The Integrated Assessment of the Impact of Climate Change on Lower Seyhan Irrigation Project

Irrigation and Drainage Sub-group
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1. Introduction

Many large-scale irrigation projects in the arid and semi-arid regions are now facing structural changes. Water management responsibilities are being transferred from governments to end-users; water distribution management is becoming more complicated by diversifying cropping patterns; and the predicted climate change may further bring constraints on water resource availability and management options. Therefore an assessment of the existing irrigation systems' capacity is important if existing irrigation systems were to adapt to social and climatic changes.

The Lower Seyhan Irrigation Project (LSIP) is one of the largest irrigation projects in Turkey, which extends to the delta plain of Seyhan river basin with a total irrigated area of 133,000 ha (**Fig.1**). Gravity irrigation is conducted with the water supply from the big reservoirs in the upper stream. However, climate change experiments project a decrease of precipitation in this region. The plain has potential drainage and salinity problems, which may deteriorate either with saltwater intrusion caused by sea level rise, or with a change of water use in the district.

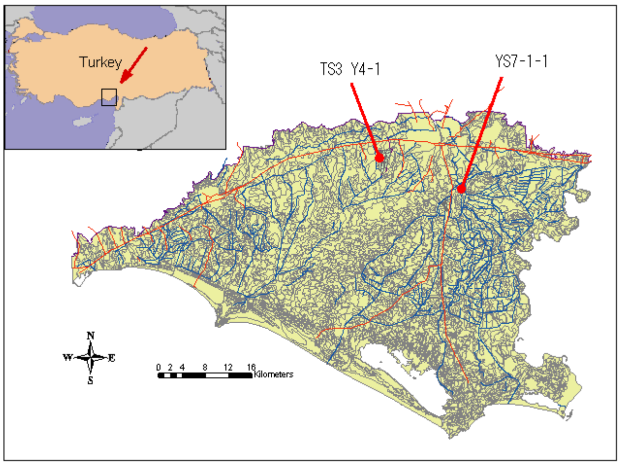


Fig. 1 Project area of the LSIP and situation of monitored canals.

The aim of the project "Impact of Climate Change on Agricultural Production System in Arid Areas," administered by the Research Institute for Humanity and Nature (RIHN) and the Scientific and Technical Research Council of Turkey (TÜBİTAK) is to analyze the systematic response of the agricultural production system towards climate change. The rapid advance in computational capacity and the introduction of GIS in recent years enabled us to integrate a wide variety of data with respect to space and time. We initiated the field work in 2002 with the ambition to collect and integrate as much data as possible and to analyze them with our newly developed model called the "Irrigation Management Performance Assessment Model" for simulating the systematic response of the whole LSIP to possible changes.

Our activity for the past five years can be classified into sub-activities below.

1) Preliminary questioning to Water Users Associations.
2) Collection of archive data related to irrigation.

3) Land use classification using remote sensing images.
4) Monitoring actual water budget of the tertiary canals in the LSIP.
5) Construction of Irrigation Management Performance Assessment Model and its validation for the small monitored area.
6) Field monitoring of salinity of soil and shallow water table in the coastal area.
7) Generation of social scenario of the LSIP in the 2070s
8) Simulation of land-use changes in the 2070s using pseudo-warming outputs and expected value-variance (E-V) model.
9) Simulation of crop growth and water budget of the whole delta using the IMPAM.

Hereafter the approach and main outcomes for each activity are explained.

2. Preliminary questioning

2.1 Visits to Water User Associations

In the summer of 2002, we tried to identify typical problems of the present system by visiting and questioning all water users associations (WUAs) in the LSIP. Although most previous research e.g. Scheumann (1997) and Cetin and Diker (2003) emphasized salinity and high water table as serious problems in the area, none of the WUAs have shown concern to those problems at the time. Instead, they were more concerned about the following four issues;

i) recent deficit of water during peak irrigation season,
ii) rehabilitation of canals,
iii) management and maintenance responsibility of drainage canals and
iv) collection of irrigation fee.

