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Analysis of water use and crop allocation for the Khorezm region in Uzbekistan using an integrated hydrologic-economic model

ABSTRACT

Sustainable and efficient water management is of central importance for the dominant agricultural sector and thus for the population and the environment of the Khorezm region. Khorezm is situated in the lower Amu Darya river basin in the Central Asian Republic of Uzbekistan and the delta region of the Aral Sea. Recently, Khorezm has experienced an increase in ecological, economic and social problems. The deterioration of the ecology is a result of the vast expansion of the agricultural area (which began in the Soviet period in Uzbekistan), the utilization of marginal land and a very intensive production of cotton on a significant share of arable land. Supplying food for an increasing population and overcoming with the arid climate in Khorezm require intensive irrigation. However, the water distribution system is outdated. Current irrigation strategies are not flexible enough to cope with water supply and crop water demand, as both are becoming more variable. The political system, with its stringent crop quotas for cotton and wheat, nepotism, missing property rights and lack of incentives to save water, has promoted unsustainable water use rather than preventing it.

The focus of this study is an analysis of more economical and eco-efficient water management and crop allocation. The effects of political incentives as well as modified technological, environmental and institutional conditions, such as the reform of the cotton sector, the introduction of water prices and the improvement of the irrigation system, are evaluated regarding regional water distribution, crop allocation and economical outcomes. As a result, the basic hydrological and agronomical balances and characteristics in the Khorezm region are highly important and need to be identified. To adequately analyze these underlying conditions, an integrated water management model was chosen. The novelty of this study is the combination of interdisciplinary aspects in a theoretically consistent modeling framework. Essential hydrologic, climatologic, agronomic, institutional and economic relationships are integrated into one coherent optimization model for the Khorezm region. The capacity of the model to consider canal water and groundwater is of special importance. Furthermore, the water balance approach (accounting for water input and output) has an advantage over the static norm approach when used to determine irrigation requirements.

Simulations with the model indicate that a modification of the regional water supply, either politically or anthropogenically induced, has a large influence on the total irrigation, groundwater and drainage-system as well as the soil water budget in Khorezm. The model simulations suggest that low water supply causes a shift in the crop allocation to less water-demanding crops such as vegetables, wheat, alfalfa and fruits, which also have a higher value added in economic terms. When higher water supply is available, the cultivation of water-demanding rice, a crop that is favored by the local population, would become more advantageous due to higher gross margins. Simulations on an improvement of water distribution and irrigation systems indicate that infiltration losses could be diminished, especially at the field level. Furthermore, this would lead to an increase in additional available crop water supply, with positive impacts on crop yields. The simulation results further indicate that a complete liberalization of the cotton sector would lead to a fundamental restructuring of the crop allocation to less water-demanding crops and higher economically valued crops. This reform of the cotton sector would also lead to a general reduction of acreage with full

compensation for the losses caused by the abolition of cotton subsidies and quota system. Marginal land could be reduced. However, the abolition of subsidies and secured crop sales prices by the government would increase the risk for farmers. Finally, the modeling results indicate that the introduction of water pricing could be an important instrument to induce environmental consumer awareness, which could lead to resource conservation. As a result of the extremely low gross crop profit margins in Khorezm, only a water price on a very low level could feasibly be implemented in this region.

KURZFASSUNG

Untersuchung der Wassernutzung und Pflanzenbewirtschaftung in der Region Khorezm (Usbekistan) unter Nutzung eines Integrierten Hydrologisch-Ökonomischen Modells

Nachhaltige und effiziente Wasserbewirtschaftung sind von besonderer Bedeutung für den dominanten Agrarsektor und damit für die Bevölkerung und Umwelt in Khorezm. Die Region Khorezm befindet sich im Unterlauf des Amu-Darya Flusseinzuggebietes in der zentralasiatischen Republik Usbekistan und in der Delta-Region des Aral Sees. Khorezm´s jetzige Situation ist gekennzeichnet durch ökologische, ökonomische und soziale Probleme. Die Schädigung der Ökologie ist im Wesentlichen durch die gewaltige Ausdehnung der landwirtschaftlichen Nutzfläche (mit ihrem Beginn während der Sowjetperiode in Usbekistan) und der steigenden Nutzung von Grenzertragsböden verursacht. Des Weiteren trägt der sehr intensive und ausgedehnte Baumwollanbau zu einer Verschärfung der Situation bei. Die Nahrungsmittelversorgung einer stark wachsenden Bevölkerung und das sehr aride Klima in Khorezm erfordern eine intensive Bewässerungslandwirtschaft. Das Wasserverteilungssystem ist allerdings überaltert und der Hauptgrund für steigende Ineffizienzen. Heutige Bewässerungsstrategien sind nicht flexibel genug, dem immer unbeständiger werdenden Wasserangebot und der sich variierenden Pflanzenwassernachfrage gerecht zu werden. Das politische System mit Subventionen und Anbauquoten für Baumwolle und Weizen, Vetternwirtschaft und fehlenden Eigentumsrechten tragen zusätzlich zu einer steigenden Wassernutzung und fehlender Nachhaltigkeit bei.

Die Analyse einer ökologisch und ökonomisch effizienteren Pflanzen- und Wasserbewirtschaftung bildet den Schwerpunkt dieser Arbeit. Die Effekte modifizierter technologischer-, umweltrelevanter- und institutioneller Rahmenbedingungen sollen hierbei bestimmt und ausgewertet werden. Die Liberalisierung des Baumwollsektors, die Einführung von Wasserpreisen oder die Verbesserung des Bewässerungssystems beispielsweise werden auf ihre Auswirkungen hinsichtlich regionaler Wasserverteilung, landwirtschaftlicher Anbaustruktur und ihrem ökonomischen Nutzen untersucht. Zu diesem Zwecke müssen im Vorfeld die wesentlichen hydrologischen und agronomischen Interaktionen und Eigenschaften der Region Khorezm identifiziert werden. Um diese zu Grunde liegenden Konditionen angemessen analysieren zu können, wurde ein integriertes Wasser-Management-Modell aufgebaut. Die Kombination von interdisziplinären Aspekten in einen theoretisch konsistenten Modellierungsrahmen stellt ein Novum in dieser Arbeit dar. Wesentliche klimatologische, hydrologische, agronomische, institutionelle und ökonomische Eigenschaften und Beziehungen sind in einem kohärenten Optimierungsmodell für die Region Khorezm integriert. Der große Vorteil dieser Modellierung liegt unter anderem auch in der Berücksichtigung von Kanal- und Grundwasser, die gerade in Bewässerungssystem von Khorezm von besonderer Wichtigkeit sind. Einen weiteren Nutzen des Modells und der darauf aufbauenden Forschungsarbeit bietet die Verwendung einer Wasser-Bilanzierungs-Methode. Im Gegensatz zu dem häufig verwendeten statischen Ansatz unter Nutzung von starren Bewässerungsnormen können

durch die Bilanzierung von „Wassereinnahmen“ und „Wasserausgaben“ wesentliche Prozesse in größerer Genauigkeit dargestellt werden.

