15. WATER MANAGEMENT

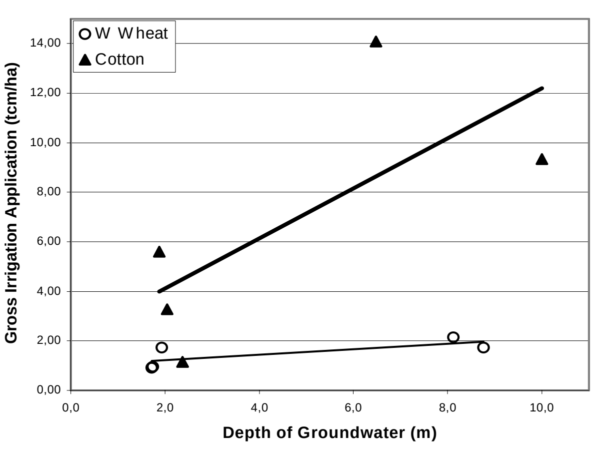
15.1 Irrigation Water Use

The variation in the use of water is considerable, both between farms and between the five republics, as described in Section 7.5. The annual water application to cotton varies from an average of over 14tcm/ha in Tadjikistan, where all is used for irrigation, to only 5.72tcm/ha in Kazakhstan, where only 1.14tcm/ha (20 percent) is used for irrigation. The overall average water application to cotton is about 7tcm/ha, approximately equal to the average evaporative demand of the crop, yet the efficiency of water application is not 100 percent.

The pattern is much the same with winter wheat, where the overall average rate of 4.67tcm/ha is not much more than the evaporative demand, but it ranges from over 7tcm/ha in Turkmenistan to less than 1tcm/ha in Kazakhstan. It seems likely that the heavy rate of use in Turkmenistan, Tadjikistan and Kyrgyzstan reflects both the plentiful supply of water for irrigation during spring and the need to leach salts in Turkmenistan.

With winter wheat, but particularly in cotton, this big difference is partly due to variation in the depth of the groundwater, as illustrated in Figure 15.1. The contribution of water by capillarity from the watertable into the rootzone is considerable (see below) and irrigators clearly take this factor into consideration. Additional factors are the greater supply of water for irrigation in the upper reaches of the rivers compared with scarcity in the lower reaches, and the steep slopes on coarse soils that characterise particularly the Tadjikistan farms.

Figure 15.1 Watertable Depth and Water Use



The need to leach the salts accumulated in the surface soil by upward mass flow in solution from the groundwater is the perceived reason for heavy use of leaching water on Uzbekistan, Turkmenistan and particularly Kazakhstan farms. In the farms of Kazakhstan, some 80 percent of all the water applied to cotton is used during the fallow season mainly for leaching. Taking into consideration that the average rooting depth of cotton is only about 0.7m, it follows that no more than about 1tcm/ha would be retained within the rootzone. The application of 4.58tcm/ha for leaching means that at least 3.5tcm/ha of water percolates below the rootzone. If the groundwater is close to the soil surface, this discharge of leaching water raises the watertable by about 1.7m. The lower terraces in Kazakhstan and Uzbekistan are flat and lateral drainage is slow, so the impact of this heavy leaching application is to raise the groundwater close to the surface and to maintain it there. This groundwater mostly is of high salinity hazard (see below) and the seasonal upward flow by capillarity is considerable, thereby creating the problem of surface soil salinity. The paradox is that the very process of heavy leaching, and particularly the cultivation of rice, sustains the salinity problem and the perceived need for leaching in poorly drained areas.

Although leaching water is applied mostly only once, crops are irrigated several times. The frequency of irrigating winter wheat on average is about the same as the frequency for cotton. Ideal irrigation schedules indicate the need for more frequent irrigation of cotton than of winter wheat, so that the schedules are approximately correct for winter wheat but the irrigation intervals for cotton are too long.

15.2 Groundwater Contribution to the Crop Root Zone

Soils with a peak of particle size distribution in the silt fraction, the typical soil of Central Asia, have the greatest upward flow of water from considerable depth. Section 7 showed that 74 percent of sample sites had a watertable closer than 3m to the surface during summer, and therefore capable of delivering a significant proportion of the irrigation requirements. Capillary rise of water from a watertable into the rootzone can wholly balance the evapotranspiration of water from the foliage making irrigation unnecessary. This is not to say that a high watertable should be regarded as a virtue, since its presence in most locations is the consequence of wastage of water. There are large economic costs involved with delivering the surplus water that causes the rise in groundwater, in providing drainage to stabilise the level, in leaching the salts that accumulate on the surface, in loss of crop yield from salinity and even in abandonment of land when the salinity becomes uncontrollable.