We have learned that the primary cause of low irrigation efficiency was due to degradation of canals. While responsibility of the management of irrigation facilities was transferred from DSI to the WUAs at the time of their establishment in 1993, main drainage canals remained to be DSI's property. This was probably due to the fact that the burden of maintenance of drainage canals was too heavy for newly established WUAs. Generally farmers don't pay attention or are not willing to pay for maintenance of drainage canals. It remains to be potential problem for the future because drainage is an indispensable part of the agricultural system in the LSIP.

2.2 Efficiency of WUA

Collection of irrigation fee determines sustainability of WUAs. Umetsu et al. (2006) addressed the relative efficiency of WUA management by suggesting alternative composite efficiency index. Data envelopment analysis was applied to compare efficiency levels with management-, engineering- and welfare-focused models. The analysis revealed that some WUAs were suffering from unfavorable management practices and there was a scope for major reorganization.

3. Collection of archive data related to irrigation

To make full use of the distributed model, we needed physical parameters with high resolution because the combined resolution of the different parameters would ultimately be determined by the dataset of the lowest resolution. In this sense, we were both fortunate and unfortunate in choosing the LSIP in terms of availability of data.

3.1 Soil

There was already an excellent soil database on GIS with high resolution established by the soil department of Çukurova University before the project was initiated. We were inspired of the high possibility of data integration when we first had a look at this database.

3.2 Meteorological data

As far as Lower Seyhan Plain is concerned, there are data from two automatic meteorological stations in Adana and Karataş available.

3.3 Irrigation intake

DSI keeps daily records of diversion from regulators to TS0 and YS0 and of direct intake from Seyhan Dam to main canals TS1 and YS1. But apart from that, even daily diversions to each main canal were not available in usable form. The method of

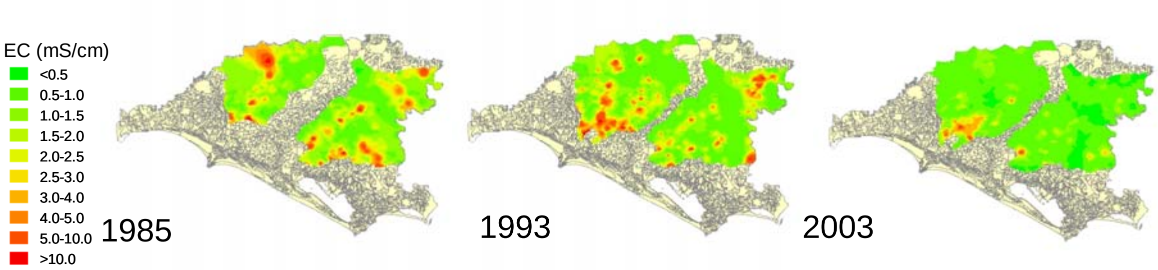


Fig. 2 Decadal change of salinity of shallow water table

building up seasonal irrigation demand was very simple, so if we had access to the cropping pattern with spatial reference, we could regenerate water demand in the past. Unfortunately, the cropping pattern record was only kept for the whole district scale. We strongly recommend DSI to be more cautious on data management, because they carry out very detailed buildup every year but not archiving those good records once they calculated the sums.

3.4 Shallow water table data

Since the 1980's, DSI has been measuring the monthly level and EC (once a year) of shallow water table (down to 4m from surface). The number of observation wells was 626 in the 1980's, and in the 1990's the number was increased to 1,134, covering nearly the entire command area of project phase I-III. The dataset of shallow water table has the highest spatial resolution of all water budget components so that the IMPAM used this data intensively for calibration of the model. When data from the 1980's, the 1990's and the 2000's were analyzed by Donma et al.(2006), it was found that EC of water table has been continuously decreasing in the most of parts as shown in Fig.2. On the other hand annual average depth of water table did not change so much.

3.5. Properties of irrigation and drainage facilities

Water flows in irrigation and drainage networks are much faster process compared to soil water movement and they can have large impacts on shallow water table fluctuations. Whereas soil hydraulic parameters have a dominant effect on water budget in a one dimensional crop water balance model, the influence of irrigation and drainage canal network density would become more dominant as we increase the calculation grid size. This networks density can be derived by the use of GIS and they can also reflect management and maintenance states. We digitized the canal networks and related properties.