Die Modellsimulationen zeigen, dass eine (beispielsweise politisch induzierte oder anthropogen verursachte) Modifizierung des Wasserangebotes in Khorezm großen Einfluss auf das gesamte Bewässerungs-, Grundwasser und Entwässerungssystem und den Bodenwasserhaushalt hat. Vor allem in Situationen mit geringem Wasserangebot deuten die Simulationen darauf hin, dass sich der Anbau hin zu weniger wasserverbrauchenden Pflanzen und zu Feldfrüchten mit höherer Wertschöpfung (wie Gemüse, Luzerne, Weizen und Früchten) verschieben würde. In Situationen mit hohem Wasserangebot ist ein Anbau von Reis durch die hohen Gewinnmargen auf einigen Flächen durchaus möglich. Die Verbesserung des Bewässerungssystems, v.a. auf Feldebene, würde zu einer Verringerung der Versickerung und damit einer zusätzlichen Wasserangebotsmenge für die Pflanzen führen. Das hätte positive Effekte auf die Erträge.

Außerdem zeigen die Simulationen, dass eine komplette Liberalisierung des Baumwollsektors zu einer drastisch veränderten landwirtschaftlichen Anbaustruktur führen würde. Die Verluste durch den Abbau von Subventionen und die Abkehr vom Quoten-System würden vollständig ausgeglichen werden durch den Anbau von Pflanzen mit geringerem Wasserbedarf aber wesentlich höherem ökonomischen Mehrwert. Auch die Gesamtanbaufläche würde sich reduzieren und Grenzertragsstandorte würden aus der Produktion ausscheiden. Die Abkehr vom jetzigen System mit gesicherten Verkaufspreisen würde auf der anderen Seite allerdings zu einer Erhöhung des Absatzrisikos der Landwirte führen. Die Einführung von Wasserpreisen in Khorezm wäre ein weiteres sinnvolles und wichtiges Werkzeug für Ressourcenschonung und ökologischer Bewusstseinsbildung der Konsumenten und Landwirte. Dies ist allerdings, so zeigen die Modellergebnisse, nur auf einem sehr niedrigen Preisniveau möglich. Die sehr geringe Gewinnspanne der Anbauprodukte lässt eine höhere Summe nicht zu.

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1 INTRODUCTION

1.1 Problem setting

The problem of water scarcity is growing as water demand continues to increase. Water needs are rising throughout the world as a result of population growth, urbanization, agriculture and industrialization. Discussions related to water use problems increasingly focus on the competition among water use sectors such as agriculture, forestry, industry, hydropower, environment, and municipal use. Furthermore, mismanagement and unfavorable climatic conditions in many regions of the world cause water demands to exceed water supply, which negatively impacts the environment, economy and society at large.

Uzbekistan is an example of a country where water withdrawals exceed renewable water resources. This deficit was most notable in water-scarce years such as 2000, 2001, and 2008. In Uzbekistan irrigation agriculture is the major water user and is characterized by large amounts of wasted water combined with low water-use efficiency. Currently irrigation water is provided at no charge.

The Khorezm region, which was used for this study, is in the Central Asian Republic of Uzbekistan and the delta region of the Aral Sea. This region is one of many examples of irrevocable, inefficient water consumption and water management. The agrarian economic tendency, based on irrigated agricultural development and the cultivation of highly water-consuming crops such as cotton and rice, has historically resulted in drastic ecological, social, and economical problems and continues to cause problems today.

The past and present water deficiencies in Khorezm and the Aral Sea basin have had a negative impact on people, the environment and the economy. During the Soviet period, the Aral Sea basin turned into the world's third largest producer of cotton (Micklin, 2000), leading to an expansion of the irrigation systems in the area. Giant reservoirs along the river catchments were created and caused increased evaporative losses. The expansion of the irrigation area, mainly for cotton but also for rice and wheat, resulted in increasing water consumption for crop-growing processes and soil leaching and, due to insufficient irrigation canal system and mismanagement, to water wastage (Létolle and Mainguet, 1996). Enormous water consumption has been observed in Khorezm, the Aral Sea basin and almost everywhere along the two main rivers in Central Asia, Amu Darya and Syr Darya; and it has resulted in water shortages to downstream users combined with the dramatic shrinking of the Aral Sea. The known as Aral Sea Syndrome has several negative effects, including local climate changes in the areas surrounding the former lake, the destruction of the ecological equilibrium, increasing water and soil salinity, dust storms, diarrheal and cancerous diseases, declining crop yields, rising groundwater levels (Giese et al., 1998), the creation of the new Aralkum desert and the total collapse of the fishery sector.

The national and international community has become conscious of the Aral Sea Syndrome over the past decades. Numerous conferences, projects and studies have been completed since the independence of Uzbekistan in 1991. However, despite intensive efforts within the last years, no significant changes in the region have been observed.

Throughout history, the population in the Aral Sea delta region has been dependent on agriculture and irrigation. Due to population growth (1.4 % annually; SCS, 2008), acreage extension and increasing pressure on land, adequate economical and eco-efficient instruments must be located to feed and employ the existing population in the area. In times of water shortages, such as 2000/2001 and 2008, it is difficult to obtain enough water for irrigation, especially in the lower reaches of the Amu and Syr Darya River. Furthermore, increasing water consumption by upstream water users will increase the pressure on water resources, especially for the Aral Sea delta and the Khorezm region. Afghanistan is just one example of an upstream user, as the country will need large amounts of water for agriculture and hydropower in the near future.

- Against this background the Khorezm region is faced with the following water-related problems:
- Low and declining levels of water availability and supply in Khorezm.
- Insufficient and inequitable water distribution within the various districts of Khorezm.
- Unfavorable crop allocation according to soil type and water supply, mainly caused by the state order system with stringent crop orders for cotton and wheat.

- Low irrigation and drainage efficiencies combined with insufficient irrigation water management, resulting in water waste.
- The sharp rise of acreage and the large amount of unfavorable and marginal soils used for agricultural purposes and the problems arising as a result, including salinity increase and a reduction in crop yields.

The situation in Khorezm requires an investigation into more efficient water use, alternative crops and crop rotation, water conservation and distribution to feed the population and to impede Uzbekistan's disconnection from the world market. Interdisciplinary, interdependent, practicable measures and the participation of local inhabitants and government are necessary to be successful.

1.2 Research objectives

One promising approach to reducing the unsustainable and negative effects of water use on the local and national ecosystem and on the population is a more efficient water and crop allocation and water use combined with a more efficient, sustainable water resources management. This study is part of the project "Economic and Ecological Restructuring of Water and Land Use in the Region Khorezm (Uzbekistan), a Pilot Project in Development Research"[1] at the Center for Development Research at the University of Bonn, Germany. It was initialized to take a holistic economic and environmental approach to improving the current situation. The goal is to develop effective and ecologically sustainable concepts for landscape and water use restructuring focusing on the Khorezm region and the involvement of the population, including farmers and scientists (Vlek et al., 2001; ZEF, 2003).

The Khorezm region is situated on one of the main rivers in Central Asia, the Amu Darya, and is within the delta region of the Aral Sea. In this study, a regional analysis for different spatial patterns of water use and crop allocation is carried out for this region.

The main objectives of the study are the detection and determination of water supply as well as crop and irrigation water demand. As a result, water availability, water use patterns and socio-economic aspects of water management in the region will be

[1] in collaboration with: State Al-Khorezmi University, Urgench, Uzbekistan; United Nations Educational, Scientific and Cultural Organization; German Remote Sensing Data Center; Institute for Atmospheric Environmental Research, Germany

analyzed. The correlation between economic outcomes of the agricultural production system and the hydrologic system is based on physical and agronomical principles. These principles are integrated using an interlinked and interactive model approach. Water balances for groundwater, surface water, drainage water, and soil water are to be established. This will provide a basis for analyses of water supply and demand for crops, yields and cropping patterns. An optimization model will maximize economic and ecological benefits according to yields, acreage, cultivation costs and sales prices and will result in a more effective crop allocation in terms of water consumption and economic cost/benefit ratios. The objective is to develop an integrated, adaptive tool with respect to the interdependencies of the hydrological regime and the economic and ecological situation and with respect to the effects and consequences of alternative water management strategies.

