WARMAP-2

Water Resources Management and Agricultural
Production in the Central Asian Republics

EC-IFAS

Executive Committee
Interstate Fund for the Aral Sea

WUFMAS

Water Use and Farm Management Survey

RECOMMENDATIONS
FOR
IMPROVING WATER MANAGEMENT
IN
DEMONSTRATION FIELDS
IN
SUMMER 1999

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SUMMARY and CONCLUSIONS

1. In April 1999 on nine representative Central Asian farms, the WUFMAS team embarked on a programme to demonstrate how to improve the in-field productivity of water on a selected field. This field is monitored together with a comparable control field that has no intervention by field staff. It is claimed that sustainable improvement will only derive from increasing crop yield at the same time as reducing water consumption; in the current socio-economic environment, attempts to improve water use efficiency alone will not be successful.

2. During a seminar for field staff in late-March, the approach was explained, tasks were assigned and initial sets of water management criteria were given to participants. Since then, some fields have been changed, selected fields surveyed, samples analysed and estimates made of infiltration parameters. Eight pairs of fields have been planted to cotton and one to rice. This paper reviews the methodology of water management and relevant data, and describes observations made during site visits to all farms by the RWG and the consultant. It presents the new output from the water management program (PUMA), and outlines the second set of recommendations made to the field staff.

3. The furrows in all the demonstration fields were either both too uneven and long (the majority), or just too long to be irrigated efficiently. With the exception of one field, the WUFMAS programme started too late for the necessary regrading of fields to be done. The only expedient was to subdivide most furrows by temporary field canals, thereby improving uniformity of slope and shortening the furrows. Mostly this advice has been followed except in S Kazakhstan, where the first irrigation has not yet been made due to shortage of water offset by recent rain.

4. At this stage, the only variables under the control of the irrigator are **time** per furrow from start to cut-off, and furrow **flow rate**. Between the demonstration fields, there is a wide range in combinations of time and rate from 4.3 hours at 2.19 l/s, to 23.3 hours at 0.10 l/s, but some fields show unexpected combinations between these extremes. These variables have an inverse relationship, but such is the complexity of the solution to the Manning equation that it is impossible to generalise it.

5. As the season advances, the crop roots penetrate deeper resulting in a steady increase in the net amount of water that needs to be applied during irrigation. Duration of irrigation increases directly with the net irrigation requirement while the flow rate remains constant. Flow rate is most directly a function of furrow length and cross-sectional profile, infiltration rate and resistance to water flow.

6. The optimal furrow flow rate is limited in many cases by the velocity of the flow causing erosion. The typical soil of Central Asia is rich in silt and poor in clay. The USBR clay fraction is rarely more than 20 percent (in contrast to Kachinsky's "physical clay" that also includes most of the particles included with silt in the USBR classification) and such soils have weak wet strength and are highly erodable. This is a serious constraint on achieving improvement of application efficiency in 4 out of 8 fields.

7. PUMA is an optimisation program, changing the combination of time and rate for the field's input parameters by iteration, stopping when the highest value of application efficiency, E_a, has been reached. E_a is defined as the ratio between net irrigation requirement and actual application. The prognosis from results of PUMA applied to data for the demonstration fields is disappointing, with only one field on the Tadjikistan farm likely to exceed an E_a of 60 percent. The average maximum E_a of eight fields when applying 60mm net is only 40 percent, hardly much improvement on previous performance.

8. The field in the Surkhandariya farm is unirrigable due to the combination of moderate gradient and slow infiltration rate. The only expedient is to slow the velocity of furrow flow, and it is suggested to do this by laying reeds in the furrows, cut from surrounding drains. The steeply sloping field in the Osh farm also is unirrigable without serious soil erosion because the crop has been planted directly down the slope. Irrigation before the field visit had eroded all the surface fine earth from the furrows exposing stones and gravel. If the furrows are not recultivated, erosion is self-limiting, as the stones will slow the velocity of flow.

9. Deep percolation loss from the rice basin is about 11mm/day representing about 18 thousand cubic metres (tcm) in a season, while the net irrigation requirement is about 6tcm/ha. If water consumption by rice is to be limited to 24tcm/ha, overflow from the basin directly into the drain collector, must be severely restricted.

10. It will be difficult for field staff to follow these recommendations. Although staff have watches to time the duration of irrigation of each furrow, there will be a serious conflict with the convenience of the irrigators. They are accustomed to opening and closing furrows in early morning to keep out of the midday sun and conduct their other business. Most prescribed durations are shorter than 24 hours and shorter also than a morning to evening irrigation, so strict supervision by WUFMAS staff will be necessary.

11. The weirs provided for measuring furrow flow will not work in the nearly horizontal fields. The only effective expedient then is to measure flow rate in the temporary field canal by Cipoletti weir and divide it by the prescribed furrow flow rate to indicate the number of furrows to be simultaneously irrigated. This should be done in all fields whether or not the Thomson weirs are in use.

12. The output of PUMA and these recommendations are only as good as the input parameters. The Manning equation is sensitive to the Kostiakov-Lewis intake parameters and so far these have not been measured with much accuracy. Assumptions have been made about the furrow shape parameters and the Manning resistance coefficients in running PUMA. Routine measurement of furrow flow characteristics has been instructed and later analysis of these data may lead to some modification of the PUMA output and a third set of recommendations.

LIST OF CONTENTS

1 INTRODUCTION 5
2 METHODOLOGY explained 6
  2.1 Land Survey 6
  2.2 Soil Survey, Sampling and Analysis 8
  2.3 Infiltration Tests and Furrow Shape 10
  2.4 Climate data 11
  2.5 Irrigation Scheduling, Net Irrigation Requirement and Rooting Depth 12
  2.6 Limitation of Tensiometers 13
  2.7 PUMA – the MIROB Water Management Program 14
3 RECOMMENDATIONS FOR IMPROVED WATER MANAGEMENT 15
  3.1 Gradient and Length of Furrows 15
  3.2 Duration and Furrow Flow Rate 15
  3.3 Furrow erosion 16
  3.4 In-field Water Application Efficiency 16
  3.5 Water Management in Rice 17
  3.6 How do Field Staff implement these Recommendations? 17
  3.7 Limitations of these Recommendations 17

LIST OF TABLES

Table	Title	Page
1	Location and Elevation of Sample Farms ………	6
2	Furrow Gradients in Demonstration Fields ………	8
3	Soil and Water Analyses in Demonstration Fields from 1997 ………	9
4	Soil Analyses in Demonstration Fields from 1999 ………	10
5	Values of Kostiakov-Lewis Intake Parameters in Demonstration Fields ………	11
6	Summary of Climate Data for WUFMAS Farms in 1997 ………	12
7	Net Irrigation Requirements for Different Rooting Depths and Depletion Factors in Demonstration Fields ………	13
8	Summary of Limitation of Tensiometer for Irrigating Cotton in Demonstration Fields ………	14
9	Average Water Management Criteria for Demonstration Fields ………	17

LIST OF FIGURES

Figure	Title	Page
1	Gradients of Selected Transects through Demonstration Fields………	7
2	Example of Infiltration Test Data Sheet and Calculation of Kostiakov-Lewis Parameters	after 10
3	Example of Estimation of Limitation of Tensiometer for Irrigating Cotton ………	after 14
4	Example of PUMA – Water Management Criteria ………	after 15

APPENDIX 1……… after page 18

1 INTRODUCTION

The Water Use and Farm Management Survey was conceived in mid-1995 following the conclusion that no reliable data were available on actual use of farm inputs. Of particular importance was the lack of data on the frequency of irrigation and the real application efficiency of water. Monitoring 10 sample fields in each of 36 farms scattered throughout the basin began in January 1996 ending in November 1998. This survey has created a valuable database summarised in WUFMAS Annual Reports and Participating Farm Reports. One significant conclusion was that only about 20 percent of water abstracted from the rivers is used by the crops of the basin. Decades of abundant and “free” water have made local users indifferent to the economic costs of wastage. The economic cost of delivering water to the field boundary is significant in most parts of the region, more so on Karshi steppe and less so in Chirchik Rayon, but an average value of US$15 per thousand cubic metres (tcm) would not be unreasonable (WARMAP 1). At economic prices, the direct and indirect costs to the national economies from unnecessary irrigation and drainage, extra water for leaching, crop loss from salinity and abandonment of land, are considerable, perhaps running into US$ billions annually.

In December of 1998, a debate arose over the most effective means to increase the agricultural productivity of water. Using average data for cotton from the database, it was shown by simulation that water productivity is most sustainably and effectively improved by together increasing crop yield while reducing water use. The WUFMAS 1999 field programme aims to demonstrate this in a selected field and by comparison with a control field on each of nine farms spread around Central Asia. Farm locations are given in Table 1.

