The integration of satellite images, GIS and CROPWAT model to investigation of water balance in irrigated area

A case study of Salmas and Tassoj plain, Iran

by

JAMSHID YARAHMADI

January 2003

Enschedeh, The Netherlands

The integration of satellite images, GIS and CROPWAT model to investigation of water balance in irrigated area

A case study of Salmas and Tassoj plain, Iran

by

Jamshid Yarahmadi

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Watershed and Environmental Management.

Degree Assessment Board

Prof. A.M.J. Meijerink (chairman) WRS Department, ITC

Dr. Ir. E.O. Seyhan (External examiner) Free University, Amsterdam

Dr. Z. Vekerdy (supervisor) WRS Department, ITC

Ir. A.M. van Lieshout (Member) WRS Department, ITC

Dr. B. Saghafian (Member) SCWMRC, Iran

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Acknowledgment

Abstract

In this research water balance was calculated for Salmas and Tassoj in the north and western-north part of Orumiyeh Lake in ten water years (1991-2001). Satellite images (Aster image), CROPWAT model, coupled with GIS were applied to compute water balance components.

Satellite images (Aster on 2nd July 2001) were used to determine type and area of cultivated crops. Nine main crops for Salmas and five main crops for Tassoj area were distinguished. Ground truth data was used as ancillary data. Lack of multi-temporal images was main problem in crop classification.

CROPWAT model was applied to calculate actual evapotranspiration and net irrigation water requirement based on local climatic data and derived crop data on satellite image processing. This model calculated net irrigation water requirement for some dominant crops such as: cereal, alfalfa, apple, almond, eggplant, potato, and sunflower in the study area.

Inflow and outflow amounts of surface water were determined using river discharge data in irrigated area, which, are equipped with hydrometers gauges. In ungauged area runoff was estimated by applying runoff coefficient method.

Groundwater uses for agricultural practices was determined using current pumping data in the Tassoj region. Groundwater uses in the Salmas area where has no pumping data was calculated by applying net irrigation water requirement approach. GIS environment was used to determine groundwater table fluctuations.

Water balance for irrigated lands in both areas was calculated by applying an On-farm water balance model. The calculated water balance shows a deciding trend in both areas, particularly in the Tassoj area.

Contents

List of tables

List of figures

1. INTRODUCTION

Water is an irreplaceable natural resource without which humans cannot exist. Also, water is the most widely spread natural substance. Humans use a small part of waters, however, i.e. the fresh water, which is about 2% of the total water amount on our globe. Therefore, in the evaluation of the water resources of any region, the amount of fresh water is considered (UNESCO July 1970).

Water resources and their spatial distribution determine the general character of any country in many respects and its potential economic development as well. Need for water tends to an annual increase in many countries due to the growth of population as well as industrial and agricultural production.

Water balance studies are one of the major fields of modern hydrology. The results of these studies enlarge the spheres of theoretical and practical knowledge, and in some cases provide the only possible way of solving scientific and practical problems, in particular, the problem of the influence of human activity on water balance elements, especially on runoff variation.

Primarily the water balance computation is consisted only as the compilation of characteristics averaged for a long–term period. Modern water balance computation is performed for a design interval (e.g. a year) and is intended to obtain information on the inflow and available water storage in the examined system, e.g. a reservoir.

One of the main components of the water balance is the water loss via evapotranspiration, which is proportional – among others – to the vegetation cover of a region. Remote sensing is a very useful research tool to identify irrigated area and classification of vegetation coverage, especially as we work in a large area, where fieldwork needs a great amount of economical and human resources, like in the Orumiyeh Lake region.

1.1 Statement of the problem

Since the study area is located in a semi-arid zone and it is one of the most important agricultural areas in Iran, and due to poor management of water resources and water consumption in agricultural fields, the water use efficiency in this sector is very low. On the other hand, by increasing use of groundwater in the irrigated areas around the Orumiyeh Lake, salt water intrusion occurs, i.e. saline water from the lake replaces the fresh groundwater.

The above problems make it important to determine the amount of available fresh water for agricultural uses and recommend a sustainable method food production with optimal water use and with minimum losses in water, soil and financial resources.

1.2 Research objectives

The main objective of this research is to develop a water balance for the irrigated area in the northern part of the Orumiyeh Lake with focusing on the following sub-objectives:

- Determine the water balance components for the study area

    o Determine the amount of irrigated lands

    o Estimate the water consumption by existing crops

    o Estimate the surface- and groundwater components

- Identify the existing limitations in the water resources in the area

- Analyse trends and identify possible solutions for a sustainable water use

The flowing questions will be answered

- How is the water balance condition in this study area?

- Regarding the water balance, which development plans can be executed in this study area?

-

1.3 General approach in water balance

Water budgets are simple in concept but more difficult to actually quantify. The complexity of a water budget characterization depends in part on the detail desired. Most water budgets are developed based on long-term averages, especially for aquifers and combined ground/surface water analyses. Water budget for surface supply systems are often developed on specific water years that are accepted to have the greatest stress on supplies.

The most basic equation for water budgets is based on the hydrologic cycle, where water moves from the atmosphere to the Earth's surface to various destinations, and finally to the atmosphere:

$$P=I+ET+R$$

Where "P" represents precipitation of all forms, "I", represents the portion of water, which infiltrates into the ground and provides groundwater recharge (infiltration), "R" represents runoff. As noted above, this equation can be applied to long-term averages, to specific years, to hydro-meteorological data, etc. the analysis for regional purpose will be difficult (Hoogeveen 2002).

1.4 Research method and steps

The following steps were used to compute different components of the water balance in the study area:

1.4.1 Climatic data analysis:

Climatic data analysis was done to prepare data for input the water budget and the CROPWAT model.

- Collecting the required data such as meteorological, discharge and groundwater data

- Consistency analysis of gathered by applying different regression method

- Filling the missing data by using linear correlation between stations

- Converting the point data to distributed (raster) data by applying interpolation method in GIS environment by ILWIS software to create rainfall map

1.4.2 Surface water

- Hydrograph analysis of the gauged rivers

- Estimating the amount of surface water used for irrigation by considering the irrigation efficiency

- Estimating the discharge of ungauged area by applying runoff coefficient method

1.4.3 Groundwater

- Time series analysis for whole wells in the study area

- Determining groundwater losses based on piezometeric wells data using ILWIS software

- Estimating the groundwater withdrawal amount based on available pumping data and applying the net irrigation water requirement approach

1.4.4 CROPWAT model

- CROPWAT model was validated and calibrated based on existing experience in Iran for different crop types in the study area

- CROPWAT model was run with meteorological and other data, which derived from image processing

- Actual evapotranspiration and net irrigation water requirement were calculated by CROPWAT model for different cultivated crops in the study area

1.4.5 Satellite images

- *ASTER* images were prepared and georefrenced in ILWIS by ground truth data

- Crop classification was done by digital interpretation by minimum distance algorithm using ILWIS software

- Fieldwork and performing confusion matrix for crop classification accuracy assessment

- Creating crop map

1.4.6 Fieldwork

Fieldwork entailed collection of hydro-meteorological data and checking crop classification accuracy as well as interview with farmers about agriculture water use, irrigation method, agricultural crops, and crop calendar.

1.4.7 Water balance

Water balance was calculated by applying an on-farm water balance approach for irrigated lands in the study area.

2.GENERAL OVERVIEW OF THE STUDY AREA

2.1 Location

The study area is located in northwest of Iran and it contains some sub-basins of Orumiyeh Lake basin (Figure 2.1.1). Some part of this area (northern part of Orumiyeh Lake) is in Eastern Azerbaijan province and other part (north-western part of Orumiyeh Lake) is in Western Azerbaijan province.

The bounding coordinates are the following:

Latitude: 37° 51′ 37″ N up to 38° 27′ 21″ N

Longitude: 44° 15′ 18″E up to 45° 40′ 29″E
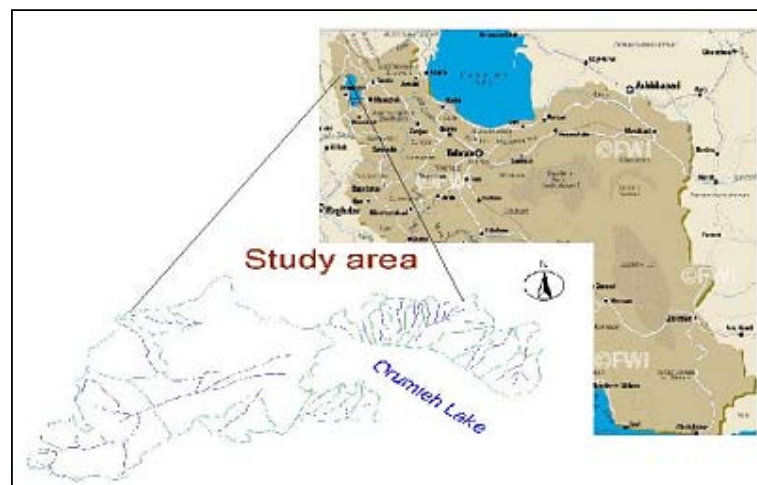
Figure 2.1.1 Location of the study area

2.2 Climate

Mean annual precipitation in the study area is 287 mm for the Tassoj and 270 mm for the Salmas regions. Maximum rainfall falls in the spring season in April (55 mm) and May (54 mm) and minimum precipitation occurs in the summer in August (4 mm) and (3mm) in the Salmas and Tassoj areas, respectively. Winter, in comparison with autumn, has more precipitation (Figure 2.2.1).

The mean annual temperature is 11.83 C° for Salmas and 11.23 C° for Tassoj. The mean maximum temperature is 16.3 C° and 17.7 C° whilst the mean minimum temperature is 4.29 C° and 6.51 C° for Salmas and Tassoj area, respectively. August is the hottest and February is the coldest month in both areas.

The mean annual wind speed in Tabriz and Khoy stations, those are closer to the study area, are respectively 152.2 and 73.1 km/day at 2meter height. Predominant wind in Tabriz is from the east and in Khoy is from the southwest directions.

For more information on climatological conditions see Appendix 2.
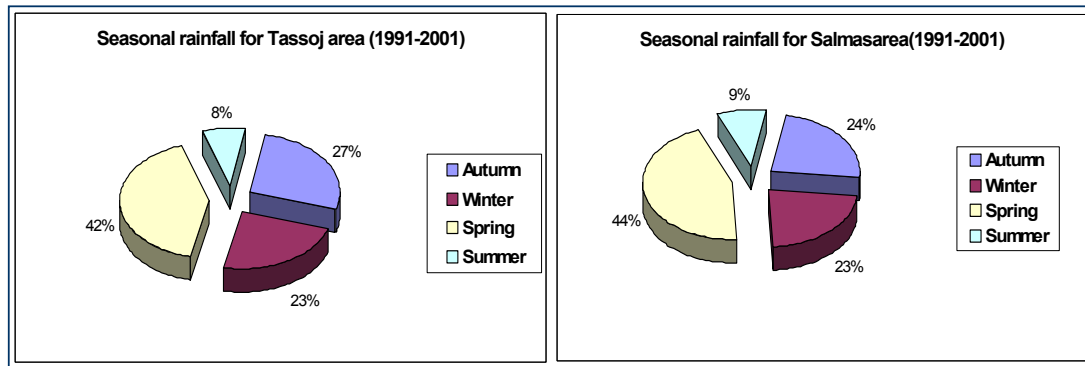
Figure 2.2.1 Seasonal distribution of precipitation in the study areas (1991-2001)

2.3 Hydrology

2.3.1 Surface water

The study area consist some seasonal tributaries and permanent rivers those are flowing into Orumiyeh Lake. In the Salmas region, the major river system is the Zola-chay and in the Tassoj region the Daryan-chay.

The Zola-chay River is the most important permanent river in the northern part of the Orumiyeh Basin, which controls the main drainage system in the region. It rises from West Mountains at the borderline of Iran and Turkey and flows from southwest to northeast along the Salmas Plain and the seasonal rivers such as Dair-Ali-chay, Drek-chay, and Khorkhoreh-chay flow during winter and spring when the precipitation is the heaviest.

The Daryan-chay River rises from north mountain ranges of Orumiyeh Lake basin. There are some independent seasonal streams such as Tyvan-chay, Chehregan-chay, etc., which flow from north to south along the Tassoj Plain into Orumiyeh Lake. The main characteristics of their sub-basins are summarized in Table 2.3.1

Table 2.3.1 Characteristics of the major rivers in the study area during 1991-2001

Rivers	Gauges	Area (km^2)	Annual discharge (MCM)			C.V.
			Max.	Min.	Avg.	
Zola-chay	Chahregh	846	242.93	40.26	124.90	0.36
Zola-chay	Yalghozagaj	1863	147.28	9.18	64.83	0.55
Dair-ali-chay	Urban	98	34.11	4.26	17.27	0.33
Dryk-chay	Nazarabad	240	256.61	11.69	31.49	0.32
Khrkhreh-hay	Tamar	218	14.74	0.0	6.06	0.62
Daryan-chay	Daryan	40	34.86	4.5	16.20	0.44

2.3.2 Irrigation

Irrigation plays a vital role in the agricultural production, but unfortunately it is performed traditionally in the Salmas and Tassoj areas. Shortage of rainfall and surface water has caused its strong dependence on groundwater. On-farm water application rates in both areas are high and irrigation practice has a low efficiency of about 34 and 36 percent for Salmas and Tassoj areas, respectively. Apart from the losses via unlined irrigation canals, the major part of the losses is at farm level via evaporation, due to inefficient irrigation practices (surface irrigation methods) and percolation to the shallow aquifers. In the recent years an increasing use of groundwater has caused a dropping of groundwater table and salinisation.

2.4 Agriculture

The economy of both regions is dependent on agriculture. Irrigated lands occupy about 20000 and 11000 hectares in Salmas and Tassoj area respectively. Tables 2.4.1 and 2.4.2 show the total irrigated area for the study regions. According to data from the Agriculture Office, winter cereals are the predominant crops in both areas. Orchards are occupying large parts of these regions: apple in Salmas, almond and walnut in the Tassoj. Other fruit-trees are cherry, apricot, pears and black cherry, etc. Other planted crops are alfalfa and summer crops: sunflower in the Salmas, tomato and eggplant in the Tassoj regions.
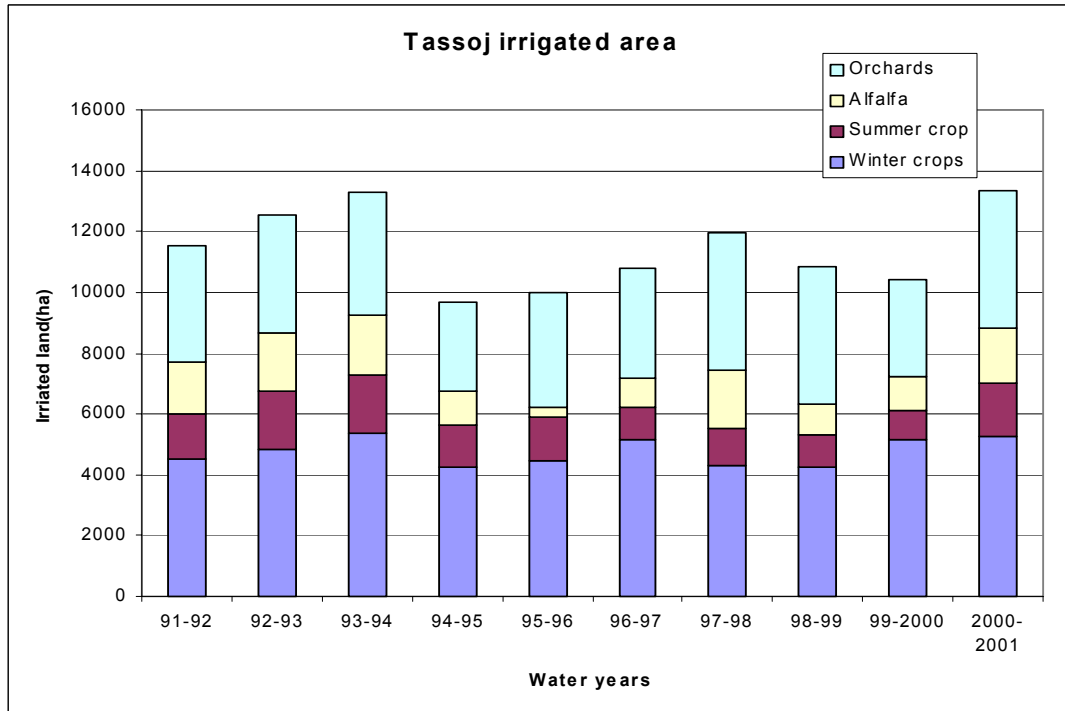
Figure 2.4.1 Irrigated lands under different crops on the Tassoj region
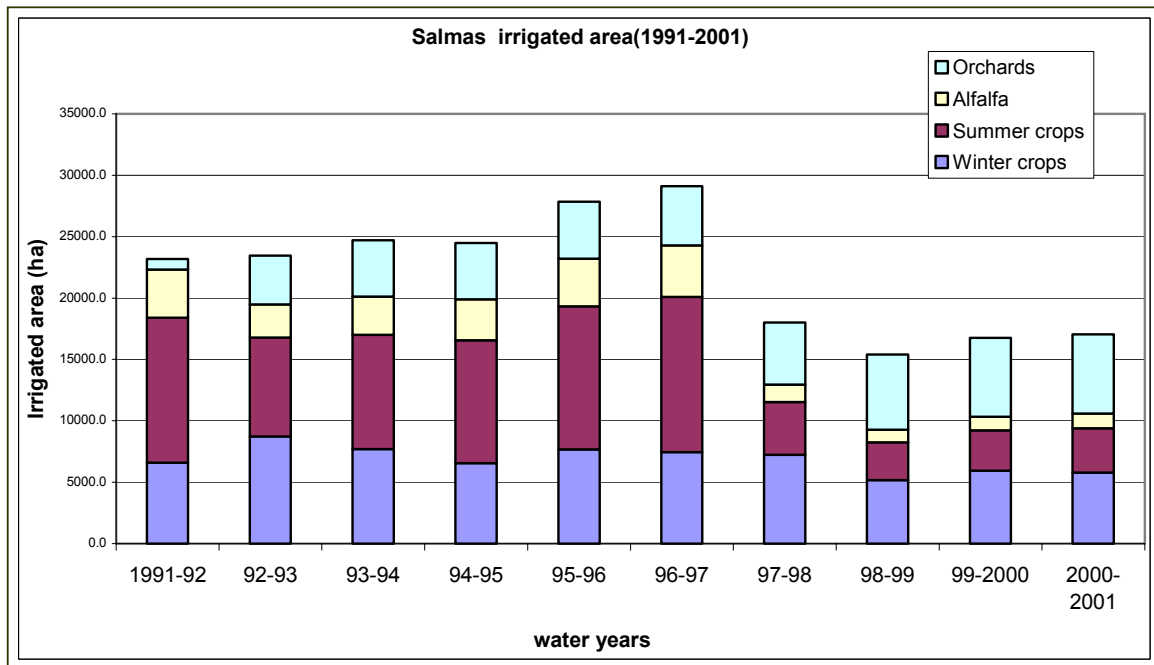
Figure 2.4.2 Irrigated lands under different crops on the Salmas region