4. Land use classification using remote sensing images.

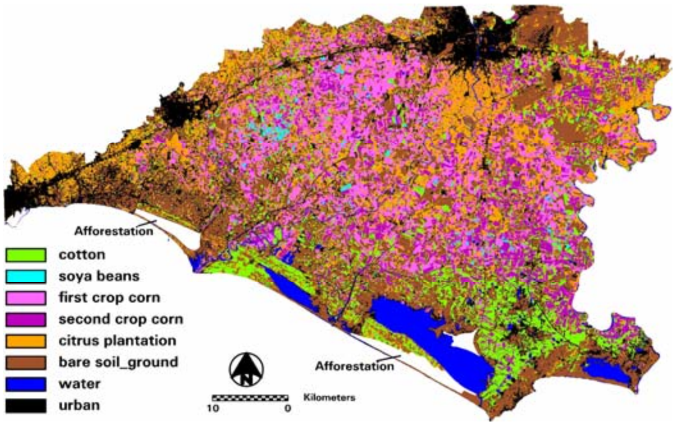


Fig. 3 Cropping pattern derived from Landsat image of August 2003.

As explained in the section 3.3, the cropping pattern for each plot should exist, but only the total cultivated area for each crop was obtainable. Since the cropping pattern would largely influence water use, an image analysis of past remote sensing data was carried out. Berberoğlu compared the Landsat image from year 2003 with the detailed cropping pattern record of a few WUAs, and succeeded in classifying major land use (Fig.3.) By following the same methodology land use in 1985 and 1993 were also classified.

5. Monitoring actual water budget of the tertiary canals in the LSIP

5.1 Irrigation method in the LSIP

Calculation of principle water demand for the LSIP is carried out in the simple manner. All WUAs use "DSI Sulamalarinda Bitki su Tutimleri ve Sulama Suyu Ihtiyaclar (1988)" for calculation of their irrigation water demands. A unit crop water demand multiplied by cultivation area is totaled for the whole command area to calculate water demand at the main canal inlet. They also consider transport loss (presently assumed as 0.8) and field application loss (presently assumed as 0.6). During irrigation season, each WUA strictly monitors water intake from the main conveyance canal to its responsible main canal to guarantee its water demand. After the transfer of operation from DSI to WUAs, there seemed to be a large inconsistency between their proposed irrigation demand before the season and their actual water intake during the season. From our impression there were several possible reasons for this.

i) WUAs were late to collect cropping plan from farmers.
ii) Some WUAs were not skillful in operating software for water demand calculation.
iii) Water loss due to deterioration of canals was not well considered.

After the intake, there is no more monitoring at the secondary or tertiary canal level. Water distribution technicians control water allocation by exchange of information via transceivers. They are capable of managing water distribution by this opportunistic method because there is enough water at a moment, but it will be very difficult if water resources become less available.

5.2 Monitoring of tertiary canals

Since there was no monitoring carried out in the past, water budget structure of the LSIP was unknown. We felt a need to monitor actual water use to provide answers to some important questions before modeling the whole system, such as ;

i) cause of low irrigation efficiency,
ii) irrigation rule of end users,
iii) actual irrigation efficiency of each land use, and
iv) relation between irrigation, drainage and fluctuation of shallow groundwater.

We chose two tertiary canals from the left and right banks of the Seyhan River (see Fig. 1) and started monitoring from the spring of 2004. YS7-1-1 in Gazi WUA on the left bank was a 'kanalet' type. Citrus and maize were mainly cultivated in the command area. TS3 Y4-1 was a concrete lined canal, which belonged to Yesilova WUA on the right bank. The main crops of this area were maize and watermelon.

During the course of measurement, we found out that farmers' actual irrigation practices were somewhat different from the rule established by DSI in the past. Firstly, water allocation within the tertiary canal was conducted on acquaintance base between farmers and they used mobile phones to communicate with each other. Secondly, distribution technicians were not strong controllers. Farmers preferred to take water from early morning and to continue until after dark. Therefore, distribution technicians were usually informed of water allocation after actual operation. Water demand tickets were not used for allocation planning, but rather used as a proof or a receipt, filled by technicians when they checked irrigation on site (Nagano et al. 2005).