The following scenario-analyses on various hydrologic conditions and socio-economic policies will be considered:

- Modification of the district-wide river/reservoir water supply.
- Introduction of water prices.
- Improvement of the irrigation and drainage system.
- Liberalization/reform of the cotton market and the farmer’s free choice of what, where and how much to crop.

The consequences of these policies and their effects on soil and water balances, crop allocation and gross margins, revenues, water values and production cost will be the major outcome of the research.

Strategies and recommendations for a more effective water use, alternative water management and allocation strategies and their effects and possibilities of implementation will complete the study.

1.3 Outline of the study

The second part of this study provides an overview of the hydrological system of the Khorezm region and the main river flowing to this region, the Amu Darya. The discussion of the economic situation, geographic settings and land use system for Uzbekistan and the Khorezm region will complete the second chapter. It will afford background information on the study area and explain why inefficiencies and mismanagement continue to exist under the given agricultural and political system and the prevailing conditions of water supply and water shortages.

The third part of this study describes the methodology and general water management models, with an emphasis on integrated economic-hydrologic and optimization models. This description will provide the theoretical background for the integrated hydrologic-economic management model. It will be followed by a detailed description of the Water Management Model that has been developed for the agronomic, hydrologic and socio-economic system of the Khorezm region. The framework, components, formulations and assumptions of this model will be explained. The structure of an integrated hydrologic-economic management and planning model for the Khorezm region will also be described. Furthermore, the specific hydrologic, economic and agronomic parameters, processes, inter-connections and formulas will be shown.

The fourth part of the study is focused on data, data reliability, assumptions, and data availability.

Parts five and six of the study cover the model validation and verification, calibration and sensitivity analysis. The validation testing consists of measuring how well a model serves its intended purposes and can thus be used as a plausibility control of the model. The validation testing also measures the model formulation and underlying parameter and data to assess the accuracy of the model. As a result, a descriptive model is introduced for model validation and calibration. A descriptive model analyzes "what is", as compared to normative models that analyze "what should be". For the descriptive model, actual data observations from 2003 are used for all relevant input parameters of water supply, cropping areas and yields. This method will be used to illustrate whether the outcomes of the model formulation and data for water balances and crop production processes are within a realistic range.

The validation is followed by a sensitivity analysis of essential hydrologic and economic parameters to test the strength and quality of the empirical specifications of the model. The sensitivity analysis is important to determine the influence and interactions of input-factors to certain output variables (Saltelli, 2008).

The normative optimization solutions are described and analyzed in parts seven and eight. The various scenario analyses and experiments and their underlying policies and modified parameters will be explained in chapter 7. The final results of the scenarios and the associated experiments on water supply changes, the liberalization of the cotton sector, the improvement of the water management system and the introduction of water pricing and its effects on the hydrologic-agronomic-economic system in Khorezm will be presented and discussed in chapter 8.

The last chapter presents the conclusions from the analyses as well as policy recommendations. This chapter will also discuss the feasibility of the implementation of each of the suggested policies. Overall conclusions of the research, the perspectives and limitations of the model and future work will conclude the study.

2 REGIONAL BACKGROUND

The following chapter is an overview on the geographic conditions and socio-economic situation in Uzbekistan and Khorezm, the case-study region. Historical circumstances, political settings, land use reforms and hydrologic-economic conditions of the region will be described to get a better understanding of the current water use patterns and the production and cropping system. This background information is necessary to understand why this research is carried out within this specific area and it underscores the need for the modeling approach. Furthermore, the information is essential for the understanding of the parameters determined in the model.

2.1 Geography and economy of Uzbekistan

The case study area, Khorezm, is situated within the Republic of Uzbekistan. Uzbekistan is part of Central Asia (see Figure 2.1) and was a constituent republic of the former Soviet Union from 1920 until the U.S.S.R. collapsed in 1991. At that time Uzbekistan became an independent republic, along with the neighboring states of Tajikistan, Turkmenistan, Kazakhstan, and Kyrgyzstan. Uzbekistan is completely landlocked and shares borders with Kazakhstan to the west and to the north, Kyrgyzstan and Tajikistan to the east, and Afghanistan and Turkmenistan to the south. It shares the Aral Sea and all its associated environmental problems (which will be described later) with Kazakhstan in the northwest. Uzbekistan is divided into 12 provinces (one of them is Khorezm), one autonomous republic (Karakalpakstan), and one independent city (Tashkent city). Uzbekistan's population is estimated at 28 million, with a growth rate of 1.7 % in 2010, and 63 % of the population is living in rural areas (SCS, 2010; World Bank, 2010). The country is blessed with significant natural resources including gold, several minerals and energy reserves, such as natural gases and oil. The main exports of the country include cotton, energy, food, metal, and chemical products. Uzbekistan is currently the world's fourth-largest cotton exporter (U.S. Department of State, 2010). The economy of Uzbekistan is primarily based on agriculture and an increasing share of the industrial sector. The agricultural output accounts for 26 % of the GDP and 28 % of the employment (SCS, 2009). The unemployment rate in agriculture is considered to be very high, mainly due to seasonal and part-time jobs. However, reliable figures are not available as no labor census is conducted in Uzbekistan. The main agricultural products are cotton, vegetables, fruits, grain and livestock. The industrial sector is primarily based on the processing of agricultural products, including cotton harvesters, textile machinery, and food processing, as well as on energy production, including gasoline, diesel, and electricity. The industrial GDP is approximately 32 % of the total GDP (SCS, 2010). The GDP growth rate was estimated to be 8.1 % in 2009 (ADB, 2010; IMF, 2010).

Figure 2.1 Map of Uzbekistan within Central Asia, including the study site Khorezm

Source: authors own presentation

The total area of Uzbekistan is approximately 447,000 km^2 (comparable to Morocco or Sweden). Of this, 22,000 km^2 is water and only around 10.5 % of the land is arable. Uzbekistan stretches 1,425 km from the west to the east and 930 km from the north to the south. The climate in Uzbekistan is extremely continental[2], with dry hot summers and cold winters. The temperatures in the summer often exceed 40°C. In the winter, the temperatures average about -8°C in the north and 0°C in the south (in

[2] BWk (arid dessert) climate classification according to Köppen/Geiger (Koeppen and Geiger, 1930-1943)

December), but they may be as low as -40°C. The frost period can last from October/November until March/April, and as a result, most areas of the country are not suitable for double cropping, except for favorable years when a few vegetables with a short growing period can be double cropped (FAO, 1997a). The majority of the country is arid, with sparse annual precipitation of less than 200 mm per year. The majority of the precipitation occurs during winter and springtime, and the summer season is very dry (Gintzburger et al., 2003). As a result, most of the agricultural area must be irrigated with water from the main rivers passing through Uzbekistan.