3. DATA ANALYSIS

Data analysis was done to prepare input data for water balance calculation and the CROPWAT model, which are discussed in chapters five and six, respectively.

The analysis was extended to climatological, discharge, and groundwater data.

3.1 Climatological data

3.1.1 Rainfall

Precipitation is the major factor, which controls the hydrology of the area. Rainfall data was gathered form eleven meteorological stations to ten water years (1991-2001). Table 3.1.1 shows the general characteristics of stations and their corresponding mean annual rainfall.

Table 3.1.1 General characteristics of the meteorological stations

Stations	Latitude	Longitude	Elevation (m)	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	Mean annual (mm)
Khoy	38° 33′	4º4 58′	1150	*	*	*	*	*	*	*	*			221.6
Tabriz	38° 11′	4º5 28′	1278	*	*	*	*	*	*	*	*			261.6
Orumiyeh	38º 11′	44º 46′	1400	*	*	*	*	*	*	*	*			283
Ghoschi	37º 54′	4º5 02′	1350	*	*	*	*	*	*	*				270
Tassoj	37º 32′	45º 05′	1390	*	*	*	*	*	*	*	*	*	*	294
Shanejan	38º 19′	45º 21′	1355	*	*	*	*	*	*	*	*	*	*	303.7
Sharafkhane	38º 08′	46º 17′	1361	*	*	*	*	*	*	*	*	*	*	266.5
Urban	38º 05′	44º 36′	1600		*	*	*	*	*	*	*	*	*	306.4
Yalghozagaj	38º 14′	44º 56′	1280		*	*	*	*	*	*	*	*	*	260.9
Chahregh	38º 14′	45º 42′	1650		*	*	*	*	*	*	*	*	*	303.7
Salmas	38º 20′	4º4 43′	1680		*	*	*	*	*	*	*	*	*	301.6

* Available data

3.1.1.1 Rainfall consistency and filling missing data

Due to the possible errors those may occur during rainfall measurements and data archiving, and in order to get more reliable and accurate data, it is needed to check the consistency of the recorded data. It was done by taking linear regression between rainfall stations (Table3.1.2).

Based on the regressions, which have been calculated in the previous section, the missing mean annual rainfall data were filled. Considering the proportion of mean annual and mean monthly rainfall for existing data the gaps of mean monthly was filled and completed.

Table 3.1.2 Correlation between rainfall stations (R²)

Stations	Sharafkhaneh	Tabriz	Orumiyeh	Khoy	Urban	Yalghozagaj	Chahregh	Salmas	Tassoj
Shanejan	0.88	0.71	0.66	0.68	0.75	0.67	0.69	0.82	0.77
Sharafkhaneh		0.87	0.67	0.70	0.70	0.75	0.78	0.68	0.65
Tabriz			0.90	0.64	0.57	0.68	0.51	0.81	0.71
Orumiyeh				0.68	0.77	0.88	0.77	0.88	0.87
Khoy					0.88	0.75	0.73	0.59	0.59
Urban						0.92	0.63	0.63	0.77
Yalghozaghaj							0.58	0.77	0.66
Chahregh								0.87	0.85
Salmas									0.68

3.1.1.2 Rainfall variability

Spatial variability of rainfall was investigated by plotting rainfall data of eleven stations in a geographical information system (GIS) using the ILWIS software.

First, the rainfall data were analysed whether the orographic effect could be defined from the existing stations. It was found, that the existing stations are located in a very narrow range of altitude (Figure 3.1.1), so this cannot be used securely for the extrapolation of rainfall values to higher altitudes in the mountains. Anyway, the correlation is not very strong, so finally this method was not used for rainfall mapping in the area.
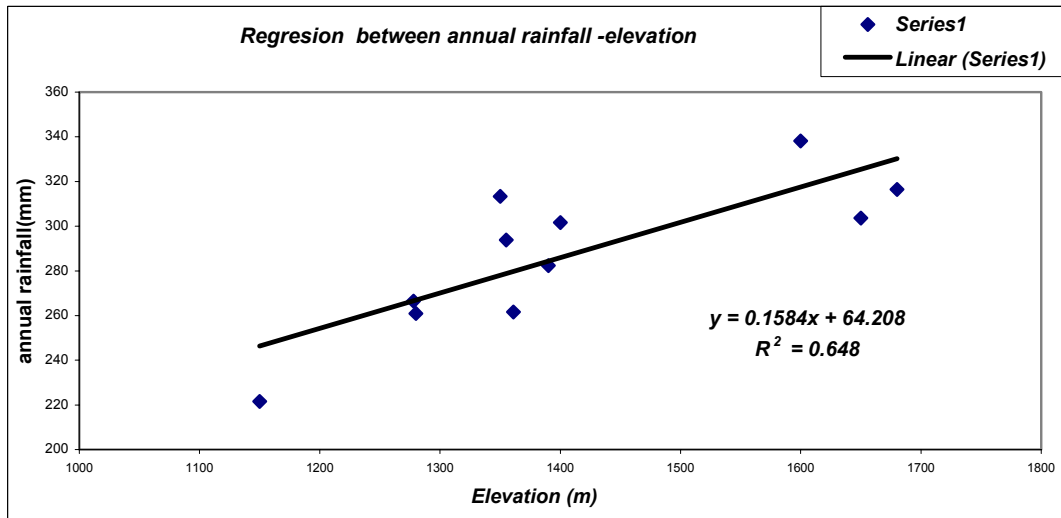
Figure 3.1.1 Regression between the annual rainfall and the altitude of the raingauge

The moving average method was applied to calculation of spatial precipitation in the study area (Figure3.1.2). Also the Thiessen polygon method was evaluated to determine the influence of each station to estimate the average precipitation in irrigated lands in the study area. In fact, the application of the Thiessen polygons and the moving average method was not giving much difference in the present case, so the simpler one, the Thiessen polygons were used in the later steps (Appendix A).
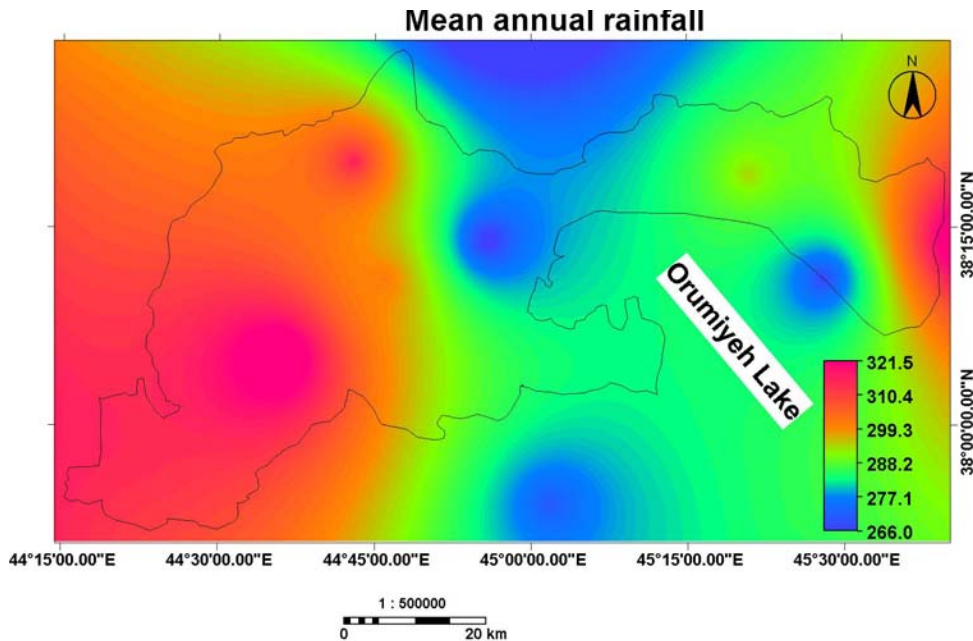
Figure 3.1.2 Mean annual rainfall map for the study area

By using the weight of each rainfall station that derived of Thiessen polygons, mean monthly rainfall in the study area has been calculated and prepared for input into CROPWAT model (Appendix A).

Figure 3.1.3 shows mean annual rainfall variability in the study area. According to this graph, the maximum rainfall has occurred in 1993-1994 and the minimum rainfall has occurred in 1999-2000.
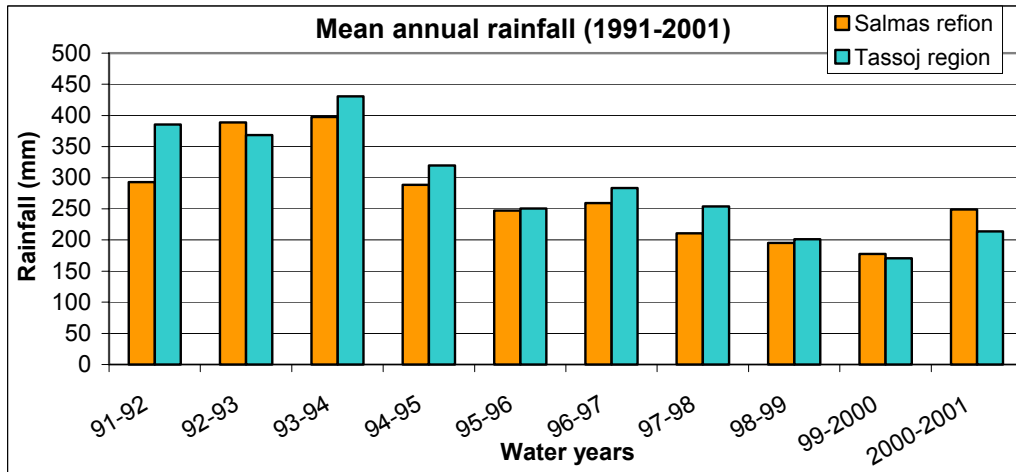
Figure 3.1.3 Mean annual rainfall

3.1.2 Temperature

Mean maximum and minimum temperature are required data for the CROPWAT model. As was described above, the meteorological stations are located in a very narrow range of altitude. Consequently, the dependence of temperature on altitude could not be examined effectively. Therefore another aspect had to be considered. As Orumiyeh Lake is the major water body in the study area and considering it's effect on climatological condition of surrounding area, it was decided to take the distance of climatological stations from the lake as an effective index.

The correlation coefficient between various climatological stations and their distance from Orumiyeh Lake are shown in Figure3.1.4. Unfortunately it was not possible to find a similar correlation between the mean minimum temperatures and the distance from the lake. This lead to the decision, that for the modelling, the temperature data of Sharafkhaneh for Tassoj, Yalgoizaghaj and Chahregh for Salmas region were used in the same manner as the rainfall data, i.e. the values of the closest stations were taken without interpolation. This solution is, in fact, identical to the Thiessen polygons.
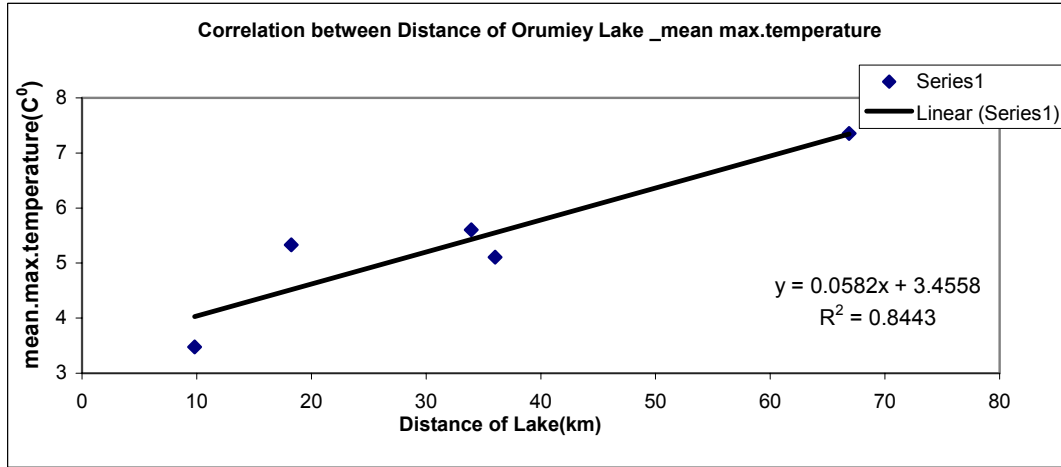
Figure 3.1.4 Regression between mean maximum temperature and the distance to the Lake

3.1.3 Wind speed

Wind speed is another parameter that is needed for the CROPWAT model. This parameter for study area was obtained from two stations. Since the wind speed that applied in CROPWAT model are in m/sec, km/day or km/hr at an elevation of two meter from the ground level, but the recorded wind speed is in Knots at an elevation of ten meter of ground level. Wind speed data converted in CROPWAT models format by using following formula (Shariati 1997).

$$U_2 = 4.868/Ln~(67.75Z\text{-}5.42)*U_z \qquad\qquad (3\text{-}1)$$

Where:

U_2 = Wind speed at two meters

U_z = Wind speed in Z meter elevation

Z = altitude of measured wind speed

Monthly wind speed data is in Appendix A.

3.1.4 Sunshine

Sunshine duration is available in total hours per month at the synoptic meteorological stations in Iran. The average daily sunshine data t is needed for the CROPWAT model. In this research, the monthly sunshine hours were converted to daily sunshine by dividing the monthly data with the number of days in the month. Data of three stations (Khoy, Tabriz and Orumiyeh) have been used (Appendix A).

3.1.5 Relative humidity

Relative humidity is another input of climatological data into CROPWAT model. In this research, the mean monthly relative humidity of Sharafkhaneh and Shnejan stations for Tassoj area, and Yalghozagaj and Chahregh stations for Salmas region were applied. Maximum Relative humidity is in the autumn and winter season and minimum relative humidity in the summer season (Appendix A).

