Chapter 7
Adaptation of Contemporary Irrigation Systems to Face the Challenges of Future Climate Changes in the Mediterranean Region: A Case Study of the Lower Seyhan Irrigation System

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Abstract The Mediterranean region will be particularly affected by climate change over the 21st century. Rising temperatures and more marked drought periods will affect spatial and temporal precipitation and hence the water resources. This paper first reviews and evaluates the current and future social and environmental pressures on water resources, including climate change. The results show that pressures are not uniform across the region and sectors of water use. The changes in temperature and precipitation predicted by the general circulation models for the Mediterranean region will affect water availability and resource management, critically shaping the patterns of future crop production. The temperatures in the Mediterranean region are expected to rise by +2 to +3 °C by 2050, then by +3 to 5 °C by 2100. The water-poor countries are likely to be the most affected by 2100, and rainfall is likely to have decreased by 20–30% in the countries to the south, opposed to merely 10% in those to the north. The Mediterranean basin is thus predicted to be particularly sensitive to climate change.

This paper also evaluates the adaptation capacity of the Lower Seyhan Irrigation Project area to the future climate change as a case study. The case study reflects the

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outcomes of the Turkish Japanese bi-lateral project entitled “Impact of climate changes on the agricultural production system in arid areas-ICCAP”. The ICCAP project was launched in the Seyhan River Basin located in the east of the Mediterranean region of Turkey. The effects of climate change on temperature and precipitation have been estimated by different models of MRI-GCM and CCSR-GCM. According to the generated scenarios by these models, the surface temperature may increase by 2.0 °C to 3.5 °C respectively by 2070. The total precipitation for the whole of Turkey may decrease by 20%, while it will decrease by 25% in the LSIP area, 42–46% in Adana (located in the Lower Seyhan Plain), and by an average of 30% in the Seyhan River Basin. However, the LSIP at present seems to have a large adaptive capacity towards climatic and social changes. To sustain its productivity, it is strongly recommended to farmers and water users’ associations to improve irrigation and water use efficiency by means of better maintenance of irrigation canals, better gate operations and employment of better application techniques. This would improve the equity of water allocation and distribution, avoid high water tables and conserve the soil. In the whole area, especially in the coastal zone, the appropriate management of subsurface drainage is vital for avoiding salinity and waterlogging. The use of the deep groundwater should be avoided because of the risk of salt intrusion.

Keywords Climate change · ICCAP agricultural irrigation · Water resources

7.1 Introduction

There has been a decrease in rainfall throughout the Mediterranean region over the past century. Most of the recent attention devoted by the relevant sciences to global warming or the greenhouse effect is paid to the impact of climate change and the increase in temperature. According to the IPCC (2007), temperatures are expected to rise by +2 to +3 °C in the Mediterranean region by 2050, then by +3 to +5 °C by 2100. However, some of the most severe impacts of climate change are likely to come not from the expected increase in temperature but from the changes in precipitation, evapotranspiration, runoff and soil moisture, which are crucial factors in water planning and management. An increase in the temperature is likely to reduce air relative humidity and raise the moisture-loading capacity of the atmosphere. The air will therefore have a higher saturation rate, leading to less cloud cover and hence decreased precipitation. Precipitation will be less frequent but more intense, while periods of drought will be longer and more frequent. Thus spatial and temporal precipitation patterns will be altered.

The regional effects of global climate change on the water cycle, therefore, risk decreasing water resources, emphasising their variability and reducing their exploitability (Milano 2010). The water-poor countries are likely to be the most affected by 2100, and rainfall is likely to have decreased by 20–30% in the countries to the south (particularly in the Mediterranean), opposed to merely 10% in those to the north (Giorgi/Lionello 2008). The ICCAP study conducted in the Seyhan river basin showed that water resources will decrease by 30% due to the effects of climate change in 2070 (ICCAP 2007).

Today, most of the southern rim of the Mediterranean countries imports more than 50% of their food requirements and demand for food grows faster than the rate of increase in agricultural production. Irrigation is often the driving factor for increasing agricultural production in this area. Consequently, huge efforts and budgets are allocated to the Mediterranean countries to develop their irrigation systems. Only 30% of the cultivated area in the region is irrigated, but produces 70–75% of the total agricultural production (Hamdy/Lacirigniola 1999). Water experts and politicians agree that there is an acute water shortage problem in the Mediterranean region. Four Mediterranean countries already have less than the minimum required water availability to sustain their own food production (750 m^3/inh/yr). By 2025, more countries will be in virtually the same situation concerning water shortage. These countries are essentially located on the southern rim of the Mediterranean basin. The crisis is already so acute that in Malta domestic water consumption exceeds 50% of the available water resources. In such places, the conventional water resources will be insufficient to even meet the domestic water demand at the beginning of the next century. Climate change is just one of the pressures facing water resources and their management over the next few years and decades in the Mediterranean.

This chapter describes the assessment of the effects of climate change on water resources, and their management in the selected irrigation systems of the Mediterranean basin countries. It also provides information on the adaptation of irrigation systems to the future climate changes in the Mediterranean region. Detailed information on the limiting factors of the water resources related to climate change is also discussed in this chapter.

7.2 Restrictive Factors on Water Resources in the Mediterranean

Currently there is an increasing pressure on water resources in the Mediterranean countries, derived from population dynamics, upgraded standard of living, economic and social development, and the use of water-consuming technologies. Different countries in the region have different problems with their water sectors. As stated by Hamoda (2004), water resources in the Mediterranean region are scarce and expensive, thus municipal and industrial water requirements are increasing sharply due to the population increase and rising incomes. However, the increased demands for water and the subsequent relevant approaches for solving water problems are mostly limited to improving management, as well as upgrading and modernising water delivery systems.

7.2.1 Population of the Mediterranean Region

Population growth, in many southern Mediterranean basin countries, is the major factor affecting water resources that reduces the water availability per capita (Fig. 7.1 and Table 7.1). Urbanisation increases urban demands, which are of high priority, and intensifies conflicts among users. For example, the Mediterranean population living in water-poor countries with less than 1,000 m^3/capita/yr could rise from 180–250 million by 2025. The populations living in the regions of water shortage, such as the Palestinian Territories-Gaza, Libya, Malta, Israel, Tunisia and Algeria, with less than 500 m^3/capita/yr could increase over the same period from 60–80 million inhabitants (Milano 2010). Apart from the local population, even the tourist population in the Mediterranean is significantly high compared with other parts of the world and faces an increasing trend in time. Accordingly, the EEA (2010) has reported that the tourist water consumption has lately been about 3–4

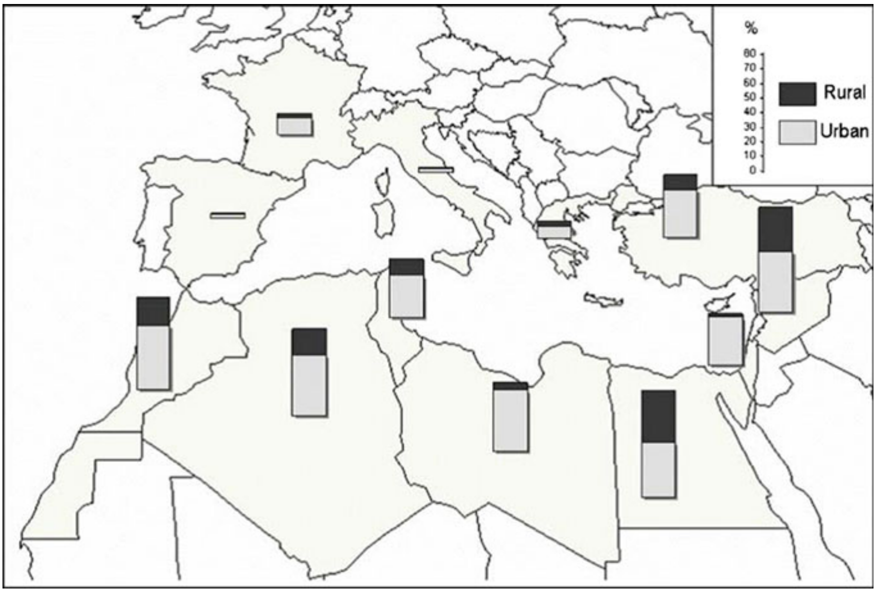

Fig. 7.1 Mediterranean countries and populations for 2025. No data is available for Lebanon, Albania, Cyprus, Malta or former Yugoslavian countries. *Source* Rearranged from Iglesias et al. (2007), Aquastat (2010)

times higher than the local demands. In some countries like Spain, Greece, France, and Turkey, the number of international tourists increases every year; and their number exceeds the total population of these countries by about one third of their population (World Tourist Organization 2010). However, touristic consumption is highly seasonal, but the tourism industry increases permanent water demand for facilities and leisure structures.

Similarly, the natural water resources in the Mediterranean region of Turkey are threatened by the tourist population, which was about 25 million in 2010. Along the Mediterranean coast of the country there are 200 golf courses, representing a demand increase of about 200 million m^3 of water. This is a small fraction of the agricultural demand at regional level. Additionally, the daily touristic water consumption is about 350–850 litres, which is about 2–4 times higher than local demand. This is documenting the serious water scarcity problem in the near future of 2025, when 200 million tourists are expected to visit Turkey (Bulut 2010). On the other hand, it is estimated that water use in the tourism sector will be 5 billion m^3 in 2023 (Evsahibioğlu et al. 2010). The other problem is the waste water production in the tourist areas of the Mediterranean coast, which was 400 million m^3/yr in 2004 and will be 1.5 billion m^3 in 2023 (Baykam 2004).

7.2.2 Environmental Factors

In general, usable water resources are always less than the potential water resources in all countries. In Turkey the total water use is less than half of the total freshwater resources (Tekinel et al. 2000; Kanber et al. 2004), and the potential use of surface water under a natural regime is only about 38% (Kanber et al. 2004). By contrast, in Egypt, Israel, Cyprus, Libya, and many other riparian countries of the Mediterranean basin, the water demand is higher than the available resources (Table 7.1).

The recurrent drought events in the region further increase the complexity of water scarcity management. Drought events in the Mediterranean have been more frequent since 1980 (Fig. 7.2) (ICCP 2007; Kitoh 2007) and have occurred two or three times in the last 20–25 years, causing social damage and severe decline in the economy of the Mediterranean region of Turkey (Şaylan/Çaldağ 2001; WWF 2007; Kanber et al. 2008). Figure 7.2 shows the time series of the annual total precipitation in Adana and the corresponding widely used drought index SPI calculated at 24-month intervals. The negative SPI values obtained after the 1990s indicate drought risk. However, drought indices do not correlate well with hydrological drought periods. This may be the outcome of the effect of the water storage capacity of Turkey, as stated by Tezcan et al. (2007) and Fujinawa et al. (2007). The Figure shows at least three periods with different precipitation trends and variability patterns. Precipitation after the 1990s has clearly followed a decreasing trend and provoked further water deficit in many areas of the country (Şaylan/Çaldağ 2001).