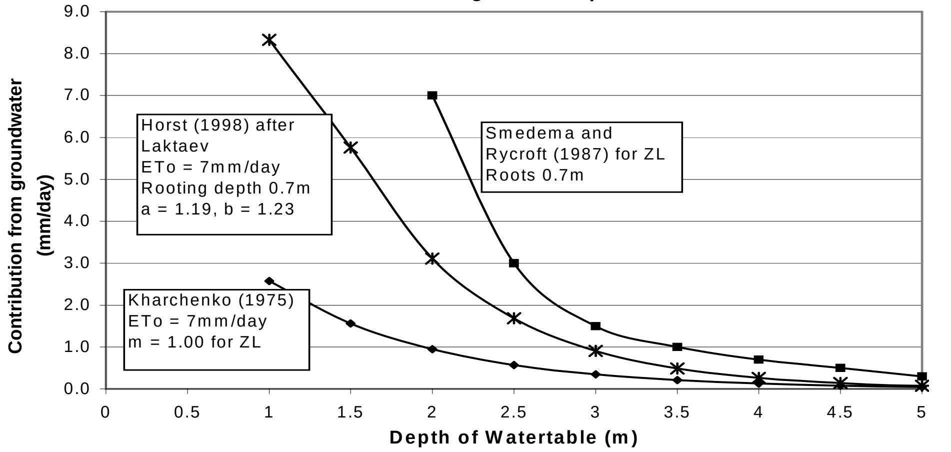
Local (ISS) and international computer models (CROPWAT, CRIWAR) for estimating ideal irrigation schedules fail to take account of the groundwater contribution. The reason may be the complexity of capillary rise, but models do exist, for example: SWACROP, Kharchenko (see Appendix 4), and graphical presentations in Land Drainage (Smedema and Rycroft, 1987) and in irrigation manuals (FAO Manual 24, CRIWAR). It is possible to estimate it separately and enter the groundwater contribution as notional rainfall in the scheduling models. Although inconvenient, it is the only solution at present.

Groundwater contribution to the crop root zone depends on groundwater depth, soil characteristics, evaporation from soil, crop evapotranspiration, and lateral drainage flow. Enumerators were asked to estimate daily contribution from the simplified table provided in their instructions (Appendix 1), but models that are more comprehensive demand the determination of more parameters. The model proposed by Kharchenko (1975) and its modifications by Laktaev and Horst (1998), are discussed in Appendix 4. The two local models are compared with data typical of international experience in Figure 15.2, using parameters for the local textural class “light loam” that approximates to the international class of “silty loam”.

There is serious disparity between Kharchenko’s data and international data, but Laktaev’s model, adjusted by Horst, generates values that are between the two. Nonetheless, the match is not good and the issues to be considered are as follows:

- The shortcoming of the international data quoted from Smedema and Rycroft (1987), is that the rate of evapotranspiration (ETc) at the time the measurements were made is not quoted. It may be assumed that as the data are discussed in the context of irrigation demand, ETc was at a moderate rate such as the 7mm/day used in this comparison. However, it is likely that as the rate of upward flow approaches the rate of evapotranspiration, the rate would fall and could not exceed the rate of ETc. It is clear from Kharchenko’s equation that groundwater contribution is very sensitive to the rate of ETc, for which Eo and ETo are adequate proxies for this purpose.

Figure 15.2 Relationship between Groundwater Depth and Contribution to Irrigation Requirement



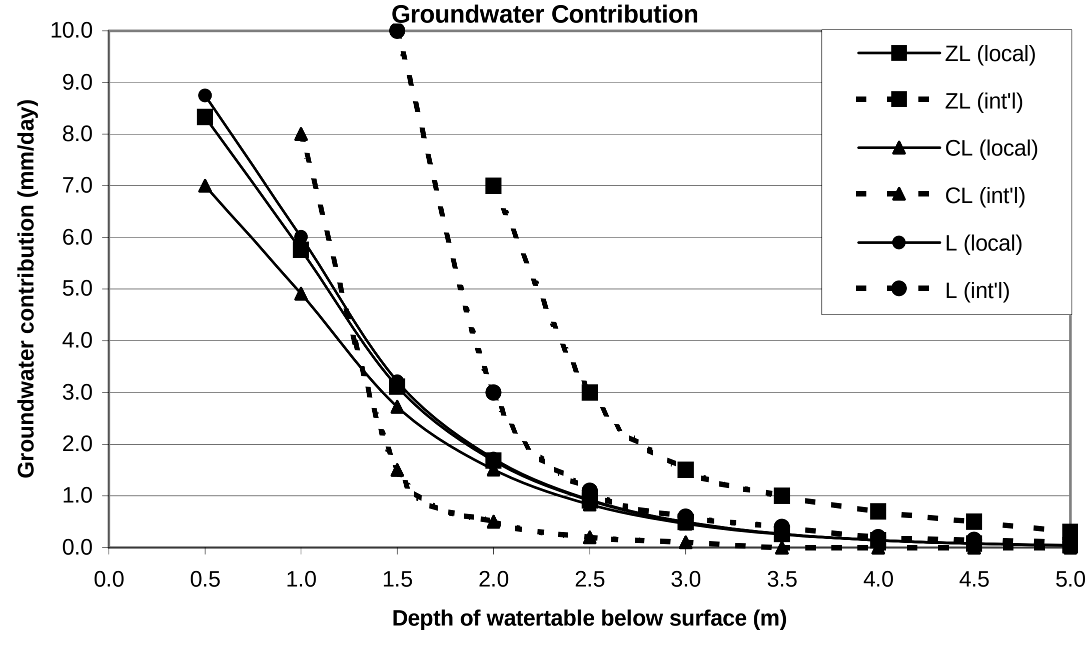
- Upward rate of flow is sensitive to proximity of the watertable to the roots because of the exponential nature of the basic relationship. Neither Kharchenko's nor Laktaev's model allows for variation in rooting depth, which is a clear oversight.

- The moisture characteristics of local soils are such that removal of 1mm from the watertable would cause it to fall by about 5mm were it not for replacement by lateral drainage. During a typical irrigation interval of 30 days, and at a potential rate of capillary flow of 7mm/day, the unrestricted fall in watertable would be more than 1m. However, a falling watertable after irrigation would markedly influence the rate of capillary flow due to the exponential relationship between capillary flow and watertable depth. Local models assume that the groundwater level is stable, and this assumption may be reasonable for much of the irrigated land of Central Asia. The rate of removal from the watertable beneath a crop may be small in relation to the potential rate of its replacement where lateral hydraulic conductivity is moderate to high. Neighbouring fields being irrigated with low application efficiency, and continuous leakage from field canals may provide adequate replenishment, and the current poor state of the drainage network would encourage the existence of stable watertables.