3.2 Surface water

3.2.1 River discharge

Surface water is one of the major parts of the water balance of the region. River discharge is measured on the Daryan-chay in the Tassoj area and at five hydrometric stations in the Salmas area. Figure 3.2.1 shows the locations of the hydrometric stations. According to this figure, Chahregh gauge is established on the upper part of the Zola-chay River at the entrance of Salmas Plain (beginning of the irrigated boundary) and Yalghozagaj gauge is located at the outlet of irrigated area in the Salmas Plain. There are some permanent streams, which arrive to agricultural fields, but they usually don't drain into Orumiey Lake. Tassoj area has a major permanent river (Daryan-chay) and some temporal streams.
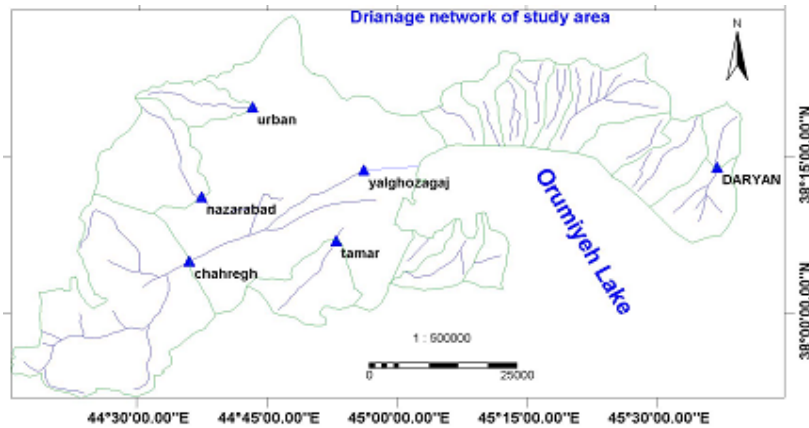
Figure 3.2.1 Hydrometric stations locations

3.2.2 Available surface water for irrigation

Available surface water for irrigation was determined using discharge data, which were recorded by the West and East Azerbaijan Provincial Water Organizations. Surface water for Salmas Plain is mainly supplied by diverted water from the Zola-chay River by two main canals. The other parts of irrigated areas, which are located along the seasonal branches of the river, are irrigated by these

branches. As mentioned above, the amount of water that forms the input and output of irrigated lands are measured at the five gauges in the Salmas irrigated area (figure 3.2.1),

Daryan-chay discharge was used as the main input surface water into Tassoj irrigated area, but there are some ungauged streams too. As it was distinguished in the fieldwork there is no outflow from this irrigated area to Orumiyeh Lake. It can be explained by existing small pool on the Daryan-chay River for agricultural and flood spreading purposes.

For the ungauged streams in the Tassoj region, the amount of runoff volumes was estimated by applying a runoff coefficient. For determining runoff coefficient the following steps were done:

- Creating average rainfall map for Daryan-chay sub basin by applying moving average method that was done in the data analyzing (Section 3.1.1.2).
- Determining weight average rainfall using the histogram of created rainfall map.
- Calculation of runoff coefficient by C = mean annual discharge / mean annual rainfall
- Applying calculated runoff coefficient for other sub basin

By applying surface water irrigation efficiency 36 and 34 percent for Salmas and Tassoj area respectively (Jamab 1998), the amount of surface water used by the crops in those areas was calculated. Table 3.2.1 and 3.2.2 shows obtained surface irrigation water amount for both area.

Table 3.2.1 Surface water uses in the Tassoj irrigated area (MCM)

Water years	Daryan gauge	Ungauged area	Total
91-92	8.3	19.5	27.8
92-93	9.3	23.2	32.5
93-94	10.5	25.3	35.9
94-95	12.6	20.9	33.4
95-96	3.7	14.9	18.6
96-97	3.6	19.1	22.7
97-98	2.8	13.9	16.7
98-99	1.6	15.1	16.7
99-2000	2.5	12.1	14.6
2000-2001	3.6	15.0	18.6

Table 3.2.2 Surface water uses in the Salmas irrigated area (MCM)

Water years	Input	Output	Total
91-92	105.9	43.6	62.3
92-93	120.6	49.0	71.6
93-94	125.4	53.4	72.0
94-95	74.4	28.6	45.8
95-96	62.4	24.3	38.0
96-97	58.4	17.2	41.2
97-98	32.2	5.6	26.6
98-99	22.8	4.7	18.1
99-2000	20.7	3.3	17.4
2000-2001	24.1	3.7	20.4

Source: The West Azerbaijan Provincial Office of the Ministry of Power

3.3 Groundwater

3.3.1 Hydrodynamic characteristics

Groundwater of the study area is studied by Jam-Ab and Tavan-Ab consulting engineers. Based on their reports, the general hydrodynamic characteristics of groundwater in both areas are given in the Table 3.3.1.

Table 3.3.1 Hydrodynamic characteristics of the Salmas and Tassoj aquifers

Plain name	Aquifer type		Area (km²)			Sediment Thickness (m)		Depth to water level (m)			Transmissivity (M²/day)		Storage coefficient (%)		
	Phereatic	Artesian	Aquifer		Plain	Max.	Min.	Min.	Max.	Mean	Max.	Mean	Min.	Max.	Mean
			Phereatic	Artesian											
Salmas	*	*	500	130	607	170	100	0.5	56	12	8.249	8	1	9	5
Tassoj	*	*	900		1395	200	85	0.7	100	20	4.752	4.3	0.04	29	5

Groundwater level varies by the topographic conditions and the amount of recharge and discharge. In other words, ground water surface slopes from the foot of the mountains (plain entrance) towards the cost of the Orumiyeh Lake in the study area. In natural conditions, when the recharge exceeds the groundwater losses in the wet period, groundwater level increases, while in the dry periods, the inverse of this condition happens. According to long-term piezometeric well data, minimum depth of water table is in May and April and maximum depth is in November and September in Tassoj and Salmas area respectively (Jam-Ab 1998)and (Tavan Ab 1996). The natural low groundwater period – since it is in the dry period of the year – coincides with the most intensive groundwater pumping for agriculture practices. Figure 3.3.1 shows monthly variation in groundwater level for Tassoj area.

From the figure, it can be concluded, that the groundwater was not recharged in the last then years properly, or the losses (i.e. pumping) were too intensive, so the natural annual fluctuation cannot be observed any more.
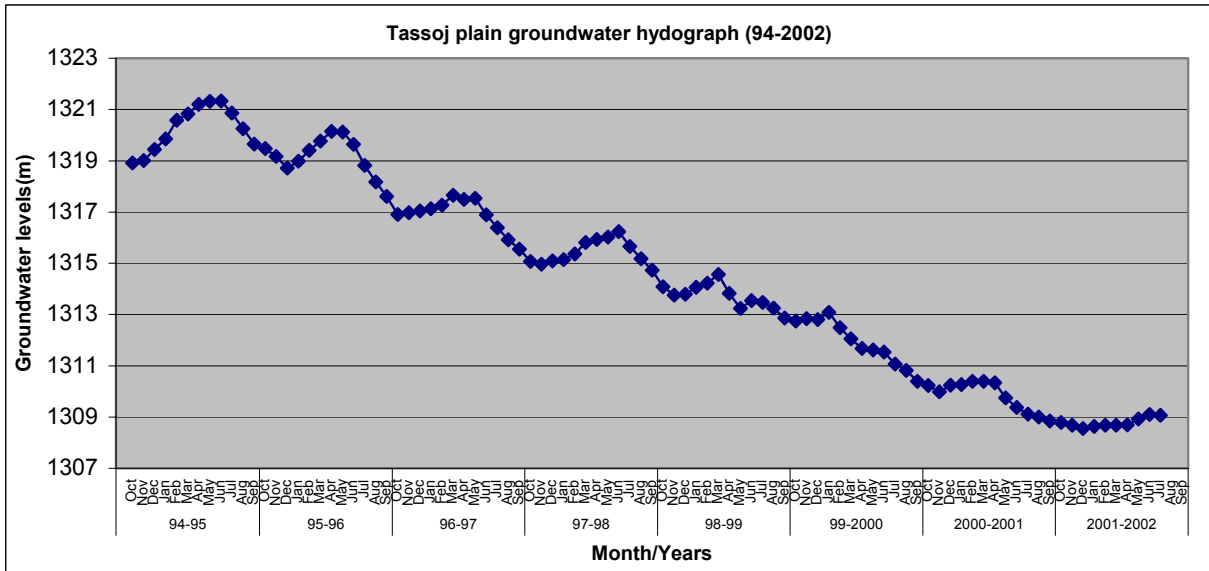
Figure 3.3.1 Groundwater hydrograph of a well in the Tassoj area

3.3.2 Groundwater withdrawal

Figure 3.3.1 also shows that there is a trend of groundwater loss. The total volume of groundwater loss during the water years of 1991-2001 for both areas was calculated using ILWIS software. The difference of the groundwater levels in the beginning and the end of the period was calculated for each groundwater well. A point map was created based on this data. Then it was interpolated using trend surface (2degree) method. Porosity coefficient was assumed 25% for both areas. Total volume of groundwater withdrawal was estimated by multiplication of the groundwater level differences with the porosity coefficient. Based on this result, total volume of groundwater losses for Tassoj and Salmas is 695 and 547 MCM respectively. Figure 3.3.2 and 3.3.3 shows loss of groundwater level for both areas.
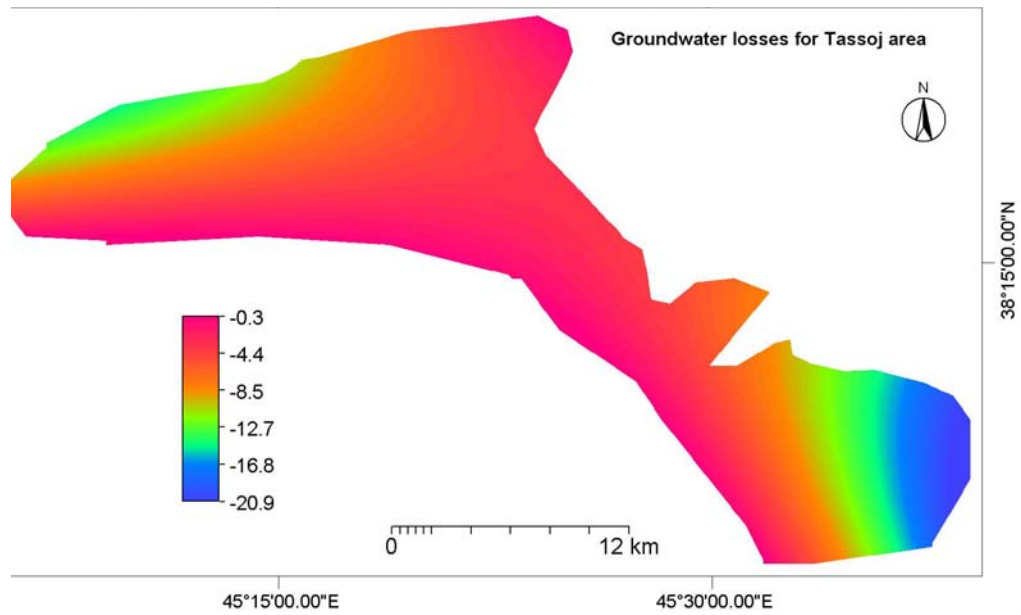
**Figure 3.3.2 Groundwater loss in the Tassoj area**
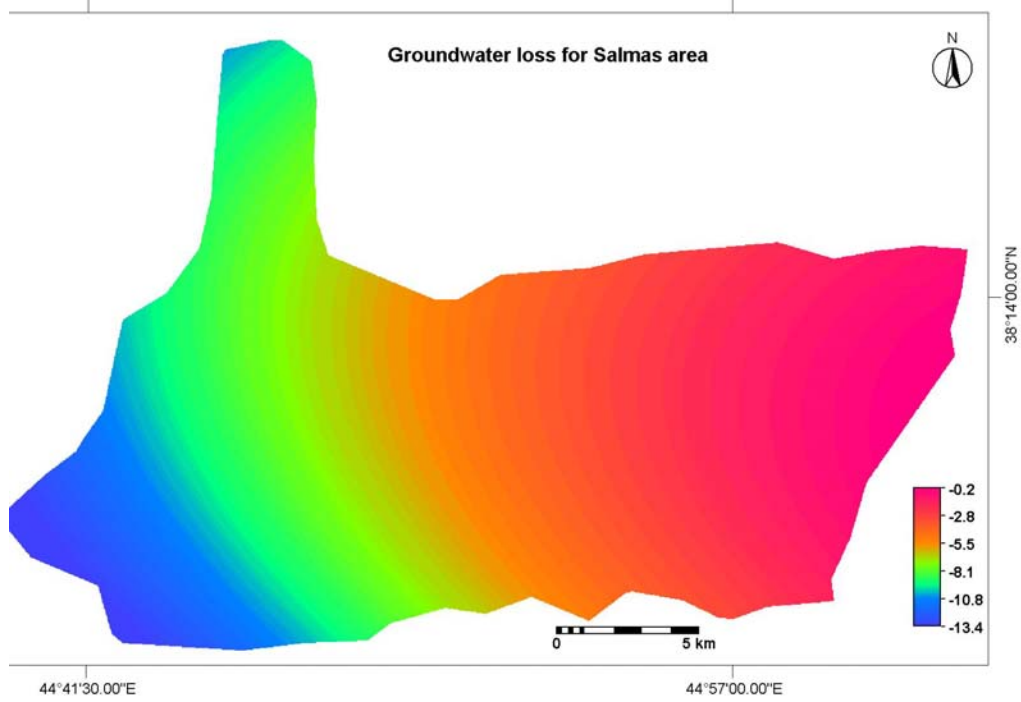
Figure 3.3.3 Groundwater loss in the Salmas area

3.3.3 Estimation of groundwater withdrawal for irrigation

For identifying amount of groundwater withdrawal for agricultural practices it is necessary to have agriculture well discharge data. In this research, it was available only for the Tassoj area. The following steps were done to estimate the amount of groundwater for irrigation practices. Results of this estimation are shown in the Tables 3.3.2 and 3.3.3.

- The basic assumption is that the crop water demand is supplied by 3 main sources; precipitation, surface water, and groundwater.

- First step is the estimation of net irrigation water requirement: It was calculated by CROPWAT model. The model takes into account the potential evaporation and the precipitation in the calculation of the net irrigation water requirement.

- The second step is the determination of the water available for irrigation from surface waters. The calculation was based on the input and output surface water of the irrigated lands (see section on surface waters, above).

- Since, two components have been calculated, the irrigation from groundwater was calculated by subtracting the known parts from total water demand. The result is the estimated groundwater use.

- The above result was validated by comparing the estimated groundwater use by existing agricultural well data in the Tassoj area. The validation proved that the above method provides a good estimate of the groundwater use, so the first three steps were applied also for the Salmas area.

Table 3.3.2 Water use for agricultural practice for the Salmas area

Water years	Net irrigation water requirement (MCM)	Supplied by Surface water (MCM)	Supplied by ground water (MCM)
91-92	97.04	62.27	34.8
92-93	107.93	71.62	36.3
93-94	117.27	72.04	45.2
94-95	124.39	45.84	78.6
95-96	126.67	38.04	88.6
96-97	127.53	41.23	86.3
97-98	104.99	26.60	78.4
98-99	99.02	18.11	80.9
99-2000	92.51	17.41	75.1
2000-2001	89.03	20.37	68.7

Table 3.3.3 Water use for agricultural practice for the Tassoj area

Water years	Net irrigation water requirement (MCM)	Supplied by surface water (MCM)	Supplied by ground water (MCM)	Agriculture wells discharge (MCM)*
91-92	57.02	27.8	29.22	27.0
92-93	66.03	32.5	33.51	30.3
93-94	72.61	35.9	36.76	35.5
94-95	60.82	33.4	27.38	27.4
95-96	67.21	18.6	48.60	45.2
96-97	72.18	22.7	49.52	46.5
97-98	83.25	16.7	66.56	64.0
98-99	83.51	16.7	66.79	63.0
99-2000	77.20	14.6	62.64	60.0
2000-2001	70.09	18.6	51.47	51.0

These data are 65% of pumping discharges. It should be noted that 65 % is the groundwater efficiency that it was calculated by Jam-Ab consulting engineers.

4. APPLIED GIS AND RS FOR CROP CLASSIFICATION

Classification in general is grouping of similar objects and separation of dissimilar ones. It can be performed by quantitive interpretation of the image based on the statistical analysis of the spectral variables. We try to classify each pixel into a limited number of discrete classes. The use of statistical algorithms for this purpose is called" statistical pattern recognition." Other techniques are based on structure measurements including the study of shape, texture, and orientation and this is called "structural pattern recognition." These procedures can be combined in the classification process (Molina 1992). In this research emphasis is on the statistical pattern recognition approach.

In this research, image processing involved crop classification using Advanced Spaceborne Thermal Emission and Reflection Radiometer (Aster) satellite images. It was done for identifying crop types plus crop planted area for the estimation of their water demands.

The image classification was done in the following steps:

- Image preprocessing
- Image classification
- Accuracy assessment
- Compilation of final crop map.