Table 7.1 Some water resources data in mediterranean countries. *Source* FAO (2005), Aquastat (2010)

Country	Total area (1000 ha)	Population (million)	Rainfall (mm/yr)	Internal usable water resources (km^3/yr)[a]	Total usable water resources (km^3/yr)[b]	Internal groundwater (km^3/yr)[c]	Total water use (km^3/yr)	Total water use (% renewable)	Potential total usable water resources per capita (m^3/capita/yr)
Albania	2875	3.14	1485	26.90	41.70	6.20	1.710	4.10	13.268
Algeria	238 174	34.37	89	11.25	11.67	1.49	6.053	51.86	339.50
Bosnia-Herzegovina	5 121	3.77	1028	35.50	37.50	–	–	–	9939
Croatia	5 659	4.42	1113	37.70	105.50	11.00	–	–	23853
Cyprus	925	0.86	498	0.78	0.78	0.41	0.213	27.30	904.9
Egypt	100 145	81.53	51	1.80	57.30	1.30	68.200	1.19	702.8
France	54 919	62.04	867	178.50	203.70	100.00	39.950	19.61	3284
Greece	13 196	11.14	652	58.00	74.25	10.30	7.760	10.45	6667
Israel	2 077	7.05	435	0.75	1.78	0.50	1.814	101.91	252.4
Italy	30 134	59.60	832	182.0	191.30	43.00	44.270	23.14	3210
Lebanon	1 040	4.19	661	4.80	4.50	3.20	1.263	28.06	1074
Libyan Arab J.	175 954	6.29	56	0.60	0.60	0.50	4.308	718.00	95.33
Malta	32	0.41	560	0.051	0.051	0.05	0.0195	38.23	124.10
Morocco	44 655	31.61	346	29.00	29.00	10.00	12.590	43.41	917.50
Occupied Palestinian Territory-Gaza	602	4.15	402	0.812	0.837	0.74	0.418	49.94	201.8
Slovenia	2 027	2.02	1162	18.67	31.87	13.50	–	–	15816

(continued)

Table 7.1 (continued)

Country	Total area (1000 ha)	Population (million)	Rainfall (mm/yr)	Internal usable water resources (km^3/yr)[a]	Total usable water resources (km^3/yr)[b]	Internal groundwater (km^3/yr)[c]	Total water use (km^3/yr)	Total water use (% renewable)	Potential total usable water resources per capita (m^3/capita/yr)
Spam	50 537	44.49	636	111.2	111.50	29.90	35.530	31.86	2506
Syrian Arab J.	18 518	21.22	252	7.13	16.80	4.84	16.690	99.34	791.4
Tunisia	16 361	10.17	207	4.19	4.59	1.49	2.837	61.80	451.9
Turkey	78 356	73.91	593	227.00	213.60	69.00	40.100	18.77	2890

[a]The values refer to both regulated and unregulated water. Real available water resources in all cases are a fraction of these values

[b]These values include transboundary water

[c]A proportion of these values in included in the total renewable resource

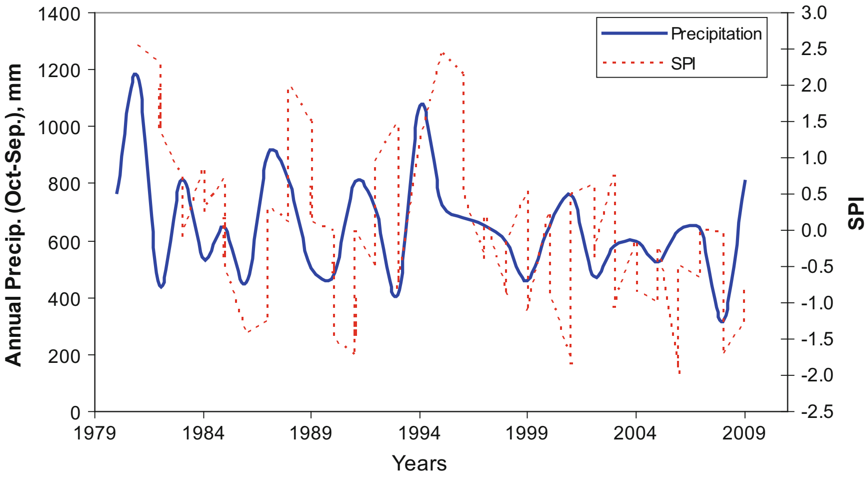

Fig. 7.2 Time series of the total annual precipitation and SPI values (24-month timescale) in Adana, Turkey. *Source* ICCAP (2007), Kitoh (2007)

7.2.3 Water Resources in Mediterranean Countries

The Mediterranean region is a transition area between a temperate Europe with relatively abundant and consistent water resources and the arid African and Arabian deserts that are very short of water except for the Nile (Giorgi/Lionello 2008). This area is a region of contrasting situations illustrated by some characteristics:

The renewable water resources (the sum of the nationwide total ground and surface waters of rainfall origin) in the Mediterranean region measure approximately 1,200 billion m^3/year, which is only about 3% of the entire renewable resources of the planet. These water resources are unevenly distributed due to the differences in climate between the northern countries and those to the south and east. 72% of the 1,200 billion m^3/year renewable water resource is in the north, 23% in the east and 5% in the south of the Mediterranean basin (Plan Blue 2009; Boucheron 2010). This major disparity in distribution, coupled with the many climatic phenomena and extreme weather events which affect the region, make the Mediterranean region one of the most vulnerable areas in the world as far as climate change is concerned. Thus renewable water resources are measured in billions of m^3/year for the northern countries, such as France, Italy, Turkey and the countries of the former Yugoslavia, whereas they are measured only in millions of m^3 in the most water-poor countries, like Malta, Libya, Cyprus, Palestinian Territories-Gaza and Jordan.

The water resources are distributed unevenly within each country. For example, in Spain, 81% of the resources are in the northern half of the country; in Morocco, the two principal drainage basins (Oum-er-Rbia and Sebou, which cover one-tenth of the territory) provide 50% of the flows; in Algeria, 75% of the renewable resources are concentrated in 6% of the territory, while in Tunisia, the north (30% of the territory) produces 80% of the resources. As stated by Tekinel et al. (2000), 31% of the renewable water resources are in the eastern and south-eastern part of Turkey, while 25.5% are in the Mediterranean region of the country. It should be noted that variable proportions of the total resources in certain countries come from outside via the trans-boundary rivers. While resources in Spain, Italy, Lebanon, Libya, Morocco and Turkey are entirely or almost entirely internal, the other States depend to a large extent on their neighbours: Egypt 98%, Syria 80%, Israel 55%, and the countries of the former Yugoslavia 45% (Boucheron 2010).

Related to populations, water resources per capita say even more about the levels of richness or poverty in the Mediterranean countries in terms of water: they range from overabundance in Albania and in the countries of the former Yugoslavia (over 10,000 m^3/year per inhabitant) to extreme water-poverty in the Palestinian Territories-Gaza and Malta, with less than 100 m^3/year per inhabitant (Hamdy/Lacirigniola 1999; Boucheron 2010). Thus today more than 160 million of the 425 million Mediterranean people estimated by the United Nations live in countries with less than 1,000 m^3/year of water per inhabitant. Tensions between resources and needs are becoming apparent in the user nations, especially when irrigation is necessary. Of these 160 million persons, 30 million are living below the line of absolute water-poverty of 500 m^3/year per inhabitant, for example in the Palestinian Territories-Gaza, Israel, Jordan, Libya, Malta and Tunisia. The other negative aspect of water use in this area is caused by the excess use of the groundwater resources. Groundwater is severely exposed in coastal areas, where the equilibrium with seawater can easily be upset. In some countries, such as Spain, Italy, Greece, Cyprus, Israel and Libya, excess pumping of groundwater has led to the abandonment of the catchments.

Pollution, whether it is localised and caused by low standards of wastewater purification, industrial discharges and accidents or widespread due to the overuse of agricultural additives or poor waste management, is also a threat to resources, and tends to increase drinking water production costs considerably. Although less industrialised than the northern countries, the countries in the south suffer just as much from the effects of similar pollution, aggravated by inadequate purification and prevention facilities as well as by the scarcity and mediocre quality of the resources. For example, Egyptian industries dump 550 million m^3 of waste – 57% of the quantity produced – into the Nile every year.

7.2.4 Possible Climate Change

The Mediterranean climate can substantially change due to the geographical location of the Mediterranean region, which lies in a transition zone between arid and temperate and rainy climates. This makes the Mediterranean a potentially vulnerable region to climatic changes induced by increasing concentrations of greenhouse gases (Gibelin/Deque 2003). According to the Fourth Assessment Report of the

Intergovernmental Panel on Climate Change (IPCC 2007), the climate over the Mediterranean basin may become warmer and drier during the 21st century. The Mediterranean climate is affected by several tropical and subtropical systems, as illustrated and explained by numerous scientists. These factors range from the El Niño Southern Oscillation (ENSO) and tropical hurricanes to the South Asian Monsoon and Saharan dust. This leads to complex features in the Mediterranean climate variability (Alpert et al. 2006).

The climate of the Mediterranean is mild and wet during the winter and hot and dry during the summer. The westward movement of storms originating over the Atlantic and impinging upon the western European coasts (Giorgi/Lionello 2008) mostly dominates the winter climate of the Mediterranean. The winter Mediterranean climate, and most importantly precipitation, are affected by the North Atlantic Oscillation (NAO) over the region's western areas (Alpert 2004), the East Atlantic (EA) and other patterns over its northern and eastern areas. The El Niño Southern Oscillation (ENSO) has also been suggested to significantly affect winter rainfall variability over the Eastern Mediterranean (Xoplaki et al. 2004; Alpert et al. 2006; Brönnimann et al. 2007). In addition to the impact of Atlantic storms, Mediterranean storms can be produced internally in correspondence to cyclogenetic areas, such as the Lee of the Alps, the Gulf of Lyon and the Gulf of Genoa (Giorgi/Lionello 2008). In the summer, high pressure and descending motions dominate the region, leading to dry conditions, particularly over the southern Mediterranean. Summer Mediterranean climate variability has been found to be connected with both the Asian and African monsoons and with strong geopotential blocking anomalies over central Europe (Xoplaki et al. 2003; Alpert 2004; Alpert et al. 2006).

On the other hand, the Mediterranean climate is affected by local processes such as the complex physiography of the region and the presence of the large water body of the Mediterranean Sea. For example, the Alpine chain is a strong factor in modifying travelling synoptic and mesoscale systems, and the Mediterranean Sea is a major source of moisture and energy for storms (Giorgi/Lionello 2008). In addition, anthropogenic and natural aerosols of central European, African and Asian origin can reach the Mediterranean, possibly influencing its climate characteristics (Alpert 2004). Because of these factors, the Mediterranean climate is characterised by a great diversity of features, resulting in a variety of climate types and great spatial variability.

Assessments of climate change projections over the Mediterranean were initiated in 1992 (Giorgi et al. 1992) and onwards. Giorgi/Lionello (2008) have used twenty-five global climate change scenarios developed by the IPCC in order to assess the impact of climate change for 2050 and 2100 (Somot et al. 2008). According to Giorgio/Lionello (2008), at the end of the 21st century, a strong warming is expected for all seasons. This warming has been described by Deque et al. (2005) as a warming that is stronger in summer than in winter (1), stronger over land than over sea (2), warmer in the eastern part of Europe in the winter (3) and in the southern part in summer (4). As an example, temperatures are expected to rise by +2 to +3 °C in the Mediterranean region by 2050, then by +3 to 5 °C by 2100

(Figs. 7.3 and 7.4). This rise in temperature is likely to reduce relative air humidity and increase the atmosphere's capacitive moisture load (Milano 2010). The future air will therefore have a higher saturation rate, leading to less cloud cover and hence decreased precipitation. Precipitation will be less frequent but more intense, whilst periods of drought will be longer and more frequent, altering the spatial and temporal precipitation patterns. A 1–2 °C rise in air temperature accompanied by a 10% reduction in the amount of precipitation may cause a 40–70% drop in the mean annual river runoff, which will substantially affect agriculture, water supplies and hydroelectricity.

