Evaluating and Managing Water Demands

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The tools simple for understanding and use were developed in the frame of IWRM-Fergana Project for management of the irrigation and agricultural practice, namely the modeling software that can be easily applied by local specialists, taking into consideration available data, in order to draw up the irrigation schedule. Three versions of the modeling software "Daily Computing the Water Balance and Irrigation Schedule" were developed. The first one is based on daily measurements of evaporation in a field. The second one, that uses the formula suggested by S. Ryzhov, is based on daily measurements of the soil water content in a field; and finally third version is based on the model «CROPWAT» [32] with using climatic data (air temperature, rainfalls, relative air humidity, wind velocity). The first two models that are used by local consultants and specialists at the provincial and regional level were designed for timing irrigations and specifying their amounts. The model "CROPWAT" is designed for forecasting and adjusting timing and amount of water applied by the regional specialists. In the process of their developing, the models "Daily Computing the Water Balance and Irrigation Schedule" and «CROPWAT» were tested and calibrated by using field data on actual soil water content. Precondition for providing the required accuracy of calculations is the reliability of daily field measurements and data on soil parameters determined on each demonstration field in the course of special field surveys.

For assessing and analyzing the actual practice of water applications, we have calculated the optimal amounts and dates of irrigations based on data on soil characteristics on each demonstration field, rainfall, evaporation, watertable depth and initial soil water content, and then compared them with amounts that were calculated based on soil moisture deficit. Irrigation water demand depends on the field water balance, crop water requirements and soil water content. Computations of daily water balances for all demonstration fields under cotton were carried out. As a result of these computations, water requirements, amounts and dates of water applications and inter-irrigation periods were established.

Monitoring of actual irrigations over the whole growing season was implemented for comparative analyzing the adequacy of actual water application rates to the estimated ones. It was determined that at the initial phase of project implementation, actual basic indicators of irrigation considerably differed from the estimated ones. For example, unproductive water applications were observed in September and October in farms of Soghd Province (Figure 5.6). In accordance with computations, the water application rates ranging from 700 to 1200 m^3/ha would provide optimal soil moisture for crops up to the end of the growing season.

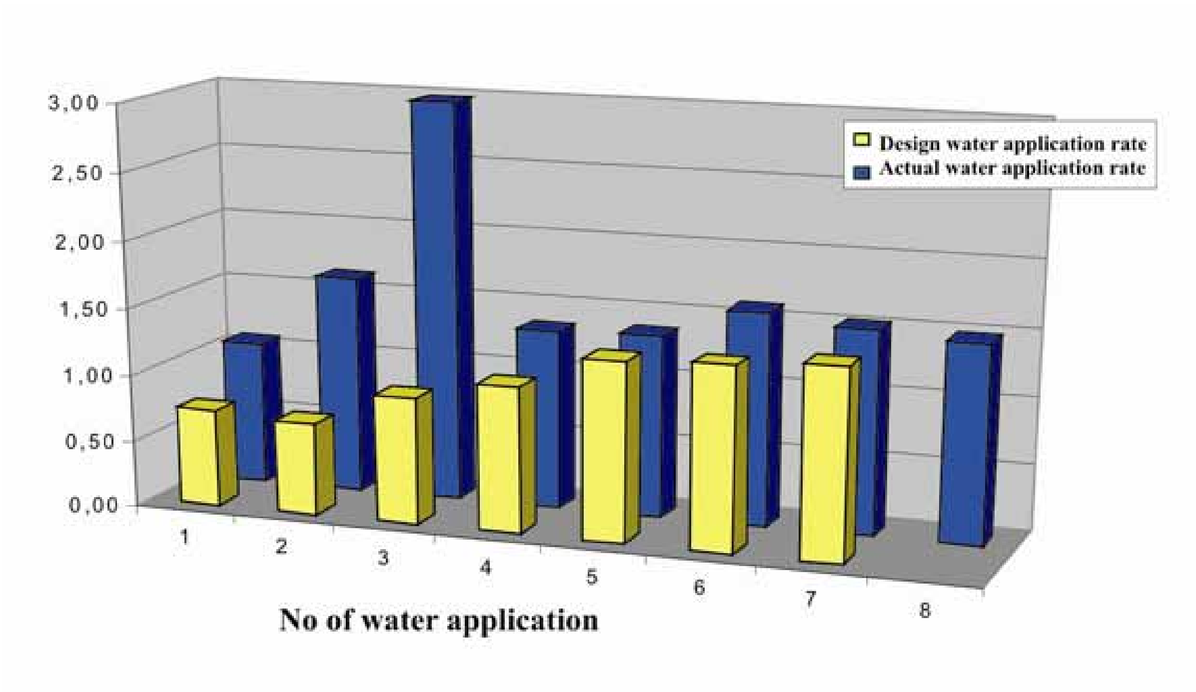

Figure 5.6 Water Application Rates in the Farm "Bokhoriston" in 2002 (000' m^3/ha)

Extra irrigations can only lead to slowdown of natural ripening of cotton and opening cotton bolls. Insufficient applications of water (both by amounts and timing) took place in farms "Sayed" and "Samatov" in July and August. In Fergana Province, actual irrigations close to the estimated irrigation schedule were observed in three farms with different soil and hydro-geological conditions. Actual irrigation norms exceed the estimated ones two times and even more in farm "Khojalol-Ona-Khodji" where thin topsoil is underlain by the pebble layer with considerable water permeability (Figure 5.7). In accordance with modeling computations more frequent water applications by smaller rates should be more efficient on these plots.

