Met Site
	29th June 2000 to 30th June 2001						
Measurement Period	Liters						
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
	Millimeters						
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	

a



b

Fig. 21. 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.

11.2. 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 figure 22. 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 certain storage capacity (Figure 23) and predict the runoff volume as shown in figure 24. More details can be found in Ragab *et al*. (2002 a,b,c) as well as in the following web:

www.ceh-wallingford.ac.uk/research/cairoworkshop

Fig. 22. Example for Rainfall harvest into mountain lakes/reservoirs, Tunisia

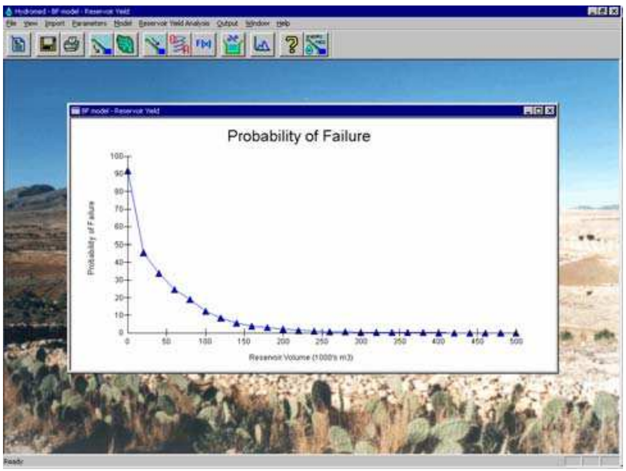


Fig. 23. Reservoir storage capacity using the HYDROMED model

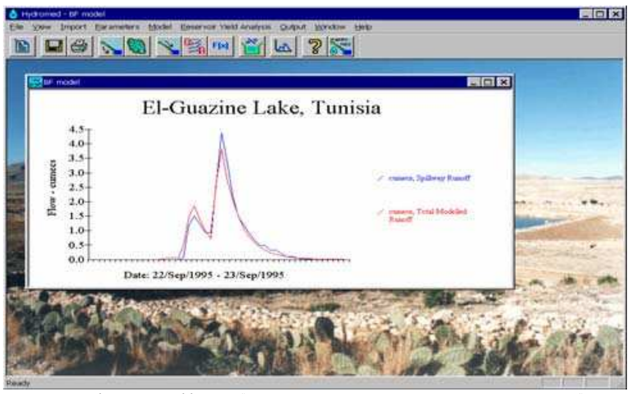


Fig. 24. Prediction of runoff volume to reservoir using the HYDROMED model

11.3. Use of 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. Figure 25 shows the experimental fields of tomato irrigated with saline water in Egypt and Syria. The model input data are shown in figures 26 to 30. These are Meteorological, irrigation, crop, soil data and initial values of soil moisture and salinity respectively. Figure 31 shows the list of possible outputs. The SALTMED model outputs are shown in figures 32 to 37. 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, downloading the software and the use of saline water can be found at the following web site:

www.ceh-wallingford.ac.uk/research/cairoworkshop

Model tests in Egypt and Syria are shown in Figures 38 and 39. The figures show that the SALTMED model is capable in predicting the tomato yield in Egypt and Syria. Other tests (e.g. soil moisture, soil salinity, water uptake, etc.) can be seen at the abovementioned web site.

Fig. 25. Using saline/brackish water to grow crops reduces the demand on fresh water