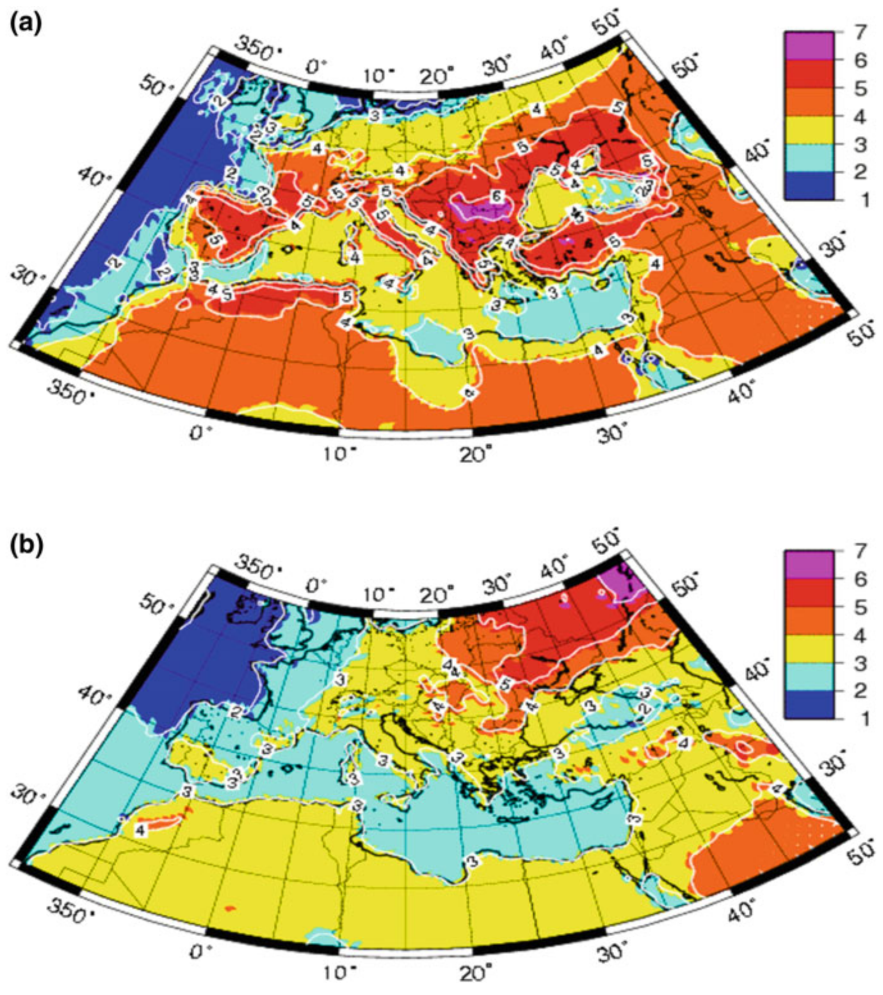

Fig. 7.3 Atmosphere-Ocean Regional Climate Model (AORCM) response to the climate change for the 30-year average 2-m temperature (in °C) between the 2070–2099 period and the 1961–1990 period **a** in winter and **b** in summer. *Source* Somot et al. (2008: 117)

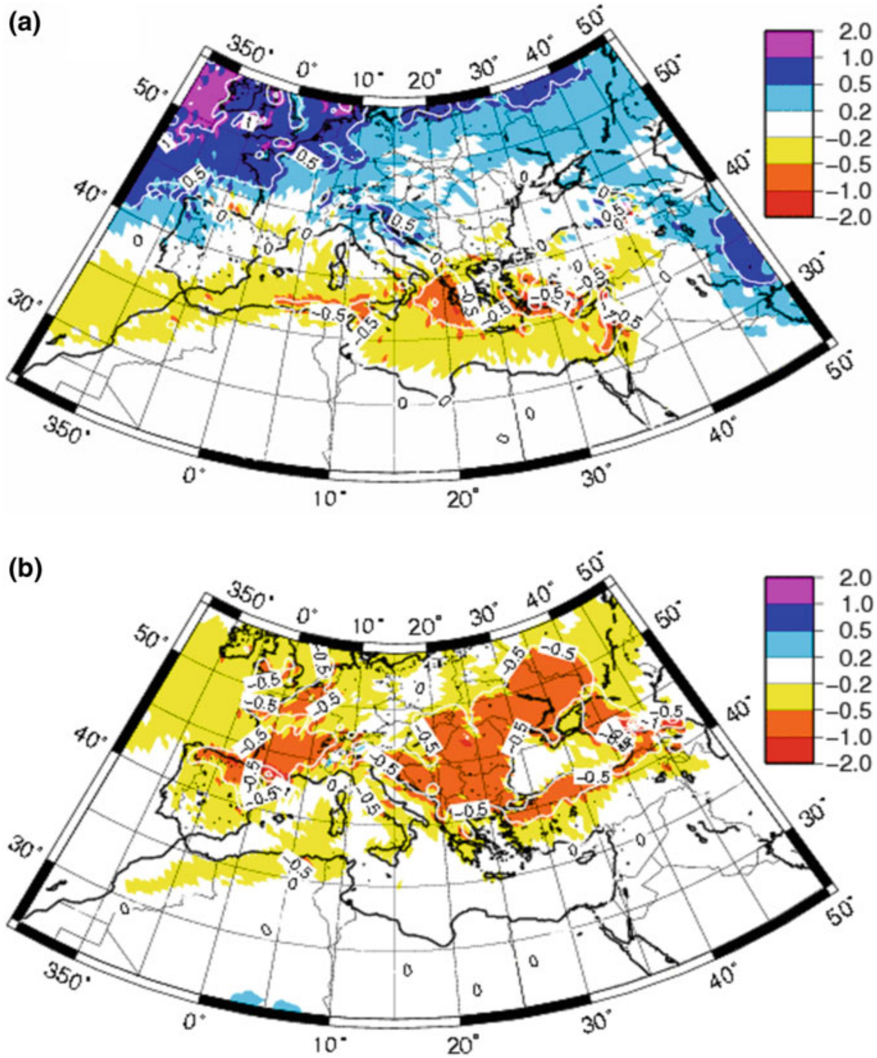

Fig. 7.4 Atmosphere-Ocean Regional Climate Model (AORCM) response to the climate change for the 30-year precipitation forecast in mm/day between the 2070–2099 period and the 1961–1990 period **a** in winter and b in summer. *Source* Somot et al. (2008: 117)

Similar work on the effects of climate change in Turkey and in the Seyhan River basin was studied by the project entitled the "Impact of Climate Change on Agricultural Production Systems in the Arid Areas (ICCAP)" for five years. This project was launched in 2002 in cooperation with the Research Institute for Humanity and Nature (RIHN) in Japan and the Scientific and Technical Research Council of Turkey (TUBİTAK) (Watanabe 2007).

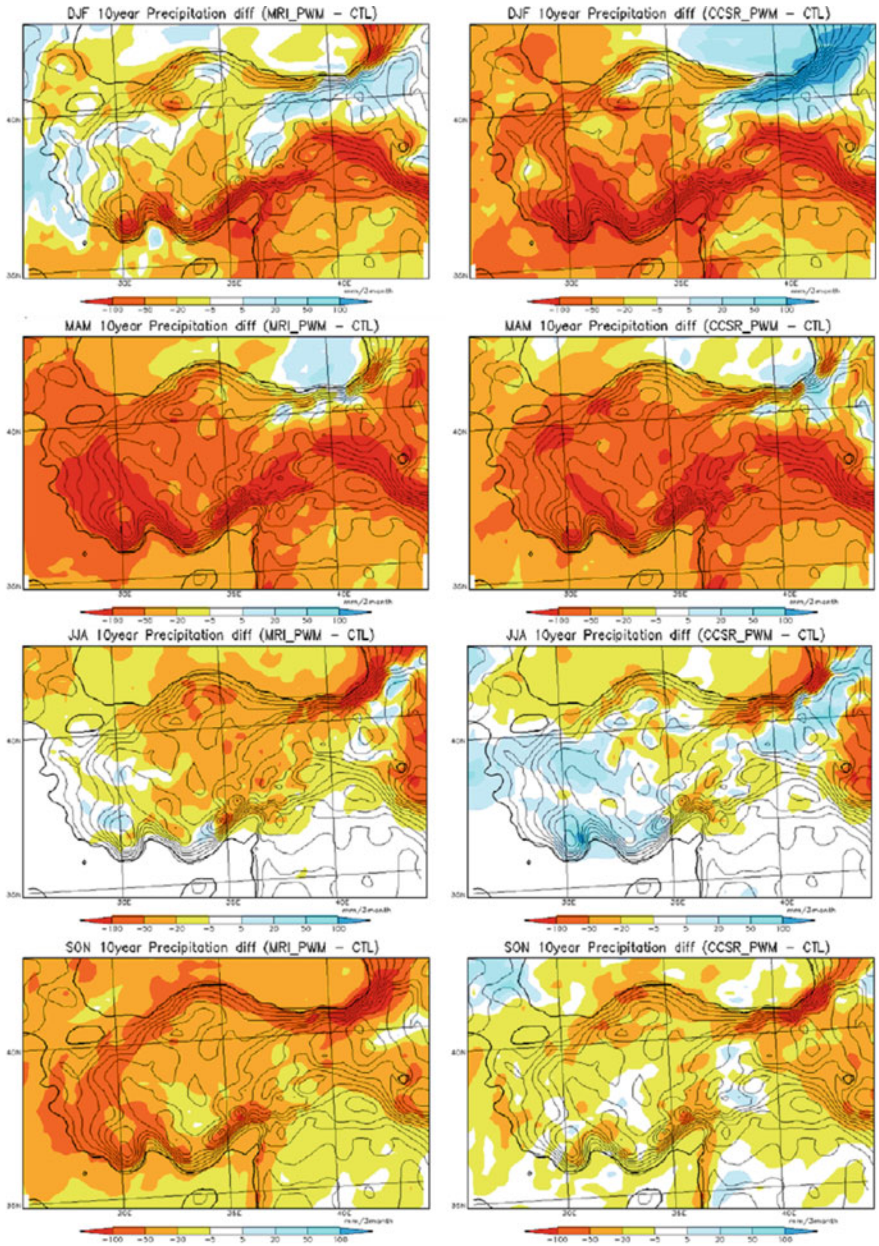

Fig. 7.5 The change in monthly-projected precipitation between the present (1994–2003) and future climate (2070–2079) by downscaling from MRI-CGCM (left) and CCSR-CGCM (right). *Source* Kimura et al. (2007: 31)

Within the research scopes of this project, researchers provided scenarios of the likely climate change in Turkey caused by greenhouse gases, in which precipitation, temperature and insulation were predicted for the period of 2070–2079. Downscaling for the ten-year climate change during the 2070s is completed for the whole of Turkey by 25 km and for the Seyhan basin by 8.3 km grid intervals. In this study, two independent General Circulation Model (GCM) projections were downscaled by only one Regional Climate Model (RCM).

Figures 7.5 and 7.6 indicate the change in monthly precipitation until 2070. The figures on the left side and right side indicate the precipitation change in the months downscaled from the Meteorological Research Institute-Coupled General Circulation Model (MRI-CGCM), and Center for Climate Science Research-Coupled General Circulation Model (CCSR-CGCM) respectively. The brown coloured areas in the figures show the decreasing projected precipitation. Moreover, a prominent decrease in the precipitation over the whole of Turkey during the winter months is illustrated. Both downscalings show that precipitation will prominently decrease in the slopes along the Mediterranean.

According to the generated scenarios, the surface temperature in Turkey may increase 2.0 °C by MRI-GCM and 3.5 °C by CCSR-GCM (Figs. 7.7 and 7.8). The total precipitation may decrease by nearly 20% except in the summer, where the difference at GCM is relatively small. The projected trend of changes in temperature and precipitation in the Seyhan River Basin is almost similar to the changes in the whole of Turkey, while precipitation is expected to decrease by about 25%.