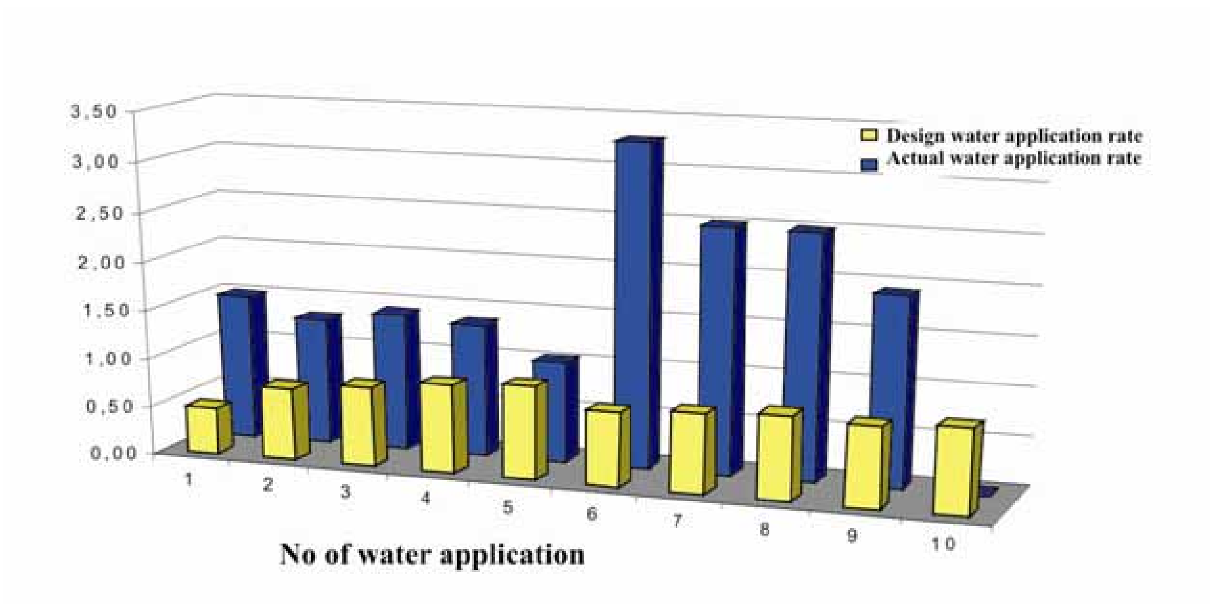

Figure 5.7 Water Application Rates in the Farm "Khojalol-Ona-Khodji" in Fergana Province in 2002 (000' m^3/ha)

There is some discrepancy in timing and amounts of actual water applications with estimated ones in the farm "Tolibjon" under implementing the same number of irrigations. It was determined that the first belated water application with a high rate disturbed the uniformity of following irrigations (both by amounts and timing). In accordance with computations of daily water balances, the optimal rates for water applications amounts to about 1100 m3/ha with an inter-irrigation period of 15 to 20 days.

In Osh Province, actual rates of water applications coincide with estimated values (only the first over-application of water was observed) but there is some discrepancy in timing. Analyzing soil water content prior to the first irrigation in the farm "Sandyk" has shown that there were not the need to apply high irrigation rates because abundant rainfalls were in May and actual soil moisture deficit on 3rd June amounted to only 505 m^3/ha while actual water application made up 1463 m^3/ha (Figure 5.8).

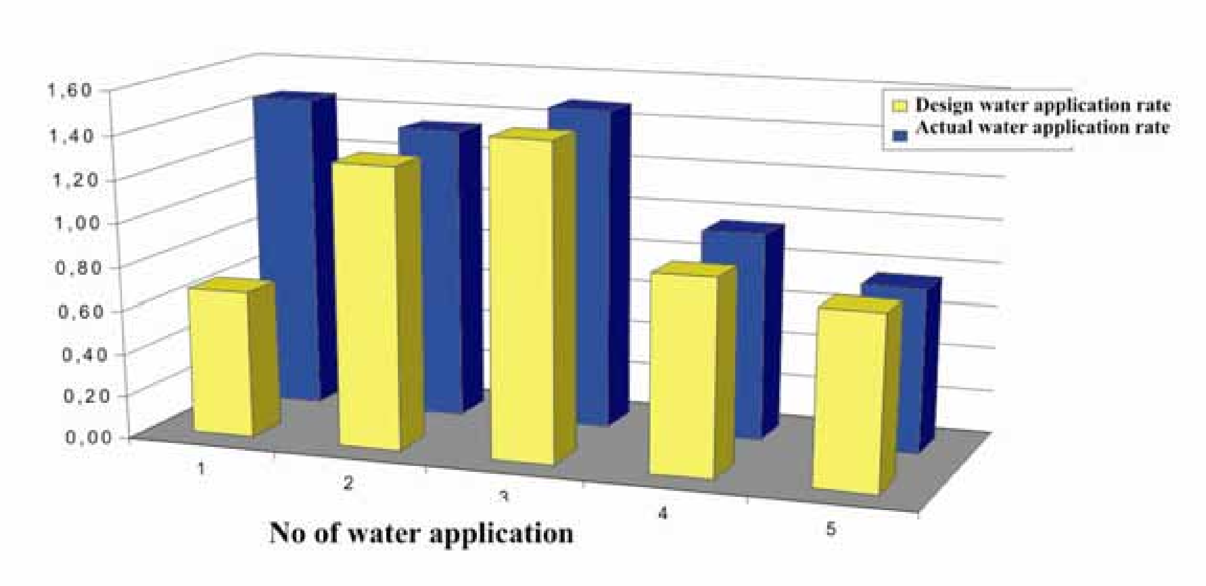

Figure 5.8 Water Application Rates in the Farm "Sandyk" in 2002 (000' m^3/ha)

Water application management based on the project recommendations:

In 2003, scheduling of irrigations basically depended on current weather conditions. This issue should be considered in detail because weather conditions in that year required considerable amendments in irrigation water use, date of sowing, and soil treatment. As subsequent months have shown, a fault in these matters was worth much. Only timely and correct measures implemented at the pilot sites have saved the 2003 yield.