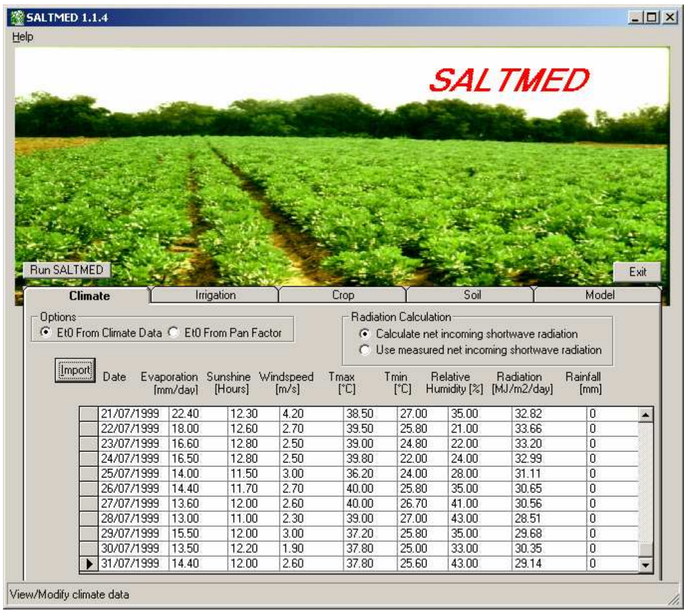


Fig. 26. Example of the meteorological data input file.

Fig. 27. Example of the irrigation data input file.

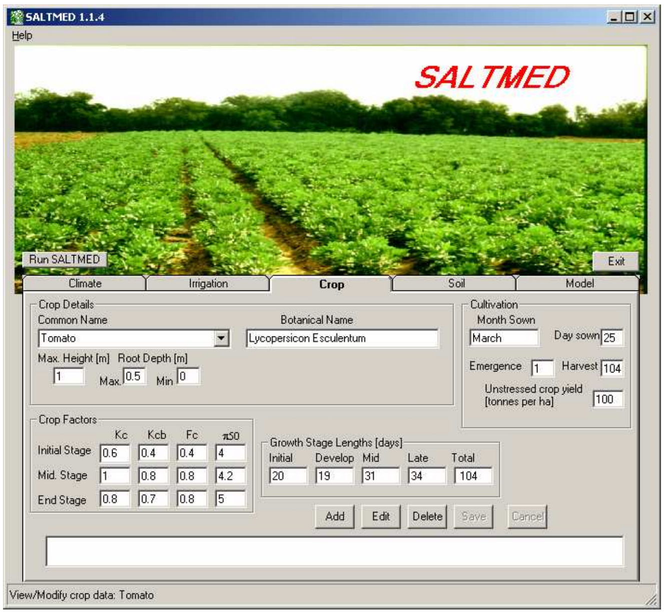


Fig. 28. Example of the crop parameters input menu.

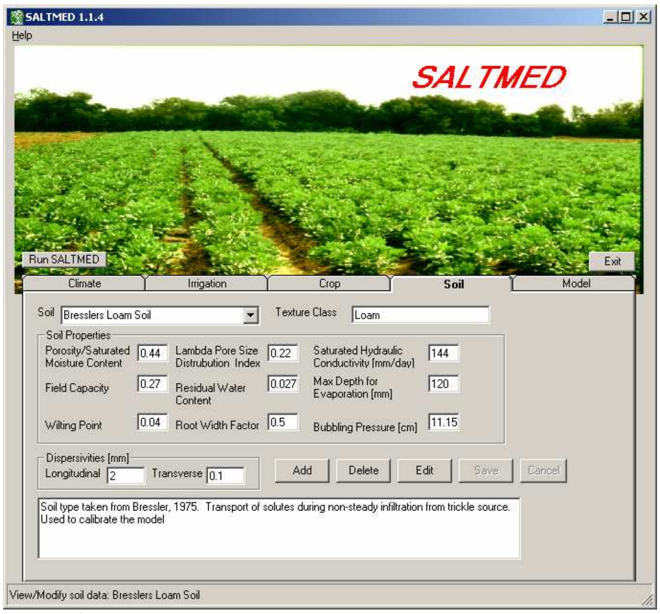


Fig. 29. Example of the soil parameters input menu.