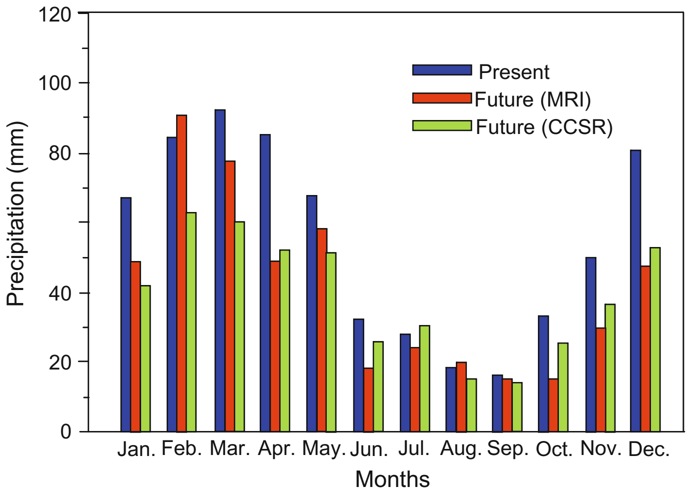

Fig. 7.6 Monthly precipitation for today (1994–2003, blue coloured) and future climate (2070–2079) in the Seyhan River Basin downscaled from MRI-CGCM (red) and CCSR-CGCM (green). Total precipitation will decrease almost 25% in Turkey, including in the Seyhan River Basin. *Source* Kimura et al. (2007: 32)

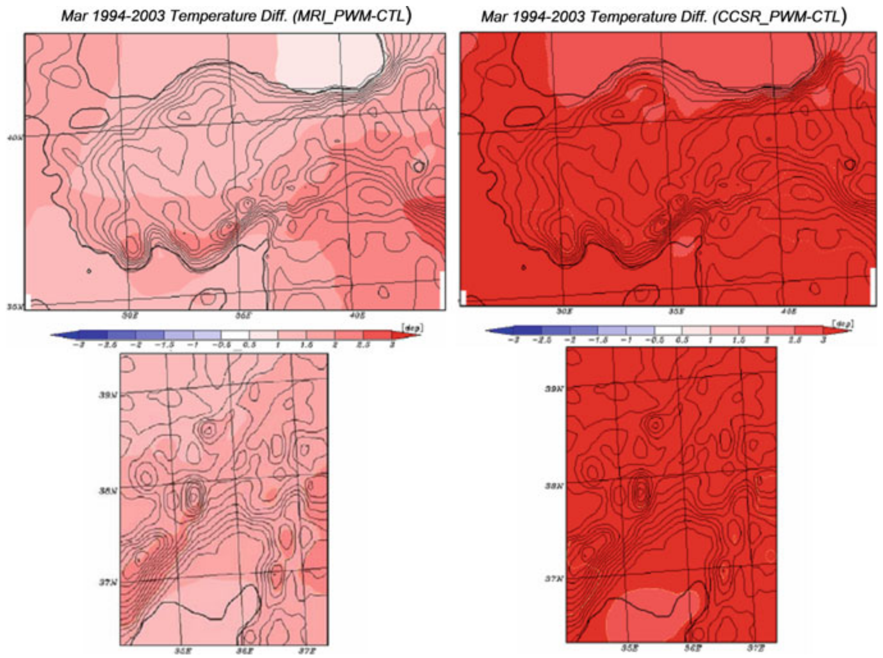

Fig. 7.7 Horizontal distribution of difference in surface temperature between the present (1994–2003) and future climate (2070–2079) in the second grid (top, Turkey) and the finest grid (below, Seyhan River Basin) of downscaling form MRI-CGCM (left) and CCSR-CGCM (right). *Source* Kimura et al. (2007: 32)

7.3 Significance of Irrigation in the Mediterranean Countries

The techniques and practices of irrigation are known to predate the Romans in the Mediterranean region, where irrigation plays a major role in the overall agricultural production. The direct impact of irrigation is represented by the increasing crop yield, productivity and farm income. The indirect effects are increasing rural employment, high economic benefit and decreasing immigration (Hamdy/Lacirigniola 1999; Shatanawi et al. 2009). Furthermore, high-level equity in the population heterogeneity is achieved by irrigation, along with poverty and gender. Many of today's agricultural crops, such as vegetables, cereals, olives, grapes and aromatic species, were grown in some countries of the Mediterranean under irrigation (Fig. 7.9). However, the main physical constraint to irrigation development in the Mediterranean countries is usually water availability. The Mediterranean region is undergoing rapid local and global social and environmental change. In addition, competition with other sectors (domestic supply and industry) is also a

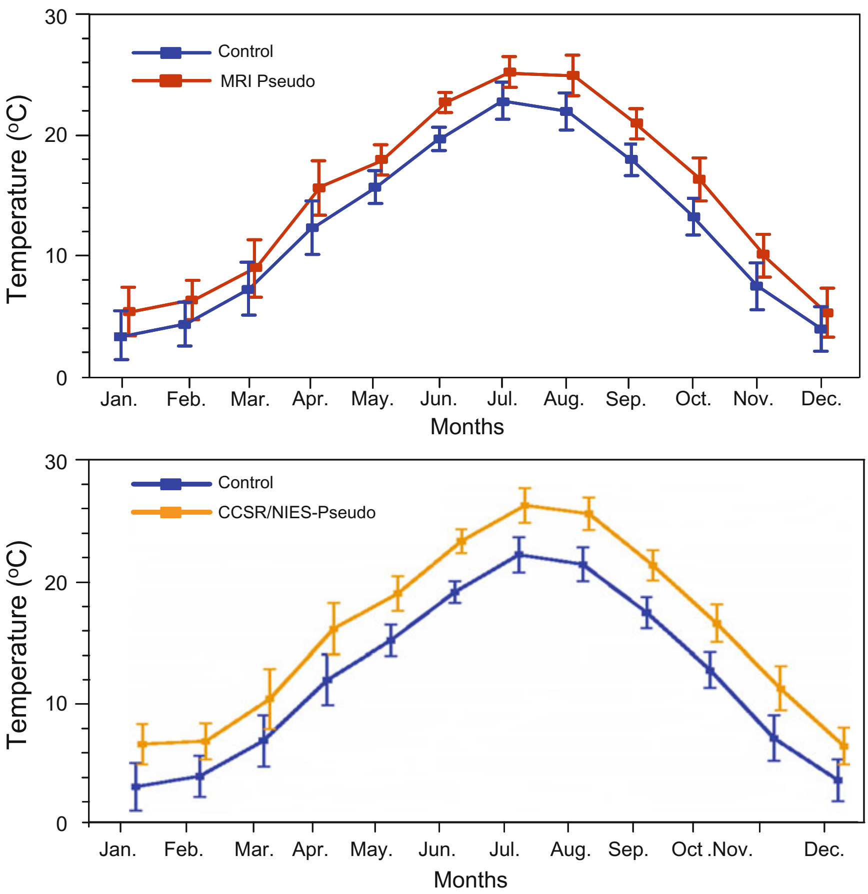

Fig. 7.8 Surface temperature for today (Control) (1994–2003) and future climate (2070–2079) in the Seyhan River Basin downscaled from MRI-CGCM (top) and CCSR-CGCM (below). Surface temperatures will increase 2.0 °C for MRI-GCM and 3.5 °C for CCSR-CGCM. *Source* Kimura et al. (2007: 33)

cause of limitation in water resources for irrigation (Hamdy/Lacirigniola 1999). All indicators point to an increase in environmental and water scarcity problems, with negative implications for current and future sustainability.

7.3.1 Management of Water Resources in the Mediterranean Basin

Water in the Mediterranean basin is not only a raw material exploitable within the limits of its availability. It is also, highly vulnerable to forms of land use and to

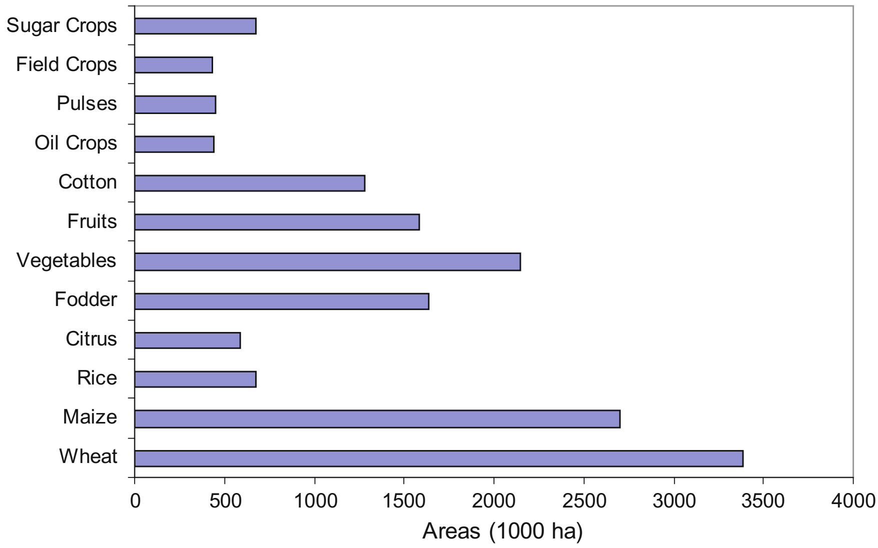

Fig. 7.9 Distribution of crops under irrigation in the Mediterranean (Aquastat 2010). Some important food and fibre crops, such as wheat, maize, rice, pulses, citrus for humans, fodder for animals and cotton, are given separately; other crops are grouped according to their properties. Sugar crops include sugar beet and sugar cane; field crops are sorghum, barley and tobacco; oil crops consist of rape, sunflower and soybean; fruits include vine, melon and bananas; vegetables and potato crops are given together under vegetables. *Source* Aquastat (2010)

numerous sources of pollution; neither is it immune to the impacts of climate change (Correia 1999).

There has recently been increasing attention to water resources management in the Mediterranean region, bearing in mind that the water resources in this area should be considered in conjunction with soil and vegetation resources. The study of Mediterranean environments and related water problems is relevant not only for this region but also for other areas in the world. Mediterranean environments are subject to very extreme conditions with respect to fluctuations in water availability and needs, causing situations of temporary or permanent scarcity and creating a need for storing water and demodulating natural regimes. Many of the approaches to deal with these problems, and some of the solutions currently adopted, may be very useful elsewhere in the future (Hamdy/Lacirigniaola 2005). The Mediterranean environment, fragile in nature, is seriously endangered by the natural trends of social and economic development of this region. Stress on the coastal areas, imbalance in the population distribution of rural and metropolitan settlements, severe water dependence, extreme sensitivity to pollution, and vulnerable equilibrium between soil and water are some of the factors to be considered in a global approach to Mediterranean environmental problems. Unquestionably, water plays a major role in this fragile environment. Not only is it an essential resource for economic growth, but also it is the most important component of the environment, with a significant impact on public health and nature conservation. Water deserves special attention in environmental studies in all regions of the world. However, in Mediterranean countries water is not simply important but essential. It is the cornerstone of all development strategies and a basic element of all planning activities (Hamdy/Lacirigniola 1994; Correia 1999; Boucheron 2010). Water resources management of the Mediterranean faces some significant constraints, such as pollution, excessive use, and silting-up of the dams (Boucheron 2010).

The failure to maintain banks in the north through terrace cultivation (which contributes to erosion), deforestation in the south and the 'artificialisation' of watercourses all contribute to irregularities in water flow and reduce renewable resources. Groundwater is severely exposed in coastal areas, where the equilibrium with seawater can be easily upset. For example, nowadays the virtually irreversible inflows of salt water caused by excessive pumping in Spain, Italy, Greece, Cyprus, Israel and Libya have led to the abandonment of catchments. The Blue Plan estimated that as early as 2010 some eleven countries would be exploiting over 50% of their resources: Morocco, Algeria, Tunisia, Libya, Egypt, Israel, Palestinian Territories-Gaza, Jordan, Malta and Syria are in the forefront, followed by Algeria, Tunisia, Cyprus and Syria. Lebanon will reach that level in 2025 (Blue Plan 2008).