The water resources in Uzbekistan are unevenly distributed. The vast plains that occupy more than two-thirds of Uzbekistan have little access to water and only a small number of lakes. The largest rivers in Uzbekistan and in Central Asia are Amu Darya and Syr Darya (Figure 2.1) and its tributaries, which originate in the mountains of Tajikistan and Kyrgyzstan, respectively. Due to the extension of the broad artificial canal and irrigation network during the Soviet period, arable land was expanded to the river valleys and marginal land was used for arable agriculture. Because the Amu Darya is the main source of water for irrigation in Khorezm (Figure 2.2), a brief overview of its significant characteristics and problems will be provided in the following section.

2.2 The Amu Darya River

The Amu Darya, known in ancient times as the Oxus, is the largest river in Central Asia. It extends approximately 2,550 km from its headwaters or 1,437 km up to the junction (Samajlov, 1956), compared with the 1,320 km of the Rhine. The Amu Darya River is formed by the junction of the Vakhsh (Tadjikistan) and Panj (Afghanistan) rivers, which rise in the Pamir Mountains of Central Asia. The river basin includes the territories of Afghanistan, Tadjikistan, Uzbekistan and Turkmenistan (Table 2.1). Its upper course and source starts off in the high Pamir Mountains of Central Asia (Afghanistan and Tajikistan), marking much of the northern border of Afghanistan with Tajikistan, flowing through the Karakum desert of Turkmenistan and Uzbekistan, and entering the southern Aral Sea through a delta (Figure 2.2). The discharge is mainly generated by snowmelt and, to an increasing degree, by melting from the glaciers in spring and summer time. Because the course of the river is extremely long and many water users and irrigated areas are located within the basin, less water is arriving in the downstream area and the Aral Sea.

The river flows generally northwest. The total water catchment area of the Amu Darya basin is 227,000 km^2 (ICWC Central Asia, 2009), compared with the 185,000 km^2 of the Rhine. The average annual sum of discharge of the Amu Darya is approximately 75 km^3. The main tributaries of the Amu-Darya basin are the Zeravshan, Surkhan, Kashka and Sherabad rivers, which flow into the river within the first 180 km. Based on the hydrographic indicators the Zaravshan and Kashka rivers belong to the Amu Darya basin. The water from these two rivers no longer reaches the river due to withdrawals for irrigation purpose and can be considered independent rivers. Furthermore, there are no other inflows within a span of more than 1,200 km flowing into the Aral Sea (Figure 2.2).

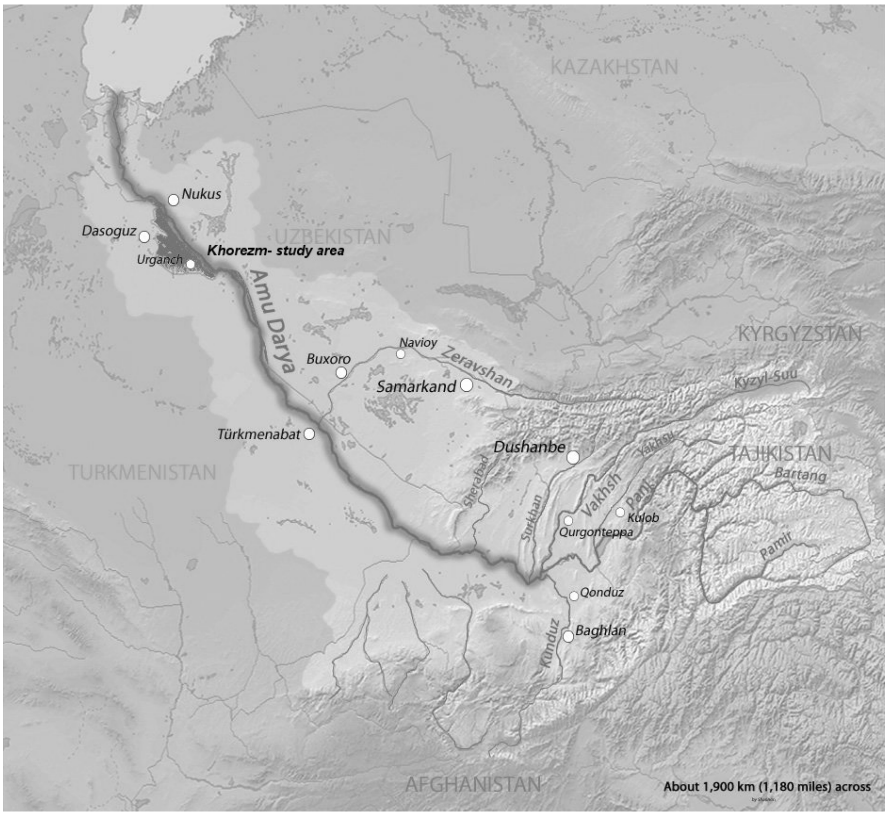

Figure 2.2 Watershed of the Amu Darya River

Source: based on DEMIS Mapserver and Wikimedia Commons, modified

The total consumption and the losses of the Amu Darya watershed account for 60-70 km^3 (compared to 28 km^3 in 1950, Kostianoy and Nosarev, 2010), the main water user is irrigation (Table 2.1). The total irrigated area of the Amu Darya river basin is about 6 million ha (compared to approx. 1.6 million in 1950; Kostianoy and Nosarev, 2010). Uzbekistan has approximately 2.3 million ha of land irrigated by the Amu Darya water and is the largest consumer of water, followed by Turkmenistan. However, most of Amu Darya's flow is generated in Tajikistan and Afghanistan (Masood and Mahwash, 2004), which have low water consumption (Table 2.1). However, this is likely to cause problems in the near future when Afghanistan requests more water or the planned dams are built.

Table 2.1 Amu Darya transboundary water characteristics

Country	**Irrigated Area**	**Water Generation/Contribution to Amu Darya**		**Water Consumption**	
	10^6 ha[a]	km^3 [a]	% of total[a]	km^3/year[b]	% share[b]
Tajikistan	0.5	49.6	66	9.5	15.4
Afghanistan	1.2	17.0	23	--	--
Uzbekistan	2.3	5.1	7	29.6	48.2
Kyrgyz Rep.	0.1	1.6	2	0.4	0.6
Turkmenistan	1.7	1.5	2	22.0	35.8
Total	*5.76*	*74.8*	*100*	*61.5*	*100*

Source: [a] USAID (2002),
[b] MinVodKhoz (1987), without Afghanistan

The Aral Sea basin receives less than 100 mm of annual precipitation. Evaporation is dominant, and approximately 1,200-1,700 mm of water currently evaporates from the surface annually. Because the water of the Amu Darya is used excessively for irrigation, the river has stopped replenishing the Aral Sea. Currently, less than 10 % of the total water amount reaches the Aral Sea (2-5 km^3/a), if any at all.

The average temperature in Central Asia has increased 0.9°C per decade with a simultaneous decrease in precipitation by 20-30 % per year since 1960 (BMZ, 2002). Rising aridity and higher temperatures intensify the evaporation processes and the lowering of the sea level (Giese, 2002).

The hydraulic system conveying the water from the river to the water user consists of a complex system of canals, tributaries, irrigation fields, impoundments, distribution systems and municipal and industrial facilities (Micklin 1991). It is described as *"one of the most complicated human water development systems in the world"* (Raskin et al., 1992) because of human interventions that have gradually modified the natural water flow and the environment along the riverbanks. Since the 1930s the Amu Darya waters have been increasingly used for large-scale irrigation projects. As a result, many irrigation canals were constructed. The largest of these canals is the Karakum canal, delivering 300 m^3/s, followed by the Karshi and Amu-Bukhara canals delivering about 100 m^3/s each. In addition to these canals, there are hundreds of smaller canals and pumping stations supplying and distributing the Amu Darya water to irrigated fields. A number of water storage reservoirs have also been constructed. As a result, an almost completely irreversible use of water has been achieved, leaving very little, if any, water to reach the Aral Sea or the Amu Darya delta region. (Coleman and Huh, 2004).