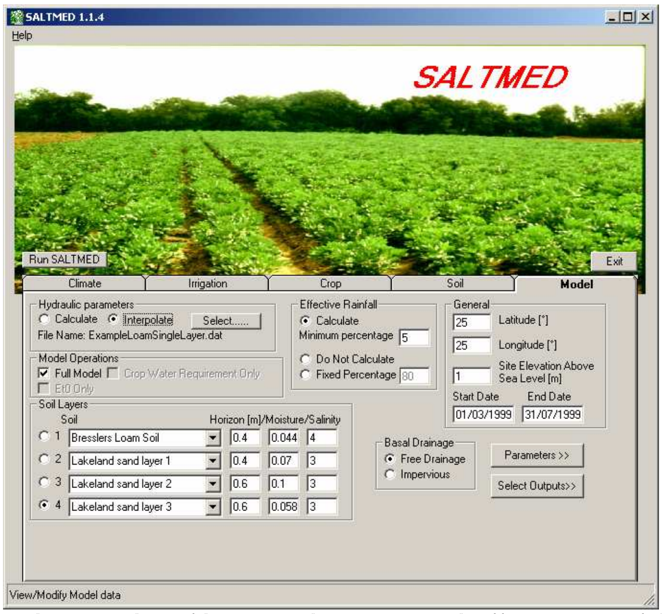


Fig. 30. The soil input data file, run, drainage and effective rainfall options.

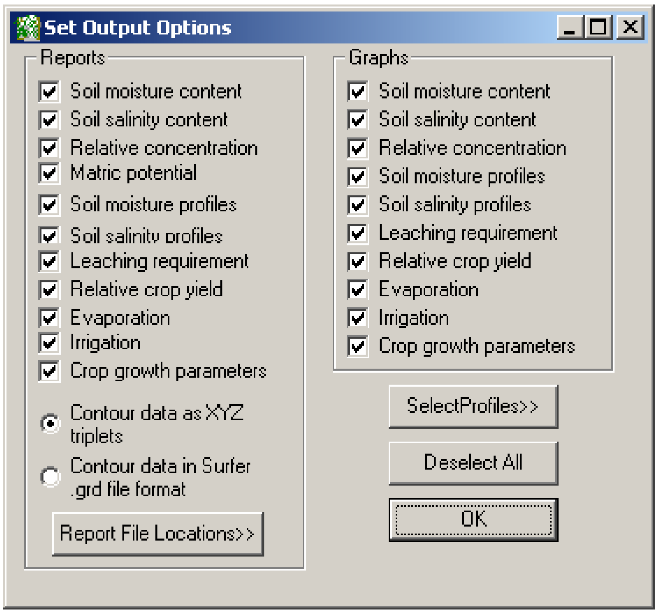


Fig. 31. The output option menu

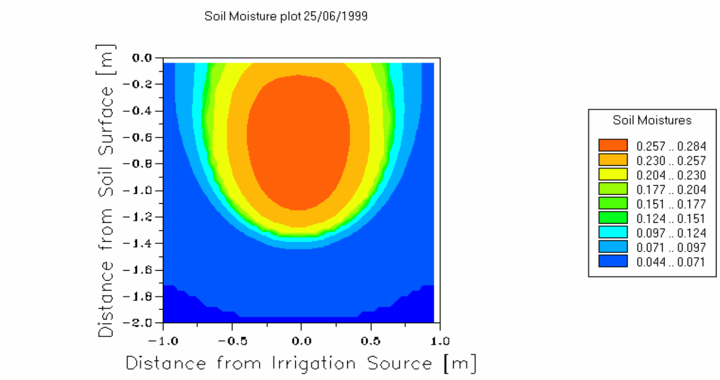


Fig. 32. Example of evolution of soil moisture profile over time under trickle line source (Bresler loam soil, 1975).

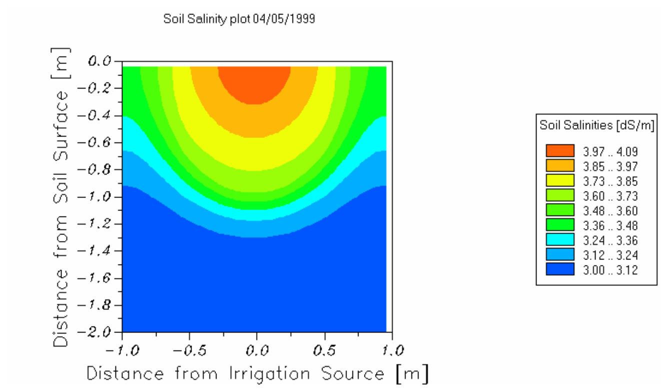


Fig. 33. Example of evolution of soil salinity profile over time under trickle line source.

