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Using Recharge Estimation by the Water Balance Method as a Baseline for Sustainable Groundwater Management in a Water-Scarce Region of Syria

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Abstract

During the period of observation, groundwater abstractions by farmers in Khanasser valley, a water-scarce region of northwest Syria were largely sustainable. This was found by using the water balance method during a period of near average rainfall. As water levels were hardly changing, it was assumed that groundwater abstractions were in balance with net recharge. Agricultural water-use was assessed by monitoring abstractions on 20% of the irrigated area. Total groundwater abstractions in agriculture were estimated by extrapolating the average water-use per crop and irrigation method to the entire mapped irrigated area. Agriculture accounted for about 75% of groundwater abstractions. Domestic water-use was added onto this and the recharge value was estimated at around 2.5% of the average annual rainfall of 210 mm by dividing total groundwater abstractions by the surface area of the two watersheds.

In the past, water levels were dropping due to cotton irrigation in the summer. Although cotton has meanwhile been prohibited in this region by government decree, the danger of overusing groundwater resources still persists due to a gradual expansion of the irrigated area. The farmers should be made aware to maintain the status quo and not to apply more than an average of about 1500 cubic meters per hectare. Water in agriculture is currently used for supplemental irrigation of wheat (60%), barley (17.5%) and cumin (4.5%) from October to May. The rest (18%) is applied in summer, mainly to vegetables and olives. Irrigated crops are compared with regard to water management and income.

Introduction

In many parts of Syria, excessive pumping has caused lowering of the water table with negative effects on the irrigation economy due to higher energy and investment costs. The Syrian Government has ratified legislation to safeguard water resources and to stop or possibly reverse the depletion of aquifers. Cabinet Decision 11 of 5/ 7/ 2000 was issued at a national level to replace the traditional

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irrigation techniques with pressurized irrigation systems within four years and to support farmers with low interest loans for this purpose. Agricultural credit for purchasing new irrigation equipment was made available also for Zone 4, provided well owners had a valid license. Zone 4 receives 200-250 mm annual rainfall and equals about 10% of Syria's land surface.

The Khanasser Valley (Figure1) is located in Zone 4, approximately 80 km southeast of Aleppo. It stretches 20 km between the Jabboul salt lake in the north and the border of the Syrian steppe near Adami village in the south. Basalt plateaus of the tertiary age border the valley in the east and west. The annual average long-term rainfall in Khanasser Valley is 209 mm with about 53 % probability (Bruggeman 2004). The deep calcareous soils in the valley have a silt loam to clay loam texture and basic infiltration rates of around 50 cm/day (Schweers et al. 2004(a). Rearing sheep is the most important source of agricultural income and land-use is dominated by the barley-livestock system. Irrigation is used only on about 4% of the cropped area. Most of the irrigation wells had been installed in the early nineties. As a result of a "well boom", the groundwater tables had dropped. At least, this was indicated by a comparison of a few wells with earlier records (Schweers et al. 2003). In 1998, irrigation of cotton from groundwater in Zone 4 was prohibited. Since then the area planted with olives has expanded and cumin was introduced as a cash crop.

Figure 1. Overview of northwest Syria with Khanasser Valley

The quantification of recharge as a criterion of sustainable groundwater abstractions in dry areas is difficult. Due to accuracy limits, values below 2% cannot be determined even with advanced isotope methods (Geyh 2003). Mathematical groundwater models are useful, but only good at representing complex realities if accurate input data are available. To collect such data is often

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beyond the scope of institutions in developing countries. Simple box models may be used as a substitute for more refined approaches. A box model is based on a simplified concept of the aquifer as a container which receives and looses water in the form of vertical recharge, groundwater abstractions, return flows, evaporation from the aquifer, groundwater inflows and outflows, water imports and exports. The changes in the water table are related to the balance of these processes and aquifer storage, i.e. the higher the storage, the less sensitive the water table reacts to changes in aquifer volume. Inflows, outflows and recharge can be grouped together as "net recharge". In case the balance of imports and exports (i.e. piped delivery of drinking water – transport of groundwater out of the watershed) and evaporation from the aquifer within the domain of the model are not significant, net recharge is in balance with net groundwater withdrawal and the change in storage:

$$R_{net} = Q_{net} \pm dS \qquad \text{(Equation 1)}$$

where:

R_{net} = net recharge (inflow-outflow+recharge)

Q_{net} = net groundwater withdrawal (abstractions-return flows)

dS = (±) change of storage in the unconfined aquifer of the watershed.

The change in storage equals the change in the average water level multiplied by the storage coefficient. For example, if an aquifer of 100-km^3 extent has 0.5% storage and the water level drops by 20 cm, it looses 100,000 m^3 (1,000,000 m^3/km^3, 100 km^3 x 0.005 x 0.2 m/m). Aquifer geometries can be determined from information on the stratification of wells or geoelectrical investigations. The storage coefficient can be computed from pumping test results. If the storage is not known for lack of reliable data, net recharge can still be approximated from well-determined groundwater abstractions if the groundwater table happens to remain at the same level over the period, i.e. if there is practically no change in storage. This method will produce an average recharge value under the condition that the average rainfall during the period of observation is near the long-term average.