The water is not supplied based on demand and is wasted by poor water management practices that result in the use of excessive quantities whenever water is available. Thus, the construction of a water distribution and management model could help balance demand and supply.

The drainage and irrigation systems are in poor condition, largely because of age and the lack of recent maintenance (Masood and Mahwash, 2004). The drainage systems are generally designed in such a way that most of the effluents are directly discharged back into the river (UN, 2005) and thus gradually aggravate the downstream water quality. The situation in Khorezm is different from this general situation because most of the drainage water from Khorezm is discharged to the Sary Kamish depression. Water salinity in the delta region has increased from 0.5-0.8 g/l to more than 2 g/l. As a result, water and soil salinity has become a major problem, mainly in the downstream area. Approximately 30 % of the irrigated areas suffer from moderate to high salinity levels (Murray-Rust et al., 2003).

The diversions of the Amu Darya for irrigation purposes and the change in its chemistry have led to large-scale changes in the Aral Sea's ecology and economy. The decrease in the fish population already dramatically reduced and eliminated the fish industry in the 1980s. The reduction of the Aral Sea also affects the regional climate. Due to the reduction of the Aral Sea and, thus, the exposure of the seabed, strong winds have caused thousands of tons of sand and soil to enter the air, negatively affecting its quality. This further reduces crop yields because heavily salt-laden particles fall on arable land. Respiratory illnesses, typhoid, and morbidity have also increased (Horsman, 2001). All of these factors are contributing to the Aral Sea Syndrome (UNESCO, 2000).

2.3 Agricultural and political settings

During the Soviet era the production of cotton was politically enforced and intensified. Uzbekistan was the largest cotton producer in the U.S.S.R. and became a raw material supplier for the rest of the Soviet Union, mainly due to the expansion of the canal network system on Syr Darya and Amu Darya during this time. It was assumed that soil and water resources had infinite availability and usability, and sustainability criteria did not play any role for policy and the local population. The environmental management during the Soviet era brought decades of poor water management and a lack of water or sewage treatment facilities. The heavy use of pesticides, herbicides and fertilizers in the fields, as well as the construction of industrial enterprises with little regard to the negative effects on humans or the environment, was also common during this time. The large-scale use of chemicals for cotton cultivation, inefficient irrigation systems and poor drainage systems are examples of the conditions that led to a high volume of saline and contaminated water entering the soil (Curtis, 2004) and into the groundwater. As a result, the quality of the groundwater and surface water, which are the main sources of drinking water, is reduced. Furthermore, the drainage water is deteriorated and causes many problems when drainage water is released directly into the river. The mineralization of the groundwater in downstream areas of the Amu Darya River can reach 5-20 g/l compared to values of 1-3 g/l in upstream areas (Crosa et al., 2006a and 2006b). The direct causes for the ecological crisis in the downstream rivers and delta regions, with the most prominent example being the “Aral Sea Syndrome”, are the following:

- The dramatic expansion of irrigation areas and associated increasing water usage for irrigation.
- The extension of cotton cultivation (mainly in monoculture) with large-scale application of fertilizers and pesticides, resulting in the contamination of drinking and irrigation water (Giese, 1998).

After its independence in 1991, Uzbekistan has retained many elements of Soviet economic planning, including central planning, subsidies, and the implementation of production quotas and price settings (Müller, 2006; Djanibekov, 2008). Major economic issues continue to be determined by the state. The government only allows limited direct foreign investment, and little true privatization has occurred other than the foundation of small enterprises (Curtis, 2004). Intended structural changes, which will be described in the following paragraphs, are occurring slowly because the state still continues to have a dominating influence on the economy and, thus, on the environment.

Agrarian reform in Uzbekistan

In the last decades of the Soviet era, Uzbekistan's agriculture was dominated by collective farms, mainly state farms (Kolkhozes, Sovkhozes). These farms had an average size of more than 24,000 ha and an average of more than 1,100 farm workers in 1990/91. Although only about 10 % of the country's land area was cultivated, about 40 % of its Net Material Product (NMP[3]) was in agriculture. Throughout the 1980s, agricultural investments and the agricultural area steadily increased. In contrast, net losses increased at an even faster rate as a result of heavy salinization, erosion, and waterlogging of agricultural soils, which inevitably place limits on the land's productivity. Nevertheless, during these decades, Uzbekistan remained the major cotton-growing region of the Soviet Union, accounting for 61 % of the total Soviet production. Roughly 40 % of the total workforce and more than half of the total irrigated land in Uzbekistan were devoted to cotton production in 1987 (Curtis 1997). According to Bloch (2002), the Soviet agricultural system had the following characteristics:

- A dominance of large collective and state farms.
- Cotton monoculture.
- Crop farming dominating the structure of agriculture, with very little livestock.
- Heavy reliance on intensive use of land, water and chemicals.

[3] NMP was the main macroeconomic indicator during the Soviet era. In its concept, it is equivalent to GDP but is calculated for the material production sector and excludes most of the services sector and the foreign trade balance (Carson, 1990).

- A lack of self sufficiency in food products, including wheat, milk, potatoes and meat.

Since its independence Uzbekistan has initiated “step-by-step” economic reforms with price liberalization and agrarian reform under strict governmental control. The agricultural sector was exposed to a sequence of reforms that had several significant effects on the organizational structure of the sector. However, the degree of independent decision making by the farmers was limited by the government. The reform is most visible in the abolition of Sovkhozes and their conversion into cooperative enterprises (Kolkhozes), which were later restructured into Shirkats during the first phase of agricultural restructuring (Pomfret, 2000)[4]. The main difference between the two forms of ownership is that a Sovkhoz is like a state enterprise in which the workers are employed at fixed wages, whereas a Kolkhoz pays its workers from its own residual earnings (Khan, 1996). The main reason for shifting to Kolkhozes was the practical consideration of relieving the state budget to finance the wage payments to the large Sovkhozy work force. Another reason for the shift was practical efficiency considerations, as the output per unit of land was higher in Kolkhozes. Furthermore, the overall unit costs were lower in Kolkhozes than in Sovkhozes (Khan and Gai, 1979; Khan, 1996). Nevertheless, the reform in post-independent Uzbekistan was not accompanied by an essential change in the management of the Kolkhozes (Djanibekov, 2008). During this time, a limited program of distributing land among private farmers was also initiated (Table 2.2). In 1994, there were about 10,400 private farms in operation, corresponding to 2 % of the sown land and covering an area of 8.6 ha per farm. These private farms had to contend with bad conditions in the beginning, as they were often allocated areas with poor soil quality and their lease contracts allowed little decision making (Trouchine and Zitzmann, 2005).