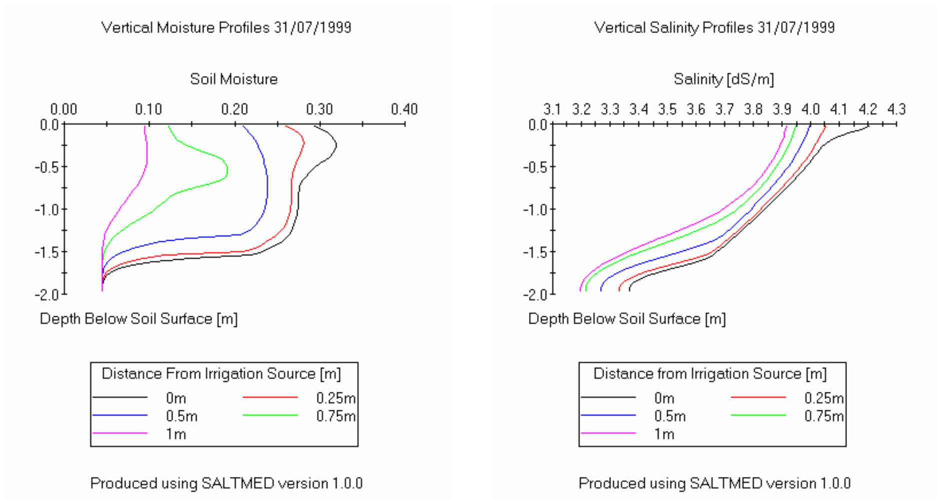


Fig. 34. Example of distribution of moisture and salinity under trickle line source.

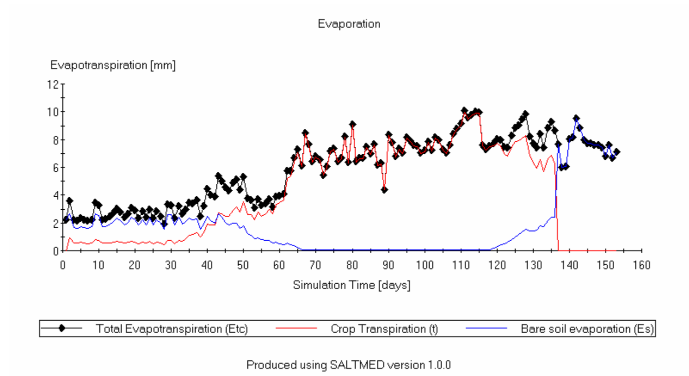


Fig. 35. Example of evolution of total crop evapotranspiration, transpiration and bare soil evaporation.

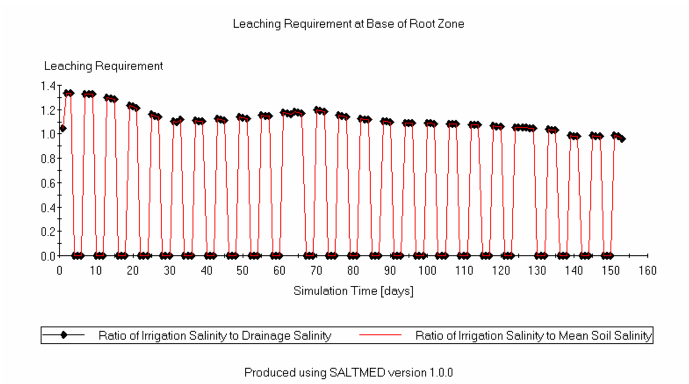


Fig. 36. Example of the leaching requirement over time.

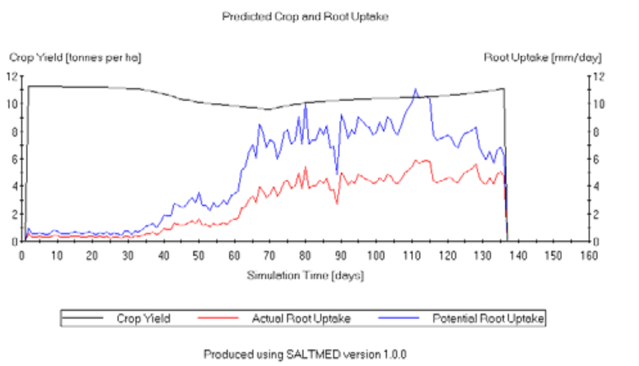


Fig. 37. Example of crop potential and actual water uptake and yield.