Materials and Methods

Rainfall was recorded from automatic weather stations. Pumping tests were made in thirteen wells and evaluated with the Jacob-Cooper and the Theiss recovery method (Krusemann and Ridder, 1970). Irrigated areas were mapped using a GPS. Agricultural groundwater abstractions were assessed by irrigation monitoring during two consecutive seasons and the resulting average abstraction volumes of the monitored areas were extrapolated to all mapped areas with the same crops and irrigation methods (Schweers at al 2004(b). Since rainfall during the monitored seasons of 2002/03 and 2003/04 was above average, a fictitious dry year with 30% higher abstractions than the average of the monitored seasons was added to estimate long-term abstraction averages for winter crops. In the case of summer crops, the findings during the monitored seasons were considered representative. Groundwater abstractions from the cretaceous aquifer were taken as 50% effective for the water balance of the first aquifer. This was based on the observation, that the deep wells need to be pumped for about two days until the water is purely cretaceous (most deep boreholes are not lined).

Domestic water use assessment was based on average abstractions per capita and per head of livestock. Population figures were taken from Mazid and Al Hassan (2002). The operator of the distribution point at Rasm Anafl in the northern part of the valley gave information on the import of Euphrates water. Export volumes to the steppe basin were estimated from observations of an elder who had observed the movement of vehicles with water containers out of the Hobs-Harbaqiye valley, a side valley of the southern watershed with low-salinity water. Agronomic and economic data were raised during interviews with farmers.

Economic data were collected through interviews in consultation with the NRMP socio-economists to get base data for the calculation of crop budgets. The rainfed net income was subtracted from the net income derived by irrigating the same crop. The differential net income (irrigated-rainfed) was then divided by the amount of abstracted groundwater to show the average incremental income per unit of water resource. Family labour, whether paid or unpaid was not accounted as a real cost. Rather, the differential net income was divided by the total family labour hours spent with the irrigated crop (including irrigation hours) to show how much extra income per hour was generated as a result of irrigation.

Results

Sustainable Groundwater Abstractions

The alluvial quaternary aquifer was mostly confined or semi-confined, with low storage (Table 1), which indicated that the water level reacted easily to changes in aquifer volume. A storage coefficient for the limestone aquifer (Paleogene) could not be determined, because in a fractured aquifer, the reaction of observation wells depends on the chance that they are situated on a fracture. Mostly, there was no reaction of observation wells, even if they were quite close to the main well. The fact, that most Paleogene wells were not very productive and that farmers used *Arabic wells* with large storage receiving water from horizontal borings of several hundred meters lengths (Hoogeveen and Zöbisch 1999), illustrated a comparatively small dimension of specific storage in the unconfined aquifer of maybe as low as $2{\cdot}10^{-2}$ m^{-1} (≈ 2%) or even lower.

Table 1. Average aquifer characteristics derived from pumping tests

Aquifer	Trans-missivity (m²/day)	Hydraulic conductivity (m/day)	Storage coefficient	Specific storage coefficient (m-1)
Quaternary	86.7	17.8	2.6E-03	3.2E-04
Paleogene	2.9	0.07	-	-

Rainfall during the period of observation was near the long-term average (Fig.2). Despite seasonal fluctuations, the water level over the entire period remained more or less constant (Fig.3). Based on the monitoring results in the 2002-04 seasons and an estimate of 30% higher water-use for a dry year (Table 2), the following rounded average water-use was computed for winter crops: 140 mm