Analyzing meteorological data in March and April enabled the regional project group to identify a more accurate sowing date for cotton that was shifted to later terms than usual. It was recommended to start the sowing season in the end of April or in the beginning of May. Most of farms under pressing of local authorities were forced to start the sowing season in the beginning of April. As a result most of private farms have re-sown cotton in May. Shifting sowing dates has predetermined adjusting the irrigation schedule. Frequent abundant rainfalls in May alternated with sunny days without precipitations did not allow determining real water demand using the simulation program for its computation. It was the situation when the soil-water content over the soil profile was sufficient but an upper soil layer started to dry up. In usual years, plants would grow normally without irrigation because in mid of May a depth of root system makes up more than 10 cm, and roots can extract required water from soils. In that year, a root system of cotton, which was behind the normal growth (a rootage depth was less than 10 cm), could not extract required water from soil horizons where the moisture content was quite sufficient. Computational models have not shown the necessity in irrigation; however, based on assessing an actual situation, the decision was made to start the first water application by small rates in farms which conducted the sowing in the first ten-day period of April. Farmers, who conducted the sowing in the end of April and in the beginning of May, have made watering only to stimulate young growth and then waited for next irrigation in June.

Planning next water applications on each demonstration site was carried out based on the formula suggested by S. Ryzhov and modeling the daily water balance. The regional group, parallel to local specialists, has set daily data on evaporation and a width of shading into the model "Daily Computing the Water Balance and Irrigation Schedule." Daily data were transferred from provinces to the regional office by e-mail. Analyzing the results of modeling for May has shown that there is not the need in irrigation under daily evaporation ranging from 2 to 8 mm/day (a cumulative soil moisture deficit amounted to 12 -24 mm).

The need in the first water application over demonstration sites has arisen since mid until the end of June. Setting a date of water application is carried out based on the results of modeling with some advance time (2-3 days); for this purpose, data on soil moisture deficit and evaporation for a past day are being analyzed. Input data for a past day are set into appropriate boxes of the computational model (a few days in advance in order to specify a date of water application ahead of time). A date of water application is checked and, if necessary, adjusted according to data on actual soil water content, which is measured by observers on demonstration field each two-three days. Pre-irrigation soil water content (a refill point) used for specifying a date of water application is accepted as 70% of field capacity (FC) for all fields on average. Following dates of irrigations were set in line with the same sequence analyzing modeling data on evaporation and soil water content.

Evaluating water applications and changes in soil water content on demonstration fields:

Assessment of soil water content was conducted using data of actual measurements in the field. Sampling to measure soil moisture was performed on demonstration field each five days in May and each three days in mid of the irrigation season. On some fields (the farm "Khojalol-Ona-Khodji"), where frequent water applications are needed, a soil water content was measured each two days. A nature of soil moisture distribution depends not only on climatic conditions but also soil properties and hydro-geological conditions in the farms and can vary even within one field.

In Soghd Province, the period of reducing soil water content from FC to the limit when the need in irrigation arises (an irrigation interval) lasts 25 to 30 days in May; in June and first half of July this period makes up 20 days; and in the second half of July and until the end of August the intensity of soil water consumption is increasing and reducing in soil water content up to "wilting point" occurs during 7-8 days (Figure 5.9).

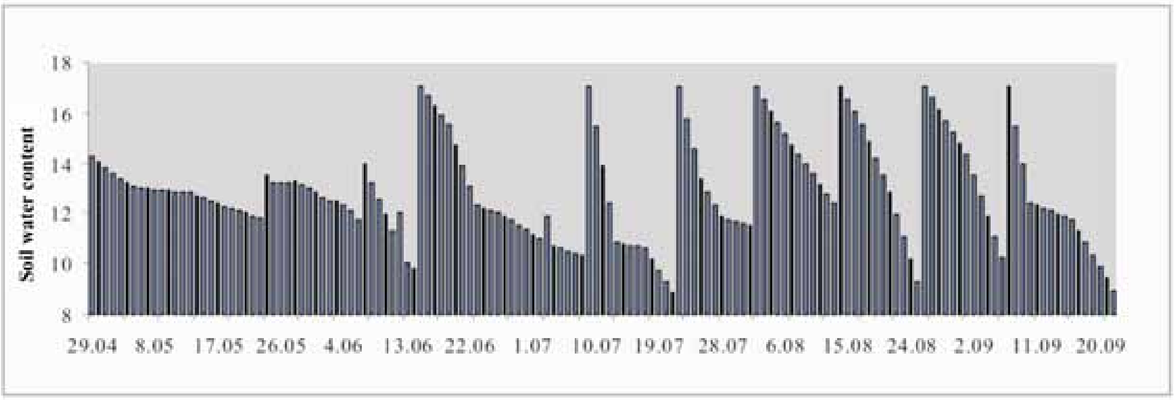

Figure 5.9 Changes in the soil water content during irrigation intervals[1]
(Soghd Province, the Farm «Bokhoriston»)

If in Soghd Province (Tajikistan) soil and hydro-geological conditions are similar in farms then in Fergana Province (Uzbekistan) these conditions considerably differ over farms and even over fields within one farm. Changes in soil water content also occur according to different patterns in different farms. In the farm "Khojalol-Ona-Khodji", after rainfalls in May and until 10th June, the period of reducing soil water content up to the limit when the need in irrigation arises lasted 20 days, then since July and until the end of the growing season, the period of consumption of water stored in soil amounted to 7 to 8 days (Figure 5.10). Absolutely other situation was observed in the farm "Turdialy" where, due to shallow groundwater table, perceptible reducing the soil water content was not observed during the whole growing season. Changes in soil moisture content on the demonstration field depend on fluctuations of watertable; and any correlation between decrease in soil water content and increase in air temperature was not revealed. Only after irrigation, reducing soil moisture close to field capacity was observed.