- Height and rate of flow of capillary rise are inversely related and are a function of soil pore diameter. Whereas in a fine textured soil the height of capillary rise may be more than 3m, the maximum daily rate is low and the daily contribution to evapotranspiration may be negligible. Conversely, if the watertable in a coarse textured soil is close to the roots, the capillary rise may completely satisfy the crop irrigation requirements. Therefore, a model to predict groundwater contribution should be sensitive to the classification of soil based on texture. As explained in Section 5, there are significant and largely irreconcilable differences between the local and international systems of soil textural classification. Effective cross-classification is possible only where particle size distribution data are available, and since local fractions are different, comparability may only be achieved by a tedious process of interpolation of the cumulative size distribution curve. Failure to correctly match soil textural classes may be contributing to the poor correlation between local and international models.

- Values of groundwater contribution generated by the improved local model are compared with internationally quoted data in Figure 15.3. The comparison is shown for three different soil textures, matched on the basis of greatest probability of similarity of texture. Not only do the models disagree in the form of the relationship, but also they reverse the relative order of magnitude of capillary flow in the three soil types. For a given watertable depth more than 1m, the greatest capillary flow rate is in silt loam by the international model but is in loam by the local model.

Figure 15.3 Comparison of Local and International Models for Groundwater Contribution



Both Kharchenko's original and Horst's modified model are used to estimate the average groundwater contribution during the months of June to September 1997. The averages of estimates for the fields in each republic are shown in Table 15.1.

Table 15.1 Groundwater Contribution Estimated by Local Models
(average data by republic)

Characteristic	Units	Kazakh-stan	Kyrgyz-stan	Tadjiki-stan	Turkmeni-stan	Uzbeki-stan	Overall
WT Depth H	cm	188	856	618	237	227	354
Reference crop ETo	mm/day	5.7	5.1	7.5	6.7	6.4	6.2
Root depth	cm	126	102	90	64	77	90
Parameter m		0.80	0.83	0.90	0.88	0.80	0.82
(1) Groundwater contribution $Ge=ETo/e^{m.H}$	mm/day	1.8	0.3	1.1	1.0	1.3	1.2
Parameter a		1.11	1.07	0.99	1.24	1.09	1.10
Parameter b		1.22	1.23	1.20	1.28	1.21	1.22
(2) Groundwater contribution $Ge=ETo.a/e^{b.[H-h]}$	mm/day	2.5	0.4	1.1	1.2	1.6	1.5

Note: (1) by equation A4.2 and (2) by equation A4.4 in Appendix 4.

For this WUFMAS Annual Report, Horst's improvement (2) to Laktaev's modifications of Kharchenko's equation (1), is to slightly increase the estimate of the daily groundwater contribution. This is due both to improved estimates of the values of the constant and exponent in the exponential model and to the introduction of a variable rooting depth with replacement of H by (H-h) in the model.

The average over all the farms of the groundwater contribution to crop water demand is estimated to be about 1.5mm daily through the period from June to September 1997. There is considerable variation from nil to more than 5mm/day between fields due to variation in watertable depth, soil texture, crop rooting depth and rate of evapotranspiration. The farm averages of estimates are given in Appendix 4. Farms 1 and 2 in Kyzl Orda have the highest daily rates of around 3mm, and farms 25 and 26 in Khorezm and farm 37 in Kanibadam are next with about 2mm. Three of the farms in Kyrgyzstan have no contribution from the groundwater, and the other farm, plus farm 14 in Tadjikistan and the two farms in S Kazakhstan have very little. At least half of the farms are likely to have sufficient capillary flow to make it necessary to account for this source of water in the irrigation schedules.

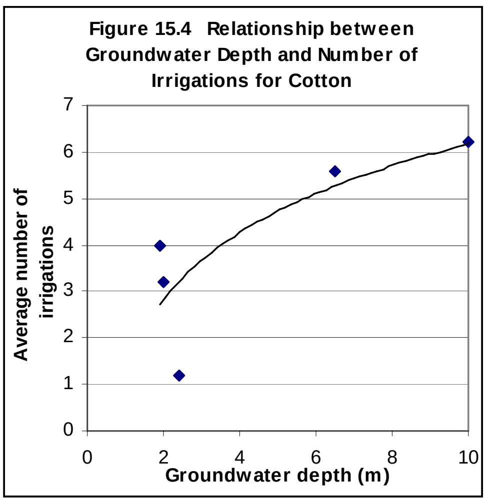
15.3 Efficiency of Water Use at Field Level

The characteristics of the average irrigation for cotton and wheat are given in Table 15.2.