[4] The first phase of reform was implemented between 1989-1997/1998 according to Khan 2005, CER 2004 or Trouchine and Zitzmann, 2005

Table 2.2 Distribution of sown land (in % of total) in Uzbekistan

Year	**Kolkhozes** (Shirkats)	**Sovkhozes**	**Private farms**	**Individual farms** (Dekhan)	**Others** [a]
1990	34.9	58.7	0.1	0.1	6.3
1991	34.0	57.7	0.1	n/a	8.1
1992	36.4	51.8	0.4	n/a	11.5
1993	47.5	39.0	0.6	n/a	12.9
1994	75.3	1.0	2.1	2.1	21.6
2004	48.6	--	34.5	10.4	6.5

Notes: [a] separate arrangements for special categories or crops, e.g., orchards and vineyards, mixed state collective forms including experimental farms

Source: Khan, 1996; Khan, 2005

During this time the land endowments to small-scale farms (i.e., Dekhan/peasant farms) also increased. Dekhans are small household plots on which families have lifelong heritable tenure and that can be used for residential and agricultural purposes. They are farmed only by family members and are an essential means of obtaining a minimal standard of livelihood. As their size, with a maximum of 0.35 ha, is sufficiently small, they are free to sell their products in the market and are not subject to any procurement quotas (Khan, 2005)[5]. They are important food producers for local markets and have no influence on the national agricultural export structure.

The major changes during this period were a sharp decline in agricultural terms of trade and a shift in relative incentives against cotton and in favor of grains. The reason for this shift was the declared self-sufficiency of Uzbekistan in grain production to feed an increasingly impoverished population and to obtain autonomy from wheat imports. With the estimated production of 3.7 million tons of wheat in 1998, which was six times the level of 1991, Uzbekistan has largely achieved the goal of drastically reducing grain imports since its independence (Kandiyoti, 2002). According to Trushin (1998) the area of cotton fields and forage decreased from 1990 to 1996. The area of cotton fields decreased from 44 % to 35 % while the area of forage decreased from 25 % to 13 %. During the same time the arable land allocated to cereals increased from 24 % to 41 %. These changes have not only resulted in a reduction of the area under cotton cultivation, but also a reduction of yield per ha. This is because at that time the productivity of Kolkhozes and Sovkhozes, which were the main producers of cotton,

[5] A more detailed description and differentiation of the various agricultural operation forms can bee seen in Appendix A.

was still declining due to insufficient management and unfavorable land conditions. The total cotton yield decreased 15 % between 1991 and 1994, and has decreased by up to 27 % since 1985 (Table 2.3).

Table 2.3 Cropped area and yield of cotton and grain in Uzbekistan

Year	Cotton		Grain	
	Area (10^3 ha)	**Yield** (t/ha)	**Area** (10^3 ha)	**Yield** (t/ha)
1985	1,989.8	2.70	969.3	1.52
1990	1,830.1	2.76	1,008.1	1.88
1991	1,720.6	2.70	1,079.9	1.77
1992	1,666.7	2.48	1,212.2	1.86
1993	1,695.1	2.50	1,280.3	1.67
1994	1,540.0	2.56	1,522.2	1.62

Source: Khan, 1996

Other than achieving self-sufficiency in wheat production the market liberalization of agricultural products, particularly cotton and wheat, was not dissolved in this first phase of agricultural restructuring. The production of those crops was still regulated by state procurements, such as state-provided inputs and state order systems, subsidies, crediting, financing and marketing. This meant that the farms did not have the liberty to make their own planting decisions (Bloch, 2002; Spoor, 2002). The state procurement system came into operation for cotton and wheat. The reason for the establishment of the cotton procurement was mainly to secure the export oriented cotton production. In this way, the state determines the cotton area, sets production targets and prices, supplies all inputs and purchases the bulk of the crop. At the time, 100 % of the harvest had to be sold to the state. The procurement for grains is basically part of the planned extension of self sufficiency in cereals. Here 50 % of the production must be sold to the state at the given procurement prices. The farmer can sell the rest to local markets if he fulfils the procurement contract (Kandioty, 2003).

The second phase, which lasted from 1997/98 through 2003, was characterized by the legal admission and promotion of private farms distinct from Dekhan farms. This phase strengthened Dekhan farming as it became evident that the productivity of Dekhan farms increased by more than 35 % in comparison to the huge farm enterprises (Kolkhozes) that saw a decline in productivity (USAID, 2005). Several new laws, giving more independence to individual farms, went into effect during this phase, beginning in 1997[6]. Occasionally the distinction between smallholders (Dekhans) and individual farmers was indicated by granting them independent juridical status as well as the right to hold own bank accounts and to transact with buyers of crops and suppliers (Kandyoti, 2002). However, they remain subject to state-determined procurement prices to this day (Trouchine and Zitzmann, 2005).

Simultaneously, the former collective farms, the kolkhozes, were being transformed into Shirkats, starting with more profitable collectives. In 2002 more than 90 % of the former collectives were transformed into Shirkats. Those that failed to be retransformed into profitable Shirkats were converted into private farms (Khan, 2005). The state is still interested in the control of the agrarian sector, and as a result, basic conditions of production remain in this phase. Despite the efforts made toward self-sufficiency, Uzbekistan is still one of the largest importers of food in Central Asia (Bloch, 2002).

Furthermore, during this time, Water User Associations (WUAs) were promoted and established, mainly in inefficient state and collective farms. These associations were tested by the Uzbek government and were responsible for the entire operation and management of the irrigation and drainage infrastructure within their territory (Wegerich, 2001).

The third phase of transformation began in 2004 and is characterized by a further conversion of poorly performing Shirkats into private farms. This was a result of many Shirkats being confronted with financial problems and showing little improvement in productivity (CER, 2004). The foundation for this decision was a Presidential Decree from October 2003 that made private farms the principal agricultural enterprises in the future by distributing the land of the Shirkats to private commercial farms. This process was nearly completed in 2007; with 217,100 private farms operating in 2007. The total area of land allotted to private farms was 5,787,800 ha, with an average of 26.7 ha per farm (SCS, 2007). During this period the WUAs increased as well, and in Khorezm 113 had been established by 2006. Each WUA had an average territory of about 2200 ha and 134 farms (RWUA, 2006 cited in Bobojonov, 2008).

[6] Law of the Republic of Uzbekistan (1998): On the Agricultural Cooperative, Tashkent, Uzbekistan.
Law of the Republic of Uzbekistan (1998): On the Farmer Enterprise, Tashkent, Uzbekistan.
Law of the Republic of Uzbekistan (1998): On the Dekhkan Farm, Tashkent, Uzbekistan.

Currently the institutional form of agriculture has been nominally transformed. The old agricultural organization structure of large cooperatives, state enterprises and Shirkats has been replaced with private commercial farms, Dehkan farms and only limited state enterprises and cooperatives for experimental research (Figure 2.3).

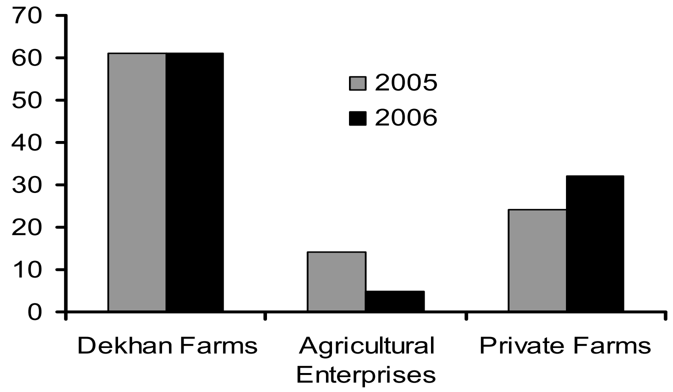

Figure 2.3 Distribution of Gross Agricultural Output (GAO) by types of farms (in %)

Source: SCS, 2007

The ongoing plans of the Uzbek Government are the further re-consolidation of farms into farms with sizes of at least 80-100 ha to ease water distribution and water rights (Abdullaev et al., 2008). However, agricultural land is still owned by the state, which leases or grants usufruct rights to private farms or Dehkan farms. The farms are subject to land tax and remain subject to the state-determined procurement prices for cotton and wheat. According to Khan (2005) the only change in the procurement system is that the procurement price for cotton and grain has been following world prices[7] since 2003. However, in most cases, this is still lower than market prices. Newly created private farms have increased noticeable over the last years. The resulting formation is a bi-modal distribution of Uzbekistan's scarce land, where a majority has very small holdings and a minority has huge landholdings that are often 200 times more than the masses.