4.1 Image pre-processing

As mentioned above, The Advanced Spaceborne Thermal Emission and Reflection Radiometer (Aster) image was used in this project. Aster provides high- spatial resolution, multi-spectral images with along-track stereo capabilities launched on the NASA spacecraft of the Earth Observing System (Terra) in 1999 (M.Abrams 2000). Aster consists of three different subsystems: The Visible and Near Infrared (VNIR) (bands 1,2,3; pixel size 15 m), the short-wave Infrared (SWIR) (bands 4 to 9; pixel size 30 m) and the Thermal Infrared (TIR) (bands 9 to 14; pixel size 90 m) (Gu.Zhixin 2002).

Successful identification of crops usually requires multi-temporal images. Unfortunately, the Aster images those covered the study area were available only for 2nd July 2001. The format of these images was L1B, which could be imported into ILWIS version 3.11 directly. Three

bands of aster images (bands 1to3) were georeferenced by ancillary data such as topographic maps and existing satellite images (Landsat TM) with reliable georefrences. Colour composite (RGB) was made with using bands 3, 2, and 1 (pixel size 15 m) that in the Aster images are normally used for the vegetation analysis. Also the Normalized Difference Vegetation Index (NDVI) as an assistant band was applied for increasing of the classification accuracy. It was done with following formula in the Aster image:

$$NDVI = (band3-band2)/ (band3+band2) \qquad (4-1)$$

Where:

NDVI = The Normalized Differential Vegetation Index

Band 3 = Near Infrared (0.76-0.86μm)

Band 2 = Visible, red (0.63-0.69μm)

Fieldwork was done in 2002 for taking training sample of different crops that it's important for supervised classification and doing interview with former to making a crop calendar to reconstruct the produced crops in 2001. Successful identification of crops requires knowledge of the developmental stages of each crop in the area. This information is typically summarized in the form of a crop calendar that lists the expected developmental status and appearance of each crop in an area throughout the year (Kiefer.R.W 2000). This information was used in the supervised classification of the images.

4.2 Image classification:

There are two approaches to extract spectral information: the supervised and unsupervised classification (Richards 1986). One should also consider a third approach, which is a "hybrid" supervised/unsupervised strategy that aspires to extract the attributes of both methods.

Unsupervised classification: By this method, image pixels are assigned to spectral classes without the user having previous knowledge about the study area. Applying clustering methods, i.e. procedures to determine the spectral class of each pixel, usually performs it.

Supervised classification: This method involves selection of areas in the image, which statistically characterize the categories of interest. The supervised approach requires prior

knowledge about the area, which can be derived from fieldwork or from reference data on the area. Information about the area has to be supplied by the user through training samples and the number of classes has to be defined as well (Salem 1995).

In this research, both of mentioned methods were used. For a primary classification the unsupervised method was used. The resulting maps gave an idea about how many separable classes exist in the study areas, and this information was used in the selection of training sets for the supervised classification. The supervised method was applied for making crop maps for both of Tssoj and Salmas areas. From the available different classification methods, the minimum distance method without threshold performed best. Finally, by using supervised method with minimum distance algorithm, nine classes were determined for Salmas area and six classes for Tassoj area. Figure 4.4.1 and 4.4.2 shows the mentioned classes with some additional classes visually interpreted from the images, for better orientation (e.g. roads, residential).

4.3 Accuracy assessment

To get an idea of the overall accuracy of the classification, user has made a test set, which contains additional ground truth data. Crossing the test set with the classified image and creation of a so-called confusion matrix is an established method to assess the accuracy of a classification (A.Gieske 2002).

Some preliminarily separated parts of the ground truth samples were employed to generate a confusion matrix for both of classified maps (table 4.3.1 and 4.3.2).

Table 4.3.1 Confusion matrix for the classification with nine categories for the Salmas area

Crop type	Alfalfa	Orchard+Alfalfa	Sunflower	Sugar beet	Cereal	Fallow	Rangeland	Squash	Bare soil	ACCURACY
Alfalfa	2519	169	29	103	30	0	29	24	2	0.87
Orchard alfalfa	250	3668	67	96	47	2	72	56	0	0.86
Sunflower	41	7	611	206	160	23	9	10	33	0.56
Sugar beet	102	10	201	913	61	2	2	1	9	0.7
Cereal	15	3	67	63	1389	197	4	53	53	0.75
Fallow	0	0	4	66	124	831	0	1	39	0.78
Rangeland	111	327	59	25	114	3	511	194	7	0.35
Sqush	24	14	30	18	118	31	33	565	7	0.67
Bare soil	0	0	7	1	40	37	0	6	393	0.81
RELIABILITY	0.82	0.87	0.57	0.57	0.67	0.74	0.77	0.62	0.72	

Average Accuracy = 70.62 %   **Average Reliability = 70.69 % Overall Accuracy = 74.76 %**

Table 4.3.2 Confusion matrix for the classification with six categories for the Tassoj area

Crop type	Cereal	Alfalfa	Orchards+ alfalfa	Sunflower	Bare soil	Rangeland	ACCURACY
Cereal	347	61	6	14	38	118	0.59
Alfalfa	0	1020	360	167	35	8	0.64
Orchards+ alfalfa	0	173	2116	95	98	5	0.85
Sunflower	0	66	62	433	69	91	0.6
Bare soil	63	22	71	21	773	106	0.73
Rangeland	63	29	27	63	185	437	0.54
RELIABILITY	0.73	0.74	0.8	0.55	0.65	0.57	

Average Accuracy = 66.04 %   **Average Reliability = 67.35 %**
Overall Accuracy = 70.78 %

According to confusions matrix, some obvious points should be noted.

- The 'alfalfa' and 'orchard + alfalfa' classes have a high reliability, because both of them planted in the large fields and they are dominant crops in the Tassoj and Salmas area.

- Unlike the perennial crops, such as alfalfa or orchards, some classes e.g. 'cereal', 'fallow', or 'rangelands' were difficult to classify. Because of the acquisition date of the images, annual crops were harvested and also some parts of the rangelands were dry. For this reason, there is some overlap between these classes.

- Except of orchards, other fields' size, especially in the Tassoj area, were very small. Due to this problem and lack of multi-temporal images, the classification was difficult and resulted in lower accuracy.

4.4 Final crop map

As the classified maps show some noise in the large homogeneous areas, the majority filter was applied to reduce isolated pixels. Final crop maps for both the Salmas and Tassoj areas were given after adding roads and residential area on classified maps (Figures 4.4.1 and 4.4.2)
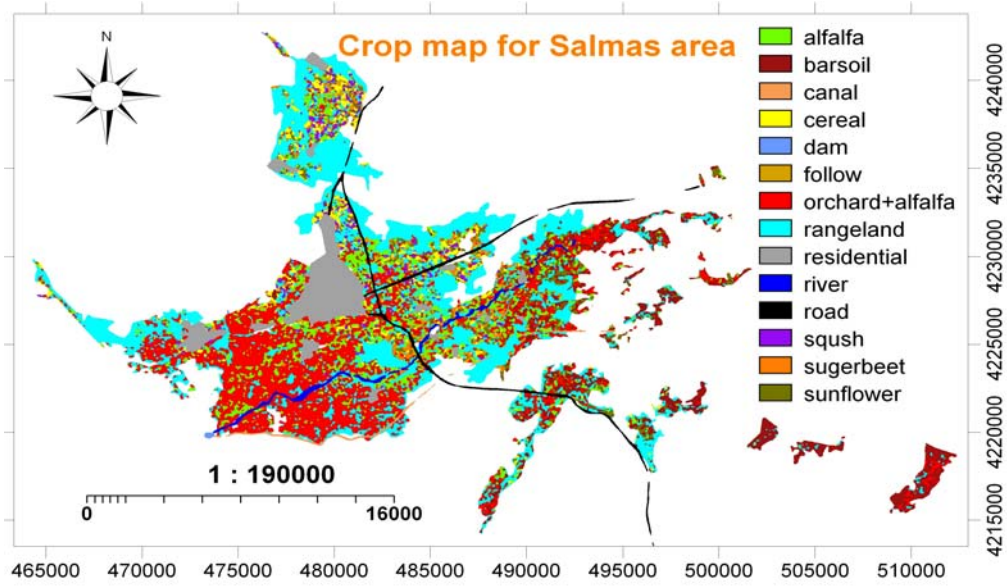
**Figure 4.4.1 Land cover and crop type map for the Salmas area**
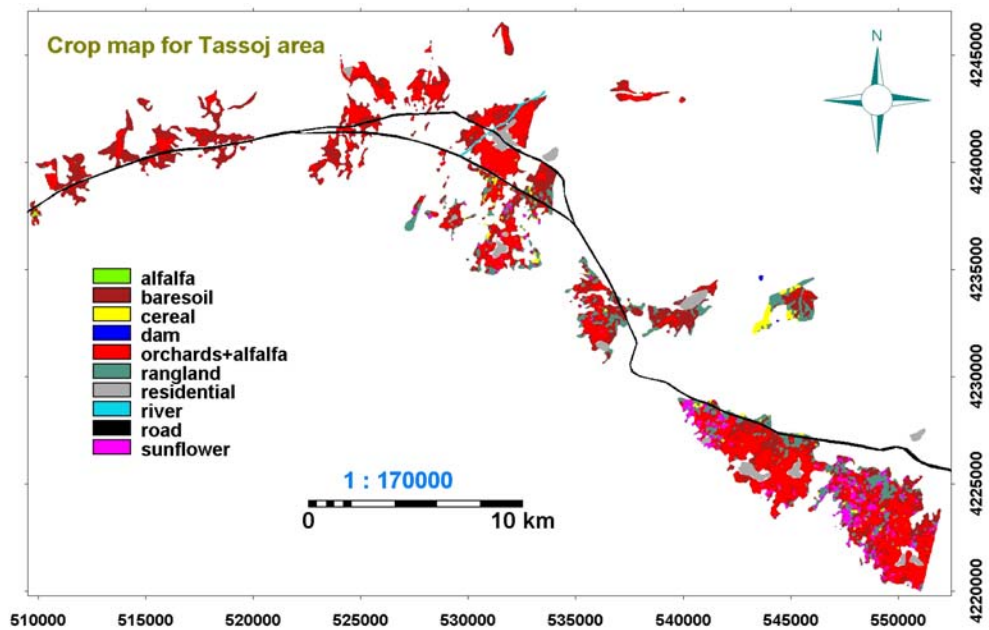
Figure 4.4.2 Land cover and crop type map for the Tassoj area

4.5 Total irrigated area

The area for each class or crop type can be found through the histogram of the classified maps. Table 4.5.1 shows the derived area for each class. It should be noted that there is a class, the 'Rangeland' that is not part of the irrigated area (cropped area), so it was taken out of the summation for the cropped area. This was needed also for comparison with crop data provided by the Provincial Offices of the Ministry of Agriculture, i.e., it was necessary to summarize all the concerned classes into a new one: irrigation area. The irrigated area estimates of Table 4.5.1 have been compared with estimation that it was made by the Provincial Offices of the Ministry of Agriculture. All data have been compiled in the Table 4.5.2.

Table 4.5.1 Area per class derived from Aster image (2nd July 2001)

Crop type	NPIX		NPIXPCT		PCTNOTUND		AREA (ha)	
	Salmas	Tassoj	Salmas	Tassoj	Salmas	Tassoj	Salmas	Tassoj
Alfalfa	110566	22572	1.66	0.04	9.6	3.62	2487.7	507.9
Baer soil	95081	233933	1.42	0.36	8.26	37.51	2139.3	5263.5
Cereal	45898	10053	0.69	0.02	3.99	1.61	1032.7	226.2
Fallow	7329	210218	0.11	0.33	0.64	33.71	164.9	4729.9
Orchard +Alfalfa	290663	103986	4.35	0.16	25.25	16.67	6539.9	2339.7
Rangeland	10115	42857	0.15	0.07	0.88	6.87	227.6	964.3
Sqush	28424		0.43		2.47		639.5	
Sugar beet	25805		0.39		2.24		580.6	
Sunflower	50593		0.76		4.39		1138.3	
Min	647		0.01		0.06		14.6	
Max	290663		4.35		25.25		6539.9	5263.5
Avg.	57125		0.86		4.96		1285.3	1403.1
StD.	75787		1.13		6.58		1705.2	2030.4
Sum	799756		11.98		69.47		**14950.5**	**14031.4**

Table 4.5.2 Area separated into new categories for comprising with satellite image

Planted Area / Crop type	Tassoj area				Salmas area			
	Agric. Office		Satellite image		Agric. Office		Satellite image	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Winter crops	5280	39.6	4956.1	35.3	5778	33.9	3336.9	22.7
Summer crop	1755	13.2	6227.8	44.4	3621	21.3	2358.5	16.0
Alfalfa	1800	13.5	507.87	3.6	1207	7.1	2487.7	16.9
Orchards + alfalfa	4500	33.7	2339.7	16.7	6431	37.7	6539.9	44.4
Total	13335	100	14031.4	100.0	17037	100.0	14723.1	100.0

The results should be interpreted with some care, because the results show some difference between the two methods. Data on cropping patterns, cropping calendars and estimated cropping intensities were available at the Provincial Offices of the Ministry of Agriculture. The data typically organized by village, and then the Provincial Offices of the Ministry of Agriculture grouped them into administrative districts. Because the boundaries of these districts are not coinciding with the irrigated system command areas, problems arise in the compilation of crop data for each command area. The discrepancies between the different crops are larger in the Tassoj area than in the Salmas area, whilst the total irrigated area was better matching in the Tassoj then the Salmas area.

Therefore, for the year of 2001, the data from the satellite image classification was used, whilst for the other years, the data from the Agricultural Office was used. In the evaluation of the final water balance, the possible errors in crop statistics had to be considered.

5.CROPWAT MODEL

CROPWAT is a computer program to calculate crop water requirements and irrigation requirements from climatic and crop data. Furthermore, this program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

Procedure for calculation of the crop water requirements and irrigation requirements are mainly based on methodologies presented in FAO irrigation and Drainage Papers No.24 "Crop Water requirements" and No.33 "Yield Response to Water." In other words, it is a program that uses the Penman-Montieth method for calculating reference crop evapotranspiration (Smith 1992).

In this project, CROPWAT software was applied to calculation of crop water requirements and crop evapotranspiration.

5.1 Irrigation requirement calculation procedure

The Penman-Monteith approach is a combination of both aerodynamic terms, as reported by the Paper No.56 of the Food and Agriculture Organization of the United National (FAO), as cited by (Noannis and Sharif 2002). The general equation is:

$$ET_0 = \frac{0.408\Delta(R_N - G) + \gamma\frac{900}{T+273}U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (5\text{-}1)$$

Where ET_o is the reference crop evapotranspiration (mm d^{-1}); R_n is the net radiation at crop surface (MJ^{-2} d^{-1}); G is the soil heat flux (MJ^{-2} d^{-1}); T is the average temperature (^{o}C); U is the wind speed measured at 2 height (m s^{-1}); [e_a-e_d] is the vapor pressure deficit (kPa); is the slope vapor pressure curve (kPa ^{o}C); (is the psychometric constant (kPa ^{o}C); and 900 is the conversion factor for daily-basis calculation.

Effective precipitation is the portion of total precipitation that is useful for crop production. Effective precipitation in this project was estimated according to the method of the USDA Soil Conservation Service. The method assumes that crops can use almost 60 to 80 percent of the precipitation up to 250 mm/month. Over 250 mm/month, crops benefit from only 10 percent of the total precipitation. In other words, as precipitation increases, its efficiency decreases:

$$P_{eff} = P_{tot}\,(125\text{-}0.2\,P_{tot})/125 \text{ for } P_{tot}<250mm \qquad\qquad (5\text{-}2)$$
$$P_{eff} = 125+0.1\,P_{tot}\quad for\ P_{tot} > 250mm$$

Where P_{eff} represents the effective rainfall in millimetres per month and P_{tot} is the total precipitation in millimetres per month. Effective precipitation values are then linearly interpolated to daily values. It should be noted that in this study, due to lack of soil properties data, rainfall losses due to deep percolation and surface runoff are not being directly taken into account in the actual soil moisture content of the root zone. The USDA method accounts for some of the losses. Irrigation requirements were calculated into CROPWAT program with this formula:

$$Irr = A\sum\nolimits_{i=1}^{365}(ET_o * K_c - P_{eff}) \qquad\qquad (5\text{-}3)$$

Where Irr is the irrigation requirement (m^3/years); A is the cultivated area (percentage of 100% total area); ET_o is the evapotranspiration (mm/day); Kc is the crop coefficient; and P_{eff} is the effective rainfall (mm/day). The crop coefficients are used in determining each crop's actual evapotranspiration. These values may vary based on the crop characteristics, planting date, crop development, and phenology, the length of growing season, and local climatic conditions (Doorenbos 1984).