Table 15.2 Irrigation Details for Cotton and Wheat and Application Efficiency

Characteristic	Units	Kazakh-stan	Kyrgyz-stan	Tadjiki-stan	Turkmeni-stan	Uzbeki-stan	Overall
From Cotton Sample Fields:							
Number of cotton sample fields	no.	13	13	10	9	52	97
No.of fields assessed by CROPWAT	no	2	2	1	2	8	15
Seasonal average watertable depth	m	2.3	10.0	5.0	1.9	2.0	3.6
No. of irrigations during growing season	no.	1	5	7	4	3	3.4
Total water applied in whole season	tcm/ha	1.1	9.7	13.8	5.0	3.4	4.8
Gross irrigation per application	tcm/ha	0.97	1.51	2.60	1.38	1.11	1.32
Potential ETc' during irrigation season	tcm/ha	5.64	5.37	8.62	8.63	7.36	7.20
Actual ETc'' during irrigation season	tcm/ha	4.12	5.12	4.86	7.13	5.67	5.71
Groundwater contribution May-mid Sep	tcm/ha	1.81	0	0	2.75	2.98	2.20
Effective Rainfall during season	tcm/ha	0.21	0.92	0.47	0.85	0.60	0.61
Water used from soil storage	tcm/ha	1.33	1.56	0.63	1.00	0.82	1.00
Net water requirement from ETc' after taking account of other water sources	tcm/ha	2.27	2.89	7.52	4.03	2.96	3.99
Application efficiency (Ea') from ETc'	%	206	30	54	81	88	55
Net water requirement from ETc'' after taking account of other water sources	tcm/ha	0.77	2.64	3.76	2.53	1.27	1.90
Application efficiency (Ea'') from ETc''	**%**	**70**	**27**	**27**	**51**	**38**	**39**
From Winter Wheat Sample Fields:							
Number of winter wheat sample fields		2	8	6	8	24	48
Average ground water table depth during growing season	m	1.7	8.1	8.8	1.9	1.7	3.7
Number of irrigations	no.	1.0	2.6	4.1	4.6	3.9	3.7
Gross irrigation per application	tcm/ha	0.96	2.15	1.74	1.74	0.91	1.36

There is a striking difference between republics in the average number of irrigations. For cotton only, but not for wheat, there is evidence that the depth of the groundwater influenced the irrigation interval (and hence the amount of water applied – see Section 15.1), as shown in Figure 15.4.



On most of the sample fields in Kazakhstan and Uzbekistan, the groundwater was sufficiently high to justify longer intervals during the peak of water demand. Conversely, the deep groundwater and availability of surface water in Kyrgyzstan, and the coarse soils in Tadjikistan, produced irrigation schedules much closer to the ideals generated by CROPWAT, that take no account of groundwater contribution.

For winter wheat, the pattern was less clear. Wheat on Kazakhstan farms followed rice and was irrigated only once. As the watertable was high from surrounding rice fields, there was no need for water for land preparation or leaching. In contrast, the need for water application for tillage and leaching increased the frequency of irrigation to more than 4 times in Turkmenistan and nearly 4 times in Uzbekistan, more than for cotton.

The net irrigation requirement of cotton, the effective rainfall and the rootzone storage contribution of water were calculated for typical fields in each farm by CROPWAT (FAO, 1997) and the contribution from the watertable by Horst's modification of Kharchenko's model. The weighted average estimate of potential ETc for cotton was 7.20tcm/ha overall but there was considerable variation between republic averages, from 5.37tcm/ha in Kyrgyzstan to 8.62tcm/ha in Turkmenistan and Tadjikistan. However, this estimate of potential ETc' is inappropriate where irrigators fail to irrigate on the scheduled date. By extending the irrigation interval and therefore irrigating fewer times during the season than the estimated ideal regime, the actual ETc'' becomes significantly less than the potential ETc. The total water applied is also reduced, while the effect of moisture stress on the crop is to reduce crop yield.

The measure of field application efficiency of irrigation that is generally used is:

Ea = Net irrigation demand of crop (ETc) / Gross application for irrigation x 100%

By using ETc' rather than ETc'', and by reducing the total water applied in this way, the efficiency of application estimated as above becomes inflated. This explains the estimate of efficiency greater than 100 percent in Kazakhstan and inflated values in other republics.

Over all cotton sample fields, groundwater supplied 54 percent of the actual ETc'' demand, taking into account utilisation of water from the storage in the rootzone and effective rainfall. After taking account of this contribution, the adjusted net irrigation requirement was 3.99tcm/ha overall, varying from 2.27tcm/ha in Kazakhstan to 7.52tcm/ha in Tadjikistan. This provides a better estimate of seasonal application efficiency, as shown in Table 15.2. The overall average Ea'' was 39 percent, or 61 percent of water applied in the field was wasted. There is considerable variation between farms and this reflects in big differences in the average estimates of Ea'' for the republics, which range from 70 percent in Kazakhstan to 27 percent in Kyrgyzstan and Tadjikistan.

A more meaningful estimate of application efficiency is based on the estimate of ETc prior to each irrigation. If the crop is not irrigated on the scheduled day and becomes stressed by moisture deficit, the stomata close and the rate of evapotranspiration falls. The modified estimate of ETc, adjusted for the groundwater contribution and effective rainfall, is expressed as percentage of the water applied when the crop is finally irrigated. This calculation can only be based on irrigation schedules in individual fields, and is the material for a more detailed study than is possible in this report.

In practice, low application efficiency results from water lost both by excessive deep percolation beyond the rootzone and by tail-escape from the end of the furrow. In fields with medium to low infiltration rates, water is unable to infiltrate into the soil during relatively short periods of irrigation leading to heavy tail-escape losses. However, low application efficiency is often attributed to excessive furrow length for the furrow gradients and infiltration rates encountered.

15.4 Gradients and Infiltration Rate in Sample Fields

The local methodology for maximising the efficiency of use of water in surface irrigation depends on the slope of the furrow and the infiltration class of the soil. The basis for characterisation of irrigation surfaces in the Central Asia was developed by Laktaev (1987) as described in Appendix 4. Classification of the 220 sample fields according to this system is shown in Table 15.3.