The vulnerability of water resources in the Mediterranean is affected by the silting-up of the dams, which is particularly prevalent in the south rim countries. The high sediment content of floodwater shortens the effective life of reservoirs, despite the high-volume "holding ponds" or "spare capacity" provided. While the loss of the effective capacity of the Mediterranean dams is currently between 0.5 and 1% per year, it is 2% in Morocco, where the reduction in regulating capacity attributable to silting-up is equivalent today to a loss of irrigation potential of 6,000 to 8,000 ha per year. This ranges from 2 to 3% in Algeria, where the lifespan of the average-capacity reservoirs is 30–50 years, and from 1 to 2.5% in Tunisia, to such an extent that, according to experts, prevention efforts like reforestation of the basins or sediment traps can only delay the inevitable end of dam-reservoir sites. This points to a crucial 'post-dam' era, with enhanced silting-up problems for the 21st century in many Mediterranean countries (Boucheron 2010) in need of utmost attention in the management of the water resources.

7.3.2 Water Availability and Water Needs in the Mediterranean Region

The availability of water for irrigation purposes in rural areas has a significant impact on poverty and social equity in the Mediterranean countries. Water in most of the Mediterranean countries, especially in the south and the east, is inherently scarce due to the arid or semi-arid conditions. Additionally, in these countries, water shortage problems are faced due to the increasing gap between supply and demand. The gap will increase more in the future due to population growth, improved standards of living, urbanisation, industrialisation and climate change (Shatanawi et al. 2009).

The hydrological system of the Mediterranean region is affected by the climatic conditions. Changes in temperature affect evapotranspiration rates, cloud characteristics, soil moisture, storm intensity and snowfall and snowmelt regimes. However, some of the most severe impacts of climate change are likely to come not from the expected increase in temperature but from the changes in precipitation, evapotranspiration, runoff and soil moisture, which are crucial factors for water planning and management. In the meantime, changes in precipitation are predicted to affect the timing and magnitude of food and droughts, shift runoff regimes and alter groundwater recharge rates. The vegetation pattern and growth rates and the changes in soil moisture regime will also be affected according to the Blue Plan (2008).

There are some relevant variations in climatic conditions in this region, despite some prevailing common characteristics. For example, northern and north-eastern countries are clearly wetter than the south and south-eastern ones. However, most areas have a water deficit, defined as the difference between precipitation and potential evapotranspiration. This deficit is larger in the south and south east (Correia 1999). Naturally, this has a direct impact on water availability, mainly through river runoff, and contributes to a corresponding regional asymmetry. Some of the most relevant data on water availability and needs in the Mediterranean region are presented in Table 7.1 based on data adapted from FAO (Aquastat 2010). From Table 7.1, water resource managers face the dilemma of ensuring future sustainability of water resources while maintaining the strategic agricultural, social and environmental targets. Taking into account the total freshwater resources, the average annual potential water availability per capita in southern Mediterranean countries is less than 1,000 m^3 per capita and year (Table 7.1). According to scientific estimations, the proportion of people who suffer from hunger and do not have access to safe drinking water was predicted to increase by half by 2015 (Blue Plan 2008).

Irrigated agriculture is the main consumer of water in the Mediterranean (Fig. 7.10). Although northern and southern Mediterranean countries differ in relation to the rate of expanding the area of irrigated land and irrigation technologies used, the evolution of irrigation in all Mediterranean countries has been remarkable over the last half century (Iglesias et al. 2007). In general, there is little development of new irrigated areas and the investments focus on the rehabilitation of existing schemes and improvement of irrigation technologies. But, nevertheless there is a rapid increase in the water demands in all countries due to the increase in economic and social activities together with the increasing demand for tourism and pressure on the ecosystems.

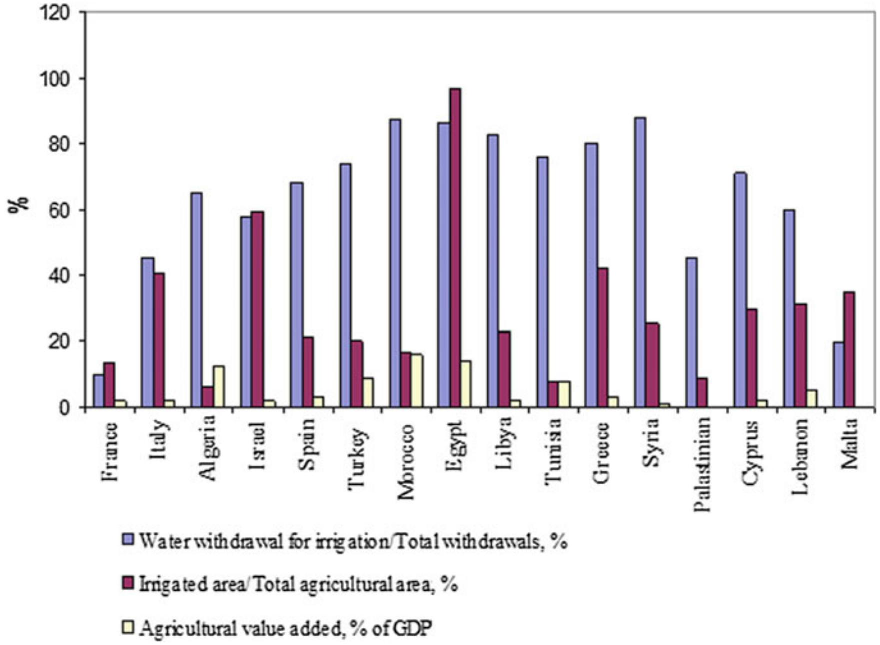

Fig. 7.10 Water use for irrigation and irrigated agricultural areas in selected Mediterranean countries. *Source* Aquastat (2010: 29)

7.4 Lower Seyhan Irrigation Project (LSIP): Case Study

7.4.1 General Characteristics

The Lower Seyhan Irrigation Project (LSIP) located on the Eastern Mediterranean coast is one of the largest irrigation projects in Turkey. It extends to the delta plain of the Seyhan River basin, with a total planned area of 175,000 ha, of which 133,000 ha has already been implemented (Fig. 7.11). The LSIP area is bound by the Mediterranean Sea on the south, by the foothills of the Taurus Mountains on the north and by the Berdan and Ceyhan rivers on the west and east respectively.

The construction of LSIP was initiated in the 1960s. The project area of 175,000 ha was divided into four areas and the construction was divided into four project phases. Phases I–III (133,000 ha) were completed by 1985. The Phase IV area, which still remains incomplete, is located in the lowest part of the project area. It has no water allocation and irrigated agriculture is practised with surplus water driven from the main canals of the completed area.

The soil in the delta is alluvial which developed from deposits of the three main rivers, namely the Ceyhan, Seyhan and the Berdan, which rise from the Taurus Mountains and flow into the Mediterranean Sea. The soils are the deepest and most fertile *Calcic Fluvisols* and *Chromic Vertisols* (Dinç et al. 1995; Çetin/Diker 2003).

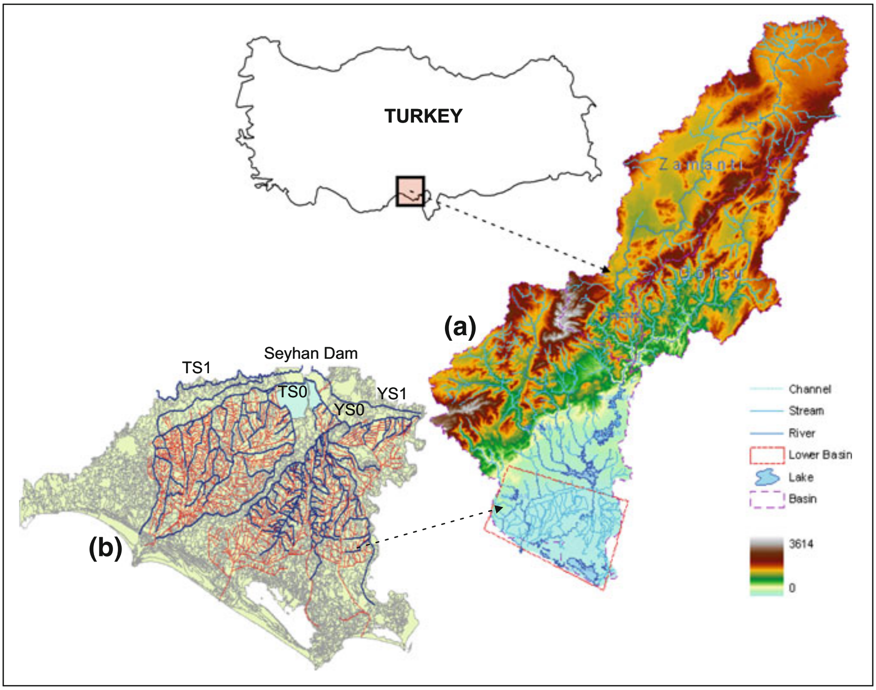

Fig. 7.11 The Seyhan River Basin (**a**) and the Lower Seyhan Irrigation Scheme (**b**). All the irrigation and drainage canals, which are of different sizes and functions, are located on the right and left banks of the Seyhan River. *Sources* Nagano et al. (2007a: 193), Tezcan et al. (2007: 64)

This plain can be regarded as one of the most important cultivated and industrial areas based on agricultural products in Turkey.

The area is divided into two parts by the Seyhan River, which flows through the plain from north to east. The part lying between the Seyhan and Berdan rivers is known as the "Seyhan Right Bank" or "The Tarsus Plain", and the part lying between the Seyhan and Ceyhan rivers is the "Seyhan Left Bank" or "The Yüregir Plain". The highest elevation in the LSIP area is about 30 m above sea level. The topography is flat and the altitude falls from the city of Adana to the Mediterranean Sea. The average slope varies from 1 to 0.1% from north towards the south (Özekici et al. 2006; Kume et al. 2007).

The climate (relatively mild and humid in the winter months) and the alluvial soil make the area highly suitable for agriculture. The average annual precipitation observed in Adana is nearly 670 mm. Most of the rain (80%) falls in the winter months. The least rainfall occurs in summer, in July and August. The mean wind velocity is 2 m/s and the annual average evaporation is 1,322 mm where 64% of this amount evaporates from May to October (Anonymous 2002).

7.4.2 Irrigation

The main irrigation water source of the project area is the Seyhan river, with its 6.3 billion m^3 annual flow rate from the watershed of 19,300 km^2. The quality of the water of the Seyhan river is suitable for irrigation (C_2S_1). The principal method of irrigation being implemented is gravity irrigation. The total annual water requirement for the Lower Seyhan Plain is approximately 1.8 billion cubic meters. The annual groundwater flow, which is 3 billion m^3, is not considered for irrigation purposes except for municipal use.

Water flow is controlled by two reservoirs, namely the Seyhan and Çatalan dams, in the upper stream of the Seyhan River. Irrigation water for the LSIP is being supplied by the Seyhan Dam and conveyed by various sizes and different types of irrigation canal. Irrigation efficiency in the LSIP is lower than 50%. The canal system of the LSIP consists of two conveyance canals, which are of 40.3 km (right) and 18.8 km (left) length, main, secondary and tertiary canals (Özekici et al. 2006). All types of canal provide in total 3,000 km for irrigation and 2,500 km for drainage (Fig. 7.11).