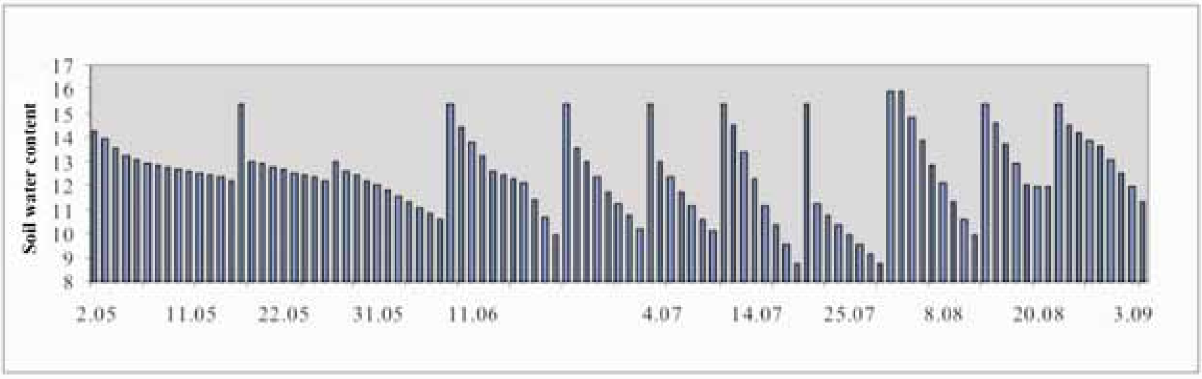

Figure 5.10 Changes in the soil water content during irrigation intervals
in the farm "Khojalkhonona Khoji"

In Kyrgyzstan, on the demonstration field under winter wheat, irrigation was needed only in May and June. At that, rainfalls in that period have conditioned the dynamics of soil water content, which is quite sufficient for proper crop growth. Decrease in soil water content started in the mid of June; and only one water application with a small rate was needed in June in the farm "Toloykon" (Figure 5.11).

[1] The *irrigation interval* is the time between subsequent irrigations.

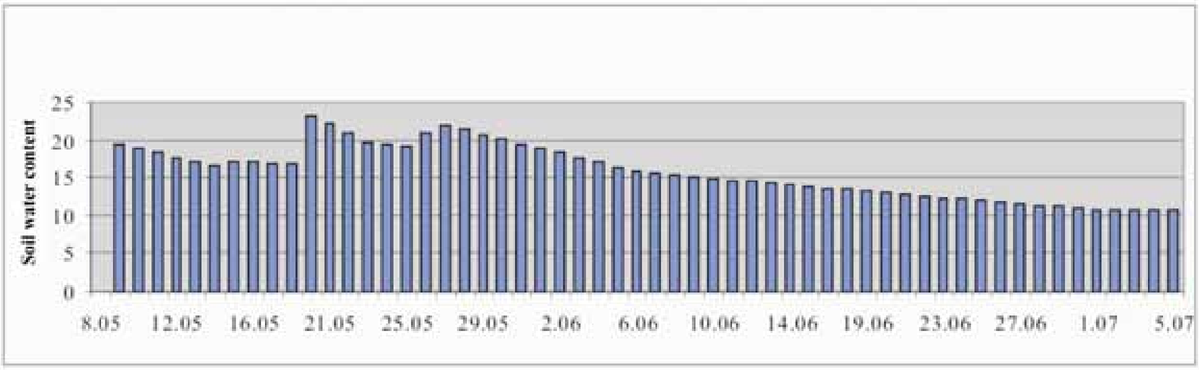

Figure 5.11 Changes in the soil water content during irrigation intervals in the farm "Toloykon" in Kyrgyzstan

Assessment of evaporation on demonstration fields: Evaluating the evaporation demand of the atmosphere was carried out by daily measurements using atmometers «Atmometers» (ET gage®) that were installed on each demonstration field. The evaporation from a field surface depends on air temperature changing over a year and a specific month. Evaporation values varied over the range of 5 to 12 mm/day during the growing season. The least evaporation values of 1 to 3 mm/day were observed in the first ten-day periods of May and June. Maximum evaporation values of 10 to 12 mm/day were being observed since the second half of June until 20th July. Although, it is necessary to note the non-typical reducing evaporation values in the end of June and in July, which sometimes were reaching 5-6 mm a day.

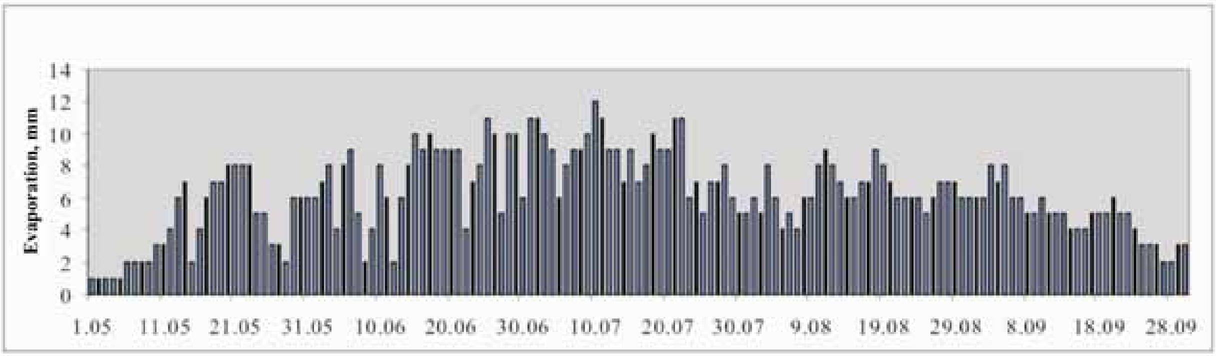

Figure 5.12 Evaporation values measured on the demonstration site "Bokhoriston"