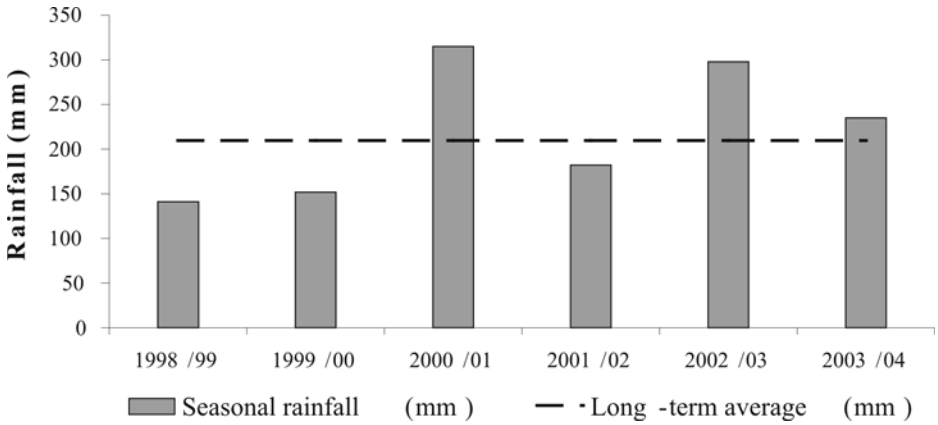

Figure 2. Seasonal rainfalls during the period of observation

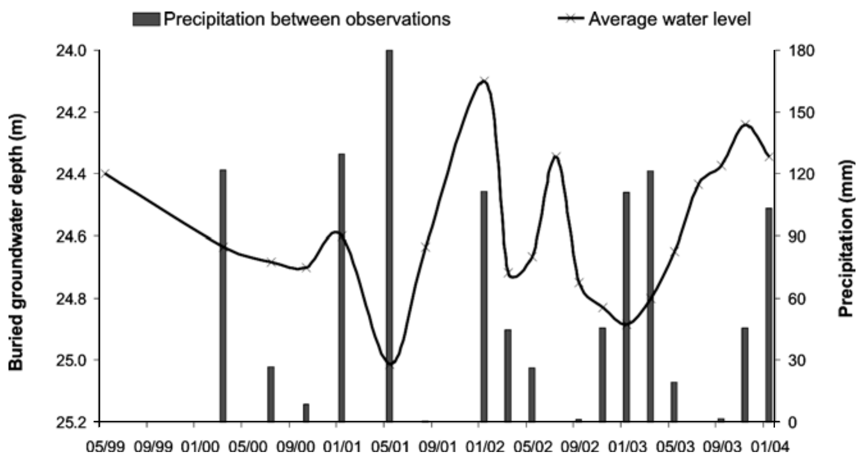

Figure 3. Fluctuations of the water level in response to precipitation

Table 2. Monitored area and water use of winter crops

Crop		Barley		Cumin	Wheat	
Irrigation method		Sprinkler	Surface	Sprinkler	Sprinkler	Surface
Monitored fields		9	5	5	12	7
Monitored area (ha)		26.8	6.8	7.8	37.5	14.6
Water-use (mm)	2002-03	95	145	27	105	327
	2003-04	134	215	84	146	320
	Dry year*	150	234	73	163	421
	Average	126	198	61	138	356

Note: *estimate (monitored average + 30%)

(wheat-sprinkler), 360 mm (wheat-surface), 130 mm (barley-sprinkler), 200 mm (barley-surface) and 60 mm (cumin-sprinkler). Under this scenario, an estimated 790,000 m^3 (82%) are abstracted for supplementary irrigation of wheat (60%), barley (17.5%) and cumin (4.5%) and 176,000 (18%) for summer crops (Table 3).

Table 6. Average agronomic data of monitored farms in 2002-04 (winter crops)

Parameters	Barley-sprinkler	Barley-surface	Barley-rainfed	Cumin-sprinkler	Cumin-rainfed	Wheat-sprinkler	Wheat-surface	Wheat-rainfed
No. of monitored fields	9	5	12	5	4	12	7	11
Monitored area,(ha)	26.8	6.8	71.7	7.8	22.5	37.5	14.6	39.2
Dominant Variety	Arabi aswad	Arabi aswad	Arabi aswad	Local	Local	Cham 6	Cham 6	Cham 6
Planting date	01/11/02	28/10/002	25/11/002	31/12/02	30/12/02	26/11/02	29/11/02	21/11/02
Harvesting date	16/05/03	14/05/03	15/05/03	15/05/03	17/05/03	26/05/03	27/05/03	27/05/03
Growing period (days)	196	198	171	135	138	181	181	187
Seed rate (kg/ha)	237	310	146	37	34	241	321	153
Yield 2002-03 (kg/ha)	2174	2762	1959	500	471	3175	3472	1856
Yield 2003-04 (kg/ha)	1464	1834	928	522	511	1696	3445	1162
Yield average (kg/ha)	1819	2298	1444	511	491	2436	3459	1509

Table 7. Average water use data of monitored farms in 2002-04 (winter crops)

Parameters	Season	Barley-sprinkler	Barley-surface	Cumin-sprinkler	Wheat-sprinkler	Wheat-surface
EC of irrigation water (dS/m)	2002-03	7.2	11.7	4.9	5.8	10
EC values (min-max)	2002-03	3.3-14.2	8.4-16.8	2.5-7.9	2.3-11.4	3.3-14.2
Crop water requirements (mm)	2002-03	372	372	259	390	390
	2003-04	379	379	269	423	423
	Average	376	376	264	407	407
Effective rain (mm)	2002-03	284	284	228	268	268
	2003-04	218	218	177	209	209
	Average	251	251	203	239	239
Net irrigation requirement (mm)	2002-03	88	88	31	122	122
	2003-04	161	161	92	214	214
	Average	125	125	62	168	168
Water-use (mm)	2002-03	95	145	27	105	327
	2003-04	134	215	84	146	320
	Average	115	180	56	125	324
Factor water-use/ Irrigation requirement	2002-03	1.1	1.6	0.9	0.9	2.7
	2003-04	0.8	1.3	0.9	0.7	1.5
	Average	1.0	1.5	0.9	0.8	2.1
WUE_{rf} (kg/ha·mm)	2002-03	9.0	9.0	2.1	6.9	6.9
	2003-04	4.3	4.3	2.9	5.6	5.6
	Average	6.6	6.6	2.5	6.2	6.2
WUE_{tot} (kg/ha·mm)	2002-03	5.7	6.5	2.0	8.5	5.8
	2003-04	4.2	4.2	2.0	4.8	6.5
	Average	4.9	5.4	2.0	6.6	6.2
WUE_{ir} (kg/ha·mm)	2002-03	2.1	5.7	1.1	12.1	5.2
	2003-04	4.0	4.2	0.1	3.7	7.1
	Average	3.0	5.0	6.0	7.9	6.2