If we only estimated water use from water demand tickets without measurements, we would have mistaken that water management was just being neatly carried out as principle. Instead, we found out that annual total of irrigation water intakes and drainage from unit area exceeded 2,500mm and 1,500mm, respectively in the upper part of the LSIP. We also found out that the majority of this large amount of irrigation intake was lost from the canal as leakage or was dropped to drainage as tail water.

6. Development of Irrigation Management Performance Assessment Model and its validation for the monitored area.

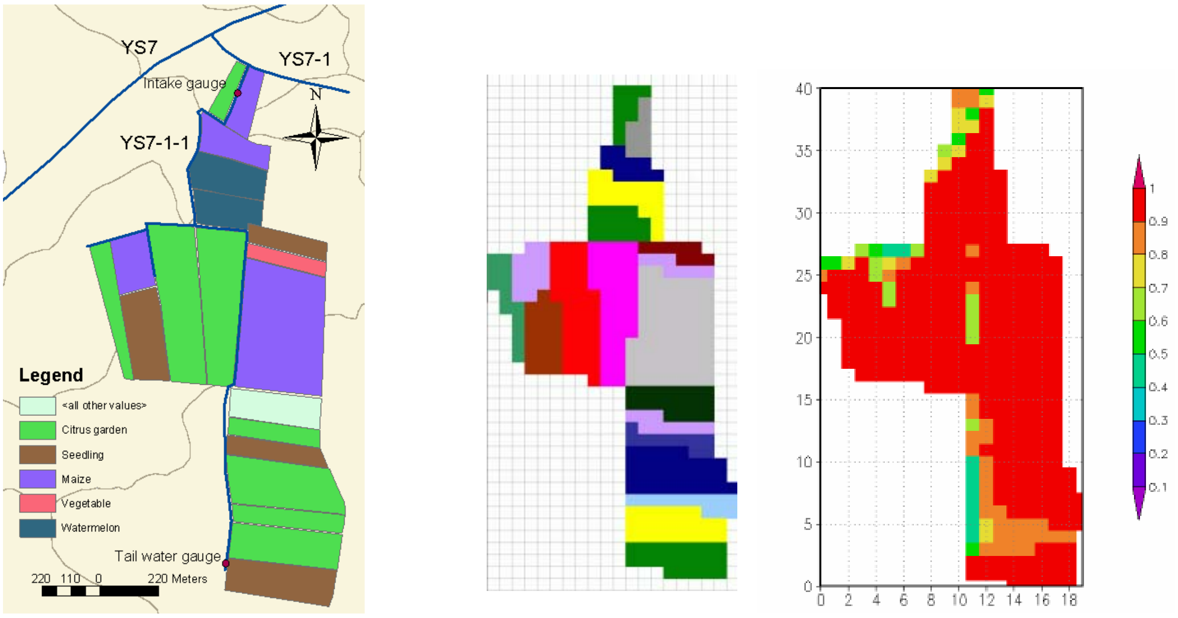
6.1 Irrigation Management Performance Assessment Model

One of the innovative parts of this project is the development of the “Irrigation Management Performance Assessment Model” (Hoshikawa et al., 2005). The IMPAM is a hydrological model specially developed for assessing performance of the irrigation system of a plot to district scale. As seen in the case of the LSIP, a large proportion of the water brought into an irrigation district moves much faster than Darcian flow i.e. flow in canal, leakage from canal recharging shallow water table, and drainage flow etc. Whereas most one-dimensional crop water balance models mainly focus on soil water balance, the IMPAM is one of the first to consider the spatial effect of an artificial water path. Another distinct character of the IMPAM is its ability to assess the effects of mixed land use. The neighboring plots have water budget interaction through water table. The IMPAM is a quasi-three-dimensional distributed model so that it can represent realistic land use.

6.2 Validation of the IMPAM at the tertiary canal level

The IMPAM was validated with observed water budget of YS7-1-1. Except for the saturated hydraulic conductivity which needed to be multiplied by ten, the model was able to represent actual water budget with actually measured soil physical parameters and with irrigation and drainage network densities (Nagano et al. 2006, Hoshikawa et al., 2006).