5.3 Required CROPWAT data

As mentioned previously, the CROPWAT model needs climatic and crop data. The preparation of the climatic data was described in the data analysis section (see Section 3.1) including mean maximum and mean minimum temperature (^oC); relative humidity (percent/month), wind speed (km/day) and daily sunshine (hrs). These data gathered from meteorological stations, and then prepared in the chapter No.3 section 3.1 as input data for CROPWAT model. Also some other data such as latitude, longitude, and altitude according to the used meteorological stations were put into model (CROPWAT needed data are in the Appendix A). As well as crop data was prepared by applying remote sensing and GIS, especially for determining crops pattern and planted area for date 2001 (see Figures 4.4.1 and 4.4.2). But for lack of multi-temporal satellite for last years, crops pattern, planted area and other ancillary crop data such as crop calendar (Table 5.3.1) were obtained from both interview in the fieldwork and the Provincial Offices of the Ministry of agriculture.

Table 5.3.1 Crop calendar for the study area

Crops	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Winter crops														
Wheat														
Barley														
Summer crops														
Sugarbeet														
Tomato														
Squash														
Egg plant														
carrot														
Potato														
Pea														
lintel														
Bean														
Mellon														
Watermellon														
Cucumber														
Maize														
Sunflower														
Onion														
All year														
Alfa-Alfa														
Graps														
Orchards														

5.4 Irrigation water requirements

According to data mentioned above, CROPWAT model was run to calculation of water requirement for different crops in the study area. The obtained results are in the Tables 5.4.1 and 5.4.2 (Appendix B shows some samples of CROPWAT output). It is necessary to explain that these calculations were done separately for each year for the dominant crops for both of the irrigated areas (Salmas and Tassoj), e.g. sunflower, eggplant and potato. In the final step, the individual crops were merged into the categories shown in Figures 4.4.1 and 4.4.2, e.g. summer crops. Lack of data about planted area individually for different crops made this classification necessary. The calculated net irrigation requirements (mm/period) for the modelled crops are presented in Tables 5.4.1 and 5.4.2.

Table 5.4.1 Net Irrigation water Requirement (mm/period) for the Tassoj area

Crops/years	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-2000	2000-2001
Winter crops	370	449.4	461.6	559.0	612.5	590.2	707.8	731.3	677.0	589.5
Summer crops	525.4	548.28	542.5	535.6	661.9	642.2	729.2	745.9	691.3	637.7
Alfalfa	843.3	832.8	880.5	1044.0	1167.0	974.9	1125.9	1182.0	1085.7	983.25
Orchards	476.8	464.98	496.3	616.1	708.7	703.8	768.7	805.9	747.8	715.9
Total	2215.5	2295.46	2380.9	2754.7	3150.1	2911.08	3331.55	3465.05	3201.83	2926.35

Table 5.4.2 Net Irrigation water Requirement (mm/period) for the Salmas area

Crops/Years	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-2000	2000-2001
Winter crops	351	375.6	432.5	438.8	463	476	546	575	560	493.9
Summer crops	312.6	385.6	395.7	406.8	427.7	398	422.7	4262	476	459
Alfalfa	816.5	807	845	830	898	835	947.7	995.5	936.8	877.6
Orchards	341.5	370.7	381	426	456.7	485	566	610	594	518
Total	1821.6	1938.9	2054.2	2101.6	2245.4	2194	2482.4	6442.5	2566.8	2348.5

5.5 Total water requirement

For the water budget calculation the total volume of irrigation water requirements was needed. In order to calculation volume of crop water requirements in the selected period, net irrigation requirement data derived from CROPWAT model (Tables 5.4.1 and 5.4.2) were multiplied with total planted area under different crops in each year. Table 5.5.1 and 5.5.2 shows the calculated total crop water requirements separately for each water year, for both the Salmas and Tassoj areas.

Table 5.5.1 Total irrigation water requirements for the Tassoj area (MCM)

Crops/ years	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-2000	2000-2001
Winter crops	16.7	21.8	24.8	23.9	27.3	30.5	30.5	30.9	34.8	31.1
Summer crops	7.9	10.5	10.4	7.2	9.5	6.8	8.8	8.1	6.9	11.2
Alfalfa	14.2	15.7	17.3	11.9	3.8	9.3	21.7	11.6	11.8	17.7
Orchards	18.2	18.0	20.1	17.8	26.6	25.6	34.5	36.7	23.7	32.2
Total	57.0	66.0	72.6	60.8	67.2	72.2	95.6	87.4	77.2	92.2

Table 5.5.2 Total irrigation water requirements for the Salmas area (MCM)

Crops/ years	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-2000	2000-2001
Winter crops	23.2	32.8	33.3	28.8	35.5	35.4	39.5	29.8	33.2	28.5
Summer crops	36.8	31.0	36.8	40.7	49.8	50.3	18.1	130.4	15.7	16.6
Alfalfa	32.1	21.6	26.2	27.7	34.8	35.2	13.5	10.2	10.3	10.6
Orchards	2.9	14.8	17.5	19.6	21.2	23.4	28.7	37.4	38.1	33.3
Total	95.0	100.2	113.9	116.7	141.4	144.3	99.8	207.8	97.3	89.1

6. WATER BALANCE

6.1 Concept of a water balance

A water balance is an accounting of all water volumes that enter and leave a 3D space over a specified period of time. Change in internal water storage must be also considered. Both the spatial and temporal boundaries of a water balance must be clearly defined in order to compute and to discuss a water balance. A complete water balance is not limited to only irrigation water or rainwater or groundwater, etc., but includes all water that enters and leaves the spatial boundaries (Burt 1999).

6.2 Methods used to compute the water balance

Precipitation provides part of the water crops need to satisfy their transpiration requirements. The soil, acts as a buffer, stores part of the precipitation water and returns it to the crops in times of deficit. In humid climates, this mechanism is sufficient to ensure satisfactory growth in rainfed agriculture. In arid climates or during extended dry seasons, irrigation is necessary to compensate for the evaporation deficit due to insufficient or erratic precipitation. Net irrigation water requirements in irrigation are therefore defined as the volume of water needed to compensate for the deficit between potential evapotranspiration and effective precipitation over the growing period of the crop. For a given period, the primary crop water balance is calculated as follows (Faures and et al 2002).

$$IWR = K_C.ET_O - P \qquad (6\text{-}1)$$

Where:

IWR is the net irrigation water requirement needed to satisfy crop water demand

K_c is a coefficient varying with crop type and growth stage

Et_o is the reference potential evapotranspiration, depending on climatic factors

P is the precipitation

Using CROPWAT the IWR was calculated for different cultivated crops in the study area. Since, the equation (6-1) has used just two main components of water balance model of an irrigated area, while there are other water balance components such as input and output of surface and groundwater. They should be considering in water balance equation. It is suggested to use the complete water balance by following equation:

$$(P + SW_{In} + GW_{In}) - (ET_a + SW_{out} + GW_{out}) = \Delta S \qquad (6\text{-}2)$$

Where:

P: the total precipitation

SW_{In}: the inflow of surface water

GW_{In}: the amounts of withdrawal groundwater

ET_a: the actual evapotranspiration

SW_{out}: the surface water that leaves the system

GW_{out}: the groundwater that leaves the system

ΔS: the water storage variation

It should be mentioned that because of lack of reliable data for groundwater flow it was decided that as a first step, input and output of groundwater consider as equal in this research. It is obvious that this assumption introduces some inaccuracies, so further investigations will be needed in the future on this topic for a more accurate approach.

6.3 Water balance the Tassoj and Salmas areas

Based on above equation, water balance was computed for irrigated lands in the study areas. Table 6.3.1 and 6.3.2 represent the calculated water balances in (MCM).

As the equation (6-2) indicates, there are seven different components. Based on the concept of water balance and CROPWAT modelling, the analysis showed the following results:

The total precipitation was divided into two main parts, which are the effective rainfall that is taken in account in CROPWAT model to estimate net irrigation water requirement and remaining part of precipitation appears as runoff and evaporation and infiltration. The direct evaporation from rainfall is relatively small, so it was considered zero. The infiltration that reaches the groundwater increases the storage. The direct runoff from rainfall is considered in the equation (6.2) as surface water that leaves the system.

As it can be clearly seen, the amount of irrigated lands has not been varied a lot in the last ten years (1991-2001). However, precipitation has been decreased from 44 to 23 MCM in the Tassoj and from 67 to 36 MCM in the Salmas areas. It can be seen that as a result of this decrease in precipitation, the amount of inflowing surface water decreased consequently. On the other hand, shortage of precipitation caused an increasing irrigation water demand.

These issues will together made more press on groundwater as the only type of available water. This point (loss of groundwater) is clearly shown in the column no.5., the calculated storage loss due to agricultural demands. As it is shown, at the beginning of analysed period the amount of storage loss is 2 MCM while in the second half of this period it has increased to 58 MCM and last few years it decreased to 37 MCM. It means that the annual storage loss has been around several tens of MCM in the dry years in the Tassoj area. In the Salmas area, in the first three (wet) years the groundwater was replenished, but then the trend is the same as in the Tassoj with a same order of magnitude.

At the beginning of the analysed period, due to proper and adequate amount of precipitation, the required irrigation water has been supplied by precipitation and inflow discharges. In the last few years, because of rainfall shortage, the total amounts of rainfall and inflow discharges do not meet the net irrigation water requirement. For instance, in the last year (2000-2001) the total irrigation water requirement was about 70 MCM but the total rainfall and inflow discharges are about 42 MCM. It shows a great amount of water deficit in Tassoj. The same problem occurred in Salmas where the irrigation water requirement was about 89 MCM (2000-2001) but the total available water was about 60 MCM.

Looking at the problem from another angle, it means that regarding the existing conditions there is a great amount of lands irrigated extra to the potential provided by the water resources, in both of the study areas. This is expressed in columns no.9 in the tables. The summary of these columns show that in the last ten years, the actually irrigated land exceeds the potentially possible by 24% and 37% in the Salmas and Tassoj areas respectively.

Table 6.3.1 Computed water balance for the Tassoj irrigated area

Water years	(1) P	(2) SW$_{In}$	(4) ET$_a$	(5) $\pm \Delta S$	(6) Net.irrig. Wt.req. (MCM)	(7) Irrigated area [ha]	(8) (6)/(7) (MCM/ha)	(9) Surplus Irrig. (ha)
91-92	44.4	27.8	74.1	-1.9	57.02	11525	0.005	-376
92-93	46.2	32.5	81.6	-2.9	66.03	12526.5	0.005	-560
93-94	57.4	35.9	108.1	-14.9	72.61	13310	0.005	-2724
94-95	30.9	33.4	70.8	-6.5	60.82	9650	0.006	-1037
95-96	25.0	18.6	76.5	-32.9	67.21	9975	0.007	-4882
96-97	30.7	22.7	86.5	-33.2	72.18	10815	0.007	-4973
97-98	27.4	16.7	94.5	-50.4	83.25	10772.5	0.008	-6526
98-99	21.8	16.7	84.3	-58.2	83.51	10500.0	0.008	-7320
99-2000	17.7	14.6	96.8	-52.0	77.20	10393.6	0.007	-7007
2000-2001	23.1	18.6	78.4	-36.7	70.09	10803.7	0.006	-5659

Table 6.3.2 Computed water balance for the Salmas irrigated area

Water years	(1) P	(2) SW$_{In}$	(3) ET$_a$	(4) SW$_{out}$	(5) $\pm \Delta S$	(6) Net.irrig. Wt.req. (MCM)	(7) Irrigated area (ha)	(8) (6)/(7) (MCM/ha)	(9) Surplus Irrig. (ha)
91-92	67.9	105.9	122.4	43.6	7.8	97.04	23167	0.004	n.a.
92-93	93.2	120.6	140.4	49.0	24.4	107.93	23447	0.005	n.a.
93-94	96.1	125.4	156.9	53.4	11.2	117.27	24708	0.005	n.a.
94-95	70.7	74.4	144.0	28.6	-27.5	124.39	24490	0.005	-5414
95-96	59.2	62.4	142.2	24.3	-44.9	126.67	23100	0.005	-8188
96-97	64.0	58.4	151.5	17.2	-46.3	127.53	23000	0.006	-8350
97-98	38.0	32.2	127.2	5.6	-62.6	104.99	18015	0.006	-10741
98-99	30.1	22.8	110.3	4.7	-62.1	99.02	15401	0.006	-9658
99-2000	25.4	20.7	100	3.3	-57.2	92.51	14309	0.006	-8848
2000-2001	36.6	24.1	109.5	3.7	-52.5	89.03	14723	0.006	-8682

1: Calculated based on interpolated rainfall data by ILWIS software

2 and 4: Estimated by applying 34 and 36 percent as surface water efficiency of input and output of rivers discharge in the Tassoj and Salmas area, respectively

3 and 6: Calculated by CROPWAT model (see chapter 5)

5: Calculated based on difference between input and output in the water balance model

7: Determined by applying Aster image for 2000-2001and for the other years the agricultural office data were used

8: Obtained by dividing the net irrigation water requirement to total irrigated area

9: Calculated by dividing column no.5 to column no. 8

CONCLUSION AND RECOMMENDATIONS

Water balances are essential for making wise decisions regarding water conservation and water management. This research defines essential ingredients of water balance in irrigated lands in the Salmas and Tassoj areas.

In this research using of remote sensing, GIS, and CROPWAT model, attempts to find reasonable answers to designed questions. According to related methodology to each chapter, it concluded as follows:

7.1 Climate data analysing

Orumiyeh Lake as a big water body affects on it's surrounding area. Lack of gauges in upper altitudes with their unevenly distribution has caused inaccurate correlation between altitude and climatic parameters in the study area. While other trials have been done to fond a relation between distances of Lake with climatic parameters. Based on this issue, the mean maximum temperature shows a reasonable relation with distance of Lake. The low accuracy of meteorological data coupled with lack of those in a uniform format caused other problems in use of them. It is recommended to establish gauges in the high elevation of the study area and also the meteorological data records in a uniform format of course with more accuracy.

7.2 CROPWAT model

The CROPWAT model is very sensitive to climatic and crop growth data. Hence, the input data of this model should have high accuracy. This model offers reasonable results for crops in comparison with fruit-trees. To run CROPWAT model one needs to calibrate and validate the obtained results with local lysimeter measurements. Due to lack of these data it was not possible to do calibration and validation for the study area. Reference manual that contains generally calibrated values for the model for different crops in Iran that it was used to validate he results. Despite these issues, since this model is one of the best tools in the world, it was applied to estimate the crop water requirement in this research.

7.3 Satellite images

Applying Aster images to agricultural crop classification is simple and gives acceptable results. The perennial crops such as alfalfa and orchards were classified with reasonable accuracy, while the annual crops could be only poorly distinguished on the image. More successful identifications of agricultural crops would have required multi-temporal images, while in this research Aster image for only one date, 2nd July 2001 was available. To identify most agricultural crops, at least two satellite images needed (middle and late growing season) to help differentiate between crops of similar appearance. According this issue, to get more accurate results, it is recommended to use multi-temporal images to agricultural crop classification. Also the time of collection of ground truth is important. For most agricultural crops, especially short season crops and areas with multiple crops grown per year, it is suggested that mapping should be done as closely as possible to the time of the satellite images acquisition. Knowledge of local farming information is essential to planning fieldwork. Also, Some time, the obtained information of farmers during the fieldwork hasn't enough reliability. Consulting with local county agricultural agents is suggested.

7.4 Water resources

Irrigation of the study area is done by traditional methods, for this reason on-farm water application rates in the regions are high and irrigation practice has a low efficiency of about 34 and 36 percent for Salmas and Tassoj area, respectively. A part from losses via unlined irrigation canals, the major part of the losses is at farm level via evaporation, due to inefficient irrigation practices (surface irrigation methods). Percolation to the shallow aquifers also takes place. Although some parts of water used for agricultural purposes are supplied from surface water in the both area, but shortage and uneven distribution of annual rainfall caused the rivers of these regions offer low discharge. This resource supplied only a little part of the agricultural demands in the examined period. Lack of irrigation canals coupled with low efficiency of surface water use (34 and 36 per cent for Salmas and Tassoj area respectively) caused the existing water cannot be used properly. It is recommended to improve the water conveyance lines and increases the surface water use efficiency.