Table 15.3 Slope and Infiltration Classes of Sample Fields
(percentage of 220 fields)

Infiltration class		High	Med high	Medium	Med low	Low	Overall
Basic infiltration rate (mm/h)		>17mm/h	11.6-12.8	6.4-10.5	3.4-6.0	1.3-3.0	
Slope class	Slope %	S	SL	L, ZL, SCL	CL, ZCL, SC	C, ZC	
Very steep	>2.50	2.3	0.5	5.5	3.2	0.5	11.8
Steep	0.75 – 2.50	2.7	0	3.6	1.8	1.8	10.0
Medium	0.25 – 0.75	2.3	0.5	3.6	0.9	0.5	7.7
Shallow	0.10 – 0.25	0.5	2.3	19.1	8.2	0.5	29.1
V shallow, flat	<0.10	0	0	26.4	8.6	6.4	41.4
Overall		7.7	1.8	58.2	22.7	9.5	100

Most combinations of slope and infiltration rate were represented by WUFMAS sample fields but the largest group, 46 percent, are the silt loam, loam and sandy clay loam soils (international classification) with shallow and very shallow slopes. The majority of fields had medium and medium-low infiltration rates, between 3.4 and 10.5mm/h, and the majority of fields have shallow slopes less than 0.25 percent (0.0025).

The common belief, that excessive furrow length is the reason for water losses, was not confirmed in most cases. In 108 fields out of 122 irrigated by furrow (89 percent) the actual length of furrows was equal to or less than the recommended maximum according to Laktaev's method. The exceptions were the fields with highly permeable soils where the length of furrows was considerably longer than recommended on all gradients (14 fields out of 122, or 11 percent).

The conclusion, on the basis of these data and the local methodology, is that the irrigation design generally is appropriate to the actual field gradients and infiltration rates. Therefore, incorrect irrigation duration and furrow flow rates are the reasons for low efficiency of irrigation water use.

15.5 Water Losses

Only water loss occurring in the sample fields is measured by the WUFMAS survey, but information about "normative" conveyancing losses, actual water deliveries and use by the farm is obtained annually and monthly from the sample farm's administration. Water losses occurring at various points on the sample farms estimated from these data are given in Appendix 4.

Distribution of water in mostly unlined canals, and the application of water to crops down furrows, cannot be achieved without some losses. "Unavoidable" losses are well documented in local design methodologies and on the assumption that these estimates are reasonable, any additional losses, by implication, could be reduced by improved management. The overall average of these "avoidable" losses is about 4.4tcm/ha or 36 percent of all the water delivered to the farm boundary. However, there is wide variation in the estimates between individual farms, from 4-7 percent on farms in Karakalpakistan to 50-58 percent on farms in Syrdariya. The reason for the apparently better water management on the farms in Karakalpakistan is an artefact caused by shortage of water in the supply canals and of much smaller than average delivery of water to these farms. Farm 27 received only 2.8tcm/ha, insufficient for the cropping pattern including about 60 percent cotton. Farm 28 received only 6.8tcm/ha, insufficient for 60 percent rice in the cropping pattern. Farms 23 and 24 also received less than average water but located on the new lands, they have high design criteria, which is the reason why poor water management resulted in high “avoidable” losses.

The conveyancing loss in the main canal system was estimated to be about 15 percent on average (WARMAP 1). The quantity of water abstracted at the headwater intake of the supply canal is estimated from the quantity of water delivered to the farm boundary, measured daily by farm and RAYVODKHOZ staff. The quantity of water delivered to the boundary of the sample fields is measured by the enumerators and the consumptive demand of the crop is estimated by CROPWAT (FAO, 1997) and takes into account the groundwater contribution and leaching requirements. These values permit the estimation of the field application loss and the loss between the farm and the field boundary. Based on the design criteria for the farm canal system, the latter may then be divided approximately into conveyancing loss and canal management loss. Average estimates of the losses by republic, and losses as percent of the headwater intake, are shown in Table 15.4. This table also shows the amount and proportion of water available for irrigation at each stage of the distribution system.

Table 15.4 Average Water Losses in the Irrigation System
tcm/ha (percent of headwater intake)

Stage and nature of water loss	Kazkh-stan		Kyrgyz-stan		Tadjiki-stan		Turkmeni-stan		Uzbeki-stan		Overall	
	Av loss	Avail water	Av loss	Avail water	Av loss	Avail water	Av loss	Avail water	Av loss	Avail water	Av loss	Avail water
Headwater intake	-	20.2 (100)	-	11.2 (100)	-	21.0 (100)	-	8.8 (100)	-	12.9 (100)	-	14.3 (100)
Conveyancing loss from river to farm boundary	3.0 (15)	-	1.7 (15)	-	3.1 (15)	-	1.3 (15)	-	1.9 (15)	-	2.1 (15)	-
Water supply at farm boundary	-	17.2 (85)	-	9.5 (85)	-	17.8 (85)	-	7.5 (85)	-	10.9 (85)	-	12.1 (85)
Conveyancing loss from farm to field boundary	4.9 (24)	-	2.4 (21)	-	3.1 (25)	-	2.4 (27)	-	2.5 (19)	-	3.1 (22)	-
Management losses from farm to field boundary	5.4 (27)	-	1.7 (16)	-	1.0 (5)	-	1.1 (13)	-	3.8 (29)	-	3.2 (23)	-
Water supply at field boundary	-	6.9 (34)	-	5.4 (48)	-	11.6 (55)	-	4.0 (45)	-	4.7 (36)	-	5.8 (41)
Field application losses	-	2.9 (14)	-	3.6 (32)	-	7.7 (37)	-	1.7 (19)	-	2.0 (16)	-	2.9 (21)
Water retained by rootzone	4.0 (20)	-	1.8 (16)	-	3.9 (19)	-	2.3 (26)	-	2.7 (21)	-	2.8 (20)	-

These estimates are based on data from the few sample farms in the WUFMAS programme but the overall average estimate of headwater abstraction of 14.3tcm/ha corresponds with the overall average recorded by the BVO. Average rates are much greater on the Kazakhstan and Tadjikistan farms, the former because of the heavy use in rice production and the latter to permit the irrigation of coarse soils on steep slopes. The Turkmenistan farms had less than average water supply, which may reflect a shortage of supply to these farms, which are not supplied from the Karakum canal.