This trial also revealed that significant percentage of leakage from the irrigation canal was quickly drained through drainage canals that ran parallel to it. From the model, irrigation water that substantially infiltrated was estimated to be 800-1000mm. It means that the majority of water was lost as leakage during transport or as tail water from the end of the canal and from each end of the field. However, a good drainage network running adjacent to irrigation canals carried away excessive water quickly out of the area and avoided water logging. Therefore, low efficiency simply seemed to have resulted from poor control of



Disaggregation into grids Calculation of actual/ potential transpiration

Fig. 4 Land use in command area of YS7-1-1, disaggregation into grids, and the example of grid calculation by the IMPAM.

water in the canal.

7. Field monitoring of salinity of soil and shallow water table in the coastal area

Out of the 175,000ha originally planned for implementation of the LSIP, 133,000 ha is now reclaimed and receiving irrigation. The remaining area, called "phase IV area," is mainly lowland near the coast, and this area until very recently did not have proper irrigation or drainage facilities. The area was seriously affected by salinity in the past because of high water table and bad drainage.

We started to monitor the spatial distribution and temporal change of the shallow water table and soil salinity by field measurements and laboratory analysis in 2005. We set twelve new observation wells and fifty fields of different land use for regular monthly observation.

Kume et al.(2006) found that among the different land use in the Phase IV area, cotton field and bare land had relatively high soil salinity (Fig. 5) and for these two land uses, NDVI and soil salinity had high correlation. When Kume et al. (2007) compared salinity distribution of shallow water table measured in 1977 and the apparent salt affected areas through remote sensing in 1990 and 2005, they found that soil salinity had decreased from 1990 to 2005, but distribution pattern of salinity still was similar to that of water table in 1977.

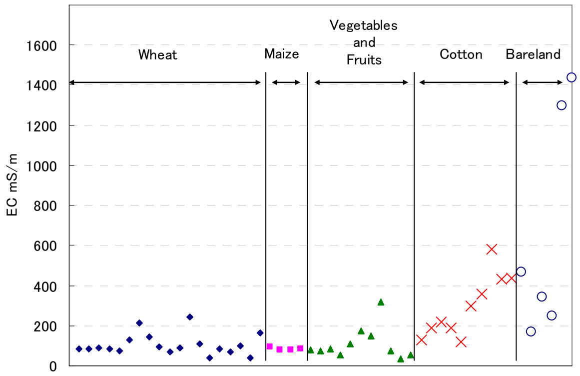


Fig.5 Relationship between land use and soil salinity

These results suggested that even in the coastal area, soil salinity has decreased with application of irrigation. Under this condition, farmers are shifting their cultivation from salt-tolerant cotton to the other varieties. However high water table still is problematic and without development of good drainage networks, the area may face even severer water logging with increase in irrigation. Another potential risk is increase in use of deep groundwater. The deep groundwater in the area has high risk of salt intrusion and this may bring devastating consequence.