Making a reliable assessment of groundwater recharge and discharge normally requires an adequate amount of good quality data on both piezometic and irrigation well measurements. The recent measurement network in the study area for groundwater is not so accurate. Despite this issue, groundwater investigation based on available data shows that groundwater resources in the Tassoj and Salmas regions supply about 60 and 65 percent of irrigation water. Groundwater hydrograph illustrated strongly decreasing groundwater table in the last ten years for Tassoj areas. Groundwater is

potentially a source of good quality water, so growth of human population coupled with rapid agricultural and industrial expansion during the last several years, has resulted a sharp rise in the demand for water in these regions and more and more groundwater is used. This has caused a lowering of groundwater table exceeding ten meters in some parts of the regions. For this reason, the study areas now face a great problem to supply enough the water of good quality for human consumption, agriculture and industry. People, who depend for their water supply on water from sallow wells, are now faced with a lower water yield or even experience a complete drying up of the wells. According to above issues, it is recommended that withdrawal of groundwater should be limited by announce of these areas as forbidden regions for water explorations. Executing flood speeding projects for increasing groundwater recharge can be useful.

7.5 Water balance

In this research, water balance was calculated at an irrigation region scale. Water balance was calculated for the Salamas and Tassoj irrigated lands on an annual basis for a period of ten years. The results, shows that the water balance in the study areas, especially in the Tassoj region strongly has a negative trend. The over exploitation of water resources is becoming more and more critical in the regions.

 Water scarcity is a major issue in the study area. Good quality water supplies are insufficient to meet rising demands from agriculture. The agriculture sector is a major user of groundwater resources. There is not an equivalent condition of demand and supply of water resources for irrigation purposes. To achieve sustainable agriculture we need to take in account this issue.

7.6 Further recommendations

Consider the water scarcity and rapid growth of human population, which needs to more foods, it is recommended:

- To improve the irrigation efficiency by changing traditional irrigation system to most efficient system such as drop irrigation and pipe irrigation and etc.
- To integrate small farms into big units to increase the irrigation efficiency.
- To changing crop pattern and cultivate crops with less water requirement.

- Water resources management should be considered in different aspect, such as supplying management, demand management, and construct management.

- To increase the pizeometric wells for having more accurate data about groundwater variations.

- To recharge groundwater by implementing flood spread projects.

- To increase the income of local people by establishing different small industries, which do not, need to more water.

8. REFERENCES

A.Gieske, N. T., M.Akbari (2002). Crop and land cover classification by Landsat 7 (july 2000) for the Zayandaeh Rud basin.

Burt, C. M. (1999). Irrigation Water Balance Fundamentals. Conference on Benchmarking Irrigation System Performance using Water Measurement and Water Balances., San Luis Obispo, CA., Irrigation Training and Research Center (ITRC).

Doorenbos, J. a. P., P.W. (1984). Crop Water Requirements. Rome, Italy, Food and Agriculture Organization of the United National**:** 144.

Faures, J. and et al (2002). The FAO Irrigated Area Forecast For 2030. Rome, Italy, FAO**:** 6-8.

Gu.Zhixin (2002). Crap mapping and crop diversity assesment based on multi-temporal RS and GIS. Agriculture,Conservatio and environment. Enschede, The Netherlands, ITC**:** 2.

Hoogeveen, J. (2002). "A regional water balance of the Aral sea basin through GIS."

Jam-Ab, C. E. (1998). Water comprehensive plan. Tehran, Power ministry, East Azerbaijan provincial water office**:** 3-1.

Kiefer.R.W, L. T. M. (2000). Remote sensing and image Interpretation, John wiley & Sons.

M.Abrams (2000). "The Advanced Spaceborne Thermal Emission and Reflection Radiomter(Aster):data products for the high spatial resolution imager on NASA's Terra platform." International jornal of Remote sensing **21**(5,847-859): 847.

Molina, I. (1992). Multistage pattern recognition utilizing high resolution remote sensing data. Enschede, ITC.

Noannis, K. and N. Sharif (2002). "A GIS interface method based on reference evapotranspiration and crop coefficients for the determination of irrigation requirements." Water International **27**(2): 233-242.

Richards, J. (1986). Remote sensing .Digital Image analysis.An introduction . Berlin, Springer-Verlag.

Salem, A. S. (1995). The application of Remote sensing and GIS in detecting citrus crop land cover variation. Enschede, The Netherlands, ITC.

Shariati, M. R. a. e. (1997). An estimate of water requirements of main field crops and orchards in Iran. Tehran, Agricultural training center.

Smith, M. (1992). CROPWAT: A computer program for irrigation planning and management. Rome, Italy, Food and Agriculture Organization of the United National (FAO).

Tavan Ab, C. E. (1996). The transferring water from Zola-chay to Shabestar plan, Power ministry,Ardabel&East Azerbaijan water office**:** 10-15.

UNESCO (July 1970). world water balance, Proceeding of reading symposium, UNESCO, AIHS-UNESCO.

Appendix A (Climatological data)

Mean monthly rainfall (mm) for Salmas regions (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Sum
1991-1992	10.7	26.1	35.4	18.6	16.1	22.9	36.6	54.3	41.2	21.6	3.8	5.8	**293.0**
92-93	5.1	26.7	35.1	26.8	37.7	50.8	60.2	102.4	39.5	8.3	3.6	1.1	**397.3**
93-94	4.3	53.5	49.8	20.9	21.7	24.9	78.9	69.2	19.4	26.6	1.6	18.1	**388.9**
94-95	15.4	58.5	25.0	12.9	15.1	12.8	26.4	51.2	54.5	10.9	0.0	6.1	**288.8**
95-96	9.6	21.3	6.4	28.5	22.3	45.2	54.0	27.8	4.8	18.7	3.4	5.1	**247.0**
96-97	16.2	6.9	53.7	14.8	12.2	33.1	22.9	36.8	20.0	39.6	0.0	2.9	**259.0**
97-98	6.3	14.0	21.8	14.2	6.1	18.0	29.5	55.5	36.7	2.3	3.8	2.6	**210.9**
98-99	5.1	4.4	9.7	18.9	10.8	11.4	51.2	48.1	11.1	12.0	6.3	6.1	**195.2**
99-2000	11.5	15.1	10.5	14.5	11.9	12.1	33.1	42.3	10.7	1.5	11.4	2.8	**177.5**
2000-2001	14.1	39.3	32.6	7.9	25.3	23.9	31.5	50.5	12.5	8.7	1.7	0.8	**248.9**
Avg.	**9.8**	**26.6**	**28.0**	**17.8**	**17.9**	**25.5**	**42.4**	**53.8**	**25.0**	**15.0**	**3.6**	**5.1**	**270.6**

Mean monthly rainfall (mm) for Tassoj regions (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Sum
1991-1992	37.5	22.8	71.5	19.4	13.2	21.0	52.3	86.5	48.5	0.7	10.7	1.3	**385.5**
92-93	5.8	52.6	48.5	27.0	30.0	26.8	90.7	72.0	10.0	4.3	0.5	0.3	**368.6**
93-94	15.0	75.8	23.2	30.3	19.7	38.0	86.5	100.5	8.7	14.8	0.0	18.7	**431.0**
94-95	19.0	73.3	26.8	13.7	25.7	24.8	63.8	33.0	13.7	2.5	0.0	23.5	**319.8**
95-96	6.8	21.8	12.3	35.3	27.0	27.7	61.5	32.2	4.8	16.3	2.7	2.0	**250.5**
96-97	20.0	24.0	30.8	22.8	5.5	31.3	26.2	24.8	10.0	80.3	4.3	3.3	**283.5**
97-98	4.7	14.0	37.5	13.6	23.6	25.7	49.3	47.3	21.1	12.0	4.5	1.0	**254.1**
98-99	15.4	7.8	10.9	20.9	21.3	11.5	51.3	37.5	16.2	4.0	1.7	2.6	**201.1**
99-2000	18.3	23.7	13.7	18.8	12.3	2.7	33.7	30.5	13.7	0.7	0.0	2.5	**170.5**
2000-2001	5.0	17.5	27.3	9.7	37.8	31.7	34.8	33.7	9.0	5.7	1.3	0.0	**213.5**
Avg.	**14.8**	**33.3**	**30.3**	**21.2**	**21.6**	**24.1**	**55.0**	**49.8**	**15.6**	**14.1**	**2.6**	**5.5**	**287.8**

Mean minimum temperature (C^o) for Salmas area (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Avg.
1991-1992	6.8	1.8	-5.1	-11	-10	-6.8	0.6	4.0	9.4	13.8	15.7	13.8	**2.73**
92-93	6.1	1.2	-5.0	-10	-11	-4.7	1.3	5.0	11.0	14.3	16.2	11.7	**3.00**
93-94	6.6	0.4	-5.2	-4.0	-5.5	-0.9	3.5	6.7	12.4	14.0	16.0	12.1	**4.67**
94-95	7.5	2.4	-5.1	-3.8	-4.5	-1.5	1.8	6.3	11.6	14.0	15.9	12.8	**4.77**
95-96	4.3	0.9	-4.8	-6.8	-6.6	-0.8	1.1	7.5	11.3	14.5	16.1	12.6	**4.10**
96-97	7.8	0.6	-1.8	-3.2	-10.6	-4.3	-0.1	6.8	11.2	14.5	17.1	12.6	**4.22**
97-98	8.0	2.7	-2.0	-6.8	-6.8	-2.9	4.8	8.3	12.2	16.3	16.2	12.8	**5.22**
98-99	5.8	1.8	-0.8	-5.0	-4.8	-1.6	2.5	6.0	10.4	15.6	16.4	13.0	**4.94**
99-2000	6.4	0.5	-3.0	-5.5	-5.7	-4.0	1.8	6.3	10.3	15.2	17.0	14.0	**4.44**
2000-2001	8.5	2.0	-3.5	-4.8	-6.0	-4.9	2.5	7.0	9.5	16.2	16.2	15.2	**4.83**
Avg.	**6.8**	**1.4**	**-3.6**	**-6.0**	**-7.2**	**-3.2**	**2.0**	**6.4**	**10.9**	**14.8**	**16.3**	**13.0**	**4.3**

Mean maximum temperature (C⁰) for Salmas area (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Avg.
1991-1992	21.7	15.8	4.9	-0.4	1.8	3.7	11.7	14.4	21.9	28.0	28.8	27.2	**14.94**
92-93	21.8	12.4	4.5	-0.2	-0.4	4.2	12.7	14.2	22.9	28.4	29.5	27.6	**14.78**
93-94	21.9	9.7	2.1	3.6	2.8	5.1	15.9	20.6	26.5	26.6	29.1	26.1	**15.80**
94-95	18.1	10.8	6.3	6.0	2.4	6.6	12.7	19.6	23.3	27.7	31.4	26.4	**15.92**
95-96	15.1	11.8	5.4	3.7	2.8	14.4	8.5	18.1	21.3	27.1	30.9	26.0	**15.40**
96-97	14.9	10.9	7.2	7.3	1.7	6.2	7.6	17.3	22.9	25.3	29.1	25.4	**14.62**
97-98	21.0	13.9	7.1	0.2	0.5	6.5	14.9	21.5	26.7	32.3	30.2	27.8	**16.87**
98-99	21.1	15.6	10.9	5.9	6.2	9.4	13.8	18.6	28.1	31.5	31.9	28.2	**18.42**
99-2000	20.0	16.8	10.5	4.8	4.7	6.9	12.3	17.9	25.4	32.0	31.3	25.0	**17.28**
2000-2001	20.5	17.8	9.0	5.5	5.5	8.0	13.0	17.0	23.0	30.0	30.7	26.5	**17.21**
Avg.	**19.59**	**13.53**	**6.77**	**3.64**	**2.78**	**7.07**	**12.29**	**17.90**	**24.18**	**28.88**	**30.27**	**26.61**	**16.12**

Mean minimum temperature (C⁰) for Tassoj area (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Avg.
1991-1992	6.8	1.8	-5.1	-11.1	-10.2	-6.8	0.6	4.0	9.4	13.8	15.7	13.8	**2.73**
92-93	6.1	1.2	-5.0	-9.6	-11.3	-4.7	1.3	5.0	11.0	14.3	16.2	11.7	**3.00**
93-94	6.6	0.4	-5.2	-4.0	-5.5	-0.9	3.5	6.7	12.4	14.0	16.0	12.1	**4.67**
94-95	7.5	2.4	-5.1	-3.8	-4.5	-1.5	1.8	6.3	11.6	14.0	15.9	12.8	**4.77**
95-96	4.3	0.9	-4.8	-6.8	-6.6	-0.8	1.1	7.5	11.3	14.5	16.1	12.6	**4.10**
96-97	7.8	0.6	-1.8	-3.2	-10.6	-4.3	-0.1	6.8	11.2	14.5	17.1	12.6	**4.22**
97-98	8.0	2.7	-2.0	-6.8	-6.8	-2.9	4.8	8.3	12.2	16.3	16.2	12.8	**5.22**
98-99	5.8	1.8	-0.8	-5.0	-4.8	-1.6	2.5	6.0	10.4	15.6	16.4	13.0	**4.94**
99-2000	6.4	0.5	-3.0	-5.5	-5.7	-4.0	1.8	6.3	10.3	15.2	17.0	14.0	**4.44**
2000-2001	8.5	2.0	-3.5	-4.8	-6.0	-4.9	2.5	7.0	9.5	16.2	16.2	15.2	**4.83**
Avg.	**6.75**	**1.42**	**-3.61**	**-6.03**	**-7.18**	**-3.23**	**1.97**	**6.37**	**10.91**	**14.82**	**16.26**	**13.05**	**4.29**

Mean maximum temperature (C⁰) for Tassoj area (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Avg.
1991-1992	21.7	15.8	4.9	-0.4	1.8	3.7	11.7	14.4	21.9	28.0	28.8	27.2	**14.94**
92-93	21.8	12.4	4.5	-0.2	-0.4	4.2	12.7	14.2	22.9	28.4	29.5	27.6	**14.78**
93-94	21.9	9.7	2.1	3.6	2.8	5.1	15.9	20.6	26.5	26.6	29.1	26.1	**15.80**
94-95	18.1	10.8	6.3	6.0	2.4	6.6	12.7	19.6	23.3	27.7	31.4	26.4	**15.92**
95-96	15.1	11.8	5.4	3.7	2.8	14.4	8.5	18.1	21.3	27.1	30.9	26.0	**15.40**
96-97	14.9	10.9	7.2	7.3	1.7	6.2	7.6	17.3	22.9	25.3	29.1	25.4	**14.62**
97-98	21.0	13.9	7.1	0.2	0.5	6.5	14.9	21.5	26.7	32.3	30.2	27.8	**16.87**
98-99	21.1	15.6	10.9	5.9	6.2	9.4	13.8	18.6	28.1	31.5	31.9	28.2	**18.42**
99-2000	20.0	16.8	10.5	4.8	4.7	6.9	12.3	17.9	25.4	32.0	31.3	25.0	**17.28**
2000-2001	20.5	17.8	9.0	5.5	5.5	8.0	13.0	17.0	23.0	30.0	30.7	26.5	**17.21**
Avg.	**19.59**	**13.53**	**6.77**	**3.64**	**2.78**	**7.07**	**12.29**	**17.90**	**24.18**	**28.88**	**30.27**	**26.61**	**16.12**

Relative humidity (RH%) for Tassoj region (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Avg.
91-92	71.5	76.5	79.3	78.0	84.5	82.0	74.5	70.5	65.5	64.7	62.2	54.0	**71.9**
92-93	75.5	74.6	78.1	78.1	84.0	79.8	74.3	72.5	64.7	66.4	61.8	59.3	**72.4**
93-94	70.0	74.0	80.3	82.3	84.9	83.0	75.0	72.7	66.7	68.4	64.5	61.8	**73.6**
94-95	67.0	74.2	80.7	83.2	80.6	81.3	74.8	79.0	65.8	68.5	62.0	60.7	**73.1**
95-96	72.9	75.4	80.5	82.3	83.3	77.5	73.5	75.3	64.5	62.0	62.0	66.4	**73.0**
96-97	73.3	76.7	79.5	80.9	86.3	81.4	69.0	76.4	68.0	63.2	65.2	66.7	**73.9**
97-98	69.6	75.4	82.6	79.4	82.4	70.3	72.7	72.5	57.7	59.5	65.4	61.7	**70.8**
98-99	63.6	65.9	70.7	76.3	65.5	71.7	69.8	65.9	57.9	57.0	61.7	58.4	**65.4**
99-2000	66.2	71.6	74.2	78.3	67.0	73.5	68.9	65.6	60.8	62.6	54.1	58.9	**66.8**
2000-2001	58.2	69.8	81.5	83.2	82.3	74.7	66.4	73.3	63.5	50.0	39.1	44.8	**65.5**
AVG	**68.78**	**73.40**	**78.73**	**80.20**	**80.07**	**77.51**	**71.88**	**72.37**	**63.50**	**62.23**	**59.81**	**59.26**	**70.6**

Relative humidity (RH%) for Salmas region (1991-2001)