The current economy of Uzbekistan is still based on agriculture. The share of crop cultivation of the total agricultural output averages 57 %, whereas animal

[7] minus transportation and custom costs, costs for intermediate participants and certification (Rudenko, 2008)

husbandry is 43 %. The total cropped area in 2006 was 3,633,600 ha and 3,557,400 ha in 2009. This area was mainly used for grains and cotton, with approximately 90% of the total grain area being wheat cultivation, and 3 % being rice. The remaining cropped area is used for forage crops and vegetables, potatoes and melons (Figure 2.4). Dekhan farms produce the majority of the potatoes and melons (88 % of total potato production) (SCS, 2007 and SCS, 2009).

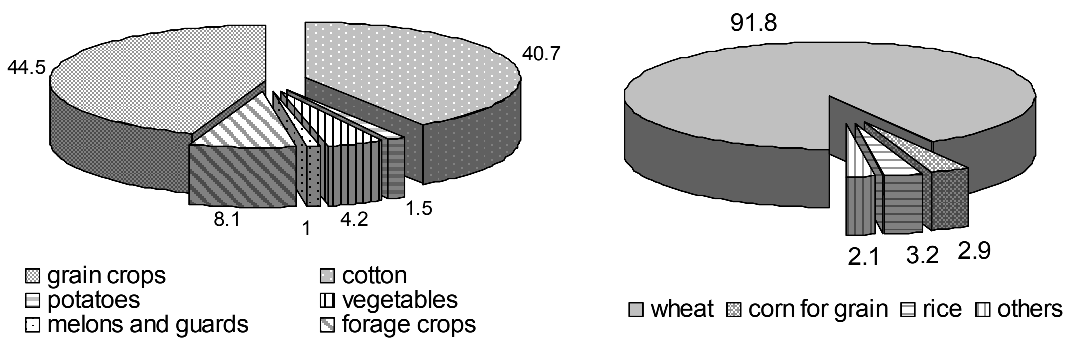

Figure 2.4 Structure of sown areas (%) and structure of grain production in 2006, in % of total gross harvest

Source: SCS, 2007

2.4 Khorezm region

To supplement the basic geographical, economic and environmental background information provided in the previous sections, a specific description of the province of Khorezm is given below. Khorezm is part of the downstream area of the Amu Darya River basin, as previously described in chapter 2.2. The region is part of Uzbekistan and is included in the country's legal and structural changes as well as its agricultural and economic issues described in chapter 2.3.

Khorezm is one of the oldest centers of civilization in Central Asia and was known for its impressively large irrigation system (Christian, 1998). Historically, Khorezm was one of three major Central Asian Khanates (Bukhara, Kokand and Khorezm) and one of the main checkpoints along the Silk Road. The people of Khorezm have traditionally been strongly involved with arts, crafting, carpet weaving, architecture, and construction. During the Soviet period, Khorezm's primary industrial sector became agriculture, specifically cotton production and processing.

2.4.1 Geographical and socio-economic settings

Khorezm is situated in the northwestern part of Uzbekistan at the lower reaches of the Amu Darya River. It is geographically located between 60° and 61.4° latitude east and 41°-42° longitude north and is approximately 113-138 m above sea level. The region is located about 350 km from the current borders of the Aral Sea. Its total area is approximately 6,300 km^2 (630,000 ha), and the climate is continental, with moderately cold winters and dry, hot summers. Khorezm is bordered by the Amu Darya River in the northeast, the Karakum desert in the south and southeast, the Kysilkum desert in the east, the Republic of Turkmenistan in the west, and the autonomous Republic of Karakalpakstan (that belongs to Uzbekistan) in the north. Large parts of the southeastern areas are part of the Kysilkum desert and are thus also part of the administrative districts of Khorezm. Because these areas do not play a role in irrigation and water allocation, they will not be considered in the study.

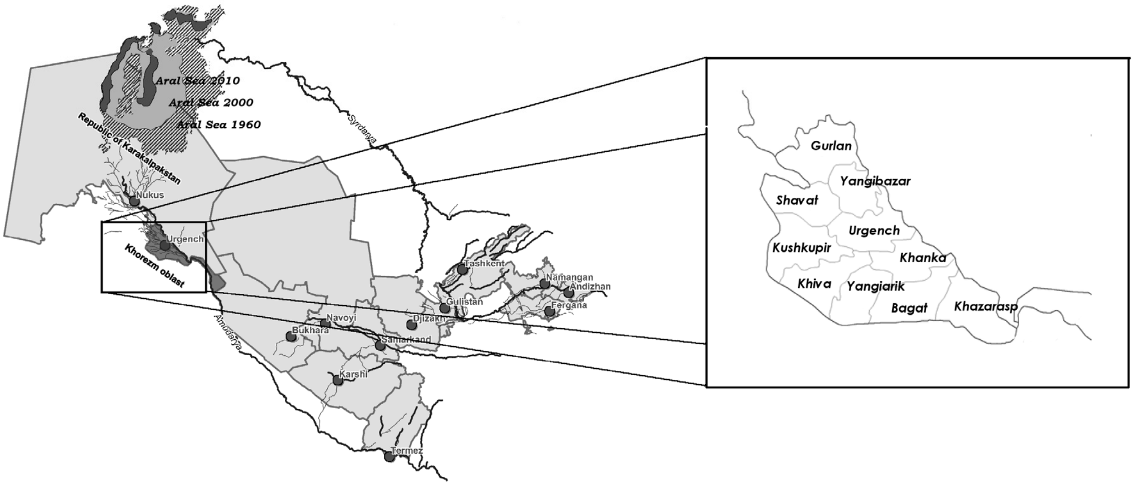

Figure 2.5 The Khorezm province in Uzbekistan and its districts

The population of the province is more than 1.5 million, with about 78 % living in the outlying areas. The population density of the region is about 250 persons per km^2 (Oblstat, 2003; Uzinfocom, 2008). The province was established in 1938 and is divided into ten administrative districts, with Urgench as the administrative center (Dickens, 2002). Urgench city had a population of 135,000 in 2008 (Xorazm.uz, 2010). Other major towns in the province are Khiva and Djuma. Six of the districts directly border on the Amu Darya River (Figure 2.5).

2.4.2 Climate

The arid and continental climate in Khorezm is characterized by long, dry, hot summers with temperatures rising to +45°C and cold winter temperatures falling as low as -25°C. The annual temperature is approximately 13°C (Glazirin et al., 1999). The coldest month is January, and the hottest is July. In January the mean minimum temperature from 1980-2000 was approximately -5°C, whereas the mean maximum temperature was around +3°C. In July the mean minimum temperature was 22°C, and the mean maximum temperature was 37°C (Glavgidromet, 2003). The majority of the limited amount of rainfall the region receives occurs in the winter and spring (Figure 2.6). The average annual precipitation in Urgench during the last 25 years is 97 mm, and it falls mainly outside of the growing season. This amount of precipitation is too low to substantially contribute to the crop growth processes and to the water balances. The potential annual evapotranspiration in Khorezm is approximately 1,500 mm (Conrad, 2006) and by far exceeds the precipitation (FAO, 2000). As the water management model is based on data from 2003, precipitation and temperature for that year are presented in Figure 2.6.