Table 1 Location and Elevation of Sample Farms

Farm no.	Farm Name	Republic	Oblast	Rayon	Deg N	Deg E	Elevation (mamsl)
3	Djambul	Kazakhstan	South Kazakhstan	Makhtaaral	40°52'	68°34'	257
9	Sadikov	Kyrgyzstan	Osh	Karasu	40°33'	72°49'	954
14	1st May	Tadjikistan	Leninabad	Zafarabad	40°17'	70°23'	300
18	Murgap	Turkmenistan	Mary	Bayram	37°33'	62°11'	240
22	Talashkan	Uzbekistan	Surkhandariya	Sherabad	37°38'	66°56'	390
24	Timur Malik	Uzbekistan	Syrdariya	Sharaf-Rashidov	40°23'	68°23'	280
28	Shortanbay	Uzbekistan	Karakalpakistan	Nukus	42°37'	59°32'	75
34	Yakkatut	Uzbekistan	Ferghana	Tashlak	40°29'	71°53'	460
35	Bukhara	Uzbekistan	Bukhara	Kagan	39°44'	64°29'	230

The selected supervisors and national co-ordinators of the programme attended a seminar in late March in Tashkent, where the objectives and the tasks of the field staff were explained. Use of farm evaporimeter pan data to calculate the daily water balance and the irrigation schedule were reviewed (as detailed coverage had been given during three earlier seminars). The internationally used principles of in-field water management were outlined for the first time. The fundamental basis of this is the Manning equation, the solution of which is too complex to present at such a seminar, but participants were given a computer demonstration of PUMA, the water management program written in 1998 for MIROB. After making assumptions about the input parameters from the database, each participant received a printout of criteria, as the first and tentative recommendations for improved water management in their fields.

Irrigation in furrows spaced mostly at 0.9m, but sometimes at 0.6m, is used to irrigate about two thirds of irrigated land in Central Asia. Apart from some over-riding socio-economic factors, the three most important constraints to improved management of water in this system are

- uneven furrow gradients,
- shallow crop rooting, highly compacted plough-pans and sub-soil, and
- ineffective drains.

It was unfortunate that approval to begin the 1999 programme came too late to intervene in the demonstration fields to remove these constraints. It is of course unlikely that effective improvement of the drainage system and lowering of groundwater would have been possible on such a small budget.

This report follows the visit of the RWG and the consultant to all the farms during May and June and the processing of data from surveyors’ reports and laboratory analysis of soil samples.

2 METHODOLOGY EXPLAINED

The first objective of irrigation is to select the best day to irrigate. This is judged by the irrigator to reflect the optimal balance between the cost of irrigation and the value of the crop product lost as a result of undue moisture stress. This is ***scheduling***, and is not the subject of this paper, but the basic methodology is summarised below.

The second objective of irrigation is to replace, as efficiently as possible, the quantity of available moisture that the crop has extracted from the soil of the rootzone prior to irrigation. This quantity is the ***net irrigation requirement***, and the operation is ***water management***, the subject of these recommendations.

It is first necessary to estimate the net irrigation requirement. The WUFMAS field staff do this indirectly while scheduling, using the evaporimeter pan and rain gauge supplied earlier to each farm. It may be measured indirectly by a measuring device in the field or directly by gravimetric analysis of soil moisture content (a tedious method, unsuccessfully deployed in the Soviet system). A tensiometer, for example, measures soil moisture tension and from its predetermined relationship with the moisture content of that soil, the net irrigation requirement may be calculated, but the serious limitations of this device are discussed below.

As water flows down a furrow from the header canal, a proportion soaks into the soil, while the remainder moves on. The water soaking-in does so at a decreasing rate until the basic infiltration rate is reached. At the top of the furrow, the intake opportunity time is long, and water that percolates down beyond the roots is lost to the crop and raises the watertable. The intake opportunity time for water to soak-in at the bottom of the furrow is much shorter but must be enough to recharge exactly the available water capacity, no more and no less. A proportion of the water that moves on without soaking-in reaches the end of the furrow, and flows out as tail escape into another canal or a drain, and is lost to the crop for which it was intended. The ratio between the net irrigation requirement and the amount actually applied is the application efficiency, $\mathbf{E_a}$. The amount of water lost from the field in these two ways is more important than is traditionally believed in Central Asia. The average value of Ea has been measured by WUFMAS at about 40 percent, that is, 60 percent of water supplied to the field is wasted. The objective of these recommendations is to maximise the value of E_a, and is the purpose of the program PUMA.

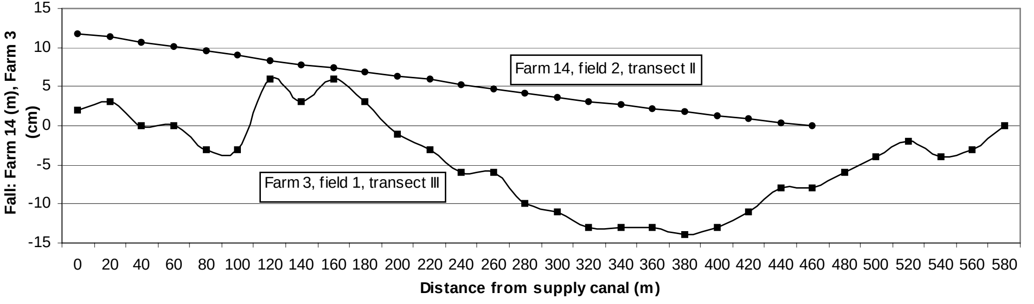
The balance between the proportions soaking-in and flowing-on is dependent on the soil and furrow characteristics, and the rate of flow of water entering from the header canal. The optimal water management criteria therefore depend on the following:

- net irrigation requirement,
- gradient, length and shape of the furrow,
- infiltration rate and resistance to flow down the furrow,
- furrow flow velocity and the soil's erosivity.

In order to apply the Manning equation (through PUMA), representative estimates of parameters for the field must first be measured. Two teams of soil surveyors were trained, visited all the fields and returned the necessary initial data on which these recommendations are based. It is unlikely that all values will be accurate and a third and later set of recommendations should be expected.

2.1 Land Survey

Figure 1 Gradients of Selected Transects through Demonstration Fields



Relative height of the land surface was measured at points on a 20m x 20m grid. Based on the vertical sections along transects, decisions were made on the sub-division of the field by temporary field canals.

From this, lengths and average gradients of furrows were determined. Examples of transects demonstrating uniformity and unevenness are shown in Figure 1. Average values of furrow lengths and gradients along measured transects are shown in Table 2. Values ranged from nil on Bukhara and Marie farms to 2 to 3 percent on Leninabad and Osh farms.