Water years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Avg.
91-92	60.6	73.6	69.7	71.0	70.7	72.9	68.3	67.3	72.5	67.6	62.5	65.8	**68.5**
92-93	66.5	72.1	73.9	75.2	66.8	71.5	72.2	72.6	73.4	71.6	71.5	69.2	**71.4**
93-94	77.8	79.5	79.7	81.3	79.1	79.0	67.6	70.8	67.9	77.7	82.4	87.3	**77.5**
94-95	75.9	77.5	72.5	75.7	75.4	71.6	65.3	67.2	70.3	66.6	59.4	63.8	**70.1**
95-96	64.4	65.5	74.7	69.1	74.7	73.2	71.0	68.3	69.5	72.4	73.7	67.5	**70.3**
96-97	70.5	71.3	72.8	74.2	65.7	72.1	69.8	70.1	65.2	68.2	68.5	70.0	**69.8**
97-98	68.5	72.0	75.1	70.6	77.2	77.2	70.3	71.9	68.0	60.5	68.5	72.4	**71.0**
98-99	67.7	70.2	75.3	75.0	72.2	64.9	65.9	69.9	60.2	63.4	67.7	73.0	**68.7**
99-2000	65.0	72.0	75.5	76.0	72.5	74.0	64.0	72.0	70.0	65.0	62.0	65.0	**69.4**
2000-2001	66.5	72.0	73.0	71.0	65.0	72.0	70.0	72.0	67.0	64.0	74.0	76.5	**70.3**
AVG	**68.33**	**72.55**	**74.20**	**73.90**	**71.91**	**72.83**	**68.41**	**70.17**	**68.38**	**67.69**	**68.99**	**71.03**	**70.7**

Mean daily sunshine for Tabriz   meteorological station (1991-2001)

Years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Sum
91-92	6.9	5.2	2.6	2.5	3.9	5.4	6.8	5.6	7.5	10.6	9.7	9.0	**75.7**
92-93	7.2	4.1	2.3	3.1	3.8	6.0	5.0	7.0	10.4	11.0	10.4	10.3	**80.5**
93-94	7.4	4.3	3.0	3.5	4.8	5.3	7.3	9.2	10.4	11.9	11.3	9.2	**87.5**
94-95	7.5	4.5	3.8	3.9	4.0	6.8	6.5	9.1	9.8	11.6	11.9	9.4	**88.9**
95-96	9.3	7.3	5.7	2.9	5.2	5.0	7.4	9.0	11.8	10.8	11.3	10.0	**95.9**
96-97	7.9	7.2	4.4	5.0	6.8	6.2	7.3	9.1	10.7	11.9	11.7	10.2	**98.3**
97-98	7.7	6.1	4.4	3.2	5.7	7.1	7.8	9.6	11.7	11.4	11.4	10.5	**96.7**
98-99	8.8	6.3	5.4	5.1	8.2	6.9	8.6	10.1	11.4	11.2	9.8	10.5	**102.2**
99-2000	8.4	6.1	5.3	5.2	7.1	7.1	8.7	9.7	11.7	11.0	9.8	11.0	**101.0**
2000-2001	6.5	5.8	5.3	4.8	6.8	7.4	8.0	10.2	10.0	11.0	10.3	10.0	**96.0**
Avg.	**7.8**	**5.7**	**4.2**	**3.9**	**5.6**	**6.3**	**7.3**	**8.8**	**10.5**	**11.2**	**10.8**	**10.0**	**92.3**

Mean daily sunshine for Khoy meteorological station (1991-2001)

Years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Sum
91-92	6.5	4.9	2.6	3.6	4.6	5.8	6.8	5.4	8.6	11.5	10.1	9.0	**79.2**
92-93	7.4	5.0	4.9	2.9	4.9	6.1	5.2	6.6	10.6	11.1	10.3	9.4	**84.2**
93-94	7.3	4.8	5.1	3.8	5.3	4.6	7.3	8.9	10.0	11.9	11.1	9.1	**88.9**
94-95	6.9	4.2	5.3	4.7	5.7	7.6	5.3	8.7	9.5	12.0	12.0	9.4	**91.0**
95-96	8.7	7.4	5.2	2.5	5.7	4.2	6.6	8.5	11.0	9.9	11.0	9.0	**89.6**
96-97	6.9	7.1	3.1	6.6	6.7	5.7	7.5	8.8	10.3	11.6	11.8	9.1	**94.9**
97-98	6.7	5.6	4.0	4.2	6.7	6.6	7.0	8.5	11.7	11.0	11.4	10.2	**93.3**
98-99	8.5	5.7	5.2	4.4	7.3	7.1	7.5	9.9	11.0	11.4	10.2	9.8	**97.7**
99-2000	7.1	5.4	5.3	4.1	7.0	6.6	7.1	8.6	9.9	10.7	10.1	9.1	**90.6**
2000-2001	7.1	5.8	5.0	4.8	6.9	7.2	7.8	8.5	10.4	10.8	10.6	8.3	**93.0**
Avg.	**7.3**	**5.6**	**4.6**	**4.2**	**6.1**	**6.1**	**6.8**	**8.2**	**10.3**	**11.2**	**10.8**	**9.2**	**90.2**

Mean monthly wind speed (km/day) for Khoy meteorological station (1991-2001)

Years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	AVG
91-92	23.3	33.2	26.6	53.2	116	63.1	86.4	26.6	26.6	23.3	16.6	16.6	**42.7**
92-93	19.9	33.2	16.6	71.5	62.3	125	116	121	104	74.8	78.8	62.3	**73.7**
93-94	58.2	91.4	28.2	70.6	24.9	78.9	95.6	116	141	41.5	45.7	49.9	**70.2**
94-95	74.8	62.3	45.7	13.3	23.3	26.6	56.5	43.2	36.6	23.3	36.6	33.2	**39.6**
95-96	66.5	116	26.6	33.7	40.7	71.5	86.4	94.3	88.9	73.9	76.4	108	**73.6**
96-97	116	118	71.5	54	58.2	116	116	145	141	125	116	183	**113.4**
97-98	166	121	116	121	104	133	133	133	162	91.4	166	129	**131.2**
98-99	175	129	154	81.8	96.8	88.1	116	130	106	75.6	93.1	77.7	**110.2**
99-2000	133	116	133	43.2	89.7	43.2	99.7	126	49.9	59.8	19.9	26.6	**78.4**
2000-2001	176	133	117	94.4	113	180	69.8	86.4	113	49.9	83.1	44.9	**105.0**
AVG	**100.9**	**95.3**	**73.5**	**63.6**	**72.9**	**92.5**	**97.6**	**102.2**	**96.9**	**63.8**	**73.3**	**73.1**	**83.8**

Mean monthly wind speed (km/day) for Tabriz meteorological station (1991-2001)

Years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	AVG
91-92	99.7	46.5	36.6	79.8	120	93.1	143	120	136	163	176	126	**111.6**
92-93	143	86.4	76.4	83.1	99.7	108	129	125	137	121	108	99.7	**109.6**
93-94	83.1	74.8	116	66.5	108	137.1	112	108	129	145	99.7	99.7	**103.9**
94-95	95.6	121	83.1	86.4	103	140	173	176	146	193	166	126	**134.1**
95-96	143	146	146	143	153	216	249	203	259	312	263	189	**201.9**
96-97	166	93.1	159	153	199	203	249	223	256	269	269	229	**205.8**
97-98	160	143	136	133	186	213	173	233	263	293	226	206	**196.9**
98-99	160	123	116	106	209	199	223	199	279	302	266	193	**198.0**
99-2000	150	140	96.4	56.5	99.7	123	146	173	196	216	198	130	**143.7**
2000-2001	153	126	86.4	66.5	136	106	152	141	183	223	199	123	**141.3**
AVG	**135.2**	**109.9**	**105.4**	**97.4**	**141.4**	**155.7**	**174.9**	**170.0**	**198.4**	**223.7**	**197.2**	**152.2**	**155.1**
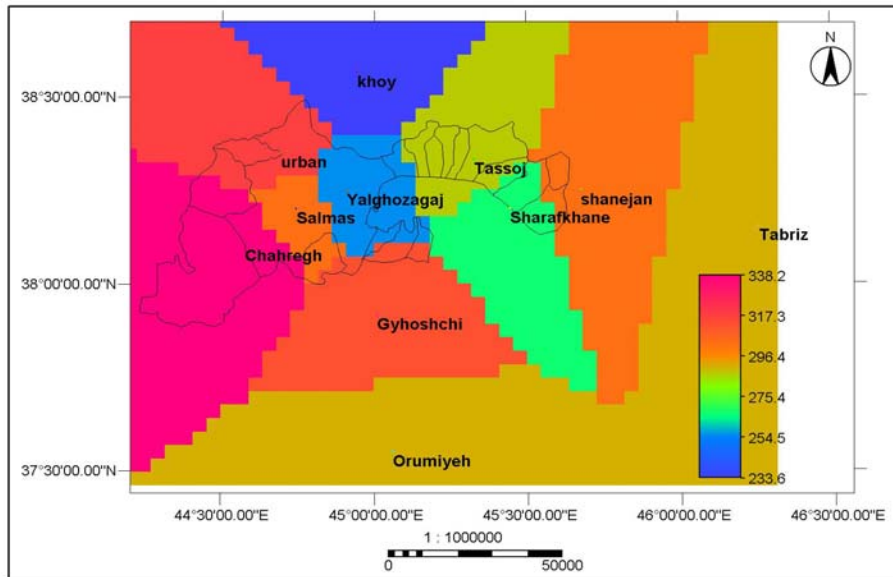
Thiessen polygon interpolation of rainfall data