On-farm conveyancing losses also are greater on average on the farms in Kazakhstan and Tadjikistan, but as a proportion of the headworks abstraction, there is little difference between republics. The estimates of “avoidable” losses, caused by poor management and maintenance of canals, vary markedly between the averages of sample farms in the five republics, from 27 percent of headworks abstraction in Kazakhstan to only 5 percent in Tadjikistan. The latter may reflect the scarcity of water in the Big Ferghana canal and the need of the farms to pump water up from the Kairakkum reservoir and from groundwater for irrigation. These differences are reflected in considerable variation in the water available at the field boundaries, from 11.6tcm/ha in Tadjikistan to only 4.0tcm/ha in Turkmenistan.

The estimated field application losses are least on the Uzbekistan and Turkmenistan farms at less than 2tcm/ha, but are most on the Tadjikistan farms at 7.7tcm/ha, due to the impossibility of irrigating the steep slopes and coarse soils efficiently. The retention of irrigation water in the rootzone depends on several factors: the soil texture and the cropping pattern, which reflects in variation in rooting depth and frequency of irrigation. Estimates varied from 1.8tcm/ha in Kyrgyzstan to 4tcm/ha in Kazakhstan. As a proportion of water abstracted at headworks, the water available to the crop was fairly consistent between republics, averaging about 20 percent overall.

This overall poor efficiency of water use should be a matter of grave concern to the Governments of the Central Asian Republics. The main reasons for such losses are:

- lack of co-ordination between the operational schedules of the main canals and readiness of irrigators to irrigate fields;
- discharge capacity of irrigation system; and mainly
- lack of real incentives for irrigators to save water.

Most water users desire to irrigate at the same time, without taking into consideration the capacity of the canal system and the soil moisture characteristics. Due to poor canal management within the farm, water users often receive water for a relatively short period, and more than can be absorbed by the rootzone during that time. This is the most typical situation in lands located in the middle and lower reaches of the rivers, and where slopes are steep and infiltration rate is low. Water users on farms with highly permeable soils and steep slopes, and especially those with big variation in altitudes, give priority to irrigating the upper fields in order to reuse the drainage water to supplement irrigation of lower lands. Part of the water lost is reused afterward as groundwater contribution to the root zone, but dependency on this cannot be justified because of its impact on secondary salinity.

In practice, there is no clear strategy for water management at farm level. There are periods when irrigation water goes directly to a tail escape and the drainage system, while during peak demand there is insufficient water to concurrently irrigate the fields that require to be irrigated. Therefore, the problem of water shortage is aggravated by poor water management. Reduction of operational water losses from on farm irrigation systems of 1 – 2 percent, and increase of irrigation application efficiency to 70 percent would allow crops an additional 2.7tcm/ha of acceptable quality irrigation water and improve land quality.

15.6 Productivity of Irrigation Water for Cotton and Wheat

The indices of productivity of irrigation water alternatively are:

- the quantity of irrigation water consumed per unit of crop production (tcm/t), or
- the amount of harvested crop yield per unit of water applied (t/tcm).

These weighted average indices, calculated from sample field data for the main crops of the region, are shown by republic in Table 15.5.

The seasonal total water supplied to the field includes pre-irrigation, which very often also is for leaching. The weighted average total irrigation application rate for cotton was 7.24 tcm/ha, including 2.04tcm/ha for leaching and pre-irrigation. The weighted average cotton yield recorded at field level was 2.33 t/ha. The overall productivity of water for cotton was therefore 0.39t of raw cotton per tcm of water applied. The corresponding value for winter wheat was 0.79t/tcm of water applied, double that for cotton. Based on the application of water for irrigation only, the productivity of cotton is much greater, at 0.96t/tcm. These estimates take no account of the economic worth of the product, as discussed in Section 12.

Table 15.5 Productivity of Irrigation Water for Cotton and Winter Wheat

Characteristic	Units	Kazakh-stan	Kyrgyz-stan	Tadjiki-stan	Turkmeni-stan	Uzbeki-stan	Overall
From Cotton Sample Fields:							
Yield from field	t/ha	2.56	2.43	1.74	2.75	2.41	2.40
Yield from sample plots	t/ha	2.52	2.51	1.69	3.32	2.68	2.60
Productivity of total water applied in year	tcm/t	2.28	3.86	8.45	2.68	2.30	3.18
Productivity of total water applied in year	t/tcm	0.45	0.26	0.13	0.40	0.46	0.39
Productivity of water for irrigation only	tcm/t	0.46	3.86	8.45	2.04	1.38	2.38
Productivity of water for irrigation only	t/tcm	2.33	0.26	0.13	0.51	1.02	0.96
From Winter Wheat Fields:							
Yield from sample field	t/ha	1.43	3.17	2.13	1.72	2.62	2.45
Yield from sample plots	t/ha	1.78	3.40	1.93	2.38	3.03	2.79
Productivity of all water applied	tcm/t	1.57	1.62	3.32	4.66	1.60	2.33
Productivity of all water applied	t/tcm	1.53	0.70	0.30	0.23	1.08	0.79

There are two reasons for the apparently greater productivity of water on wheat than cotton. Firstly, the wheat plant is everywhere more effective in accumulating energy as dry matter as starch than the cotton plant is in fibre and seed, for a given amount of water consumed. The second reason is that winter wheat receives a significant proportion of its seasonal water demand as rainfall, which is not taken into account in this index.