8. Generation of social scenario of the LSIP in the 2070s

8.1 General setting of the scenario

The response of the irrigation system towards

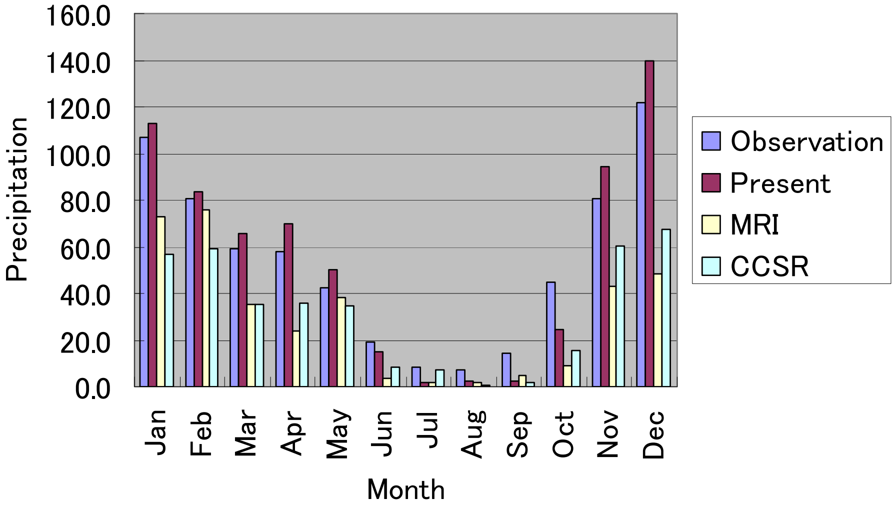


Fig. 6 Comparison of observed and projected precipitation in Adana

Table 1 Irrigation water requirement of major crops in LSIP

		MRI-GCM		CCSR-GCM	
crop	(a) 1990s irrigation water requirement (mm/year)	(b) 2070s irrigation water requirement (mm/year)	(b)-(a) future increase in water requirement (mm/year)	(c) 2070s irrigation water requirement (mm/year)	(c)-(a) future increase in water requirement (mm/year)
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
II maize	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

Source: (a) Nuran Özgenç, Faruk Cenap Erdoğan. (1988) DSI irrigated crop water consumption and irrigation water requirement.
(b),(c) Estimated from the average precipitation decrease in 2070s from peud-warming experiment (Kimura et al., 2006). We used the same level of evapotranspiration in 2070s based on the results that the decrease in duration days trade offs the increase in precipitation increse by climate change.

climate change can vary with assumed socio-economical settings. Along with two scenarios for pseudo-climate output (MRI and CCSR), we assumed four sets of social scenarios. The four scenarios shown below correspond to general scenario assumed to integrate activities of all subgroups. For details, please refer to the paper "Generated social scenarios and basin conditions for the final integration" in this report.

Present: Same availability of water and same state of infrastructure as present.

Scenario 1: Passive and low investment scenario. The maintenance level of canal declines from present. Phase IV area would not be irrigated.

Scenario 2: Pro-active and high investment scenario. The maintenance level of canal improves from present. Phase IV area would be irrigated.

Scenario 3: Same setting as the scenario 2. Additionally, groundwater uptake occurs in the low lying area. On the whole LSIP average, 150mm of new groundwater use is assumed to occur.

8.2 Simulation of changes in land use in the 2070s

Using the available water calculated for the Seyhan and Çatalan reservoirs in the upstream with given pseudo climate and general social scenario of the basin , Umetsu et al. (2006) projected land use change in the 2070s using expected value-variance (E-V) model. As shown in Fig. 6, precipitation around Adana is projected to decrease significantly in the winter time according to the pseudo warming experiment. Table 1 shows the crop water demand in the 2070's according to climate change. The water demand would significantly increase for fruits because of water shortage in the early spring. Vegetables would have larger water demand for the same reason. Table 2 shows the assumed water use efficiency and cultivated area in the scenarios. Table 3 shows the result of simulation for the land use. Citrus would remain constant around 20% and in the case of scarce water supply, water melon would emerge. Watermelon is usually cultivated only once in five years to avoid replant failure. In order to take into account the crop rotation of watermelon, weighted average of watermelon (1 year) and maize (4 years) was used for the simulation.

9. Simulation of crop growth and water budget of the whole delta using the IMPAM

9.1 Setting of the Simulation

Dirichlet boundary conditions were used for the

Table 2 Water availability in the LSIP under the climate change and water development scenario

			MRI-GCM			CCSR-GCM			
		Base	**Scenario 1** climate change with low water development	**Scenario 2** climate change with high wate development	**Scenario 3** climate change with high water development with 150mm GW	**Scenario 1** climate change with low water development	**Scenario 2** climate change with high wate development	**Scenario 3** climate change with high water development with 150mm GW	
		2002	2070s	2070s	2070s	2070s	2070s	2070s	
(a)	conveyance efficiency	0.8	0.6	0.8	0.8	0.6	0.8	0.8	
(b)	application efficiency	0.6	0.6	0.7	0.7	0.6	0.7	0.7	
(c)=(a)x(b)	total efficiency	0.48	0.36	0.56	0.56	0.36	0.56	0.56	
(d)	actural water released for LSIP	1424	1523	1112	1112	1294	854	854	million m3
(e)=(d)x(c)	actural water available for LSII	683.5	548.1	622.7	622.7	465.8	478.5	478.5	million m3
(f)	total service area of LSIP	1,168,830.0	1,168,830	1,168,830	1,168,830	1,168,830	1,168,830	1,168,830	decare (da)
(g)=(e)/(f)	water availability per decare	585	469	533	683	398	409	559	m3/da (mm)
(h)	total service area with IV complete			1,450,980	1,450,980		1,450,980	1,450,980	decare (da)
(i)=(e)/(h)	water availability per decare with IV complete			429	579		330	480	m3/da (mm)