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Table 3. Agricultural groundwater abstractions

Crops		Irrigation method	Average water use (m^3/ha)	Northern watershed		Southern watershed		Total area			
				Area (ha)	WU@ (m^3)	Area (ha)	WU (m^3)	Area (ha)	WU (m^3)	Area (ha)	WU (m^3)
Winter crops	Wheat	sp*	1400	77.9	109060	143.7	201180	221.6	37.0	310240	32.2
	Wheat	su**	3600	26.2	94320	53.9	194040	80.1	13.4	288360	29.9
	Reflowwh (8%)	su	-288		-7546		-15523			-23069	-2.4
	Barley	sp	1300	38.8	50440	50.5	65650	89.3	14.9	116090	12.0
	Barley	su	2000	7.1	14200	21.2	42400	28.3	4.7	56600	5.9
	Reflowba (4%)	su	-80		-568		-1696			-2264	-0.2
	Cumin	sp	600	21.8	13080	46.7	28020	68.5	11.4	41100	4.3
	Others (e.g. lentils)	sp	800	1.6	1280	0.1	80	1.7	0.3	1360	0.1
	Total/areal average		1611	173.0	274266	316.0	51451	490.0	81.7	788417	81.7
Summer crops	Vegetables	su	3300	2.5	8339	6.0	19800	8.5	1.4	28139.1	2.9
	Vegetables	dr***	4500	1.0	4500	2.8	12600	3.8	0.6	17100	1.8
	Cotton	su	13500	2.7	36450	5.6	75600	8.3	1.4	112050	11.6
	Olives	su	300	19.8	5940	16.4	4920	36.2	6.0	10860	1.1
	Olives	dr	250	1.4	350	2.3	575	3.7	0.6	925	0.1
	Olives	ta	140	17.3	2422	28.9	4046	46.2	7.7	6468	0.7
	Others (Pistachios)	su	160	2.8	12600	3.0	480	3.0	0.5	480	0.0
	Total/areal average		1600	45.0	58001	65.0	118021	110.0	18.3	176022	18.3
	Total / areal average		1609	218.0	332268	381.0	632172	599.0	100.0	964439	100.0

@WU = Water use, *sp = Sprinkler, **su = Surface basin, ***dr = Drip

In contrast to the situation in 1998/99 (Hoogeveen and Zöbisch 1999) when sprinkler irrigation was exceptional, during the period of 2002-2004, sprinklers were used on 64% of the irrigated area and delivered 49% of the total irrigation water (Fig.4). The rest was mainly basin irrigation. Return flow from surface irrigation was roughly estimated at 8% (wheat) and 4% (barley).

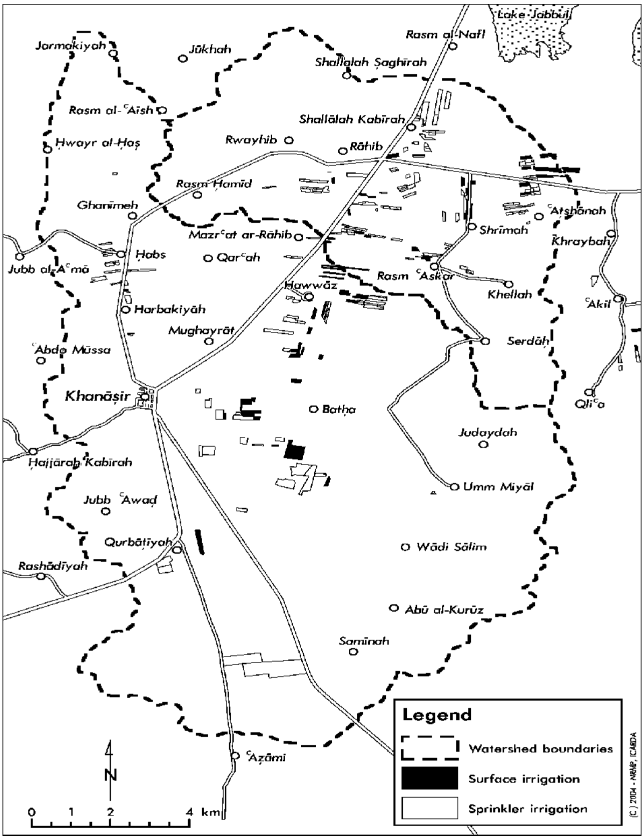

Figure 4. Khanasser Valley, 2002-03 cropping season: Fields irrigated by sprinkler irrigation and surface irrigation (from Schweers et al. 2004(b)

Net water import into Khanasser valley amounted to 30,000 cubic meters or 10% of total domestic abstractions (Table 4). The domestic water-use per capita was approximately 54 litres per day (l/day), 10 litres more than the middle-east average (FAO 2004). According to the estimate, total drinking water consumption reached 100,000 litres. Local and migrant sheep consumed nearly as much water as the inhabitants of the valley. The remainder, about 50% of the total was used for cleaning, washing, and the irrigation of vegetables in home gardens.

Under the condition, that during a period of average rainfall groundwater abstractions were largely in balance with recharge, the net recharge estimate (+/-20%) ranged from 1.9% to 2.9% of the long-term seasonal average (Table 5). For an irrigated area of 600 ha, this results, in an average equivalent abstraction of 160 mm/ha.