Lower values of evaporation and precipitations have predetermined scheduling of irrigations (in May and at the beginning of June, irrigation was not required on all pilot fields). There is some distinction in evaporation values over the regions and some private farms. Maximum mean evaporation rates over the whole growing season were observed in Soghd Province in Tajikistan (7-8 mm/day), at the same time, in Fergana Province in Uzbekistan, mean evaporation rates were ranging from 6 to 7 mm/day, and in Osh Province in Kyrgyzstan from 4 mm/day in the upper zone (the farm "Toloykon") to 7 mm/day in the lower zone (the farm "Sandyk").

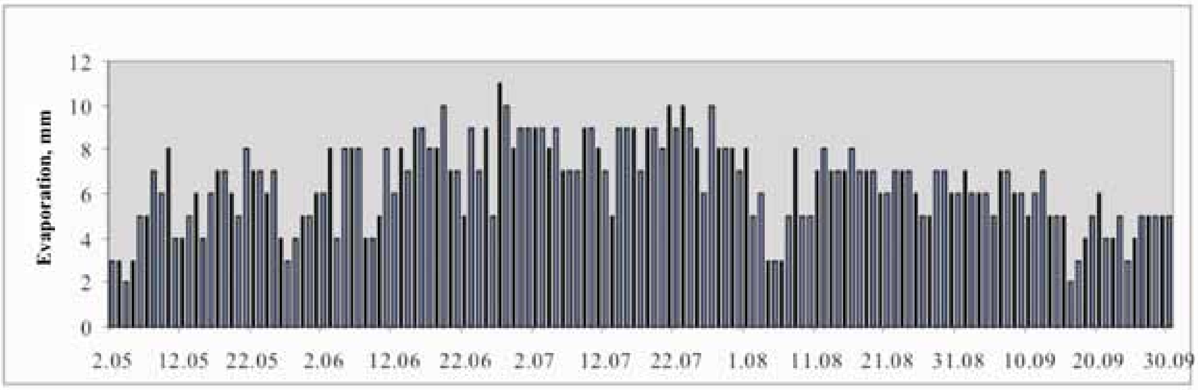

Figure 5.13 Evaporation values measured on the demonstration site "Khojalkhonona Khoji"

Soil moisture content against evaporation on the demonstration fields: A set of data on soil moisture conditions and evaporation over the growing season allowed us to find out the correlation between these parameters. Measurements of evaporation rates and soil water content in 2003 and 2004 enabled us to compare the soil moisture-evaporation relations for the years with different weather conditions. Both parameters are key factors affecting the irrigation schedule. Under field conditions there are not real possibilities for real-time measurements of soil moisture content but data on evaporation measured at the weather stations are always exist and, moreover, in many instances, satisfactory correlations between air temperatures and evaporation are available. Weather conditions in 2003 have predetermined lower values of daily evaporation and, as a result, more sustainable storage of water in soils. In 2004, weather conditions were more favorable for agriculture with the stable air temperature regime and less amount of rainfalls during the growing season. These conditions, in turn, resulted in higher daily evaporation rates and less sustainable storage of water in soils. The soil water content as a function of evaporation is illustrated in Figure 5.14 (the private farm "Sayed").

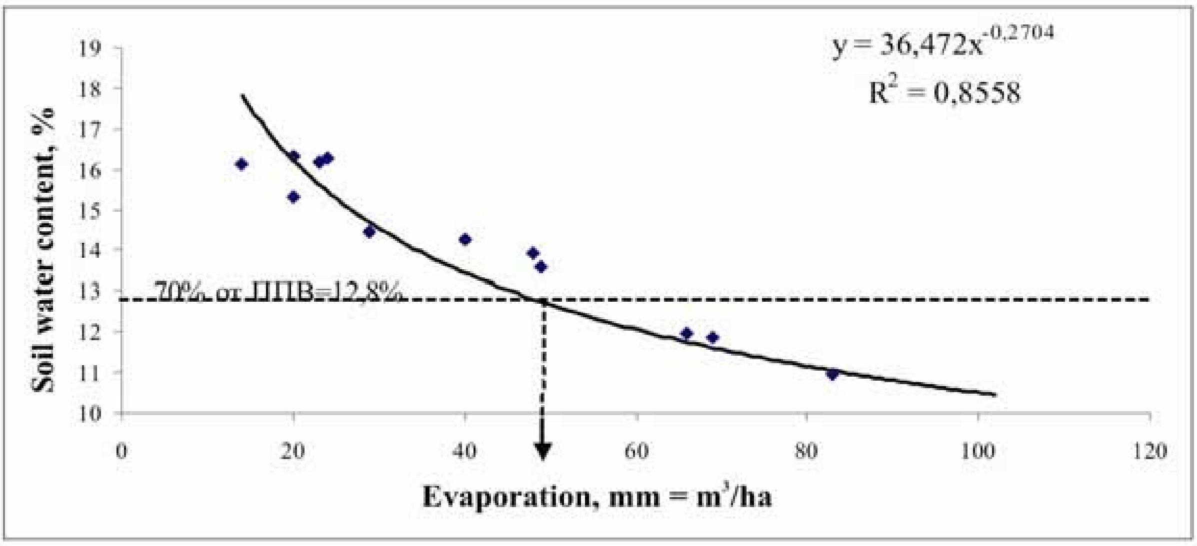

Figure 5.14 Soil water content as a function of evaporation at the demonstration site "Sayed"

We recommended this approach for day-to-day forecasting pre-irrigation soil moisture content and timing irrigations if such correlations will be established for each soil-hydrogeological-climatic zone. Under achieving a certain value of daily evaporation (this is happened later in 2003 and earlier in 2004), the soil water content is decreasing up to the level when crops are subjected to water stress (soil moisture deficit). Analyzing the changes in evaporation rates and soil water content has shown that at the project demonstration sites a soil moisture deficit that can cause water stress of crops takes place when total evaporation over an irrigation interval is ranging from 50 to 120 mm, on average. Depending on soil and hydrogeological conditions, the amount of water applied (a net volume of water application in a field) to replenish a depleted soil water storage varies over the range of 500 m^3/ha to 1200 m^3/ha.