These productivity indices of water are not very much less than in comparable locations worldwide, but the reason is that these crops in Central Asia depend heavily on the contribution of water from the watertable. With irrigation application efficiency very low in Central Asia, more irrigation would be required to produce current yields were it not for the very significant groundwater contribution. Higher application rate would reduce the productivity index well below international norms. It has been observed repeatedly in this report, that this is not a justification for the high watertables sustained by wastage of irrigation water, on account of the considerable economic costs of water, drainage and secondary salinity.

The productivity of water is greatest in Kazakhstan and Uzbekistan and least in Kyrgyzstan and Tadjikistan. The reasons again are mainly the impact of the groundwater contribution in reducing the irrigation requirement. The additional factor in Tadjikistan is the impossibility of furrow-irrigating cotton efficiently on the steep slopes with coarse soils.

15.7 Irrigation Water Quality

The origin of most irrigation water is snowmelt and as such the water should be ideal for irrigation. Considerable contamination of the rivers and canals by drainage returns takes place in the middle reaches and this reflects in the analyses. In some places, shortfall in the supply of water leads to the pumping of drainage and groundwater for irrigation.

Salinity affects a crop through osmosis at the root surface that results in the crop having trouble in absorbing sufficient water. Salinity hazard in irrigation water traditionally in Central Asia has been measured by the total concentration of dissolved solids (TDS in g/l). There is further characterisation in terms of the chloride concentration, and the ratio of chloride to sulphate. A similar system has been used elsewhere, except that the total concentration of soluble salts (TSS) replaces TDS, on the assumption that TDS may be inflated by organic solutes and colloidal clay. The appeal of this system is that it requires a minimum of equipment; a container, a filter, an oven and a balance. The fundamental drawback of the TDS/TSS system is that the relationship between osmotic pressure of a solution and its TDS depends on the chemical composition of the solution. For monovalent salts like sodium chloride, the relationship is almost linear over the range encountered in the field, but the osmotic pressure of the main contributor to TDS, calcium sulphate, is almost zero.

For this reason, TDS and TSS are fundamentally **not** suited for use in Central Asia, where the sulphates of calcium and magnesium are the predominant salts in most irrigation waters (see Section 7). The osmotic pressure of a solution is difficult to measure directly, and although it can be calculated from detailed analysis of the constituent ions, this is also a lengthy laboratory process. Electrical conductivity is most commonly used internationally as the most effective approximation to osmotic pressure, as it is easy to measure in the field using a portable conductivity bridge. The relationship between EC_w and concentration of the salts, and hence their osmotic pressure, is linear over the likely range. Unfortunately, the linear coefficient (slope) depends on the salt, and whereas saturated calcium sulphate has maximum EC_w of 2.2, other salts found in irrigation water have much higher values. Although for these reasons ECw is not a perfect measure of osmotic pressure and salinity hazard, it is more meaningful and more convenient than TDS.

A second point needs clarification. If present, sodium, chloride and bicarbonate ions will contribute to the EC_w, and if concentrations are high, they will be the cause of salinity hazard. However, these ions have a completely independent effect on the crop, and may do so at concentrations lower than those that would cause salinity. These effects are concerned with the biochemistry of ionic absorption and metabolism in the plant, loosely termed “toxicity”, and physical characteristics of the soil. International criteria establish specific limits of concentration of these ions as shown in Section 7, Table 7.6.

The relationship between average total dissolved salts (TDS) and electrical conductivity (EC_w) in irrigation water samples from the 36 WUFMAS farms is shown in Figure 15.5. The linear trendline has an R-squared value of 62 percent, significant at P=0.001 percent. Were the irrigation water to be dominated by a single salt then a clear linear relationship, with a higher R-squared value, would be expected. The scatter of points is likely to be caused by a combination of variable salt composition and sampling errors.

Figure 15.5 Total Dissolved Salts and Conductivity of Irrigation Water

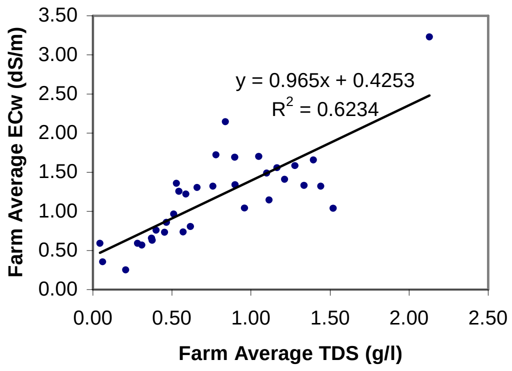


Figure 15.6 Conductivity of Irrigation Water and Altitude

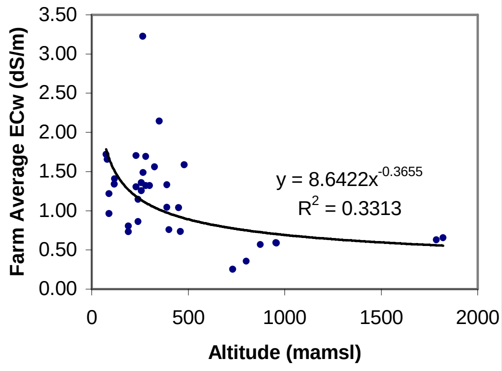


Figure 15.6 shows the plot of farm average salinity of irrigation water, against the altitude of the farm. The R-squared value of the fitted power curve at 33 percent is not high, yet is highly significant (P=0.001 percent). Nonetheless, there is a wide scatter of points, which makes this simple relationship not very useful. Apart from the inevitable sampling errors, it is likely that the impact of drainage returns and the variable hydrogeology of the tributary rivers are responsible.