Table 4. Domestic groundwater abstractions

Domestic water-use		Estimated per-capita consumption (m^3/day)	No. of days	No. of residents		Water use (m^3/yr)		
				North	South	North	South	Total
Drinking water, sanitation	Residents	0.020	365	5475	5775	39968	42158	82125
	Migrants	0.020	240	1825	1925	8760	9240	18000
	Total	-	-	7300	7700	48728	51398	100125
	Water import	-	-	-	-	30000	20000	50000
	Effective	-	-	-	-	18728	31398	50125
Livestock	Residents	0.005	365	12000	28000	21900	51100	73000
	Migrants	0.005	90	6000	14000	2700	6300	9000
	Total			18000	42000	24600	57400	82000
Other	Cleaning, Washing, Gardens	-	-	-	-	60909	89946	150855
	Water export	-	-	-	-	-	21000	21000
Total domestic	-	-	-	-	-	104237	199743	303980

Table 5. Total water-use and recharge estimates

	North		South		Total	
	m^3	%	m^3	%	m^3	%
Agricultural water use	332268	34.5	632172	65.5	964439	76.0
Domestic water use	104237	34.3	199743	65.7	303980	24.0
Total water use	436504	34.6	831915	65.4	1268419	100.0
Watershed area (ha)	7640	30.3	17610	69.7	25250	100.0
Water use (mm)	5.7		4.7		5.0	
Average rainfall (mm)	209		209		209	
Net recharge (%)	2.7		2.2		2.4	
NR x 0.8 (%)	2.2		1.8		1.9	
NR x 1.2 (%)	3.3		2.7		2.9	

Agricultural Water Management

Seed rates of wheat and barley (Table 6) were found to be higher than recommended by the Ministry of Agriculture (Haddad 2004). To explain the difference, some farmers mentioned bird damage and claimed to have better results with higher seed rates. Irrigated yields in the monitored seasons were more representative of average conditions than rainfed yields, which were higher due to good rainfall in the 2002-03 season. Rainfed wheat yields in 2003-04 were also comparatively good.

The salinity of the irrigation water applied to winter crops was highest for barley, lower for wheat and lowest for cumin (Schweers et al. 2004(a). More saline water was used preferably with surface irrigation methods. On average, about one third more water was applied to winter crops than needed to satisfy the crop water requirements (Table 7). In this context, the irrigation water-use efficiency is defined as the differential yield (to rainfed yield) in kg per ha·millimetre of abstracted irrigation water. For sprinkler-irrigated wheat (7.9 kg/mm), it was higher than the rainwater use efficiency (6.2 kg/mm). In the wet 2002-03 seasons, supplemental sprinkler irrigation achieved the best water productivity (12.1 kg/mm). In the following season with just above average rainfall and a long dry period in spring, surface irrigation was more productive.

Physical water-use efficiency ratios are meaningful to compare yields within one crop or between irrigation methods, whereas the economic efficiency of water resources can better support decisions of choice. Table 8 shows an economic comparison of irrigated crops grown in Khanasser valley: Grazing lambs in early spring increases the profitability of sprinkler-irrigated barley. According to Pape-Christiansen (2001), 144 kg life weight gain during 6 weeks of grazing produce 13,700 SL (Syrian Lira) gross incomes. In return to labour input, wheat turned out to be the most profitable crop. Irrigation of cumin at low application rates yielded 14 SL per ha·mm. The economic water use efficiency (net income/ irrigation) of summer crops was higher than that of winter crops, which derive only an incremental income (to the rainfed income) from irrigation. The profitability per land unit was highest in the case of irrigated vegetables. Olives achieved the best irrigation benefit.

Discussion

Sustainable Groundwater Abstractions

During a trial with surface-irrigated wheat in the 2003/04 seasons, the soil water balance showed an excess of about 25% of total supplied water (rain + irrigation) over crop evaporation. The average of twelve soil moisture measurement locations was equivalent to 109 mm or 27% of irrigation. It was assumed that most of the drained water, (about two thirds) would be temporarily stored below the root zone (105 cm) in the deep soils and still evaporate from there during the following dry season. The effective return flow would then be approximately 8%. The resulting value is in the range of irrigation return-flow values mentioned by Hobler (2002) for Agricultural Productivity Zone 4.

Farmers of Rahib-Roehib mentioned that they harvest about 30% more on drip-irrigated plots than on surface-irrigated plots. They found, that the amount of water used per unit area had been higher with drip irrigation. Most vegetables, e.g. cucumber have a shorter growth period than cotton, which requires 6-7 months. They are grown successively on adjacent plots, which reduce the irrigation volume per unit area. For cotton, Haj-Dibo (2003) observed irrigation amounts of 8500 m^3 (drip) and 11500 m^3 (furrow) in two fields near Tel Hadya. Hoogeveen et al. (1999) determined an average of 34,000 m^3 in Khanasser Valley. In South-Australia, tomatoes and cotton received similar amounts of water: 5500 – 14,500 m^3 (Thomson 2004). Irrigation of olives was low due to the fact that the average age of plantations in Khanasser was only about 5-6 years. Few farmers used drip-irrigation for olives, like the owner of well No. 89, who filled a reservoir from his well that had enough water for only 1-2 hours/day and irrigated the olives by