Appendix B (samples of Cropwat model output)

```
11/16/2002                                          CropWat 4 Windows Ver 4.2
*******************************************************************************

                          Crop Water Requirements Report

*******************************************************************************

- Crop  # 1           : ALFALFA (perennial, dormancy 1 Nov)
- Block #             : [All blocks]
- Planting date       : 12/3
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%


-------------------------------------------------------------------------------
Date    ETo     Planted  Crop     CWR     Total   Effect.  Irr.     FWS
                Area     Kc       (ETm)   Rain    Rain     Req.
        (mm/period) (%)           ---------- (mm/period) ----------  (l/s/ha)
-------------------------------------------------------------------------------
12/3    13.62   100.00   1.00     13.62   7.59    0.00     13.62    0.23
22/3    16.61   100.00   1.00     16.61   9.12    0.00     16.61    0.27
1/4     19.84   100.00   1.00     19.84   10.87   0.00     19.84    0.33
11/4    23.20   100.00   1.00     23.20   12.68   0.00     23.20    0.38
21/4    26.55   100.00   1.00     26.55   14.37   2.75     23.80    0.39
1/5     29.79   100.00   1.00     29.79   15.75   6.16     23.63    0.39
11/5    32.81   100.00   1.00     32.81   16.62   7.26     25.55    0.42
21/5    35.51   100.00   1.00     35.51   16.82   7.01     28.49    0.47
31/5    37.79   100.00   1.00     37.79   16.23   3.36     34.43    0.57
10/6    39.59   100.00   1.00     39.59   14.80   0.00     39.59    0.65
20/6    40.84   100.00   1.00     40.84   12.56   0.00     40.84    0.68
30/6    41.52   100.00   1.00     41.52   9.69    0.00     41.52    0.69
10/7    41.59   100.00   1.00     41.59   6.52    0.00     41.59    0.69
20/7    41.06   100.00   1.00     41.06   3.58    0.00     41.06    0.68
30/7    39.95   100.00   1.00     39.95   1.25    0.00     39.95    0.66
9/8     38.28   100.00   1.02     38.98   0.00    0.00     38.98    0.64
19/8    36.12   100.00   1.05     37.98   0.00    0.00     37.98    0.63
29/8    33.53   100.00   1.09     36.37   0.00    0.00     36.37    0.60
8/9     30.60   100.00   1.10     33.66   0.00    0.00     33.66    0.56
18/9    27.42   100.00   1.10     30.16   0.00    0.00     30.16    0.50
28/9    24.10   100.00   1.10     26.51   0.00    0.00     26.51    0.44
8/10    20.74   100.00   1.10     22.81   0.00    0.00     22.81    0.38
18/10   17.46   100.00   1.10     19.21   0.71    0.00     19.21    0.32
28/10   14.38   100.00   1.10     15.82   4.91    0.00     15.82    0.26
7/11    11.59   100.00   1.10     12.75   7.72    0.00     12.75    0.21
17/11   9.20    100.00   1.10     10.12   10.19   0.00     10.12    0.17
27/11   7.27    100.00   1.10     8.00    11.58   0.00     8.00     0.13
7/12    5.87    100.00   1.10     6.46    11.65   0.00     6.46     0.11
17/12   5.02    100.00   1.10     5.52    10.54   0.00     5.52     0.09
27/12   5.95    100.00   1.10     6.55    8.79    0.00     6.55     0.11
6/1     6.38    100.00   1.10     7.02    7.50    0.00     7.02     0.12
16/1    5.80    100.00   1.10     6.38    6.50    0.00     6.38     0.11
26/1    5.86    100.00   1.10     6.44    5.75    0.00     6.44     0.11
5/2     6.57    100.00   1.09     7.16    5.37    0.00     7.16     0.12
15/2    7.91    100.00   1.07     8.49    5.43    0.00     8.49     0.14
25/2    9.83    100.00   1.06     10.38   5.96    0.00     10.38    0.17
7/3     5.79    100.00   1.04     6.05    3.32    0.00     6.05     0.20
-------------------------------------------------------------------------------
Total   815.94                   843.07  274.38  26.55    816.52   [0.37]
-------------------------------------------------------------------------------

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
*******************************************************************************
D:\CROPWA~2\ALF912.TXT
```

```
11/16/2002                                    CropWat 4 Windows Ver 4.2
*****************************************************************************

                      Crop Water Requirements Report

*****************************************************************************

- Crop  # 1            : Sunflower
- Block #              : [All blocks]
- Planting date        : 30/4
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%


-----------------------------------------------------------------------------
Date    ETo    Planted  Crop     CWR     Total   Effect.   Irr.    FWS
               Area     Kc       (ETm)   Rain    Rain      Req.
        (mm/period) (%)          ---------- (mm/period) ----------  (l/s/ha)
-----------------------------------------------------------------------------
30/4    29.48  100.00   0.35     10.32   15.63   14.43     0.00    0.00
10/5    32.52  100.00   0.35     11.38   16.56   15.26     0.00    0.00
20/5    35.25  100.00   0.38     13.58   16.84   15.52     0.00    0.00
30/5    37.58  100.00   0.59     22.21   16.33   15.08     7.13    0.12
9/6     39.43  100.00   0.82     32.31   14.98   13.90     18.40   0.30
19/6    40.74  100.00   1.05     42.68   12.81   11.99     30.69   0.51
29/6    41.48  100.00   1.15     47.70   10.00   9.48      38.21   0.63
9/7     41.61  100.00   1.15     47.85   6.84    6.63      41.22   0.68
19/7    41.14  100.00   1.15     47.31   3.84    3.83      43.48   0.72
29/7    40.08  100.00   1.15     46.09   1.50    1.50      44.60   0.74
8/8     38.47  100.00   1.10     42.42   0.00    0.00      42.42   0.70
18/8    36.36  100.00   0.81     29.66   0.00    0.00      29.66   0.49
28/8    33.81  100.00   0.49     16.77   0.00    0.00      16.77   0.28
-----------------------------------------------------------------------------
Total   487.95                   410.28  115.33  107.63    312.58  [0.40]
-----------------------------------------------------------------------------

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
*****************************************************************************
D:\CROPWA~2\SUN912.TXT
```

```
12/18/2002                                         CropWat 4 Windows Ver 4.2
******************************************************************************

                        Crop Water Requirements Report

******************************************************************************

- Crop  # 1              : Winter Wheat  (planting October, frost winter)
- Block #                : [All blocks]
- Planting date          : 28/9
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 40%


------------------------------------------------------------------------------
Date    ETo     Planted Crop     CWR     Total   Effect.  Irr.    FWS
                Area    Kc       (ETm)   Rain    Rain     Req.
        (mm/period) (%)          ---------- (mm/period) ----------  (l/s/ha)
------------------------------------------------------------------------------
28/9    24.10   100.00  0.30     7.23    0.00    0.00     7.23    0.21
8/10    20.74   100.00  0.30     6.22    0.00    0.00     6.22    0.18
18/10   17.46   100.00  0.30     5.24    0.71    0.69     4.54    0.13
28/10   14.38   100.00  0.30     4.31    4.91    4.80     0.00    0.00
7/11    11.59   100.00  0.30     3.48    7.72    7.42     0.00    0.00
17/11   9.20    100.00  0.30     2.76    10.19   9.70     0.00    0.00
27/11   7.27    100.00  0.30     2.18    11.58   10.95    0.00    0.00
7/12    5.87    100.00  0.30     1.76    11.65   10.99    0.00    0.00
17/12   5.02    100.00  0.30     1.51    10.54   9.97     0.00    0.00
27/12   5.95    100.00  0.30     1.79    8.79    8.34     0.00    0.00
6/1     6.38    100.00  0.30     1.92    7.50    7.17     0.00    0.00
16/1    5.80    100.00  0.30     1.74    6.50    6.28     0.00    0.00
26/1    5.86    100.00  0.30     1.76    5.75    5.63     0.00    0.00
5/2     6.57    100.00  0.30     1.97    5.37    5.31     0.00    0.00
15/2    7.91    100.00  0.30     2.37    5.43    5.38     0.00    0.00
25/2    9.83    100.00  0.30     2.95    5.96    5.86     0.00    0.00
7/3     12.25   100.00  0.36     4.46    6.94    6.73     0.00    0.00
17/3    15.08   100.00  0.48     7.20    8.31    7.95     0.00    0.00
27/3    18.20   100.00  0.59     10.75   9.97    9.42     1.33    0.04
6/4     21.51   100.00  0.70     15.14   11.78   11.02    4.12    0.12
16/4    24.88   100.00  0.82     20.33   13.55   12.59    7.74    0.22
26/4    28.19   100.00  0.93     26.22   15.11   13.97    12.25   0.35
6/5     31.34   100.00  1.04     32.69   16.26   14.99    17.70   0.51
16/5    34.21   100.00  1.14     38.96   16.82   15.49    23.47   0.68
26/5    36.70   100.00  1.15     42.21   16.63   15.35    26.86   0.78
5/6     38.75   100.00  1.15     44.56   15.62   14.47    30.10   0.87
15/6    40.28   100.00  1.15     46.33   13.77   12.84    33.49   0.97
25/6    41.25   100.00  1.15     47.44   11.19   10.55    36.90   1.07
5/7     41.63   100.00  1.15     47.87   8.11    7.79     40.08   1.16
15/7    41.40   100.00  1.11     45.75   4.98    4.92     40.84   1.18
25/7    40.57   100.00  0.84     33.91   2.43    2.43     31.48   0.91
4/8     39.18   100.00  0.53     21.00   0.29    0.29     20.71   0.60
14/8    18.90   100.00  0.31     5.87    0.00    0.00     5.87    0.34
------------------------------------------------------------------------------
Total   688.27                   539.88  274.38  259.29   350.93  [0.31]
------------------------------------------------------------------------------

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
******************************************************************************
D:\CROPWA~2\WW912.TXT
```

```
12/20/2002                                          CropWat 4 Windows Ver 4.2
********************************************************************************

                         Crop Water Requirements Report

********************************************************************************

- Crop  # 1             : Apple (cool season 15 Nov.)
- Block #               : [All blocks]
- Planting date         : 24/4
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 40%


--------------------------------------------------------------------------------
Date    ETo      Planted  Crop     CWR      Total    Effect.  Irr.     FWS
                 Area     Kc       (ETm)    Rain     Rain     Req.
        (mm/period) (%)            ---------- (mm/period) ----------  (l/s/ha)
--------------------------------------------------------------------------------
24/4    27.54    100.00   0.70     19.28    14.83    4.81     14.47    0.42
4/5     30.73    100.00   0.70     21.51    16.07    6.88     14.63    0.42
14/5    33.66    100.00   0.70     23.56    16.76    7.48     16.08    0.47
24/5    36.24    100.00   0.70     25.37    16.73    7.21     18.16    0.53
3/6     38.38    100.00   0.70     26.87    15.89    6.24     20.63    0.60
13/6    40.02    100.00   0.70     28.01    14.20    4.79     23.22    0.67
23/6    41.11    100.00   0.70     28.77    11.75    3.12     25.66    0.74
3/7     41.60    100.00   0.70     29.12    8.75     0.61     28.51    0.82
13/7    41.49    100.00   0.70     29.05    5.58     0.00     29.05    0.84
23/7    40.79    100.00   0.70     28.55    2.85     0.00     28.55    0.83
2/8     39.50    100.00   0.70     27.65    0.63     0.00     27.65    0.80
12/8    37.68    100.00   0.70     26.38    0.00     0.00     26.38    0.76
22/8    35.38    100.00   0.70     24.77    0.00     0.00     24.77    0.72
1/9     32.68    100.00   0.70     22.88    0.00     0.00     22.88    0.66
11/9    29.67    100.00   0.70     20.77    0.00     0.00     20.77    0.60
21/9    26.43    100.00   0.72     18.98    0.00     0.00     18.98    0.55
1/10    23.09    100.00   0.75     17.34    0.00     0.00     17.34    0.50
11/10   19.74    100.00   0.79     15.49    0.00     0.00     15.49    0.45
21/10   16.51    100.00   0.82     13.50    1.92     0.00     13.50    0.39
31/10   13.51    100.00   0.85     11.50    5.72     0.00     11.50    0.33
10/11   10.83    100.00   0.88     9.58     8.54     0.00     9.58     0.28
20/11   8.57     100.00   0.92     7.86     10.74    0.00     7.86     0.23
30/11   6.80     100.00   0.95     6.46     11.74    0.00     6.46     0.19
10/12   5.56     100.00   0.98     5.47     11.42    0.00     5.47     0.16
20/12   4.87     100.00   1.00     4.87     10.05    0.00     4.87     0.14
30/12   6.54     100.00   1.00     6.54     8.33     0.00     6.54     0.19
9/1     6.15     100.00   1.00     6.15     7.18     0.00     6.15     0.18
19/1    5.75     100.00   1.00     5.75     6.24     0.00     5.75     0.17
29/1    6.00     100.00   1.00     6.00     5.59     0.00     6.00     0.17
8/2     6.90     100.00   1.00     6.90     5.34     0.00     6.90     0.20
18/2    8.43     100.00   1.00     8.43     5.54     0.00     8.43     0.24
28/2    10.50    100.00   1.00     10.50    6.21     0.00     10.50    0.30
10/3    13.06    100.00   1.00     13.06    7.32     0.00     13.06    0.38
20/3    15.99    100.00   0.98     15.73    8.79     0.00     15.73    0.46
30/3    19.18    100.00   0.96     18.33    10.51    0.00     18.33    0.53
9/4     22.52    100.00   0.93     20.87    12.32    0.00     20.87    0.60
19/4    12.53    100.00   0.91     11.34    6.82     0.00     11.34    0.66
--------------------------------------------------------------------------------
Total   815.94                     623.20   274.38   41.15    582.05   [0.46]
--------------------------------------------------------------------------------

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
********************************************************************************
D:\CROPWA~2\AP912.TXT
```

```
11/28/2002                                       CropWat 4 Windows Ver 4.2
*******************************************************************************

                         Crop Water Requirements Report

*******************************************************************************

 Crop  Egg plant
 Block #,[All blocks]
 Planting date,20/5
 Calculation time step =, 10 ,Day(s)
 Irrigation Efficiency =,40%


-------------------------------------------------------------------------------
Date,    ETo,    Area, Crop Kc,  ETm, Total Rain, Effect. Rain,  Net Irrigation Req., Field
Water Supply
,(mm/period),(%),,(mm/period),(mm/period),(mm/period),  (mm/period), (l/s/ha)
-------------------------------------------------------------------------------
20/5,   48.30,  100.00,  0.45,   21.74,  9.92,   0.00,   21.74,   0.63,
30/5,   51.10,  100.00,  0.45,   22.99,  4.08,   0.00,   22.99,   0.67,
9/6,    53.30,  100.00,  0.45,   23.99,  0.00,   0.00,   23.99,   0.69,
19/6,   54.85,  100.00,  0.53,   29.22,  0.00,   0.00,   29.22,   0.85,
29/6,   55.71,  100.00,  0.68,   38.03,  0.00,   0.00,   38.03,   1.10,
9/7,    55.85,  100.00,  0.83,   46.49,  0.00,   0.00,   46.49,   1.35,
19/7,   55.25,  100.00,  0.98,   54.28,  0.00,   0.00,   54.28,   1.57,
29/7,   53.95,  100.00,  1.05,   56.65,  0.00,   0.00,   56.65,   1.64,
8/8,    51.97,  100.00,  1.05,   54.57,  0.00,   0.00,   54.57,   1.58,
18/8,   49.36,  100.00,  1.05,   51.83,  0.00,   0.00,   51.83,   1.50,
28/8,   46.20,  100.00,  1.05,   48.51,  0.00,   0.00,   48.51,   1.40,
7/9,    42.56,  100.00,  1.04,   44.17,  0.00,   0.00,   44.17,   1.28,
17/9,   38.55,  100.00,  0.96,   37.14,  0.00,   0.00,   37.14,   1.07,
27/9,   34.29,  100.00,  0.88,   30.17,  0.00,   0.00,   30.17,   0.87,
7/10,   15.49,  100.00,  0.82,   12.66,  0.00,   0.00,   12.66,   0.73,
-------------------------------------------------------------------------------
Total,  706.73,,,              572.42, 14.01,   0.00,   572.42, [1.14],
-------------------------------------------------------------------------------

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
*******************************************************************************
D:\CROPWA~1\EGG221.CSV
```

```
11/26/2002                                            CropWat 4 Windows Ver 4.2
*******************************************************************************

                         Crop Water Requirements Report

*******************************************************************************

 Crop  # Almond (cool season 15 Nov.)
 Block #,[All blocks]
 Planting date,20/4
 Calculation time step =, 10 ,Day(s)
 Irrigation Efficiency =,40%


-------------------------------------------------------------------------------
Date,ETo,Area,Crop Kc,ETm,Total Rain,Effect. Rain,Net Irrigation Req.,Field Water Supply
,(mm/period),(%),,(mm/period),(mm/period),(mm/period),(mm/period),(l/s/ha)
-------------------------------------------------------------------------------
20/4,   25.54,  100.00,  0.57,   14.56,  21.81,  10.55,   4.01,   0.12,
30/4,   29.30,  100.00,  0.57,   16.70,  25.66,  13.32,   3.38,   0.10,
10/5,   33.17,  100.00,  0.57,   18.91,  27.75,  14.58,   4.32,   0.13,
20/5,   37.01,  100.00,  0.57,   21.10,  27.25,  13.88,   7.22,   0.21,
30/5,   40.69,  100.00,  0.57,   23.19,  23.69,  11.21,  11.98,   0.35,
9/6,    44.05,  100.00,  0.57,   25.11,  17.26,   7.11,  18.00,   0.52,
19/6,   46.93,  100.00,  0.57,   26.75,   9.03,   2.78,  23.97,   0.69,
29/6,   49.19,  100.00,  0.57,   28.04,   1.57,   0.23,  27.81,   0.80,
9/7,    50.70,  100.00,  0.57,   28.90,   0.00,   0.00,  28.90,   0.84,
19/7,   51.35,  100.00,  0.57,   29.27,   0.00,   0.00,  29.27,   0.85,
29/7,   51.04,  100.00,  0.57,   29.09,   0.00,   0.00,  29.09,   0.84,
8/8,    49.72,  100.00,  0.57,   28.34,   0.00,   0.00,  28.34,   0.82,
18/8,   47.37,  100.00,  0.57,   27.00,   0.00,   0.00,  27.00,   0.78,
28/8,   44.02,  100.00,  0.57,   25.09,   0.00,   0.00,  25.09,   0.73,
7/9,    39.74,  100.00,  0.57,   22.65,   0.00,   0.00,  22.65,   0.66,
17/9,   34.67,  100.00,  0.59,   20.45,   0.39,   0.00,  20.45,   0.59,
27/9,   29.03,  100.00,  0.63,   18.18,  12.65,   0.00,  18.18,   0.53,
7/10,   23.08,  100.00,  0.66,   15.30,  14.08,   0.00,  15.30,   0.44,
17/10,  17.20,  100.00,  0.70,   12.03,   7.84,   0.00,  12.03,   0.35,
27/10,  11.84,  100.00,  0.74,    8.71,   3.95,   0.00,   8.71,   0.25,
6/11,    7.55,  100.00,  0.77,    5.83,   5.43,   0.00,   5.83,   0.17,
16/11,   5.00,  100.00,  0.81,    4.04,  11.06,   0.21,   3.83,   0.11,
26/11,   4.96,  100.00,  0.85,    4.20,  17.75,   6.12,   0.00,   0.00,
6/12,    4.80,  100.00,  0.88,    4.24,  22.29,  10.52,   0.00,   0.00,
16/12,   4.80,  100.00,  0.90,    4.32,  22.54,  10.58,   0.00,   0.00,
26/12,   5.14,  100.00,  0.90,    4.63,  17.25,   5.97,   0.00,   0.00,
5/1,     6.71,  100.00,  0.90,    6.03,   9.47,   0.15,   5.88,   0.17,
15/1,    7.69,  100.00,  0.90,    6.92,   4.44,   0.00,   6.92,   0.20,
25/1,    8.41,  100.00,  0.90,    7.57,   3.15,   0.00,   7.57,   0.22,
4/2,     9.11,  100.00,  0.90,    8.20,   0.90,   0.00,   8.20,   0.24,
14/2,    9.99,  100.00,  0.90,    8.99,   0.47,   0.00,   8.99,   0.26,
24/2,   11.19,  100.00,  0.90,   10.07,   5.22,   0.00,  10.07,   0.29,
6/3,    12.80,  100.00,  0.90,   11.52,   6.18,   0.00,  11.52,   0.33,
16/3,   14.87,  100.00,  0.88,   13.14,   7.91,   0.00,  13.14,   0.38,
26/3,   17.41,  100.00,  0.86,   14.89,  10.86,   2.54,  12.35,   0.36,
5/4,    20.39,  100.00,  0.83,   16.86,  14.92,   5.29,  11.57,   0.33,
15/4,   11.43,  100.00,  0.81,    9.21,   9.19,   3.96,   5.25,   0.30,
-------------------------------------------------------------------------------
Total, 917.88,,,            580.02, 361.95, 119.01, 476.81, [0.38],
-------------------------------------------------------------------------------

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
*******************************************************************************
D:\CROPWA~1\ALM912.CSV
```

```
11/25/2002                                      CropWat 4 Windows Ver 4.2
*******************************************************************************

                         Crop Water Requirements Report

*******************************************************************************

 Crop  # 1 ,TOMATO
 Block #,[All blocks]
 Planting date,20/4
 Calculation time step =, 10 ,Day(s)
 Irrigation Efficiency =,70%

 ------------------------------------------------------------------------------
 Date,ETo,Area,Crop Kc,ETm,Total Rain,Effect. Rain,Net Irrigation Req.,Field Water Supply
 ,(mm/period),(%),,(mm/period),(mm/period),(mm/period),(mm/period),(l/s/ha)
 ------------------------------------------------------------------------------
 20/4,  25.54,  100.00,  0.60,   15.33,   21.81,   10.56,   4.77,    0.08,
 30/4,  29.30,  100.00,  0.60,   17.58,   25.66,   13.30,   4.28,    0.07,
 10/5,  33.17,  100.00,  0.60,   19.90,   27.75,   14.49,   5.41,    0.09,
 20/5,  37.01,  100.00,  0.68,   25.05,   27.25,   13.74,  11.31,    0.19,
 30/5,  40.69,  100.00,  0.81,   33.13,   23.69,   11.07,  22.06,    0.36,
 9/6,   44.05,  100.00,  0.95,   41.91,   17.26,    7.03,  34.88,    0.58,
 19/6,  46.93,  100.00,  1.09,   51.09,    9.03,    2.78,  48.31,    0.80,
 29/6,  49.19,  100.00,  1.15,   56.57,    1.57,    0.25,  56.32,    0.93,
 9/7,   50.70,  100.00,  1.15,   58.31,    0.00,    0.00,  58.31,    0.96,
 19/7,  51.35,  100.00,  1.15,   59.05,    0.00,    0.00,  59.05,    0.98,
 29/7,  51.04,  100.00,  1.15,   58.70,    0.00,    0.00,  58.70,    0.97,
 8/8,   49.72,  100.00,  1.13,   56.32,    0.00,    0.00,  56.32,    0.93,
 18/8,  47.37,  100.00,  1.03,   48.70,    0.00,    0.00,  48.70,    0.81,
 28/8,  44.02,  100.00,  0.91,   40.13,    0.00,    0.00,  40.13,    0.66,
 7/9,   20.46,  100.00,  0.82,   16.85,    0.00,    0.00,  16.85,    0.56,
 ------------------------------------------------------------------------------
 Total, 620.53,,,            598.60,  154.03,   73.21,  525.40, [0.60],
 ------------------------------------------------------------------------------

 * ETo data is distributed using polynomial curve fitting.
 * Rainfall data is distributed using polynomial curve fitting.
 *******************************************************************************
 D:\CROPWA~1\TMO912.CSV
```