Table 2 Furrow Gradients in Demonstration Fields

File: Demo field slopes

Transect no.	Section 1			Section 2			Section 3			Section 4			Section 5			Over-all
	Length m	Drop m	Slope	Length m	Drop m	Slope	Length m	Drop m	Slope	Length m	Drop m	Slope	Length m	Drop m	Slope	Length m
Farm 3, field 9																
1	35		uneven	320		0.0008	228		0.0008							583
2	33		uneven	320		0.0009	231		0.0007							584
3	109		uneven	240		0.0008	234		0.0006							583
4	105		uneven	240		0.0006	240		0.0003							585
5	20		uneven	320		0.0006	240		0.0003							580
6	60		uneven	280		0.0006	240		0.0003							580
7	80		uneven	260		0.0005	222		0.0002							562
Farm 9, field 2																
1	133	1.90	0.01429													133
2	170	2.80	0.01647													170
3	198	4.10	0.02071													198
Mean 2-3	*184*		*0.01859*													
4	210	4.90	0.02333													210
5	221	5.70	0.02579													221
6	225	6.40	0.02844													225
Mean 4-6	*219*		*0.02586*													
7	161	4.80	0.02981													161
8	143	4.40	0.03077													143
9	178	5.70	0.03202													178
Mean 7-9	*161*		*0.03087*													
10	229	6.50	0.02838													229
11	227	6.30	0.02775													227
12	215	5.60	0.02605													215
Mean 10-12	*224*		*0.02739*													
13	195	5.10	0.02615													195
14	159	4.40	0.02767													159
15	164	4.00	0.02439													164
Mean 13-15	*173*		*0.02607*													
16	133	3.20	0.02406													133
17	135	3.50	0.02593													135
18	130	3.70	0.02846													130
Mean 16-18	*133*		*0.02615*													
Farm 14, field 5																
1	475	12.61	0.02655													475
2	453	11.94	0.02636													453
3	450	11.81	0.02624													450
4	444	11.71	0.02637													444
5	426	10.58	0.02484													426
6	425	10.37	0.02443													425
7	423	10.19	0.02412													423
8	400	9.54	0.02385													400
Mean 1-8	*437*		*0.02534*													
Farm 18, field 9: almost horizontal but very uneven, furrow slopes from nil to 0.0045 in different directions																
Farm 22, field 10																
1	20	0.00	0.00000	140	0.32	0.0023	20	0.00	0.0000	180	0.48	0.0027	0	0.00		360
2	40	0.00	0.00000	120	0.29	0.0024	20	0.00	0.0000	180	0.51	0.0028	0	0.00		360
3	20	0.00	0.00000	140	0.30	0.0021	20	0.00	0.0000	180	0.60	0.0033	0	0.00		360
4	40	0.00	0.00000	120	0.25	0.0021	20	0.00	0.0000	180	0.47	0.0026	0	0.00		360
5	60	0.00	0.00000	100	0.21	0.0021	20	0.00	0.0000	160	0.42	0.0026	20	0.00	0.0000	360
6	40	0.00	0.00000	120	0.21	0.0018	40	0.00	0.0000	158	0.39	0.0025	0	0.00		358
Mean 1-6				*123*		*0.0021*				*173*		*0.0028*				
7	160	0.27	0.00169	40	0.00	0.0000	120	0.22	0.0018	27	0.00	0.0000	0	0.00		347
8	160	0.38	0.00238	20	0.00	0.0000	46	0.00	0.0000	0	0.00		0	0.00		226
Farm 24, field 9																
9	140	0.18	0.00129	90	0.11	0.0012	60	0.10	0.0017	70	0.25	0.0036				360
10	140	0.30	0.00214	90	0.08	0.0009	60	0.11	0.0018	70	0.40	0.0057				360
11	140	0.34	0.00243	90	0.05	0.0006	60	0.12	0.0020	72	0.32	0.0044				362
12	140	0.34	0.00243	90	0.07	0.0008	56	0.07	0.0013	70	0.43	0.0061				356
13	140	0.48	0.00343	90	-0.06	-0.0007	56	0.08	0.0014	70	0.36	0.0051				356
Mean 9-13	*140*		*0.00234*	*90*		*0.0006*	*58.4*		*0.0016*	*70.4*		*0.0050*				
14	140	0.51	0.00364	100	-0.13	-0.0013	48	0.09	0.0019	52	0.23	0.0044				340
15	140	0.45	0.00321	100	-0.10	-0.0010	53	0.15	0.0028	47	0.13	0.0028				340
16	140	0.26	0.00186	100	0.07	0.0007	50	0.07	0.0014	50	0.08	0.0016				340
17	140	0.36	0.00257	100	-0.04	-0.0004	50	0.13	0.0026	50	0.08	0.0016				340
Mean 15-17	*140*		*0.00255*	*100*		*-0.0002*	*51*		*0.0023*	*49*		*0.0020*				
Farm 34, field 1																
1	282	0.79	0.00280													282
2	281	0.80	0.00285													281
3	279	0.70	0.00251													279
4	275	0.71	0.00258													275
5	272	0.77	0.00283													272
6	264	0.75	0.00284	20	0.00	0.0000										284
7	282	0.75	0.00266													282
8	281	0.77	0.00274													281
9	279	0.74	0.00265													279
10	280	0.58	0.00207													280
Mean 1-10	*278*		*0.00265*													
Farm 35, field 10: almost horizontal but very uneven, furrow slopes from nil to 0.0017 in different directions																

2.2 Soil Survey, Sampling and Analysis

The profile description was made in a soil pit in the field. A proving-ring cone penetrometer was used to record the penetration resistance in soil horizons and identify the existence of plough pans and other indurated horizons.

Undisturbed soil cores and composite soil samples were taken in 1996, 1997 and 1999, and analysed in the SANIIRI laboratory for soil texture, moisture characteristics, bulk density, porosity and salinity in a 1:1 soil:water suspension. Chemical analysis data from 1996/97 are summarised in Table 3 and 1999 data are summarised in Table 4.

Table 3 Soil and Water Analyses in WUFMAS 1999 Demonstration Fields

Oblast	**Unit**	**S Kaza-khstan**	**Osh**	**Lenin-abad**	**Marie**	**Surkha-ndariya**	**Syr-dariya**	**Karak-alpakia**	**Fergh-ana**	**Bukhara**
Farm No.		**3**	**9**	**14**	**18**	**22**	**24**	**28**	**34**	**35**
Demonstration Field No.		**3**	**av**	**5**	**5**	**5**	**10**	**9**	**9**	**10**
Crop (1999)		Cotton	Cotton	Cotton	Cotton	Cotton	Cotton	Rice	Cotton	Cotton
Soil Analysis (data for fields)		9	av.	3	3/7	4/7	1/5	3	6/10	6
pH		7.7	-	-	7.9	7.6	7.6	7.7	-	7.7
ECe 1996	dS/m	1.0	0.5	1.2	0.7	1.4	1.2	2.5	1.4	1.7
ECe 1997	dS/m	1.0	-	-	1.7	4.3	5.4	4.6	-	3.3
Hazard class		**0**	**0**	**0**	**0**	**2**	**2**	**2**	**0**	**1**
HCO3	me/100g	0.20	-	0.2	0.20	0.18	0.25	0.25	0.23	0.2
Cl	me/100g	1.83	-	0.85	0.42	1.69	1.69	1.83	0.49	1.27
Hazard class		**2**	-	**1**	**0**	**2**	**2**	**2**	**0**	**2**
SO4	me/100g	12.91	-	6.87	4.04	4.38	2.91	16.86	5.28	3.77
Ca	me/100g	7.73	-	3.49	0.88	1.63	3.50	10.23	2.75	2.74
Mg	me/100g	3.70	-	1.48	0.62	0.66	0.99	2.47	1.11	0.99
Na	me/100g	1.83	-	2.22	2.92	3.83	0.35	4.96	2.22	1.22
Hazard class		**1**	-	**1**	**1**	**2**	**0**	**2**	**1**	**1**
K	me/100g	0.26	-	0.18	0.20	0.21	0.02	0.13	0.15	0.26
K/(K+Na)	%	12	-	8	6	5	5	3	6	18
Na/Total cations	%	14	-	30	63	61	7	28	36	23
Cl/SO4	ratio	0.1	-	0.1	0.1	0.4	0.6	0.1	0.1	0.3
Salinity type		SO_4	SO_4	SO_4	SO_4	$Cl:SO_4$	$Cl:SO_4$	SO_4	SO_4	$Cl:SO_4$
Irrigation water (average)										
EC	dS/m	1.4	0.8	1.3	0.9	1.3	1.3	1.7	0.7	1.7
Hazard class		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
HCO3	me/l	0.9	0.8	1.2	0.8	1.6	1.9	1.3	0.9	-
Cl	me/l	2.9	1.1	3.4	2.8	4.3	3.6	5.5	1.2	-
SO4	me/l	2.5	4.0	17.3	3.8	10.0	6.5	6.0	6.8	-
Ca	me/l	2.6	3.0	8.4	4.0	5.4	5.5	6.0	2.8	-
Mg	me/l	1.6	1.0	7.7	3.0	5.4	4.3	4.0	3.6	-
Na	me/l	0.7	1.8	5.6	0.5	4.9	2.0	2.6	2.4	-
K	me/l	0.0	0.1	0.2	0.0	0.2	0.1	0.1	0.1	-
SAR		0.6	1.3	1.9	0.2	2.5	0.9	1.2	1.4	-
Hazard class		**0**	**0**	**0**	**0**	**0-1**	**0**	**0**	**1**	**-**
Groundwater (average)										
EC	dS/m	2.7	-	-	6.7	12.0	9.7	5.6	2.0	6.4
Hazard class		**1**	-	-	**2**	**2**	**2**	**2**	**1**	**2**
HCO3	me/l	2.1	-	-	2.9	2.6	3.7	2.6	1.6	1.2
Cl	me/l	6.0	-	-	36.6	59.6	37.1	27.6	1.0	10.1
SO4	me/l	26.2	-	-	69.4	67.6	90.2	39.8	7.1	29.1
Ca	me/l	6.0	-	-	19.3	14.4	21.5	19.0	1.6	5.4
Mg	me/l	14.8	-	-	39.5	37.6	47.3	30.6	6.2	13.4
Na	me/l	12.5	-	-	47.7	76.9	61.7	19.4	1.7	20.6
K	me/l	0.4	-	-	1.5	2.4	1.9	0.6	0.1	0.6
SAR		4.1	-	-	8.5	15.8	10.7	3.9	1.3	10
Hazard class		**0**	**-**	**-**	**0**	**0**	**0**	**0**	**0**	**0**

Note: some demonstration fields were changed after preparation of this table

Table 3 gives an interpretation of some analyses in terms of the hazard classes established by FAO and local institutes. Soil salinity, as measured by electrical conductivity of a saturation extract, EC_e, varies from non-saline in farms 03, 09,14, 18 and 34, to slightly saline in farm 35 and moderately saline in farms 22, 24 and 28. Neither local Na nor Cl salinity classes correspond well with EC_e except inasmuch as farms 22 and 28 have the same rating on all measures. Farm 24 rates as saline in EC_e due to high levels of $MgSO_4$ and $CaSO_4$ but not NaCl.