Table 8. Water use economy of irrigated crops in Khanasser valley (in SL/ha)

Crop		Winter crops					Summer crops			
		Barley		Cumin	Wheat		Vegetables		Olives	
Irrigation method		Sprinkler	Surface	Sprinkler	Sprinkler	Surface	Drip	Surface	Drip	Surface
Income	Yield (kg/ha)	*1819*	*2298*	*525*	*2436*	*3459*	*45283*	*40250*	*2464*	*1971*
	Income (SL/ha)	12733	16086	25200	25578	36320	259783	196458	73929	59143
	Yield of byproduct, e.g. straw (kg/ha)	*3092*	*3907*	-	*4141*	*5880*	-	-	-	-
	Income from byproduct (SL/ha)	7731	9767	-	10353	14701	-	-	-	-
	Other income, e.g. grazing (SL/ha)	13680	-	-	-	-	-	-	-	-
	Total income	34144	25853	25200	35931	51020	259783	196458	73929	59143
Expenditure (excl. family labour)	Cultivation	800	2000	1488	800	2000	2000	2000	960	960
	Establishment	2296	2880	2716	39534	5034	8367	8667	381	381
	Fertilization	2226	3442	1268	3372	3832	46000	46000	4520	4520
	Crop protection	-	-	1535	950	950	27750	27750	2207	2207
	Irrigation	1656	2500	750	1719	4500	8100	3650	1125	749
	Harvest	2760	4103	3542	4041	6035	20000	20000	24000	24000
	Other operation costs	6840	-	-	-	-	41073	28750	5255	5255
	Capital costs	7060	4180	7060	7060	4180	22210	3000	4180	4180
	Total expenditure	23638	19105	18358	21896	26530	175499	139817	42629	42253
Irrigated net income	10505	6748	6842	14035	24490	84284	56642	31300	16890	
Rainfed	*Grain yield*	*1011*	*1011*	*494*	*951*	*951*	-	-	-	-
	Gross income	11372	11372	23712	14027	14027	-	-	-	-
	Expenditure	4878	4878	17724	6670	6670	-	-	-	-
	Net income	6494	6494	5988	7357	7357	-	-	-	-
Differential income (irrigated - rainfed)	4012	254	853	6678	17133	-	-	-	-	
Water	*Irrigation amount (mm)*	*130*	*200*	*60*	*140*	*360*	*450*	*330*	*90*	*60*
	Net irrigation benefit/cost (SL/mm/ha)	30.9	1.3	14.2	47.7	47.6	187.3	171.6	347.8	281.5
Labour	Irrigation labour (hrs/ha)	88	133	50	92	240	141	219	30	40
	Other family labour (hrs/ha)	126	44	228	48	66	2295	2295	1284	1284
	Total family labour (hrs/ha)	214	177	278	140	306	2436	2514	1314	1324
	Irrigation labour income (SL/hr)	18.7	1.4	3.1	47.7	56.0	34.6	22.5	23.8	12.8

Note: SL= Syrian Lira

gravity. Tubeileh et al. (2004) calculated an irrigation requirement for mature trees in Khanasser valley.

A complete water balance would have to include an outflow component in the form of underground leakage into *sabkhas*, lake Jabboul in the northern watershed and the Karaitch depression (Wolfart 1966) in the southern watershed. In this study, the lower parts of the watershed, where water is too saline for irrigation have not been included in the domain of the water balance (see delineation of watersheds in Figure 4). An outflow component was not considered, as the water levels in the upper part of the basin were reflecting the balance between water use and net recharge (= recharge – outflow).

It must be conceded that there are a number of uncertainties in the water balance, from the accuracy and representativeness of the abstraction assessment to the concept that recharge during the period of observation was in balance with groundwater abstractions. Yet, an average value of 1500-m^3/ha abstractions for an irrigated area of around 600 ha could be taken as a point of departure for delineating sustainable groundwater abstractions. However, further observations should be made to validate the dimension of an average sustainable abstraction value.

Agricultural Water Management

Despite the fact, that on average, the physical water-use efficiency of sprinkler-irrigated wheat was 25% higher than surface-irrigated wheat, for the two observed seasons, the net irrigation benefit per unit of water (SL/ha·mm) and labour (SL/labour hr) was equal for both methods (~50 SL). Moreover, the net irrigation benefit per unit of land was about twice as high in the case of surface irrigation due to higher yields. A categorical condemnation of surface irrigation as "out-of-date" in dry areas, such as Agricultural Stability Zone 4 of Syria is certainly not justified. Surface irrigation deserves a more differentiated view. Farmers with lower quality water usually have no alternative for staple food production in such areas. Farmers like well owner No. 27 from Atshaneh village proved that surface irrigation, with good land levelling and diligent irrigation management can easily top the water use efficiency of sprinkler irrigation under near average seasonal rainfall conditions (WUE_i > 20 kg/ha·mm; EC_i 3.2 dS/m; P = 235mm).