Adjustment of the irrigation schedule based on analyzing the irrigation practice at demonstration sites:

Measuring a watertable depth

Reforming the agricultural sector in Central Asian countries resulted in division of large collective farms into small private farms. At that, the system of irrigation water allocation among farms has been changed. In the past, irrigation water allocation based on the principles of crop water requirement zoning and was being carried out by the district water management organizations that were responsible for delivering irrigation water towards the border of a collective or state farm. Irrigation specialists of the collective farm were responsible for irrigation water distribution among the irrigated units (brigades) within these farms. Crop water requirements were established based on area-averaged data and sometimes did not meet the actual requirements of crops in water. Such an approach to irrigation water rate setting was justifiable since irrigation engineers and agronomists were implementing irrigation water allocation within a farm taking into account a flow rate of uniform irrigation water supply specified by the district water management organization. In this case, experienced agronomists and irrigation engineers could adjust the irrigation schedule to actual requirements of specific crops in water.

However, most of farm managers could not adjust the planned irrigation schedule which, on the one hand, was limited by the irrigation water supply rates and, on the other hand, by modified soil and hydrogeological conditions on the given area. As far back as in collective farms, the question regarding the contradiction of the planned irrigation schedule to actual requirements of specific crops in water under modified soil and hydrogeological conditions was being raised. After division of large collective farms into small private farms 10 to 20 hectare in area, decisions on water allocation and specifying the irrigation rates became more problematic. First of all, the methodology for scheduling irrigation water allocation among private farms is absent. Secondly, there are not the well-founded irrigation rates and procedures of scheduling irrigation for specific areas in private farms. Initial studying of water use in private farms has shown that the lack of well-founded irrigation schedules (amounts and timing of water applications) results in stochastic use of irrigation water by farmers during the whole

Atmometer (ET gage®)

growing season. Wrong use of irrigation water results in water losses, over-irrigation in some areas and insufficient water applied in other areas, as well as in low land and water productivity.

Therefore, it is important to develop the scientifically grounded irrigation schedules for different crops and soil and hydrogeological conditions, based on which WUAs can develop the well-founded plans of water use, specifying reasonable volumes of irrigation water supply to private farms. In this respect, a key project objective is to study actual crop water requirements at demonstration sites and develop recommendations on scheduling water applications.Project monitoring and evaluation of irrigation water use on demonstration fields that are described in the following sections in detail has allowed to specify the amounts and timing of each water application and to adjust the irrigation schedule for private farms located within the pilot WUAs: “Sayed” in Soghd Province in Tajikistan; “Turdialy” in Fergana Province in Uzbekistan; and “Nursultan-Aly” in Osh Province in Kyrgyzstan. Based on project findings, the modified irrigation schedules were recommended for appropriate WUAs (Tables 5.3; 5.4 and 5.5). The existing (design) irrigation schedule for above-mentioned private farms was developed based on the crop water requirement zoning performed in the 1960s and 1970s. During past decades, water-management, soil and hydrogeological conditions in many irrigated schemes have changed. As a result, the former crop water requirement zoning and design irrigation schedule do not fit with current conditions. For example, irrigated farmlands of the private farm “Turdialy” belonged to Zone II with the automorphic soil formation process[2] according to the former crop water requirement zoning, however, after many years of irrigation and raise of watertable these irrigated farmlands now belong to Zone VII with hydromorphic[3] soil formation process. As a result, the irrigation schedule has to be also changed for the growing season.

Table 5.3
Adjustment of the irrigation schedule for the private farm “Turdialy”

	April	**May**			**June**			**July**			**August**		
Ten-day period	3	1	2	3	1	2	3	1	2	3	1	2	3
Design irrigation schedule	0.00	0.0	0.0	0.5	0.5	0.6	0.6	0.8	0.9	0.8	0.6	0.5	0.5
Recommended irrigation schedule	0.00	0.94	0.00	0.00	0.76	0.00	0.74	0.00	0.48	0.00	0.00	0.00	0.00

As shown in Table 5.3, in practice, water application was needed in the first ten-day period of May. However, according to the irrigation schedule based on the crop water requirement zoning, water application was planned in the third ten-day period of May i.e. the difference between actual and design dates of water application amounts to 20 days. Such a shift in the irrigation schedule results in mismatching of the water use plan and required irrigations. As a result, either reducing crop productivity takes place or modification of WUA’s water use plan and respectively planned water allocation along an irrigation canal as a whole are required.

Comparison of the irrigation schedule based on the crop water requirement zoning and actual irrigation schedule at the demonstration site is illustrated in Figure 5.15. The figure shows that according to the water use plan developed by the WUA, irrigation was not planned for the period since the end of April until the beginning of May, and in July water application rates exceed necessary ones five times; at the same time, irrigation water supply that does not match the real needs of crop in water under existing soil and hydrogeological conditions was planned.