The quality of the irrigation water and groundwater in terms of their suitability for irrigation in most cases is good. There is a slight hazard from the sodium absorption ratio (SAR) of the irrigation water on farms 22 and 34. The SAR hazard relates not to the effect on the crop, but to imbalance between Na and divalent cations causing deflocculation of clay with consequent fall in soil permeability and rise in salinity. With typically only a small clay fraction and little HCO_3^- in local soils and water, the hazard cannot be regarded as serious. It was found during the RWG visit to farm 22 that the irrigation water is a 1:1 mixture of fresh and drainage water (but demonstration field 10 is supplied with fresh water only).

The source of the soil salinity therefore is not the irrigation water but secondary salinity from the watertable. The water loss during irrigation is much greater than the leaching fraction so no special provision need be made other than pre-irrigation before sowing if rainfall is insufficient to reduce surface salinity.

Table 4 Summary of Laboratory Analyses of Soil Samples from Demonstration Fields (July 1999)

Farm no.	Field no. *	Sample depth (cm)	Stones & gravel (% w/w)	Texture in fine earth (USBR % w/w)			Textural classification		Salinity by $EC_{1:1}$	Soil moisture (% v/v)			Bulk density (g/ml)	Porosity in core (% v/v)
				sand	silt	clay	USBR	Local	dS/m	pF=2.0	pF=4.2	AWC		
3	**1D**	0-10	<1	36	47	17	L	mL	1.3	25.2	17.5	7.8	1.39	0.48
		20-25	<1	40	46	14	L	mL	1.1	28.9	14.2	14.8	1.48	0.44
		35-40	<1	29	53	18	ZL	mL	1.9	30.2	18.2	12.0	1.65	0.38
		50-55	<1	32	60	8	ZL	lL	2.5	29.4	15.0	14.4	1.45	0.45
	10C	0-10	<1	30	55	15	ZL	mL	1.9	23.1	13.0	10.1	1.15	0.57
		10-35	<1	43	52	5	ZL	conS		28.3	15.1	13.1	1.35	0.49
		35-47	<1	35	53	12	ZL	mL		31.4	17.6	13.8	1.57	0.41
		47-77	<1	36	53	11	ZL	lL		26.6	12.1	14.5	1.34	0.50
9	**2D**	0-5		36	50	14	L	lL	0.5	27.2	14.8	12.4	1.59	0.40
		25-30		37	51	13	ZL	mL	0.5	28.4	16.0	12.4	1.48	0.44
		60-65		35	52	9	ZL	lL	0.4	21.2	8.9	12.4	1.42	0.47
	1C	0-5		36	53	41	ZL	lL	0.7	25.8	11.6	14.3	1.40	0.47
		25-30		37	52	11	ZL	lL	0.6	26.9	11.9	15.0	1.40	0.47
		60-65		36	58	6	ZL	lL	0.5	28.3	10.5	17.8	1.40	0.47
14	**5D**	0-35	34	72	23	5	SL	conS	0.6	21.6	7.7	13.9	1.23	0.54
		35-40	46	75	19	6	SL	conS	0.4	17.8	9.8	0.8	1.32	0.50
		40-60	43	72	24	5	SL	conS	0.4	14.2	6.4	7.8	1.22	0.54
		>60	48	78	20	2	LS	S	0.5	22.0	9.8	12.2	1.28	0.52
	4C	0-30	n/a	90	5	5	S		1.9					
		30-60	n/a	94	4	2	S		0.5					
18	**7D**	10-15	<1	48	43	9	L	lL	4.1	24.8	13.6	11.3	1.59	4.00
		35-40	<1	59	34	7	SL	conS	2.3	27.1	15.6	11.5	1.45	0.45
		60-65	<1	68	23	9	SL	conS	4.6	29.9	11.7	18.2	1.61	0.39
	9C	10-15	<1	46	39	15	L	lL	2.7	29.0	21.3	7.7	1.55	0.42
		35-40	<1	45	40	15	L	lL	0.8	27.9	21.8	6.1	1.63	0.39
		60-65	<1	48	37	15	L	mL	1.1	27.0	20.2	6.8	1.57	0.41
22	**10D**	0-37	<1	27	43	30	CL	hL	1.1	24.9	17.7	7.2	1.24	0.53
		37-66	<1	33	46	21	L	hL	2.1	30.0	21.7	8.3	1.56	0.41
		66-78	<1	28	48	24	L	hL	2.3	23.0	13.9	9.1	1.58	0.41
		79-100	<1	30	64	6	ZL	lL	2.9	35.8	28.1	7.7	1.62	0.39
	10C	0-30	<1	30	40	30	CL	hL	1.8	29.8	20.2	9.7	1.44	0.46
		30-47	<1	38	43	20	L	mL	2.8	29.3	23.1	6.2	1.60	0.40
		47-55	<1	48	33	19	L	mL	2.6	29.9	21.9	8.0	1.51	0.43
		55-100	<1	34	45	21	L	mL	3.3	30.5	22.0	8.5	1.56	0.41
24	**9D**	5-10	<1	69	26	5	SL	conS		19.7	10.1	9.6	1.25	0.53
		25-30	<1	63	28	9	SL	conS	1.2	20.9	7.7	13.2	1.65	0.38
		65-70	<1	62	37	1	SL	lL	1.0	26.3	11.9	14.5	1.40	0.47
		87-92	<1	49	47	4	SL	S	1.2	36.0	21.6	14.4	1.34	0.50
	9D	5-10	<1	63	32	6	SL	conS	3.9	23.1	14.1	9.0	1.62	0.39
		40-45	<1	64	31	5	SL	conS	4.2	20.7	9.7	11.0	1.41	0.47
		75-80	<1	41	56	3	ZL	S	3.6	25.2	10.7	14.5	1.29	0.52
28	**9D**	0-37	<1	39	52	9	ZL	lL	3.6	31.6	24.0	7.6	1.32	0.50
		37-65	<1	37	54	9	ZL	lL	1.0	40.8	25.7	15.1	1.46	0.45
		65-80	<1	41	58	1	ZL	conC	0.8	28.7	21.1	7.6	1.34	0.50
		80-100	<1	34	63	3	ZL	conS	0.7	32.0	24.2	7.9	1.33	0.50
34	**1D**	0-5	<1	44	41	15	L	mL	1.1	27.0	16.4	10.6	1.32	0.50
		25-30	<1	42	39	19	L	mL	1.3	33.0	21.8	11.3	1.50	0.44
		65-70	<1	55	32	13	SL	lL	0.8	25.2	12.9	12.2	1.42	0.47
	5C	0-5	<1	52	37	11	L	lL	1.0	24.2	16.2	8.0	1.47	0.45
		25-30	<1	52	36	12	L	lL	1.1	26.8	19.7	7.2	1.69	0.36
		50-55	<1	53	38	9	SL	lL	0.5	26.2	18.5	7.6	1.67	0.37
		70-75	<1	59	32	9	SL	lL	0.5	32.3	23.3	8.6	1.55	0.42
35	**10D**	0-20	<1	38	55	7	ZL	mL	0.6	23.8	10.4	13.4	1.12	0.58
		20-49	<1	40	46	14	L	mL	0.6	27.2	14.9	12.3	1.41	0.47
		49-71	<1	40	45	15	L	mL	0.4	27.3	14.3	13.0	1.29	0.52
		71-100	<1	29	54	17	ZL	mL	0.8	26.1	12.7	13.4	1.32	0.50
	7C	0-15	<1	36	50	14	ZL	mL	2.1	30.2	14.4	15.8	1.23	0.54
		15-66	<1	36	48	16	L	mL	1.7	31.8	16.0	15.8	1.43	0.46
		66-100	<1	65	28	7	SL	conS	2.0	26.96	12.7	14.2	1.39	0.48

Note: * D = demonstration field, C = Control field

The bulk density values in Table 4 reveal some very compacted subsoils. Values greater than 1.4g/ml are root-restricting in silty soils and values greater than 1.6g/ml are impenetrable by roots, although some roots may penetrate the cracks between peds. The net result is that rooting depth is severely restricted, and as will be seen below, this seriously limits the potential for improvement in water management.

2.3 Infiltration Tests and Furrow Shape

Infiltration data were collected from two tests per field using a double-ring infiltrometer. In view of the variability of data, it is unfortunate that three tests were not made as recommended by the consultant.