Source: (d) Water level for Scenario 1 and Scenario 2 was estimated by the Seyhan basin hydrology model (Tanaka et al. 2006).
Base water level is from DSI (2002) Briefing of WUA and Year 2002 Management Activity Report, DSI Region VI, Adana;
(f) from DSI (2003b) Transferred Irrigation Association Year 2002 Observation and Evaluation Report,
DSI Region VI, Lower Seyhan Irrigation Project, Operation and Maintenance Department.

Table 3 Simulated cropping pattern with climate and social scenario

Scenario	Base case	MRI-S1	MRI-S2	MRI-S3	CCSR-S1	CCSR-S2	CCSR-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
Vegetables	7.0	4.4	3.6	6.4	3.0	3.2	4.7
Watermelon & 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 (YTL/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						

*The case of risk aversion parameter set as 0.01

northern and southern boundaries. Level of shallow water table at northern boundary that was along the foot of mountains was fixed at 5 m below the ground surface. The southern boundary that was on the coast was set to 0 m in simulations for the present climate and 0.8 m in the simulation for the projected climate. Neumann condition (zero flux) was assumed for eastern and western boundaries.

Soil type was set as homogenous silt for the whole delta As initial level of water table was unknown, five-year spin-up was conducted before calculation for 1994 – 2003 in each case.

Spatial resolution was 1000m x 1000m. Time step for crop growth and water management was 1-day. Other hydrological elements were calculated with 0.5 day time step.

9.2 Level of shallow water table

Level of shallow water table in simulations with projected climate data were all lower than that in the base run (Fig.7). Although higher sea water level (0.8 m) was given to the simulations with projected climate data, only water table within 3 km from the coast at most was affected. Water table was more sensitive to the degree of management. It is very apparent in comparison of four scenarios in Fig. 7. In general, the

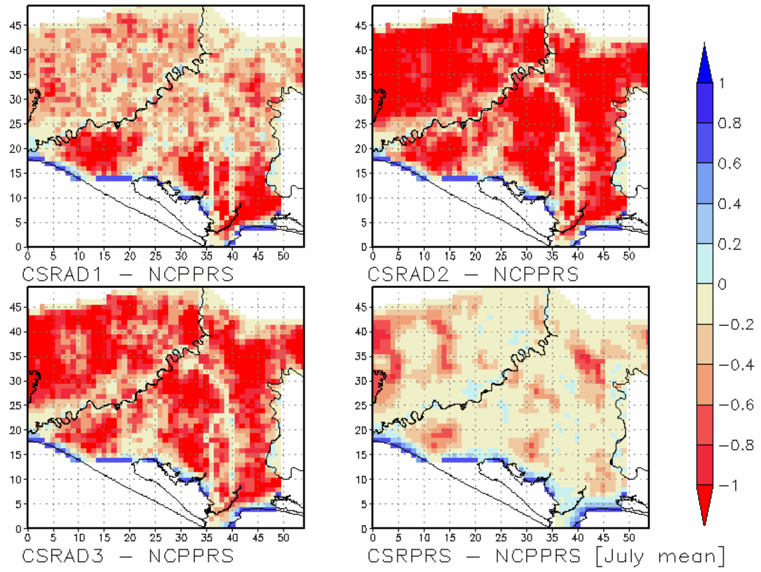


Fig.7 Comparison of water table level between present and different adaptation scenarios (The case of CCSR runs in july average, scenario 1: top left, scenario 2: top right, scenario 3: bottom left, present landuse: bottom right).