[2] Soil formation without participation (upward recharging) of groundwater
[3] Soil formation with participation of groundwater (according to the classification of Soviet soil scientists)

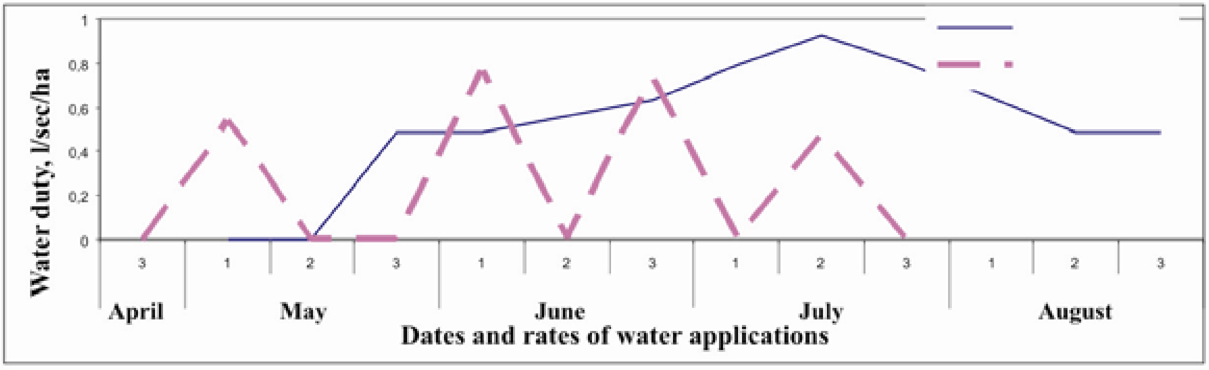

Figure 5.15 Comparison of the irrigation schedule based on the crop water requirement zoning and actual irrigation schedule at the demonstration site "Turdialy"

In Soghd Province, the actual number of water applications at the demonstration site was less than according to the irrigation schedule based on the crop water requirement zoning; and crop water requirements were also lower in comparison with design ones (Table 5.4 and Figure 5.16).

Table 5.4
Adjustment of the irrigation schedule for the private farm "Sayed"

Month	IV			V			VI			VII			VIII			IX
Ten-day period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1
Design irrigation schedule	0.13	0.51	0.13	0.0	0.29	0.61	0.7	0.8	0.91	0.99	1.1	1.3	1.03	0.82	0.72	0.36
Recom-mended irrigation schedule	0.0	0.0	0.0	0.0	0.0	0.63	0.0	0.99	0.0	1.07	0.0	1.41	0.66	0.79	0.69	0.91

In Osh Province, there are differences in timing, number of irrigations and water application rates for winter wheat (Table 5.5).

Table 5.5
Adjustment of the irrigation schedule for the private farm "Nursultan-Aly"

Month	Sep	Oct			Nov			Apr			May			June		
Ten-day period	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

Month	Sep	Oct			Nov			Apr			May			June		
Design irrigation schedule	0.93	0.0	0.0	0.33	0.33	0	0.0	0.46	0.5	0.41	0.37	0.45	0.45	0.32	0.32	0.1
Recom-mended irrigation schedule	0.0	0.0	0.0	0.28	0.85	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.59	0.0

Based on the results of comparative assessment, we have adjusted the irrigation schedule, taking into consideration specific soil and hydrogeological conditions on project demonstration fields (Table 5.6).

One of key components predetermining fair water allocation is clear information on actual crop water requirements, taking into consideration time-dependent hydrogeological, soil and climatic conditions. Therefore, in the frame of the IWRM-Fergana Project, the applicability of out-of-date norms and crop water requirement zoning that were approved more than 20 years ago have been analyzed for the whole territory within the SFC command area using the available data in Fergana Province. Analysis has shown that areas with GWT over the range of 1.5 to 2 m increased and, at the same time, areas with GWT over the range of 2 to 3 m decreased and areas with GWT ranging 0 to 1 m appeared; part of areas with a watertable depth more than 5 m has shifted to the range of areas with a watertable depth of 3 to 5 m. Increase in areas referring to Zones VII, VIII and IX (the crop water requirement zoning) practically in all districts is illustrated in Figure 5.16.