The farming system in the area can be characterised as high-input agriculture. Suitable soil, climate and topographical conditions, in addition to the rich water resources of the Seyhan River basin, allow various crops to be grown throughout the year. In response to the Mediterranean climate, farmers on the upstream part of the basin have been cultivating rain-fed winter wheat. However, in the LSIP area, agricultural crops have been irrigated mainly during the dry season from spring to autumn. Crops under irrigation are mainly wheat, maize, cotton, citrus, vegetables and watermelon. Wheat is irrigated depending on the amount of precipitation and its season. Their cultivation areas are about 20, 45, 9, 13, 4 and 6% of the total area respectively (Hoshikawa et al. 2007).

Figure 7.12 illustrates the change in the planned water release to the LSIP area in the past two decades. The amount of water has been increasing with time, mainly due to the shift in the cropping pattern and substantial increase in the irrigated area of the Phase IV area near the coast, where farm plots had not been fully consolidated (Nagano et al. 2007b). The other significant change was the transfer of the responsibility for water management from DSİ to the newly established water users associations (WUAs) in the mid 1990s. Due to the many uncontrolled problems, such as the degradation and destruction of the canals, precipitation anomalies and conflicts between WUAs, the actual amount of water release seems far more than its planned level. Although there is a lack of consistent recording of the actual diverted water, it is estimated from some data that the recent actual release is nearly 2 km^3.

Groundwater level exists only 1–2 m below the ground surface in most parts of the LSIP. Some areas of the LSIP have severe problems due to poor drainage and salt accumulation induced by the shallow water table (Çetin/Diker 2003). Therefore, implementation of the irrigation was coupled with installations of subsurface drainage and construction of drainage canal networks. By the 1980s, DSİ

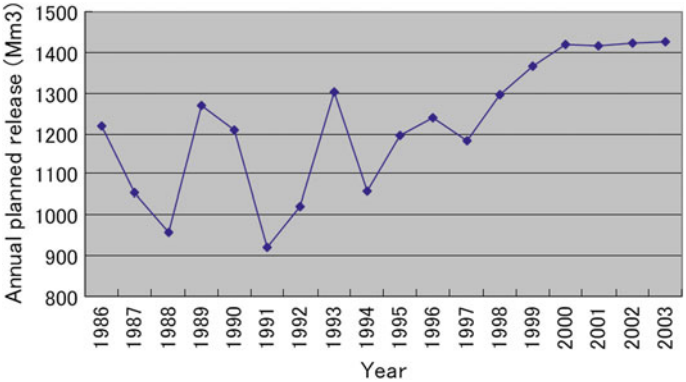

Fig. 7.12 The amount of the released irrigation water to the LSIP area during the last two decades. *Source* Nagano et al. (2007b: 212)

started monitoring the shallow groundwater level and salinity once a year over the entire irrigated area (Fig. 7.13).

The high water table that is the outcome of the inefficient irrigation practices is still problematic without the development of good drainage networks. Consequently, the area may even face severe waterlogging with the increase of irrigation.

Another potential risk is the increase in the use of deep groundwater. The deep groundwater in the area is at high risk of salt intrusion, and this may cause devastating consequences. Soil salinity decreased from 1990 to 2005, whereas the distribution pattern of salinity was still similar to that of the water table (Kume et al. 2007). Soil salinity has decreased in the LSIP area, including the coastal zone, with the application of irrigation.

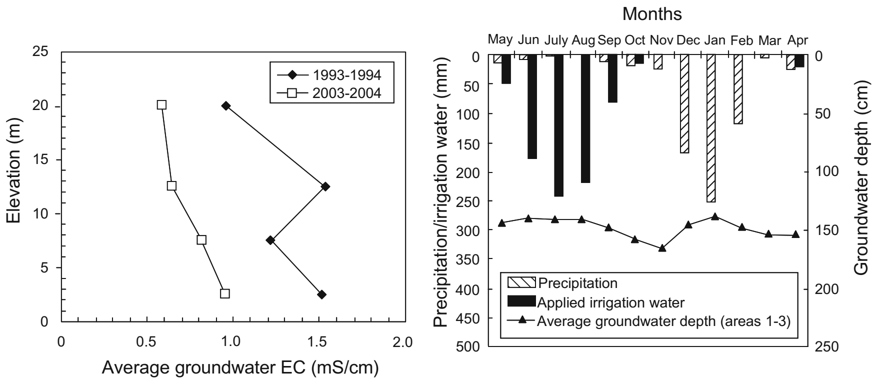

Fig. 7.13 Fluctuation of the groundwater depth (right), and groundwater EC values according to the elevation of the monitoring wells (left) in the LSIP area in 2003–2004. *Source* Kume et al. (2007: 206)

7.4.3 Adaptation of the LSIP Outcomes to Climate Change

7.4.3.1 Hydrology and Water Resources

According to the results obtained from the General Circulation Models (GCMs) of the ICCAP, the snow storage and stream runoff in the Seyhan Basin is liable to decrease under a warmer climate in the future (2070–2100) (Fig. 7.14). For the future, the following three scenarios are considered for the LSIP, (a) Land and water will be the same as at present, (b) Adaptation 1: land and water use will be under low-investment conditions; and (c) Adaptation 2: land and water use will be under high-investment conditions.

Figure 7.14 shows that, the maximum snow water equivalent (SWE) is almost 0.4 Gt in the present climate but it will decrease to 0.1 Gt under the future climate. For the Seyhan delta (irrigated area) the annual evaporation is about 800 mm, and nearly 500 mm of irrigation water must be supplied during the growing season in the hot and dry summer. As a consequence of the reduced snow cover; these areas will receive more shortwave radiation (albedo effect), and this increased energy will contribute to the increased evaporation in the spring. As reported by Fujinawa et al. (2007), the increased energy will also cause a decrease in the crop maturity period, but the amount of irrigation water requirement will increase because of the higher evaporation demand during the growing season and reduction in the soil moisture at the beginning of the growing period. According to the results given by Tezcan et al. (2007), the decrease in the mean annual snow storage is about 14.56 km^3 in the warming up period. The major decrease will occur in Aladağlar, the south-east slopes of the Erciyes and the north of the Göksu Basin. The decreased snow storage will influence the discharge of the springs in the Zamanti and Göksu Basins which feed the Seyhan River.

Similarly, future inflow will decrease markedly compared to that of the present. In addition, the decreases of inflow predicted to occur in April, May and June will

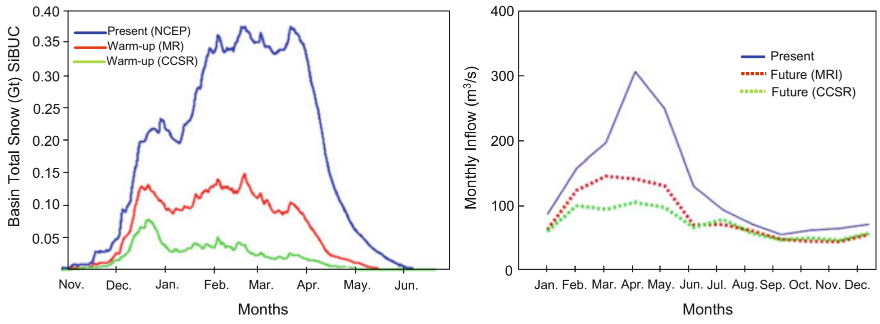

Fig. 7.14 Total snowfall in volume equivalent to water (Gt) (left) and the changes in Seyhan River flow (right) predicted from different models of MRI (red), CCSR (green) and present (blue). *Source* Fujinawa et al. (2007: 56)

be greater than those of the other months, and the peak monthly inflow will occur earlier than at present, consequently decreasing radically. Fewer flood events are estimated to occur during the warm season, when the decreased river flow may lead to water scarcity in the LSIP area (Watanabe 2007). However, Tezcan et al. (2007) have reported that the months for peak flow will be the same in both the present and warm up periods using the Mike-She simulation program.

The reliability index, which is defined as the ratio of water supply to water demand, is the indicator of the water demand if satisfied by the supply of a reservoir or the degree of water scarcity. The reliability index at present is about 0.4, which indicates low water stress; however, it ranges from 0.4 to 0.7 in the future for Adaptation 1 (high water stress) and 0.5–1.0 for Adaptation 2 (extremely high water stress) (Fujinawa et al. 2007). As a consequence, the reservoir volume in the future and Adaptation 1 will be less than at present, and in a few cases the reservoir will be void of water. The reliabilities of the dams in future and Adaptation 1 will change from 0.95 to 1.0 based on the precipitation projections of MRI and CCSR models respectively. In Adaptation 2, the reservoir is frequently empty and reliability ranges from 1.0 to 0.7 according to future data projected by the MRI and CCSR models.

On the other hand, climate change is predicted to decrease the water budget elements in the warm-up period compared to the present. The CCSR climate data reveal a greater decrease than those of the MRI data. The decrease in the actual evapotranspiration is limited by decreased precipitation (Table 7.2). Precipitation may decrease by 29.4 (MRI) and 34.7% (CCSR) in the warm-up period, which is predicted to decrease the river flow by 37.5 and 46.4% respectively. Consequently, the groundwater recharge in the whole of the Seyhan Basin will decrease by 24.7 and 27.4%. The majority of the springs in the basin will become dry due to the decline of the groundwater level below the spring level.

Groundwater resources in the LSIP area will be drastically influenced by climate change. Decreasing the recharge of the Seyhan River will cause the decrease in the subsurface recharge to the LSPP area from the higher elevations in the north of the region. The change in groundwater storage in the LSIP area due to climate change is shown in Fig. 7.15. The most significant impacts are the reduction in the recharge in the higher elevations and the increase in the abstraction due to the limitations of surface water resources. Decline in the head will also cause saline water intrusion to the LSIP area. In the case of a 50% increase in the groundwater abstraction in the

Table 7.2 Decrease of the water budget elements in the warm-up period with respect to the present conditions (mm). *Source* Tezcan et al. (2007: 69)

Water budget elements	MRI	CCSR
Precipitation	29.4	34.7
Actual evapotranspiration	16.9	16.9
River flow	37.5	46.4
Discharge to the Medit. Sea	50.0	54.2
Recharge	24.7	27.4
Spring discharge	50.0	50.0

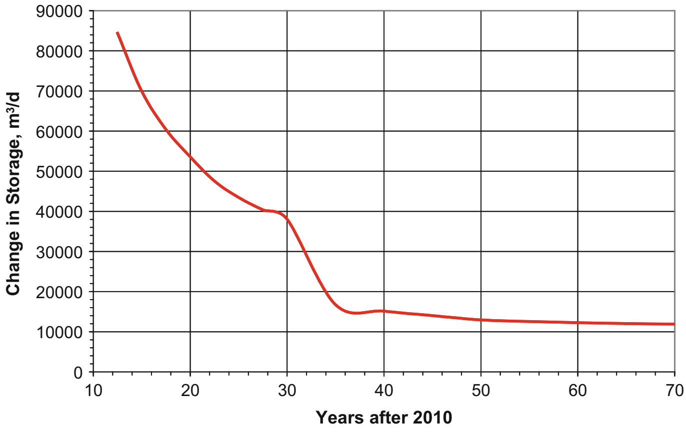

Fig. 7.15 Impact of climate change on groundwater storage in the Lower Seyhan Delta Plain. *Source* Tezcan et al. (2007: 65)

warm-up period of 2080, the seawater intrusion will reach 10 km inland (Tezcan et al. 2007). At the same time, in the coastal zone of the LSIP area, the groundwater salinity will reach 25% of the seawater composition.

7.4.3.2 Crop Productivity

The Seyhan River Basin and especially the LSIP area is an important food production area for Turkey and the European Union. The Seyhan River Basin is suitable for different types of rain-fed crops in the north and for irrigated crops in the southern part. The major crops grown in the LSIP area are maize, wheat, cotton, citrus and vegetables. Most of the winter crops, such as wheat, are grown in the rain-fed area north of the LSIP.