An example of the record sheet and the Excel program to calculate the Kostiakov-Lewis infiltration parameters is illustrated in Figure 2. The water level was allowed to fall by not more than 10mm before recording time and level, and recharging to the maximum mark. The figure shows actual data for the second test in sample 7 field of farm 35, Bukhara oblast, where the coefficient *k* (curvature) was 0.002m/min, exponent *a* was 0.002, and the linear coefficient *fo*, the basic infiltration rate, was 0.00014m/min. The equation fitted the data closely, the recorded cumulative infiltration being 173mm after 16h and the calculated equivalent was 176mm. The extrapolated 24h infiltration was 0.25m, a moderately slow rate by international standards. Table 5 summarises the estimated parameters from tests done in the demonstration fields in April and May.

Table 5 Values of Kostiakov-Lewis Parameters Estimated from Double-Ring Infiltration Test Data in Demonstration Fields

Farm no.	Field (1)/ Replicate	Kostiakov-Lewis parameters			At end of test (mm)		After 24h	Infiltration class (2)
		k	a	fo	Measured	estimated	(m/day)	
3	1D-I	0.0030	0.424	0.00026	210	214	0.44	Mod. Slow
	1D-II	0.0030	*	0.00026	176	*	*	*
	3-I	0.0030	0.430	0.00027	211	215	0.46	Mod. Slow
	3-II	0.0020	0.491	0.00020	162	167	0.36	Mod. Slow
	10C-I	0.0030	0.473	0.00025	234	240	0.45	Mod. Slow
	10C-II	0.0020	0.546	0.00050	395	351	0.83	Moderate
	Mean	**0.0027**	**0.473**	**0.00029**	**231**	**237**	**0.51**	Moderate
9	1C-I	0.0030	*	0.00036	211	*	*	*
	1C-II	0.0050	*	0.00031	166	*	*	*
	2D-I	0.0010	0.083	0.00008	64	64	0.12	Slow
	2D-II	0.0020	*	0.00029	159	*	*	*
	Mean	**0.0028**	**0.083**	**0.00026**	**150**			
14	5D-I	0.0070	0.258	0.00011	126	127	0.20	Mod. Slow
	4C-I	0.0350	0.562	0.01000	1404	1542	16.49	Very rapid
	Mean	**n/a**	**n/a**	**n/a**				
18	7-I	0.0060	0.334	0.00095	579	630	1.44	Moderate
	7-II	0.0070	0.152	0.00004	49	49	0.08	Slow
	7-III	0.0030	0.425	0.00020	166	169	0.35	Mod. Slow
	9DC-I	0.0030	*	0.00021	130	*	*	*
	9DC-II	0.0070	0.189	0.00011	89	89	0.19	Mod. Slow
	Mean	**0.0052**	**0.275**	**0.00030**	**203**	**234**	**0.51**	Moderate
22	10D-I	0.0010	0.443	0.00040	321	329	0.60	Moderate
	10D-II	0.0050	0.375	0.00042	371	376	0.68	Moderate
	10C-I	0.0020	0.427	0.00043	317	324	0.66	Moderate
	10C-II	0.0020	0.609	0.00040	341	362	0.74	Moderate
	Mean	**0.0025**	**0.464**	**0.00041**	**338**	**348**	**0.67**	Moderate
24	9D-I	0.0030	0.221	0.00014	130	131	0.22	Mod. Slow
	9D-II	0.0050	0.295	0.00015	158	159	0.26	Mod. Slow
	9C-I	0.0040	0.235	0.00003	44	44	0.07	Slow
	9C-II	0.0020	0.392	0.00003	50	50	0.08	Slow
	10-I	0.0022	0.407	0.00048	210	201	0.73	Moderate
	10-II	0.0027	0.325	0.00018	171	162	0.29	Mod. Slow
	10-III	0.0041	0.248	0.00012	111	107	0.20	Mod. Slow
	10-IV	0.0030	0.313	0.00026	176	178	0.40	Mod. Slow
	Mean	**0.0030**	**0.323**	**0.00026**	**167**	**162**	**0.41**	Mod. Slow
28	9D-I	0.0150	0.214	0.00008	149	149	0.02	Very Slow
	9D-II	0.0030	0.099	0.00012	125	125	0.18	Mod. Slow
	10C-I	0.0020	0.362	0.00010	87	88	0.17	Mod. Slow
	10C-II	0.0002	0.608	0.00012	105	99	0.19	Mod. Slow
	Mean	**0.0051**	**0.321**	**0.00011**	**117**	**115**	**0.14**	Mod. Slow
34	1D-I	0.0030	0.428	0.00008	104	105	0.18	Mod. Slow
	1D-II	0.0040	0.441	0.00008	118	119	0.21	Mod. Slow
	5C-I	0.0100	0.258	0.00020	178	179	0.35	Mod. Slow
	5C-II	0.0040	0.225	0.00008	77	77	0.14	Mod. Slow
	Mean	**0.0053**	**0.338**	**0.00011**	**119**	**120**	**0.22**	Mod. Slow
35	7C-I	0.0020	0.466	0.00026	292	298	0.43	Mod. Slow
	7C-II	0.0020	0.440	0.00014	173	176	0.25	Mod. Slow
	10D-I	0.0030	0.299	0.00002	53	53	0.06	Slow
	10D-II	0.0040	0.311	0.00002	64	64	0.07	Slow
	Mean	**0.0028**	**0.379**	**0.00011**	**146**	**148**	**0.20**	Mod. Slow

(1) Note: D = demonstration field, C = control field

(2) Rates: very slow = <0.02m/d, slow = 0.02-0.12m/d, mod slow = 0.12-0.48m/d, moderate = 0.48-1.44m/d, rapid = 1.44-6.0m/d, very rapid = >6.0m/d Source: Booker Tropical Soil Manual, p69, Longman 1991

Water management criteria are fairly sensitive to furrow shape and field staff have been instructed to record typical shape characteristics. In the PUMA model, the furrow shape is determined by interrow spacing and two shape parameters, p1 and p2. For these recommendations, a wide trapezoidal section is assumed with values of 0.432 and 1.29 for shape parameters p1 and p2 respectively, excepting for the field in Farm 22, Surkhandariya oblast which is almost unirrigable. A furrow profile-measuring device has been prepared for future use and new values for parameters may replace those used in this report.

2.4 Climate data

Monthly climate data has been collected from the nearest Glavhidromet station to the farm. Long-term data have been reported in the WUFMAS annual reports but data for 1997 are summarised in Table 6.