Barley was apparently not worth irrigating unless it served to bridge a serious gap in moisture supply at a crucial development stage. However, this statement does not take into account the fact that the farmers are using barley – which is more in the case of irrigated production - as ration for sheep fattening, a largely profitable enterprise. Similarly, the irrigation of barley for the purpose of rearing sheep in early spring, when other grazing sources are rare, is a profitable activity. Especially lambs can grow well on the fresh barley shoots. Sprinkler irrigation is the method of choice, because it stimulates vegetative growth, at least if the water is not saline and the air temperature still moderate. The farmers are watering barley quite intensively until tillering. Then the sheep must be kept out, not to harm generative growth further than already the case from the reduction of assimilating biomass. Generally, barley is not receiving much water after grazing has stopped.

On average, irrigating cumin was profitable, however, profitability depends on the market price of cumin, which undergoes frequent fluctuations. In the context of this study, a price of near 50 SL/kg was assumed representative as cumin prices were fluctuating within a range of about 30 SL/kg to 70 SL/kg. Irrigating cumin after flowering and with an EC of more than 6 dS/m was usually not beneficial. In some cases too much water boosted the growth of weeds that ended up suffocating the tiny plants. Cumin cultivation is labour intensive. Weeding and harvesting were quite costly if cheap family labour was not available. Herbicides, such as Afalon® could be applied without harm to the host crop only during the early development stages.

Growing vegetables appeared to be quite financially attractive, besides being a source of healthy food that carries an opportunity benefit for not having to be purchased at higher rates than the production cost and transported from far. However, this enterprise requires experience, skills and a considerable amount of labour. Plots of 5 donum (0.5 ha) demand about 1200 labour hours or 200 man-days per summer season. Investment costs for drip equipment were approximately 100,000 SL/ha with short depreciation periods for tubes and fittings. Sufficient income is therefore needed to pay back the investment. Some risks remain in form of market price fluctuations and diseases or pests. Good quality water (< 4 dS/m) is conditional, since many vegetables, for example cucumber yield less than 50% of their potential at an EC of the irrigation water above 4 dS/m (Ayers and Westcot 1994). According to Tubeileh et al. (2004), care must be taken with intercropping of olives and vegetables, as they could be a source of *Verticillium* wilt for the trees.

In view of the relatively low irrigation requirement of olives trees, the economic efficiency of applying water to olives was found to be high. Whereas the assumption that olives do not yield without irrigation or water harvesting in Khanasser valley may not be true in exceptionally good rainfall years, the yield of rainfed olives in the valley remains below a commercially lucrative level under average rainfall conditions. The popularity of olive trees as a potential source of income was evidenced by the cumulative number of trees planted (Tubeileh et al. 2004). With sufficient quality water (~ 6 dS/m; Gucci and Tattini 1997), more land than water, family members who can help with the harvest, and with knowledge of tree husbandry, olive groves are clearly of interest to farmers in Khanasser valley. Provided Syria manages to further promote export sales of good quality olive oil, the price level should remain profitable.

With few options available, the Khanasser farmers usually opt for a mix of products, practicing risk minimization. Unknown external factors, such as marketing, prices and policies make rational optimization of water resource use a difficult task. On most farms land is not the limiting production factor. Besides water, being the scarcest, labour availability can also be decisive. Farmers with sheep have a preference for barley, those with access to family labour opt for summer crops or cumin if they speculate on a short-supplied market, and those with few children to help in agriculture might prefer extending the irrigated area grown with wheat. Of course, the construction of wells and the purchase of pumps and motors or pressurized irrigation systems require capital, which poorer farmers simply lack. Therefore the financial resources, including income from activities outside the farm, also determine what is feasible.

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The crop rotation in this marginal environment is fairly monotonous. So far, only crops, which can provide some yield without irrigation, have occupied a lasting position in the production system. This only confirms that Khanasser farmers are avoid risks and do not prefer to depend entirely on irrigation. It would be most desirable to increase the diversity of the current crops rotation, for example, with drought resistant legumes and oil crops. Sturdy windbreaks, which produce fodder or wood, could reduce advective evaporation and save some soil moisture for better plant production. Manuring the Khanasser soils is expensive, but it is worth the investment. Apart from creating better soil fertility and structure, manure also improves soil moisture characteristics (Martens and Frankenberger 1992). Not only irrigation, but also the right management of soil moisture in rainfed systems can help improve the productive and economic potential in dry areas. As long as it remains within the sustainable limits (~ 150mm on around 600 ha), irrigation is acceptable in Khanasser valley, but one should keep in mind that the economic benefit from irrigation is often marginal and sometimes negative. Some farmers are helping themselves with record keeping and simple accounting to check profitability and keep past agronomic and economic data for reference.

Summary and Conclusions

Since the water level was predominantly stable during the period of observation and since the storage coefficient found during pumping tests was not high act indicated conditions of responsiveness to changes in storage. It was concluded that at the present rate, groundwater use in Khanasser valley was largely sustainable and in balance with an estimated 2-3% average annual net recharge. At 50-60 l/capita·day, domestic water use including the watering of sheep consumed roughly 25% of 1.3 million m^3 annual abstractions from the first aquifer. The rest was consumed by irrigation. From the water balance estimate, an average seasonal abstraction of 150 mm/ha from the first aquifer on 600 hectares was considered acceptable. This finding was largely credited to a change in the composition of the irrigated area starting at the end of the nineties, with more and more olives and the near total disappearance of cotton after it was banned from tube well irrigation in Agricultural Stability Zone 4.