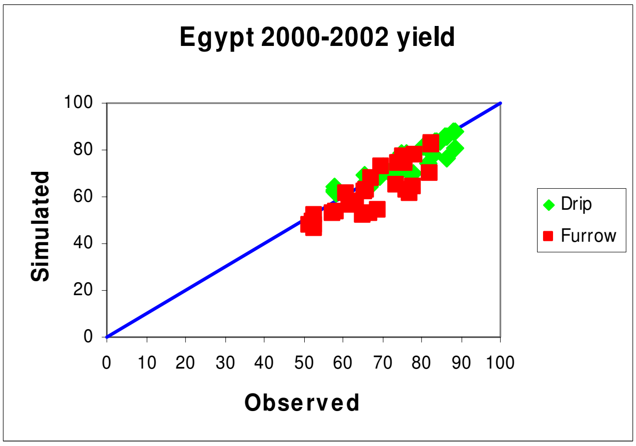


Fig. 38. Comparison between simulated and observed tomato yield under furrow and drip irrigation using saline water, Egypt, 2000-2002.

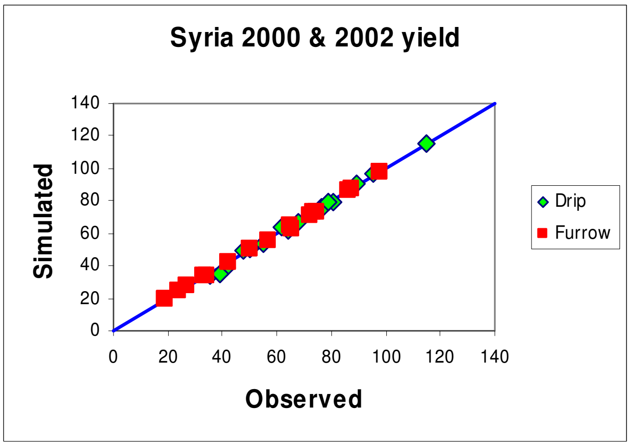


Fig. 39. Comparison between simulated and observed tomato yield under all drip and furrow irrigation using saline water, Syria, 2000-2002.

Conclusions

Drought is the most complex of all natural hazards as it affects more people than any other hazard. Drought should not be viewed only as a physical phenomenon or natural event as it has subsequent negative impact on the economic, environment and the society. The recent drought events highlighted the vulnerability of our societies to this natural hazard. In order to combat drought, a management strategies for short and long term should be in place. The drought Management strategies should include:

I. Climate forecasting, Design and Implementation of common monitoring system,

II. Developing new water supplies (through construction of dams, reservoirs, wells and canals, controls flooding and captures water otherwise lost to the sea, use of use of non-conventional water resources such as treated wastewater, desalinated brackish and saline water, water transfers, artificial precipitation, and conjunctive use of surface and groundwater), developing innovative solutions to increase the water supply (new solutions to harvest rainwater i.e. artificial precipitation and desalinate seawater and developing salt tolerant crops that can be irrigated with saline water),

III. Adopting rea - time management of supplies (i.e. reallocation of supplies among different users at crises time to ease water constraints),

IV. Adopting more efficient demand management system (i.e. reducing water losses, modification of water demand at farm level, using low water consumption systems in industry and urban development, development of cropping pattern for less water consumption, developing appropriate regulations and guidelines) and reducing demand (i.e. using advanced technology to monitor flows and pressure to detect leaks and prevent water wastage, adopting price incentive to encourage savings, using more efficient irrigation systems, adopt supplementary and deficit-irrigation and reusing treated wastewater of cities and farms),

V. Reducing drought impacts in Agriculture, Environment and society, coordination and organization (establishing national drought commission and subcommittee for monitoring, impact and vulnerability assessment and mitigation and responses) and strategic planning for short and long term (an effective planning process should take place before the onset of drought and implemented before drought starts until some time after it has ceases) and

VI. Minimizing the drought impacts through development of early warning system, reallocation of water resources, use of drought resistant plants, and development of a drought contingency plan. Simply, there is need to adopt an integrated water supply and demand management to combat drought.

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