Table 6 Summary of Climate Data for WUFMAS Farms in 1997

Farm No	Temp Mean Month	Degree -days >15°C	Temp Mean Month Max	Temp Abs Max	Temp Mean Month Min	Temp Abs Min	Rain in Month	Eo in Month	Relative Humidity	Wind Speed	Bright Sun-shine	ETo (Pen-man)	Solar radi-ation
	°C		°C	°C	°C	°C	mm	mm	%	m/sec	h	mm	MJ/m3
Average of 12 months													
3	15.6	182	23.7	32.9	7.9	0.3	21.7	-	61	1.82	9.4	104.2	18.9
9	12.8	124	19.6	26.7	7.8	1.4	27.1	-	61	1.33	8.6	102.0	19.0
14	16.1	168	23.7	27.8	11.1	5.6	16.2	6	42	5.60	7.9	88.3	16.0
18	17.8	215	26.6	34.8	10.0	5.3	16.0	-	46	2.88	8.7	136.1	18.3
22	18.9	225	24.9	32.2	13.8	8.0	24.5	-	50	4.40	9.9	160.5	34.8
24	15.3	170	22.9	30.9	8.6	1.8	28.2	-	58	2.26	8.9	107.0	18.3
28	13.6	173	21.3	30.5	5.7	-1.1	10.0	-	58	4.20	9.2	118.1	18.0
35	15.9	183	24.2	33.2	8.4	2.7	22.2	-	57	3.73	9.5	139.4	19.6
Total over 12 months													
3		2179					260	0			84	729	132
9		1490					299	0			69	816	152
14		1843					178	43			71	265	48
18		2576					192	0			104	-	201
22		2694					294	0			109	-	348
24		2045					339	0			98	-	201
28		2074					120	1014			111	-	198
35		2199					267	0			95	-	196
Maximum over 12 months													
3	29.7	499	40.2	45.4	20.2	16.0	57.9	0	83	4.80	13.2	197.8	28.5
9	26.7	415	35.2	39.4	19.0	14.3	68.1	0	74	1.90	12.1	179.2	27.0
14	28.5	482	36.8	40.0	23.1	17.5	69.0	16	75	14.00	13.1	199.1	28.4
18	32.1	581	39.6	45.9	25.2	21.3	47.4	0	65	4.70	12.5	238.7	27.9
22	32.4	586	39.4	43.6	25.8	23.1	87.7	0	74	4.80	12.9	283.6	162.0
24	29.6	504	37.9	43.8	21.9	17.8	78.2	0	72	3.60	13.2	207.4	28.6
28	29.9	515	37.2	43.0	21.7	16.5	59.6	249	78	9.00	12.2	231.3	27.1
35	30.0	508	38.2	46.0	21.5	18.8	81.0	0	76	4.90	13.1	266.9	28.5
Minimum over 12 months													
3	1.1	0	6.2	16.0	-3.6	-17.2	0.0	0	40	1.20	4.6	15.5	7.2
9	0.0	0	5.6	12.0	-3.0	-13.2	0.0	0	47	0.70	3.3	18.5	6.2
14	1.1	0	6.9	12.6	-1.9	-8.7	0.0	0	0	1.60	0.0	27.7	7.5
18	5.2	0	11.2	19.6	-4.2	-10.5	0.0	0	28	1.30	4.4	40.9	7.9
22	7.4	0	12.3	20.6	2.4	-4.9	0.0	0	31	4.10	6.3	54.6	9.9
24	0.8	0	8.9	15.8	-6.0	-17.3	0.0	0	40	1.10	4.6	30.9	7.3
28	-3.5	0	2.4	9.8	-19.0	-23.2	0.0	0	48	2.40	5.2	17.5	7.1
35	2.5	0	9.2	18.4	-11.8	-13.4	0.0	0	37	2.60	5.2	26.9	7.9
Standard deviation													
3	10.8	200	12.8	10.7	8.9	12.4	20.8	-	15	1.06	3.0	75.0	8.1
9	9.9	191	12.6	9.7	9.1	9.2	19.8	7	39	3.76	4.3	96.1	11.0
14	10.1	232	10.8	8.6	10.0	10.7	16.9	-	13	1.01	2.8	71.9	7.2
18	9.4	228	10.0	8.0	8.4	9.7	30.9	-	15	0.19	2.6	93.3	45.3
22	10.5	196	11.3	10.5	10.0	11.8	29.2	-	12	0.78	3.0	67.5	7.6
24	11.7	191	12.4	11.0	10.2	12.5	9.7	-	10	0.49	2.8	78.2	7.3
28	10.6	205	10.4	8.6	10.7	11.3	27.3	-	15	0.62	2.9	89.2	7.3
35	10.6	205	10.4	8.6	10.7	11.3	27.3	-	15	0.62	2.9	89.2	7.3

2.5 Irrigation Scheduling, Net Irrigation Requirement and Rooting Depth

The principle of irrigation scheduling by WUFMAS is to record the daily evaporation (Eo) from a Class A Pan, convert it to reference crop evapotranspiration (ETo), and to crop evapotranspiration (ETc) by coefficients, and to irrigate when the total since the last irrigation equals the readily available moisture in the rootzone.

Table 7 Net Irrigation Requirement in mm for Different Rooting Depths and Depletion Factors in Demonstration Fields

Use of Table: It shows the approximate net irrigation requirement (in mm) of each demonstration field by rooting depth of the crop and the maximum acceptable percentage depletion of the total available moisture in the rootzone (D). The value of D for cotton should be 50-60% during maximum vegetative growth, 65% during peak flowering, 50-60% during peak boll-filling, and 65% during boll maturation. AWC is from laboratory analysis of soil samples in 1999.

Farm no.	**Field no.**	***Depletion factor (%)***	**Rooting depth (cm)**												
			30	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
3	**1**		***Weighted average AWC (mm/m)***												
			78	*96*	*113*	*115*	*118*	*123*	*126*	*128*	*130*	*131*	*132*	*133*	*134*
		50	12	19	28	34	41	49	57	64	71	79	86	93	101
		55	13	21	31	38	46	54	62	70	78	87	95	103	111
		60	14	23	34	41	50	59	68	77	86	94	103	112	121
		65	15	25	37	45	54	64	73	83	93	102	112	121	131
9	**2**		***Weighted average AWC (mm/m)***												
			124	*124*	*124*	*124*	*124*	*124*	*124*	*124*	*124*	*124*	*124*	*124*	*124*
		50	19	25	31	37	43	50	56	62	68	74	81	87	93
		55	20	27	34	41	48	55	61	68	75	82	89	95	102
		60	22	30	37	45	52	60	67	74	82	89	97	104	112
		65	24	32	40	48	56	64	73	81	89	97	105	113	121
14	**5**		***Weighted average AWC (mm/m)***												
			80	*80*	*77*	*75*	*74*	*73*	*73*	*73*	*72*	*72*	*72*	*72*	*72*
		50	12	16	19	23	26	29	33	36	40	43	47	50	54
		55	13	18	21	25	28	32	36	40	44	48	51	55	59
		60	14	19	23	27	31	35	39	44	48	52	56	60	64
		65	16	21	25	29	34	38	43	47	52	56	61	65	70
18	**7**		***Weighted average AWC (mm/m)***												
			113	*113*	*113*	*114*	*121*	*131*	*138*	*144*	*148*	*151*	*154*	*156*	*158*
		50	17	23	28	34	42	52	62	72	81	91	100	110	119
		55	19	25	31	38	46	58	68	79	90	100	110	120	131
		60	20	27	34	41	51	63	75	86	98	109	120	131	143
		65	22	29	37	44	55	68	81	93	106	118	130	142	154
22	**10**		***Weighted average AWC (mm/m)***												
			78	*77*	*75*	*76*	*77*	*78*	*79*	*81*	*81*	*81*	*80*	*80*	*80*
		50	12	15	19	23	27	31	36	40	45	48	52	56	60
		55	13	17	21	25	30	34	39	44	49	53	57	62	66
		60	14	18	23	27	32	37	43	48	54	58	63	67	72
		65	15	20	24	29	35	41	46	53	58	63	68	73	78
24	**9**		***Weighted average AWC (mm/m)***												
			96	*105*	*114*	*116*	*119*	*123*	*126*	*129*	*130*	*132*	*133*	*134*	*134*
		50	14	21	29	35	42	49	57	64	72	79	86	94	101
		55	16	23	31	38	46	54	63	71	79	87	95	103	111
		60	17	25	34	42	50	59	68	77	86	95	104	112	121
		65	19	27	37	45	54	64	74	84	93	103	112	122	131
28	**9**		***Weighted average AWC (mm/m)***												
			78	*78*	*78*	*87*	*100*	*102*	*98*	*96*	*94*	*92*	*91*	*90*	*89*
		50	12	16	20	26	35	41	44	48	52	55	59	63	67
		55	13	17	21	29	38	45	49	53	57	61	65	69	74
		60	14	19	23	31	42	49	53	57	62	67	71	76	80
		65	15	20	25	34	45	53	58	62	67	72	77	82	87
34	**1**		***Weighted average AWC (mm/m)***												
			78	*96*	*113*	*115*	*118*	*123*	*126*	*128*	*130*	*131*	*132*	*133*	*134*
		50	12	19	28	34	41	49	57	64	71	79	86	93	101
		55	13	21	31	38	46	54	62	70	78	87	95	103	111
		60	14	23	34	41	50	59	68	77	86	94	103	112	121
		65	15	25	37	45	54	64	73	83	93	102	112	121	131
35	**10**		***Weighted average AWC (mm/m)***												
			134	*134*	*132*	*130*	*129*	*129*	*130*	*130*	*131*	*131*	*131*	*132*	*132*
		50	20	27	33	39	45	52	58	65	72	79	85	92	99
		55	22	29	36	43	50	57	64	72	79	86	94	101	109
		60	24	32	40	47	54	62	70	78	86	94	102	110	119
		65	26	35	43	51	59	67	76	85	93	102	111	120	128

The available water capacity (AWC) is the moisture contained in the soil between the suction pressures (tensions) of pF2.2 and 4.2, field capacity and permanent wilting point respectively. Readily available moisture (RAM) is defined as the proportion of the AWC in the rootzone that may be depleted by the crop without causing economic loss of yield. The RAM therefore is a function of rooting depth, depletion factor (D) and AWC. AWC has been measured by the SANIIRI laboratory and values are shown in Table 4, and weighted average values for different rooting depths in demonstration fields are shown in Table 7. The table shows the RAM values for these different rooting depths and a range of depletion factors appropriate for cotton, from 50 to 65 percent.

The RAM is the amount of water on the day of irrigation that has been extracted by the crop from the rootzone since the last irrigation (or rainfall) and therefore is equal to the net irrigation requirement. The depletion of soil moisture is determined each day by field staff and the net irrigation requirement is easily obtained. The values of net irrigation requirement in Table 6 in relation to rooting depth and depletion factor are given as a guide, because it is one of the input data to the PUMA water management program.