Wheat is the most dominant crop in the LSIP area and is grown as a winter crop under rain-fed conditions. Sometimes it is irrigated depending on the precipitation. In recent years, the total wheat production in the Adana province is about 1.3 million tons on average, produced on 0.31 million ha cultivated area, 0.42 million tons of which is obtained from the LSIP area. The second widespread crop of the LSIP area is maize, which is grown in the summer under irrigation. Its total production is 18% of the total wheat production. Accordingly, the two most widespread crops, namely wheat and maize, of the LSIP, are considered for climate change predictions.

Wheat sown in due time and late in the winter is grown under irrigation (drip) and rain-fed conditions, whereas irrigated maize is grown as the first crop and second crop after wheat. During the experiments, some crop growth parameters, such as ET, yield, plant height, LAI, HI and WUE, are measured and used for the

Table 7.3 Water balance components for wheat and maize. *Sources* Ünlü et al. (2007: 100)

Items	Wheat			Maize		
	1994–2003 observed	2070–2100 estimated	Diff. (%)	1994–2003 observed	2070–2100 created	Diff. (%)
Precip. (mm)	531.1 ± 184.7	510.6 ± 209.5	−4.0	47.5 ± 23.8	24.0 ± 18.0	−47.6
Evapo. (mm)	373.9 ± 30.6	333.0 ± 24.2	−10.9	399.9 ± 29.8	−1.7	393.1 ± 33.9
Irrig. (mm)	74.8 ± 72.8	67.4 ± 1.32	−9.9	371.1 ± 49.4	+3.3	383.3 ± 44.2
Biomass (t/ha)	16.5 ± 1.39	14.33 ± 1.37	−13.1	27.0 ± 1.53	−25.1	20.6 ± 1.34
Yield (t/ha)	5.11 ± 0.73	4.83 ± 0.7	−5.5	15.19 ± 1.29	−31.0	10.48 ± 1.0
Growing period (day)	183.4 ± 6.3	167.4 ± 5.4	−8.7	115.2 ± 3.6	−8.1	105.9 ± 0.7

calibration of the SWAP Model (Soil-Water-Atmosphere-Plant). Wheat and maize growth, yield and other growth parameters are estimated by the SWAP Model for future climatic and soil conditions of the 2070s to 2100s. Water balance components for the wheat-growing period are depicted in Table 7.3.

Table 7.3 shows the effect of the higher predicted temperatures and less rainfall on wheat production in the future climate. Higher temperatures are predicted to cause shorter growing periods and lower water balance components in the wheat-growing season than those of the future. The higher concentration of CO_2 is predicted to enhance photosynthesis and increase crop yields. However, the higher temperatures of the summer months will increase the water requirements for irrigation. The yield of the conventional rain-fed wheat depends on the rainfall in the winter from November to May (Kanber et al. 2007).

Similarly, the second crop maize yield will decrease because of the reduced grain weight caused by the short growing period. Future grain yield decreases due to the increased temperatures are to be expected more drastically under rain-fed conditions. Grain yield reductions due to the increased temperatures will occur even under irrigated conditions. Moreover, grain weight increases will not be sufficient to compensate for the reduced grain numbers. This indicates that high temperatures will also have an adverse effect on grain growth.

7.4.3.3 Irrigation and Drainage

Land use in the 2070s: Climate change will influence evapotranspiration due to the decrease in precipitation, especially in the wintertime. However, the spatial distribution of ET is different in the whole of the basin. ET values increase in the north of the basin, but decrease in the south, especially in the areas of crop production and natural vegetation during the warm-up period. The reduced ET in these areas is due to the lack of available soil water in the root zone to evaporate. In these zones, irrigation water requirement will be greater in the future because of the decrease in precipitation.

Table 7.4 Yearly irrigation water requirement (IWR) for the major crops in LSIP during the warm up period of 2070. *Source* Nagano et al. (2007a: 194)

Crops	Present[a] 1990s	MRI-GCM		CCSR-GCM	
		IWR (mm)	Diff. (mm)[b]	IWR (mm)	Diff (mm)
Fruit	762.1	848.6	+86.4	778.8	+16.6
Citrus	661.4	749.0	+87.6	724.4	+63.0
Maize	569.0	611.0	+42.0	594.2	+25.2
Soybean	539.0	559.9	+20.9	546.2	+7.2
Cotton	524.2	583.0	+58.8	569.3	+45.1
Maize II	391.4	385.9	−5.5	380.3	−11.1
Vegetable	229.2	302.0	+72.8	289.2	+60.0
Melon	195.9	195.2	−0.7	239.6	+43.7

[a]From the DSİ

[b]Differences between present and future values were estimated from the pseudo-warming experiment

Table 7.4 shows the crop water demand in the 2070s according to climate change. According to the table, the water demand for fruit crops would significantly increase due to water shortages in the early spring. Vegetables would have a greater water demand for the same reason.

Similarly, irrigation efficiencies, cultivated area, and the amount of water release from the Seyhan dam to the LSIP area will be affected by the future climate change (Table 7.5). Nagano et al. (2007a) reported that efficiencies of conveyance and application will be the same as in the present in the S1 scenario (passive and low investment scenario predicting a decline in the maintenance level of the canals compared to the present in non-irrigated Phase IV area conditions). However, the relevant efficiencies are estimated to increase in the S2 and S3 scenarios (S2 and S3: pro-active and high investment scenarios), where the maintenance of the canals will be improved compared to the present conditions seeking to irrigate the Phase IV area i.e., the lowlands of the LSIP with the highest groundwater uptake. On the whole, an average of 150 mm of new (future) groundwater use is assumed to occur in the LSIP area. In these scenarios the same soil physical properties and the geology and terrain characteristics of the LSIP area were used for both models of MRI and CCSR. The actual water release for LSIP increases 7% in S1, whereas it decreases 22% in S2 and S3 for MRI-GCM. These results are also used for the CCSR-GCM scenarios of the future. The decrease in water availability estimated for IWr is nearly 50% of the present in the S2 and S3 scenarios, whereas it is predicted to remain constant in the total service area of the LSIP in the warm-up period of 2070. However, the water availability for a unit area will decrease drastically in the future for both models. All figures on the water management estimated by CCSR-GCM are lower than those by MRI-GCM.

Table 7.6 shows the results of the simulation for the future land use. Citrus would remain constant around 20% and, in the case of scarce water supply, watermelon would emerge. However watermelon is usually cultivated only once

Table 7.5 Water availability in the LSIP under climate change and water development scenarios. *Source* Nagano et al. (2007a: 195)

	Present 2002	MRI-GCM (2070s)			CCSR-GCM (2070s)			Unit
		S1	S2	S3	S1	S2	S3	
Ec	0.8	0.6	0.8	0.8	0.6	0.8	0.8	
Ea	0.6	0.6	0.7	0.7	0.6	0.7	0.7	
Ei	0.48	0.36	0.56	0.56	0.36	0.56	0.56	
IWr	1424	1523	1112	1112	1294	854	854	10^6 m^3
Waa	683.5	548.1	622.7	622.7	465.8	478.5	478.5	10^6 m^3
Area	1168.83	1168.83	1168.83	1168.83	1168.83	1168.83	1168.83	1000 da
WA/da	585	469	533	683	398	409	559	m^3/da
AreaT			1450.98	1450.98		1450.98	1450.98	1000 da
WA/ da*			429	579		330	480	m^3/da

Note Ec, is conveyance efficiency; Ea, application efficiency; Ei, total efficiency (Ec × Ea); IWr, actual water release for LSIP; Waa, actual water available for LSIP (Ei × IWr); Area, total service area of LSIP; AreaT, total service area with Phase IV area complete; S, water development scenarios, WA/da*, actual available water for AreaT

Table 7.6 Simulated cropping pattern for future climate in 2070 and social scenarios. *Source* Nagano et al. (2007a: 190)

	Base case	MRI-GCM			CCSR-GCM		
		S1	S2	S3	S1	S2	S3
Available Water (mm)	585	469	429	579	398	330	480
Citrus	22.0	22.1	22.1	21.9	21.9	18.3	21.8
Cotton	59.3	24.0	15.1	48.3	4.3		26.0
Vegetable	7.0	4.4	3.6	6.4	3.0	3.2	4.7
Watermelon, and Maize		41.3	51.7	12.9	64.0	78.5	38.8
Fruit	11.6	8.3	7.5	10.4	6.8		8.6
Gross revenue (TL/da)	717.9	706.9	702.6	715.6	696.4	670.0	707.9
Shadow price of water		0.101	0.117	0.056	0.164	0.137	0.116
Idle water (mm)	23.5						

every five years to avoid replant failure, thus requiring use of a particular crop rotation approach when setting up simulation studies based on the weighed average of watermelon cultivated for one year and maize cultivated for four years (Nagano et al. 2007a).

Regarding the predicted future land use change due to the decrease in the available water together with the projection of the present revenue-water demand relation, cotton seems to become the major crop in the less water deficit conditions. However, in severe water deficit conditions the combination of watermelon with maize would become the major crop. Citrus would also have a stable land-wise distribution unless a severe water deficit (<350 mm) occurs.

Fluctuation of groundwater depth and salinity: For the simulations on groundwater depth and salinity, the groundwater depth at the northern boundary was assumed to be fixed at 5 m below the ground surface by Nagano et al (2007a). On the other hand, at the southern boundary on the coast, the present climate was set to 0 m and to 0.8 m for the projected climate for the simulation. The level of groundwater table in simulations with projected climate data was lower than in the present conditions (Fig. 7.16). The water table within 3 km from the coast was mostly affected by the higher seawater level (0.8 m) and was more sensitive to the degree of management (Nagano et al. 2007a).

According to the simulations, the level of groundwater depths may increase in the future climate compared to the present climatic conditions. So, the shallow water table in the LSIP is projected to be lower in the 2070s. This will be caused by the decreased precipitation and the amount of the irrigation water. In general, the risk of higher water table occurrences seems less likely to occur due to the projected

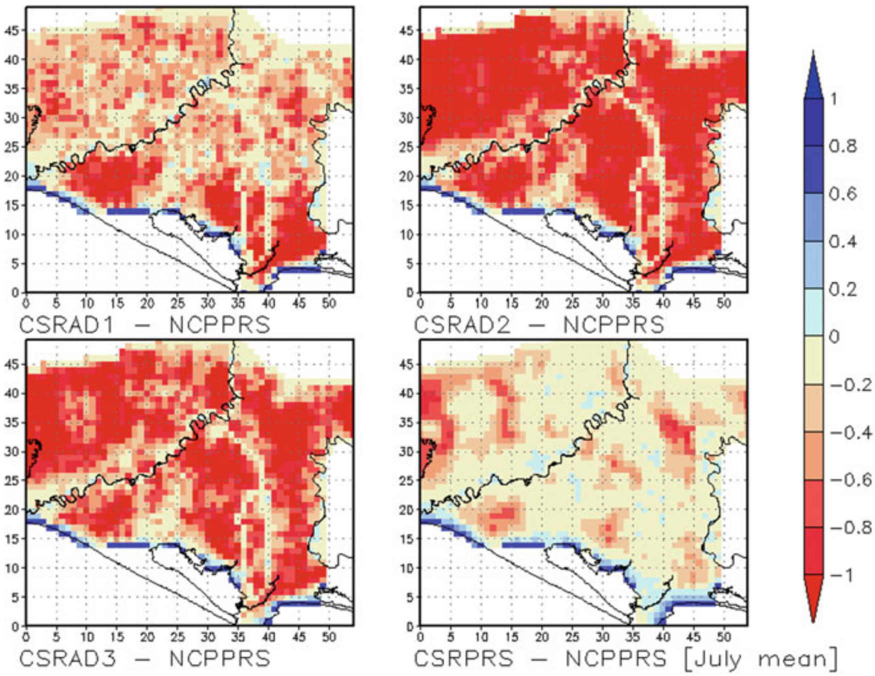

Fig. 7.16 Comparison of groundwater table levels between present and warm-up conditions of the future with different adaptation scenarios (the case of CCSR runs in July average; Scenario 1: top left, Scenario 2: top right, Scenario 3: bottom left and present land use: bottom right). *Source* Nagano et al. (2007a: 194)