Using both TDS and chloride as local salinity criteria, the typical irrigation water presents a moderate salinity hazard in all republics excepting Kyrgyzstan. However, on the bases of international salinity criteria, electrical conductivity (EC_w), chloride concentration and sodium absorption ratio (SAR), the situation overall is less serious. By far the best water quality is in Kyrgyzstan, the upper reaches of the Syrdariya River, where the average values of EC_w are 0.54-0.59dS/m. The situation is somewhat worse on the farms in Kazakhstan than in Uzbekistan and Turkmenistan, particularly in 1997.

Data from farm 21, Surkhandariya oblast, Uzbekistan, is shown in Table 15.6 to illustrate the relationship between irrigation water salinity and soil salinity, where water from different sources was used for irrigation. Snowfall during the winter of 1995/96 was abnormally slight, there was shortage in the irrigation canals during the 1996 season, and fields 9 and 10 were irrigated using drainage water. The seasonal average EC_w of the drainage water used for irrigation was almost 2dS/m and in consequence, by May 1997 the soil salinity had increased by 115 and 214 percent respectively since the previous May. During the same period, fields 4 to 7 received only irrigation water from the main canal, with EC_w of about 0.7dS/m, and in two fields there was slight increase and in two fields slight decrease in salinity. This example confirms the importance of the quality of irrigation water.

Table 15.6 Salinity of Irrigation Water and Soil at Farm No.21

Characteristic	Unit	Date	Field number									
			01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Soil salinity ECe	dS/m	1996	0.4	0.4	0.5	0.6	0.6	0.6	1.7	1.0	1.3	1.0
		1997, May	0.6	2.5	1.3	0.8	0.9	0.6	1.1	3.0	2.8	3.2
Salinity change	%	From 96 to 97	38	553	163	43	45	-6	-35	196	115	214
Irrigation water, EC_w	dS/m	1996 season	1.2	1.1	1.2	0.7	0.8	0.7	0.7	0.7	1.9	1.9

Calcium and magnesium are the predominant cations in all republics except Tadjikistan. The majority of irrigation water samples had less than 10me/l but concentrations were slightly more in Kazakhstan than in Uzbekistan. Potassium concentration is very low throughout, no samples having more than 2me/l. The farms in Leninabad (14 and 37) are served by the tail end of the Big Ferghana Canal, and shortage of water requires the use of supplementary water pumped up from the Kairakkum reservoir and groundwater from the tubewell drains. From one or other of these sources, the water is contaminated with sodium, which gives the water a serious sodicity hazard in about a third of samples. About 10 percent of samples from Uzbekistan farms in 1996 were seriously sodic and 29 percent were moderately so. This result was not apparent in the data from 1997 samples and may indicate greater use of groundwater for irrigation in the very dry season of 1996.

Almost everywhere, sulphate is the dominant anion, indicating that calcium and magnesium sulphates are the main salts in solution. A significant proportion of samples with more than 10me/l of these salts only occurred in Tadjikistan and Uzbekistan in the dry season of 1996 did, but this anion is more beneficial than hazardous. Chloride levels are slightly higher in parts of Uzbekistan but mostly are not hazardous. Using the international threshold of 10me/l, for high chloride hazard in surface irrigation water, only 2 percent of samples in 1996 were above this level and 3 percent in 1997. Fewer samples were measured in 1997 and as these tended to be the more saline locations, hazardous levels of chloride were a higher proportion, about 10 percent in Uzbekistan and Kazakhstan. Chloride levels in the irrigation water in most cases were highest during the spring.

All water samples are alkaline but the bicarbonate concentrations, up to 3.6 me/l in Kazakhstan and 4.0me/l in Uzbekistan, are not high. Two thirds of samples from Kazakhstan showed moderate hazard for sensitive crops in 1996, but measurements in 1997 and elsewhere in both years were mostly in the low hazard class. The impact on soil alkalinity is discussed in Section 5.

15.8 Drainage and Groundwater

The majority of samples of drainage and groundwater from Uzbekistan and Kazakhstan farms were seriously saline, presenting a major hazard to soil and crops if used for irrigation. The proportions in Turkmenistan and Tadjikistan are smaller but nonetheless significant.

Sodium presents a significant hazard in the samples from all republics except Kyrgyzstan, and there are some particularly high values from the Turkmenistan farms. Sulphate is the predominant anion indicating that the main salt being dissolved by the ground and drainage water is sodium sulphate. Soils are mostly rich in gypsum but only further study could establish if the sodium originated by concentration of salts in irrigation water by evapotranspiration or it was mobilised from marine residues by rising watertables. Chloride is not a major contributor to salinity on most farms except for some very high levels, together with sodium, on the Turkmenistan farms where clearly sodium chloride is present in soils.

High levels of sulphates of the divalent cations mitigate the effect of high levels of sodium and the SAR values are not hazardous.