The schedule must take account of the contribution by capillary rise from the watertable to satisfying the water need of the crop. Most of the demonstration fields have high groundwater, thereby making it more difficult to demonstrate the benefits of scientific management of irrigation. The modified Laktaev equation (WUFMAS 1997 Report) for estimating the daily groundwater contribution is used in the daily water balance.

2.6 Limitation of Tensiometers

Tensiometers seem to be a popular concept in Central Asia as an alternative basis for irrigation scheduling. World wide, they are commonly integrated into drip irrigation systems and used for scheduling irrigation of vegetable crops. A tensiometer directly measures soil moisture tension and from its predetermined relationship with the moisture content of that soil, the moisture content at the time of measurement may be interpolated. The main drawback of a tensiometer, apart from the skill and time necessary to install them in the field, is the maximum tension that they can record. Although the dial is commonly calibrated to 1000mbar, air comes out of solution in the water column, forms bubbles, and invalidates the reading at a suction pressure greater than about 800mbar. This critical value reduces with altitude, at a rate of about 11mbar per 100m rise.

Table 8 Summary of Limitation of Tensiometer for Irrigating Cotton in WUFMAS Demonstration Fields

Farm No	**3**	**9**	**14**	**18**	**22**	**24**	**28**
Farm name	Djambul	Sadikov	1st May	Murgap	Talashkan	Timur Malik	Shortanbey
Oblast	S Kazakhstan	Osh	Leninabad	Marie	Surkhandariya	Syrdariya	Karakalpakia
Republic	Kazakhstan	Kyrgizstan	Tadjikistan	Turkmenistan	Uzbekistan	Uzbekistan	Uzbekistan
Field no.	**1**	**2**	**2**	**7**	**10**	**9**	**9**
Date of sample	1997	1997	1997	1997	1997	1997	1997
Depth of sample (cm)	70	70	70	30	30	70	70
Altitude of farm (m)	257	954	300	240	390	280	75
Limit of tensiometer reading (mbar)	821	743	816	823	806	819	842
Soil texture by USBR	ZL	ZL	fLS	fSL	ZCL	L	ZL
Soil texture by Kachinsky	medium loam	heavy loam	loamy sand	loamy sand	light clay	medium loam	medium loam
Available Water Capacity (mm/m)	165	143	140	115	124	135	80
Soil moisture tension (mbar) when							
Depletion of AWC is 50%	2080	1958	1290	1250	1869	1194	795
Depletion of AWC is 55%	2561	2358	1572	1562	2345	1488	975
Depletion of AWC is 60%	3130	2811	1917	1959	2914	1861	1201
Depletion of AWC is 65%	3799	3316	2340	2464	3585	2335	1482
Soil moisture tension (pF) when							
Depletion of AWC is 50%	3.33	3.30	3.12	3.11	3.28	3.09	2.91
Depletion of AWC is 55%	3.42	3.38	3.21	3.20	3.38	3.18	3.00
Depletion of AWC is 60%	3.50	3.46	3.29	3.30	3.47	3.28	3.09
Depletion of AWC is 65%	3.59	3.53	3.38	3.40	3.56	3.38	3.18
Limit of tensiometer reading (pF)	2.93	2.89	2.91	2.92	2.91	2.94	2.93
Limit of tensiometer reading in terms of D (%)	**30**	**28**	**38**	**40**	**33**	**42**	**51**

Maximum percentage depletion (D%) of AWC in rootzone for optimal irrigation

Barley	55	Grass	50	Potatoes	25
Beans	45	Groundnut	40	Safflower	60
Beets	50	Lettuce	30	Sorghum	55
Cabbage	45	Maize - grain	60	Soyabean	50
Carrots	35	Maize - silage	50	Strawberry	15
Cotton	65	Melons	35	Sugarbeet	50
Cucumber	50	Onions	25	Tomato	40
Orchards	50	Peas	35	Vegetables	20
Grapes	35	Peppers	25	Wheat	55

Source: CROPWAT Manual, FAO Irrig. and Drainage Papers No 45

An Excel program to estimate soil moisture tension at different degrees of depletion of the AWC is illustrated by an example for Farm 18 in Figure 3. Table 8 shows the use of the program to calculate the soil tension from the corresponding moisture characteristics of the soil in seven of the demonstration fields, and a range of depletion factors (D) for cotton.

The bottom line of Table 8 shows the limit of reliable reading of the tensiometer for the seven fields, in terms of the depletion of the AWC. With the possible exception of the field in Karakalpakistan (which is ponded to produce rice in 1999) in all cases the irrigation of cotton should be at a soil moisture tension far off the scale of the tensiometer. In these circumstances, use of a tensiometer to signal the day of irrigation would result in too frequent irrigation and high costs. In reality, the water would not be available in the canal, nor the irrigators willing to comply without some incentive that they do not enjoy at present. The footnote to Table 8 gives the FAO values for D for different crops and from which it can be seen that only scheduling of sensitive vegetable and fruit crops is possible by tensiometer at these farms.

2.7 PUMA – the MIROB Water Management Program

It is not the intention of this paper to detail the Manning equation, and certainly not the involved methodology for solving an equation with five simultaneous variables. The methodology is fully described in FAO Irrigation and Drainage Paper No. 33. At the design stage, furrow length and gradient can be adjusted within the limits imposed by the considerable cost and technical problems of moving large volumes of topsoil. In the shorter term, temporary field canals may shorten furrows and different implements may vary the interrow spacing, the furrow cross sectional profile and increase rooting depth by subsoiling. At the time of irrigation, these input parameters and values are fixed, and only the furrow flow rate (Q in l/sec) and the duration (t) from start to cut-off at the head of the furrow in hours are under the control of the irrigator. Judgement needs to be used to decide the value of the Manning Resistance Coefficient (n) which may vary from 0.04 for rough (newly cultivated soil) to 0.02 for soil already smoothed by rain or irrigation. If the furrow is weedy or blocked by residual stones (after erosion of the fine earth), the value of n may be much greater, up to 0.15.

A program in Excel called PUMA, employing the utility “solver”, was prepared by the consultant to MIROB under the auspices of the irrigation component of the World Bank Cotton Sector Development Project in 1998. An example to illustrate the input and output data is shown in Figure 4. The benefit of “solver” is that it rapidly iterates around the loops of the solution, changing the values of the two controllable variables, flow rate and duration, until stopping when the combination that maximises E_a is reached.

The output of PUMA applied to the basic data and solved for different furrow length, furrow gradient and net irrigation requirement, is summarised for each demonstration field in Annex 1. These are the water management criteria.

3 RECOMMENDATIONS FOR IMPROVED WATER MANAGEMENT

3.1 Gradient and Length of Furrows

The furrows in **all** of the demonstration fields surveyed are too long and too uneven to be irrigated as they have been in the past, if efficiency of water use is to be improved. The original design length varies from 125m on farm Murgap (18) in Marie oblast, to nearly 600m on farm Djambul (03) in S Kazakhstan. More to deal with the problem of uneven slope, many of the fields normally are sub-divided by temporary field canals, which shortens the furrows at the same time.

Most fields are unacceptably uneven, and cutting of temporary field canals could not solve the problem in all cases. The demonstration fields in farms 18 and 35, Marie and Bukhara oblasts, are almost level and have furrows falling in opposite directions in the same field, making improved water management almost impossible. The long furrows on Djambul Farm (03) rise at the start and end, and must be sub-divided and supplied by different field canals, leaving an undrained sump in the middle of the field. The field of farm Talashkan (22) in Surkhandariya oblast is bisected by a ridge, and before the arrival of the RWG a field canal was already cut along it to irrigate the lower half of the furrows. The field of farm Yakkatut (34) in Ferghana oblast is more uniform than most, but a change in soil texture towards the middle of the field has encouraged the field staff to cut a field canal at about the mid-point. This had been suggested as necessary at the March seminar from the earlier PUMA output.

The two steeply sloping fields of farm Sadikov (09) of Osh oblast and 1st May (14) of Leninabad oblast are relatively uniform, particularly the latter. Both are unirrigable at their design lengths and have been subdivided by several temporary field canals. It was recommended during the March seminar that with slopes in excess of 3 percent the Osh field would be unirrigable unless the cotton rows could be planted obliquely across the slope. The supervisor reported that on arrival back after the seminar the field already had been planted directly down the slope as normal. Before the arrival of the RWG, he had already realised the need to sub-divide the furrows by a midway, temporary field canal, but was persuaded of the need to further sub-divide these furrows by two extra canals. The supervisor of the Leninabad field was advised at the March seminar to sub-divide the furrows more than 400m long with more than 2 percent gradient, by at least three field canals. These had been cut before the first irrigation and the farm staff acknowledged that the field was much easier to irrigate, but a further canal is recommended for the lowest section.