Growing cumin had become quite common in the crop rotation, and some of it was irrigated. This made sense in case of a significant deficit before flowering, provided, the water was of an appropriate quality. Barley was unattractive as a source of cash income by itself. However, the sheep economy benefited from an increased production of ration feed and a source of grazing on sprinkler-irrigated fields after the birth of lambs in early spring. Wheat accounted for 50% of the irrigated area (about three-fourth of it under sprinkler irrigation) and 60% of irrigated volume. In view of a high irrigation productivity (6-8 kg/ha·mm), labour productivity and considering the price of wheat during the period, at the product price of the period of observation, wheat was still a good source of income for the farmers of Khanasser valley: 48 Syrian Lira per ha·mm and about 50 SL per family labour hour (~1 US $) with application of 140 mm (sprinkler) and 360 mm (basin) and corresponding yields of around 2400 kg/ha (sprinkler) and 3500 kg/ha (basin).

Family labour was an asset for those farmers who ventured into vegetables or olives due to the high labour requirement. On the observed farms, drip-irrigated vegetables were better supplied with water and therefore more productive. With good performance and sufficient demand of vegetable products, the income per ha could be as high as 84,000 SL/ha, but this required 2400 labour hours. Olives were also labour intensive, especially at harvest, which becomes costly without cheap family labour. The net benefit per unit of good quality water applied to well-adapted olive varieties with proper management was highest: around 300 SL/ha·mm at 75 mm/ha for mature orchards. In a water-scarce area like Khanasser such high water productivity is an advantage. Due to related costs, an incremental benefit from irrigation cannot be taken for granted and water needs to be applied wisely to be profitable. The fragility of the natural environment was reflected by a fragility of the production system and its economic viability even with the use of irrigation. As socio-economic factors and environmental factors are intricately linked, the economic feasibility of agricultural enterprises is a key element conditioning the sustainable use of natural resources in marginal dry areas.

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References

Ayers R.S. and Westcot, D.W. 1994. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev.1. FAO, Rome, Italy.

Bruggeman, A. 2004. Long-term computations based on meteorological observations by ICARDA and GRUZGIPROVODKHOZ, 1982, unpublished.

FAO. 2004. Country water profiles. Aquastat internet database.

Geyh, M. 2004. Verbal statement of the isotope specialist Prof. Geyh on the difficulty of determining low recharge rates with istotope methods due to limitations of the detection limits and piezometric acuracy. Meeting with ICARDA water resource scientists on 31 May 2004, Aleppo.

Haddad, A. 2004. Personnal communication. Agronomy section, Natural Resource Management Programme, ICARDA.

Haj-Dibo, A. 2003. Field notes: Comparative water–use of cotton with furrow irrigation and drip irrigation on a clay soil near Tel Hadya in the summer of 2002.

Hobler, M. 2002. Personnel communication at BGR/ACSAD, Damascus.

Hoogeveen, R.J.A. and Zöbisch, M. 1999. Well inventory and groundwater in the Khanasser Valley, Syria. Report on a field study in northwestern Syria. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. Mimeo.

Krusemann, G.P. and Ridder, de, N.A. 1970. Analysis and evaluation of pumping test data. – Bulletin11, ILRI, Wageningen, the Netherlands.

Martens, D.A. and Frankenberger Jr., W.T. 1992. Modification of infiltration rates in an organic-amended irrigated soil. Agronomy Journal 84: 707-717.

Pape-Christiansen, A. 2001. Intensification of Rainfed Agriculture in Northern Syria – Implications of Perennial Crops and Irrigation on Farm-Household Development. In: Farming and Rural Systems Economics Vol 102 (Eds., Doppler W. and Bauer, S.). Wissenschaftsverlag Vauk Kiel K.G., Kile; Germany. 279 p.

Schweers, W., Bruggeman, A., Rieser, A., Abu-Zhakem, B., Asfahani, J., Kadkoy, N. and Kasmo, B. 2003. Assessment of groundwater resources for sustainable management in the Khanasser valley, northwest Syria. Proceedings of ACSAD/BGR Workshop on Soil and Groundwater Quality: Monitoring, Management and Protection, Amman, 23-25 June, 2002.

Schweers, W., Oweis, T. and Rieser, A. and Singh, M. 2004a. Farmer-participatory research on water-use efficiency and irrigation benefit of wheat production in a low-rainfall zone of Syria. Deutscher Tropentag 2004. Berlin, October 5-7, 2004. Conference on International Agricultural Research for Development, Humboldt-Universität, Berlin. 8p.

Schweers, W., Bruggeman, A., Rieser, A. and Oweis, T. 2004b. Water-use by farmers in response to groundwater scarcity and salinity in a marginal area of Northwest Syria. Journal of Applied Irrigation Science 39(2): 241-252.

Thomson, T. 2004. The range in irrigation practices in South Australia. Unpublished technical note.

Tubeileh, A., Bruggeman, A. and Turkelboom, F. 2004. Growing olives and other tree species in marginal dry environments. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. 106 p.