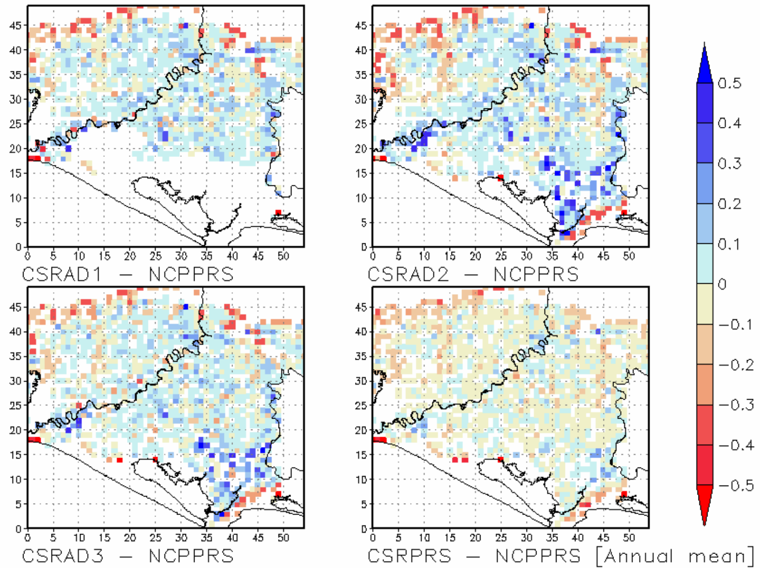


Fig.8 Comparison of the degree of water deficit (actual/potential transpiration) between present and different adaptation scenarios (The case of CCSR runs in annual mean, scenario 1: top left, scenario 2: top right, scenario 3: bottom left, present landuse: bottom right).

risk of higher water table seems less likely to happen due to projected decrease in precipitation and due to decrease in water supply. Water logging only partially occurred along the coast.

9.3 Crop growth

Due to increased evaporation demand of the air, plant transpirations for all scenarios were projected to increase. Therefore more irrigation water was applied to satisfy the need of plants. Significant water stress did not occur because cropping pattern was first determined with available water supply. Even for the case of present management with projected climate, the deficit did not occur. Root zone was kept wet as water table was not so far from the surface. It means that there is enough adaptive capacity for the LSIP towards climate change, if crops are to be chosen adequately with available water resource or application techniques are to be improved.

10. Conclusions

From the analysis of present situation, we have found the followings.

1) Irrigation water is excessively used in the present situation, due to degradation canals and due to low awareness of farmers or water users association for water saving. Water use efficiency is as low as 40%.
2) Salinity prone area has been decreasing in the LSIP for the last two decades mainly because of excessive irrigation and good drainage networks that carried away washed salts. However water table still remains to be high because of the leakage from the canal and the lower area still face the risk of water logging.
3) Water Users Associations in the LSIP is suffering from their difficult economic situation because the size of each WUA is too small.

From our projections with pseudo warming experiments and social scenarios, we have found the followings.

1) In the 2070s, precipitation in Adana is projected to decrease by 42-46% and this decrease would mainly occur in the winter time.
2) Even under this huge decrease of precipitation the reservoirs upstream would have enough capacity for irrigating the LSIP. With additional irrigation development in the upstream, available water decreases and land use must be planned accordingly.
3) There would be need for irrigation in the early spring to save tree crops and vegetables from drier winter.
4) Shallow water table in the LSIP is projected to lower in the 2070s, due to decrease of precipitation. Management of irrigation water and land use would have larger influence on shallow water table than climate change.
5) Land use would change with available water. With the projection of present revenue-water demand relation, cotton seems to become major crop in the less water deficit condition where as in the severe water deficit combination of water melon with maize would become the major crop. Citrus would have stable percentage unless severe water deficit (<350mm) occurs.
6) The coastal area may face higher water table due to sea level rise. This suggests the need of good drainage networks. Use of deep groundwater in the lower plain would increase the risk of salt water intrusion and resulting devastating situation.

As a system, the Lower Seyhan Irrigation Project at present seems to have large adaptive capacity towards climatic and social changes. To sustain its productivity, we strongly recommend farmers and water users association to improve water use efficiency 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 table and conserve the soil in the long term. In the whole area and especially in the coastal zone, good management of subsurface drainage is vital for avoiding salinity problem and water logging. The use of deep groundwater should be avoided for its risk in salt contamination.

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