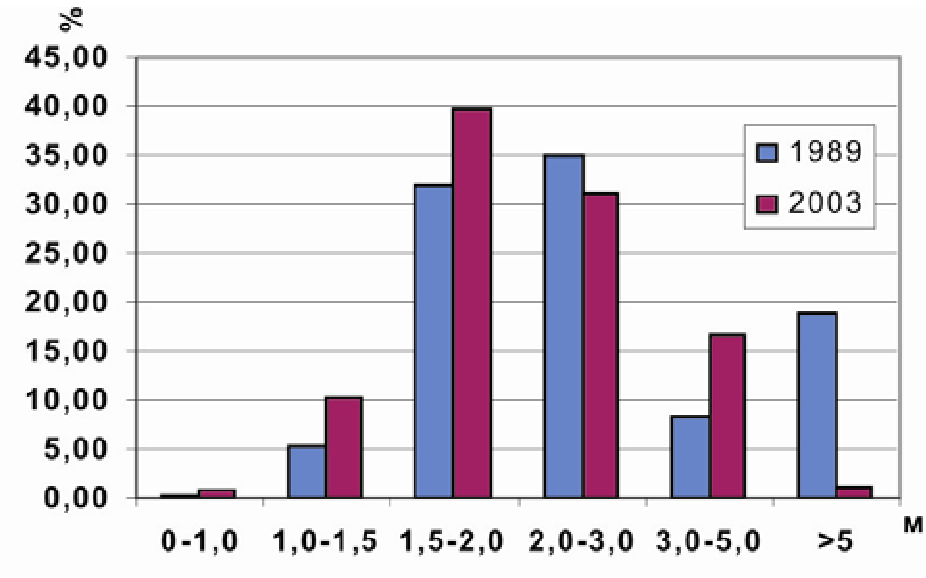

Figure 5.16 Changes in watertable depth, Fergana Province, Uzbekistan

Table 5.6

Adjusting the irrigation schedule at demonstration sites under the IWRM-Fergana

Demonstration site	Water duty zone	Soil characteristics	Irrigation season	Number irrigations	Water application rate, m^3/ha		Water requirement, m^3/ha		Ten-day water duty
					Net	Gross	Net	Gross	liter/sec * ha
Soghd Province									
WUA "Obi Zerafshan" (design zoning)	II	Automorphic (GWT > 3 m), medium thick layer, weak-stony loamy sand and sandy-loam soil	IV - IX	15	500-600	600-800	6566	8550	0.6-1.3
Demonstration site "Sayed"	II	Automorphic shallow stony sandy-loan underlain with pebble layer	IV - IX	7 - 8	500-600	600-800	4995	6166	0.6-1.4
Fergana Province									
Farm "Turdialy" (design zoning)	II	Automorphic (GWT > 3 m) medium thick layer, weak-stony loamy sand anc sandy-loam soil	IV-IX	9	500-600	600-800	5600	7500	0.5-0.9
Demonstration site "Turdialy"	VIII	Hydromorphic (GWT of 0.5-1.5 m) shallow stony sandy-loam underlain with pebble layer	IV-VIII	5	500-600	600-900	2976	3429	0.7-1.0
Osh Province									
WUA "Japalak" (design zoning)	4a	Automorphic (GWT > 3 m)	IX-XI IV-VI	2 4		600-800 600-1000		1400 3000	0.7-0.9 0.3-0.5
Demonstration site "Nursultan- Aly"	4a	Automorphic (GWT > 3 m) thick sandy-loam and loam soils, undulating relief	X-XI IV-VI	1 1 (2)	900 400	1200 500	900 400	1200 500 (1000)	1.4 0.5

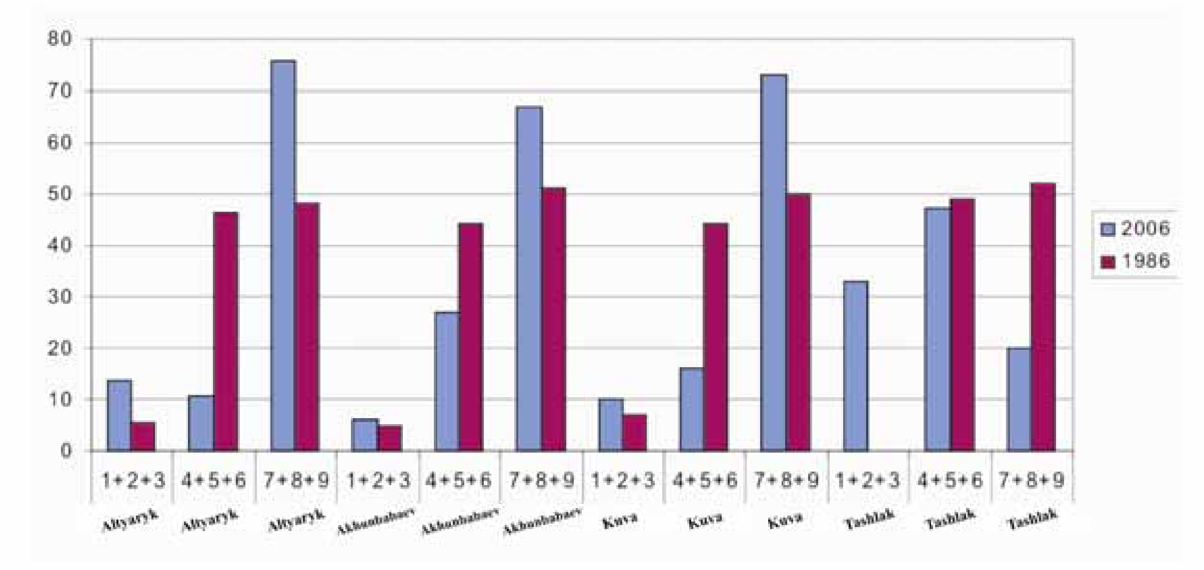

Figure 5.17 Changes in distribution of irrigated area per the crop water requirement zones in Fergana Valley

Estimating irrigation water demand for the SFC command area was performed separately for Fergana and Andijan regions, using the following data: areas adjusted to the modified crop water requirement zones; existing crop pattern and areas. The following calculation procedure was employed:

1. Specifying the areas in each modified crop water requirement zone, applying the GIS;
2. Areas under each crop were taken from the database;
3. Percentage of each crop from the total cropped area were calculated since maps of crop pattern are not available;
4. Areas under various crops in each modified crop water requirement zone were calculated proportionally these percentages;
5. Irrigation water demand was calculated as multiplication of an area under specific crop by its water requirement;
6. Crop water requirement is computed for the period since 1st April until 1st October; and
7. Crop water requirement were computed using the program GROPWAT that was calibrated for cotton, new varieties of winter wheat, maize and alfalfa. Water requirements for other crops were specified using the manual "Crop water requirement zoning and irrigation scheduling in Fergana Valley."

Net irrigation water requirement (without accounting the irrigation system efficiency) computed for the whole SFC command area encompassing all crop water requirement zones in Fergana and Andijan provinces amounts to 522 mln. m^3 (Fergana Province – 397 mln. m^3, and Andijan Province – 125 mln. m^3);

and gross irrigation water requirement – 695 mln. m^3 (Fergana Province – 529 mln. m^3, and Andijan Province – 166 mln. m^3).