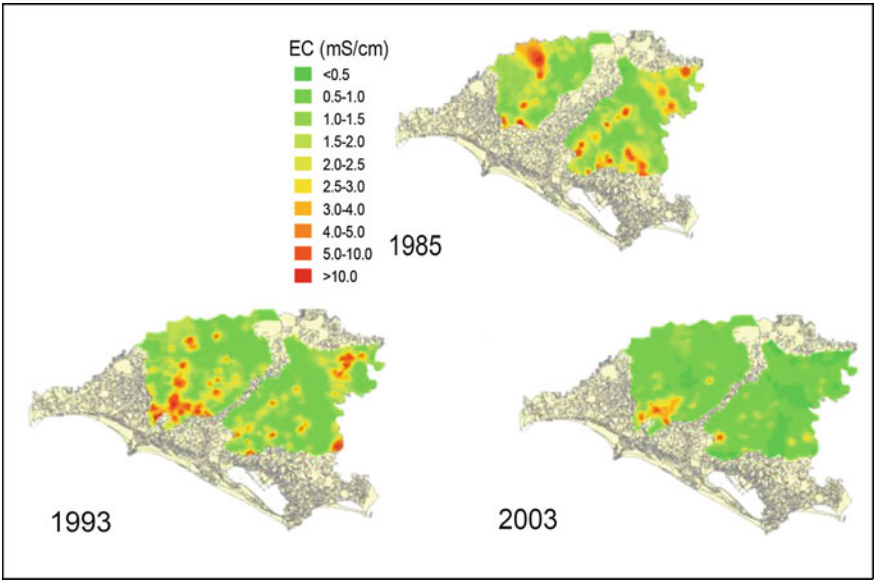

Fig. 7.17 Electrical conductivity of the shallow water table during the different years in July in the LSIP area. *Source* Nagano et al. (2007b: 213)

decrease in precipitation and the water supply. Waterlogging is only partially projected to occur along the coast, where irrigation management has in the present and will in the future have considerable influences on the shallow water table. The influence of irrigation management on the shallow water table will most likely be higher than the change predicted to occur due to the climate.

Sodium contents dominantly contribute to increasing salinity in the LSIP area, where measurements were conducted during the peak irrigation season in July. Although there may have been dilution effects by the increased irrigation, it is quite definite that the shallow water table has been consistently decreasing over the years (Fig. 7.17).

Salinity was severe when rain-fed agriculture was widespread before the implementation of the irrigation system. In those days, the summer dryness was the major driving force for the rising salt in the soil. However, after the implementation of the farmer-based excess irrigation practices, the soil water flux in the summer was reversed, consequently leaching the soluble salts in the soils. Additionally, the low sodium Seyhan Dam waters have been an irrevocable advantage for leaching salinity in the area (Nagano et al. 2007b).

Irrigation performance: The actual irrigation practices of the farmers/water user associations in the area of LSIP are somewhat different from the regulations established by the DSİ in the past. The contemporary regulation-based problems are the outcomes of the lack of or insufficient communication between the farmers and water distribution technicians concerning the allocation of water within the tertiary canals and the insufficient control of irrigation water by technicians. Additionally, the inconsistencies between the initial design of the management programmes and gradually diversifying land use also brought conflict over water allocation. Moreover, the amount of irrigation demand is projected to increase from 100 to 170 mm and the duration of irrigation to extend from early spring to late autumn due to the considerable decrease in precipitation in the winter period via climate change.

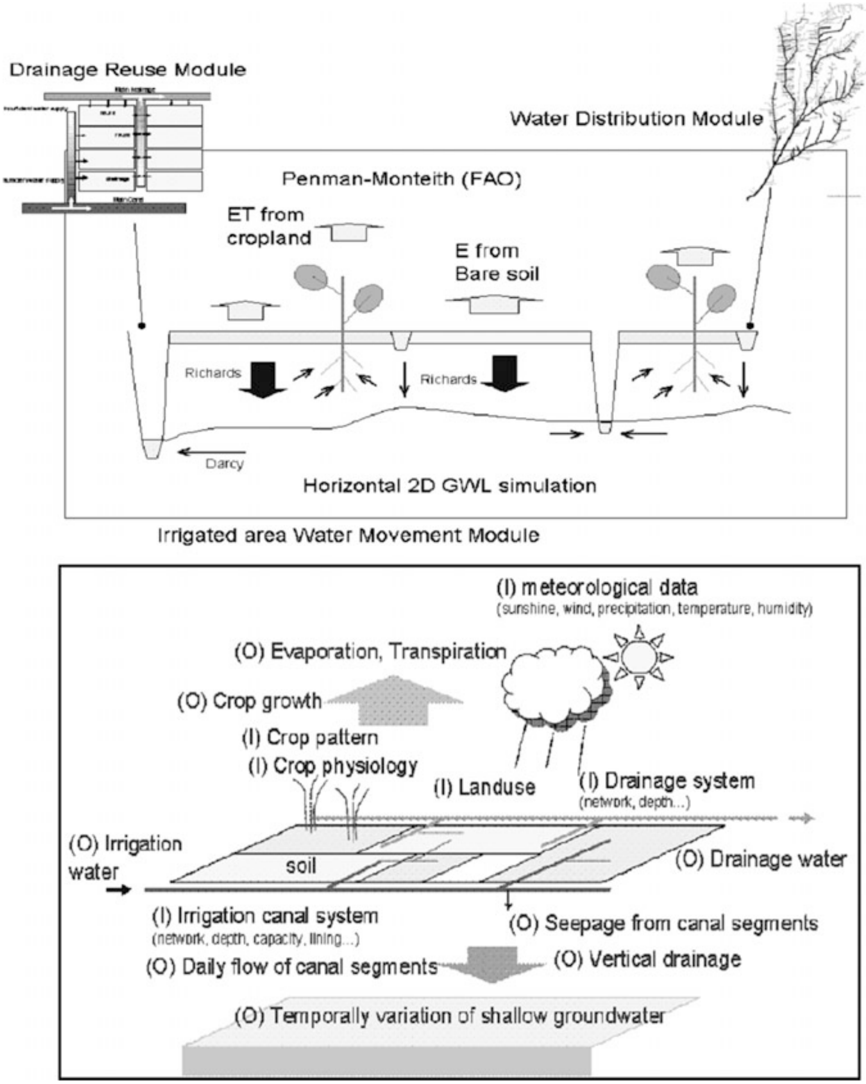

Fig. 7.18 Concept of calculation of the IMPAM (upper), and its important hydrological elements, input (I) and output (O), in irrigated agriculture (lower). *Sources* Hoshikawa et al. (2007: 220), Nagano et al. (2007c: 654)

The high water table is projected to be lower in the 2070s following the transition from gravity irrigation to drip irrigation in citrus gardens, which will enhance the fall in the water level and help users adapt to the future water deficit. Ultimately, the Nagano et al. (2007c) study conducted for irrigation performance in the area highlights the need for an integrated water distribution programme that could include the canal networks, mixed land use, crop growth and water balance.

The Irrigation Management Performance Assessment Model (IMPAM) (Fig. 7.18) was applied to the LSIP for simulating the effects of climate change on the flexibility of the irrigation system, systematic assessment of itsperformance, and diagnosis for sustaining productivity. The model was primarily calibrated to the water budget structure of a specific irrigation district and later the adaptive capacity of the district towards the projected climate change for the 2070s was tested. On the other hand, this calibrated model was used for learning and developing decisions for the future vulnerabilities of the present irrigation management programme and assessing the effect of possible adaptations concerning climate change (Hoshikawa et al. 2007).

From the outcomes of the IMPAM, irrigation efficiencies (around 40%) and irrigation water losses are estimated to decrease in the future. The annual total of irrigation water intakes and drainage exceed 2,500 mm and 1,500 mm respectively in the upper part of the LSIP. It is also determined that the majority of this large amount of irrigation intake was the water that was not lost from the canal as leakage or dropped to the drainage system as tail water.

7.5 Conclusions

The ultimate statement of this chapter derived from the above mentioned research and modelling studies is, briefly, that agriculture in the LSIP area may be affected by the future predicted climate change. In the 2070s, the precipitation in Adana is projected to decrease by 42–46%. The decreased precipitation would mainly occur in the winter period. There would be need for irrigation in the early spring for the tree crops and vegetables to cope with the drier winter. Additionally, the irrigation demand would increase and the irrigation period would become longer under the assumed climate change. For this reason, the LSIP may have to change crop and irrigation management to adapt to situations with less water availability. The LSIP has two large-scale reservoirs in the upstream as water sources. The decreasing river discharge based on climate change would necessitate the determination of a resource-wise adaptive capacity. However, the 30,000 ha of additional irrigation development in the Phase IV area will cause an extra water deficit in the future.

Moreover, the irrigation and drainage infrastructure is already aged and deteriorated so that the carrying capacity would farther deteriorate without proper maintenance. Low conveyance and application efficiencies are both contributing to high water table problems. Therefore, the management of the canal system would be the key factor determining the system-wise adaptive capacity of the LSIP. For conserving the adaptive capacity against possible climate change, it is strongly recommended that irrigation efficiencies, both application and conveyance, must be improved in the LSIP. In this context, improved irrigation efficiencies would point to the enhanced maintenance of the canals, gate operations, and application techniques. This will lead to the equity of allocation and the prevention of the high water table, along with appropriate soil conservation in the long term. This will also be useful in the coastal area seeking un-irrigated management and, in turn, the consequent absence of drainage networks. However, the coastal area may face higher water tables due to a sea level rise as foreseen by the changing climate projections. This may suggest the need for good drainage networks or, more appropriately, a land-water management programme based on the natural properties of the wetland area that would consider halophyte management. Use of deep groundwater for conventional agriculture would increase the risk of salt water intrusion from the sea and cause devastating outcomes.

Additionally, for enhancing an adaptive capacity for the LSIP area to climate change, effective modifications in the strategies of water use and irrigation system management should be accomplished. The gravity water delivery system should be transformed to a closed delivery system, and serious precautions must be taken immediately to prevent erosion and sedimentation in the water basin and water storage structures. This effort would subsequently provide high level effectiveness for the water supply and water use.

Highly efficient drip and sprinkler irrigation networks should be widely implemented in the LSIP area to irrigate cash crops and increase the efficiency of water use. However, other adaptations can be developed by the increased use of groundwater as a source of irrigation to cope with the hazards of the forthcoming climate change. Nevertheless, in many parts of the plain, the deep aquifers are saline and their degree of recharge is still questionable. Moreover, excess exploitation of the groundwater in the coastal area would surely increase seawater intrusion, causing devastating outcomes. This suggests the need for good drainage networks and the use of river waters with increased irrigation efficiencies.

Consequently, as reported by Nagano et al. (2007a), the LSIP at present seems to have large adaptive capacity towards climatic and social changes. To sustain its productivity, it is strongly recommended that farmers and water user associations improve irrigation and water use efficiencies by means of better maintenance of canals, better gate operation, and employment of better application techniques. This would improve equity of water allocation, avoid high water tables, and conserve the soil in the long term. In the whole area, especially the coastal zone, good management of subsurface drainage is vital to avoid salinity and waterlogging. The use of deep groundwater should be avoided because of the risk of salt build-up.

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