The field in farm Timur Malik (24) in Syrdariya oblast was inspected by the Regional Working Group prior to planting and was found to be very uneven because of poor ploughing. The farm director agreed to make a Case Magnum tractor available and modify the linkage of local land planes and sub-soilers to fit. The levels in the demonstration field were much improved by these operations, but are still far from perfect. The field was ripped at 1m intervals across the slope, but as the soil was moist at the time, the ploughpan probably was not fully shattered by the ripping operation. In places, small “sinkholes” appeared over the lines of ripping after the first irrigation. However, the five times greater basic infiltration rate in the demonstration compared with the control field is considered justification enough for this operation, and the apparently much better crop growth is a bonus.

3.2 Duration and Furrow Flow Rate

Provided the field is irrigated on the optimal day, the net irrigation requirement in relation to rooting depth and appropriate depletion factor for the growth stage is shown in Table 7. As the season progresses, the roots penetrate more deeply and the net irrigation requirement increases in proportion. At the same time, the irrigation interval would lengthen were it not for the fact that the daily evapotranspiration from the crop is increasing, at least until the end of July. Due to the compacted subsoil in most fields, the rooting depth is not expected to much exceed 0.7m, except in Farm 14. The net irrigation requirement, unless the crop is stressed far beyond the ideal day of irrigation, therefore will not exceed about 60mm.

Reference to the water management criteria in Annex 1, shows that duration of irrigation is most closely an inverse function of the furrow flow rate and a direct function of the net irrigation requirement. The furrow flow rate, on the other hand is much more a function of the infiltration rate, and the furrow gradient, length and cross section. The inverse relationship between duration and furrow flow rate means that if other conditions minimise the furrow flow rate, then the duration is much longer. This is illustrated in Table 9 using average criteria for eight farms.

Table 9 Average Water Management Criteria for WUFMAS Demonstration Fields
(for a net irrigation requirement of 60mm, n = 0.04)

Farm no.	Field no.	Furrow length (m)	Furrow gradient (m)	Furrow flow rate (l/s)	Duration to cut-off (h)	Application efficiency (Ea %)
3	1	280	0.0006	1.56	6.3	42
9	2	50	0.0230	0.17	19.3	23
14	5	80	0.0250	0.26	7.2	65
18	9	60	0.0005	0.36	6.1	41
22	10	150	0.0025	0.99	18.4	12
24	9	90	0.0010	0.25	9.2	59
34	1	140	0.0025	0.46	5.7	54
35	10	120	0.0001	0.33	22.0	25

Source: output of PUMA with average field parameters. Note: farm 28 is under rice so PUMA output is not relevant.

For the same net application of 60mm, the criteria range from 6.3 hours at a rate of 1.56 l/s (farm 03) to 19.3 hours at a rate of 0.17 l/s (farm 09). However, note that farm 34 requires a shorter time than farm 03 but at only a fraction of the flow rate, and farm 22 requires almost the duration of farm 09 but with much greater flow rate. Therefore, due to the complexity of the effects of field parameters on the best solution, it is impossible to generalise water management criteria between fields.

Farm 22 is unirrigable and an exceptional case, because PUMA was unable to find a solution. The reason is the combination of relatively steep gradient and low infiltration rate. It is impossible to adequately irrigate the crop unless the velocity of water flow is slowed, and is recommended to do this by cutting reeds from the surrounding drains and laying them in the furrow bottoms. This has the effect of increasing the Manning resistance coefficient (n) and enables PUMA to find the solution shown.

3.3 Furrow erosion

An overriding constraint on PUMA finding a solution to the Manning equation is not to exceed the maximum velocity of furrow flow that would cause soil erosion. PUMA calculates the velocity of flow from the flow rate and furrow characteristics. In USBR nomenclature, soil particles between 0.05 and 0.002mm diameter are silt, less than 0.002mm are clay, and are not to be confused with classes used locally, defined by Kachinsky. Typical soils in Central Asia have high silt and low clay fractions, with their low wet strength are the most erodable of all, and a furrow flow velocity of more than 8m/min will cause erosion. Soils with more than 20 percent clay are rare, but where they occur, the maximum flow velocity may safely be increased to 13m/min.

Erosion is a serious limiting factor to the solution on several of the demonstration fields, but most obviously on farms 09 and 14 where slopes are steeper. On arrival of the RWG at farm 09, the consequence of erosion caused by an earlier irrigation was very obvious, with stones and gravel remaining isolated in the furrow bottom after the fine earth had been washed away. This is a self-controlling situation, since these residual stones will slow the furrow velocity and minimise future erosion, as long as there is no further interrow cultivation.

3.4 In-field Water Application Efficiency

In view of the serious limitations that have been discussed above to the scope for improvement in the standard of water use in the demonstration fields, the prospect of WUFMAS achieving its water management target for 1999 is not encouraging. Even were the field staff to follow the recommended water management criteria to the letter, the estimates of Ea for most fields are only moderate and in some cases are low. Only in one field on farm 14, on the colluvial slopes of the Syrdariya River in Tadjikistan where former estimates of E_a have been very low, is it possible that with good management E_a will exceed 60 percent.

The main reason for the expected low values of E_a is the shallow rooting depth of cotton in Central Asia. From the tables criteria in Annex 1, it may be seen that E_a increases sharply with increase in the net irrigation requirement. With roots rarely extending below 70cm, the net irrigation requirement, as explained above, will seldom exceed 60mm. Were it possible to provide the conditions for roots to extend deeper, the net irrigation requirement would then approach or even exceed 100mm and the potential E_a would increase markedly. This is the greatest challenge to improving the application efficiency of water in Central Asia.

The other factor with marked effect on E_a is the furrow length, with optimal length generally rather shorter than is the local conventional wisdom. There is, however, a clear optimum at intermediate length, since E_a falls when furrows are too short.

3.5 Water Management in Rice

When the RWG visited farm Shortanbey (28) in Karakalpakistan, the basins for the rice had been well prepared except that no attempt had been made to puddle the soil to reduce the deep percolation loss. This had been estimated in 1995 by the consultant at 12mm daily, and the rate of fall in water level during May 1999 in the demonstration field from 300 to 200mm confirmed the rate at about 11mm daily. Over a period of 150 days, the deep percolation loss is up to 18tcm/ha, three times greater than the evaporative demand of the crop. Even without tail escape losses, that in a wet year are considerable, the value of E_a is less than 25 percent.

The crop had been sown by broadcasting ungerminated seed into 200mm of very cold water in May. During the visit two weeks later, predictably there was no sign of germination, and later reports confirmed that germination was very poor. This is not acceptable agronomy for serious rice production in an area with a short window of suitable climatic conditions.

3.6 How do Field Staff implement these Recommendations?

Apart from following the recommendations above to cut temporary field canals and shorten furrows, the irrigator only needs to be aware of the optimal duration of irrigation and furrow flow rate for each section of the field. It is recommended that supervisors should place small posts in the field where there is a marked change in furrow length and/or gradient and attach a label to each. When the net irrigation requirement for the next irrigation has been projected, the appropriate values of time and flow rate shown in these tables of criteria may be added to the labels.

Timing the irrigation from start to cut-off of flow into the furrow ought to be easy since watches are freely available. However, these recommendations seriously conflict with customary practice, in which duration is a function of the convenience of the irrigator. Strict supervision will be necessary if required durations are to be observed.

Adjusting the furrow flow to the prescribed rate is very difficult to do in practice. A number of furrow-size Thomson weirs have been supplied, but a minimum hydraulic head is required between the upstream and downstream sides of the weir to give accurate readings. This condition cannot be met in several of the more horizontal fields. It is important to measure the flow rate in the supply or temporary field canal with the Cipoletti weirs supplied, close to the block of furrows being irrigated. This supply flow rate, divided by the prescribed furrow flow rate, gives the number of furrows that may be simultaneously irrigated. This check should be made even if the Thomson weirs are in use in individual furrows.

Management of the rice basins is more straightforward, but care is necessary in minimising the rate of overflow from the basins. This is particularly true in the area of the demonstration field, since most basins discharge directly into drainage collectors and are not cascaded.

3.7 Limitations of these Recommendations

The final requirement of the field supervisors, as explained at the March seminar, is to be aware that these recommendations are only as good as the values of the input parameters to the PUMA program. The model is sensitive to the Kostiakov-Lewis parameters and these have been inadequately measured so far. The model is also sensitive to the furrow shape parameters and the Manning resistance coefficient, and only assumed values have been used in these recommendations. Calibration of furrow flows has been conducted by field staff, and these data will later be used, where possible, to adjust the values of the parameters used, and a third set of recommendations will be issued.

ANNEX 1

WATER MANAGEMENT CRITERIA AND RECOMMENDATIONS FOR DEMONSTRATION FIELDS