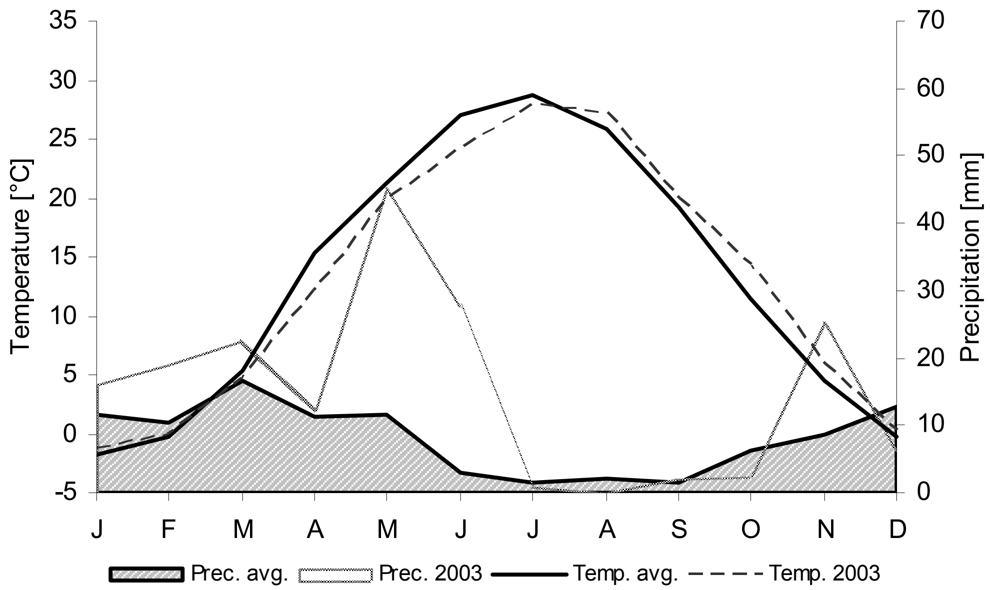

Figure 2.6 Climatic conditions in Khorezm

Notes: Climate chart for the meteorological station in Urgench (41°34'N - 60°34'E): Average values of temperature [13°C] and precipitation [97mm] for the observation period.

Sources: Glavgidromet (2003) for 1980-2000 and Rosgidromet (2007) for 2003

It is worth noting that the amount of rainfall in the springtime increases compared to the average, but the temperature during this season has not differed over a 25-year period. According to Kotlyakov (1991) and Spoor (2007), the frost-free period has been shortened from more than 200 days per year to approximately 170 days. The first frost starts about ten days earlier, which complicates soil leaching and crop growth, especially for winter wheat. Furthermore, potential double cropping between October and March/April can be difficult or even impossible due to frequent frosts.

2.4.3 Soils

The soil formation and the evolution of the soil profile in Khorezm are mainly influenced by the Amu Darya River and the irrigation agriculture (Tursunov, 2006). The soils of the Amu Darya delta consist of alluvial deposits from the river containing light, medium and heavy loams and rarely consisting of loamy sands (Schäfer et.al, 2001). However, the soils situated directly at the river bed consist of sand and loamy sand.

Soils and soil texture in Khorezm are very heterogeneous. Until the 1970s the soils of the major irrigated area were very fertile and high in humus, nitrogen and carbonate content, resulting in a high agricultural potential (Tusurnov 1984, cited in Schäfer et al., 2001). Seventy percent of the area was classified as meadow-alluvial loamy soils (Xerosols, Fluviosols) with very few sand fractions, while the remaining is desert sandy soils consisting of more than 90 % sandy fractions. Furthermore buggy-meadow, takyr-meadow, boggy, grey-brown and takyr soils can be found in Khorezm (Kienzler, 2010; Ibrakhimov, 2007).

The intensification of irrigation caused a degradation of the soils as they became arid, which resulted in increasing salinity, a loss of humus content (by 20 %) and a loss of fertility. Due to this aridity, the hydromorphic meadow soils began transitioning into alkaline automorphic soils (Stulina and Sektimenko, 2004). The overall productivity decreased approximately 30-40 % (UN, 2001; EcoInformPrognoz, 2001). According to Ibragimov (2007) and Riskieva (1989) (both cited in Kienzler, 2010), the soils in Khorezm are now characterized by a very low soil organic matter content (SOM; 0.33-0.6 %) and a high carbonate rock content. Because the natural fertility of the soils is low, crops require additional chemical fertilizers (Khamzina, 2006). In periods of drought, the soils are crusted (takyric soils according to FAO classification; Scheffer and Schachtschabel, 1998). These soils could potentially evolve into pure takyr, solontschak (silty and salty) or desert sandy soils. Most of the soils can be subclassified as phreatic and salic soils, as a shallow groundwater level above 5 m influences soil, and salinity accumulation often occurs within the soils.

2.4.4 Water

Given the arid climate in Uzbekistan and especially in the Khorezm region, irrigation water from the Amu Darya River and the Tuyamuyun reservior is essential for agricultural production. The fundamental importance of water for Uzbek and the Khorezmian agriculture became increasingly evident in the years 2000, 2001 and 2008, when the overall water supply was dramatically decreased due to droughts. Food shortages arose as a result of a decline in production, particularly in those regions that were at the tail end of the river, such as the Khorezm province. The local inhabitants fear that the number of drought years will increase. Within the three drought years mentioned above, the water supply decreased approximately 50 % compared to 20-year annual averages (SIC-ICWC, 2007/2009). The crop production decreased drastically as a result of the low water supply. The production of rice decreased by 84 %, cotton by nearly 33 %, and potato, vegetable and fruit production between 25 % and 50 % (FAO/WFP, 2000).

The majority of the current irrigation and drainage system in Khorezm originated during the Soviet time. Depending on water availability, between 2 and 5 km^3 of water for irrigation purposes is diverted from the Amu Darya River and from the Tuyamuyun reservoir, which is situated upstream and southeast of Khorezm (OblVodChoz 2001-2004; Upradik 1999-2005; SIC-ICWC 2007).

The existing irrigation canal system is primarily driven by gravity. Water application at the field level is mainly by furrow irrigation.

Figure 2.7 shows the very dense water distribution system, which is built in a hierarchical system with main, inter-farm and on-farm canals. According to Conrad, 2006 the combined length of the canals is more than 16,000 km. Only 11 % of the canals are lined (Ibrakhimov, 2004).

Some of the central problems of the irrigation scheme are the poor efficiency caused by design problems, the lack of maintenance and the aged system. As a result, insecurity of the water supply is increased when water availability is limited (Müller, 2006). Currently about 20 % of the water used for irrigation is lost in the inter-farm system. The inside-farm system is characterized by more considerable water losses. The irrigation equipment, control devices and technologies are outdated and need to be either repaired or replaced. The transition to a market economy has resulted in a lack of economic incentives and financial resources to improve the irrigation systems. Furthermore, neither land-use nor water-use practices encourage efficient water use.

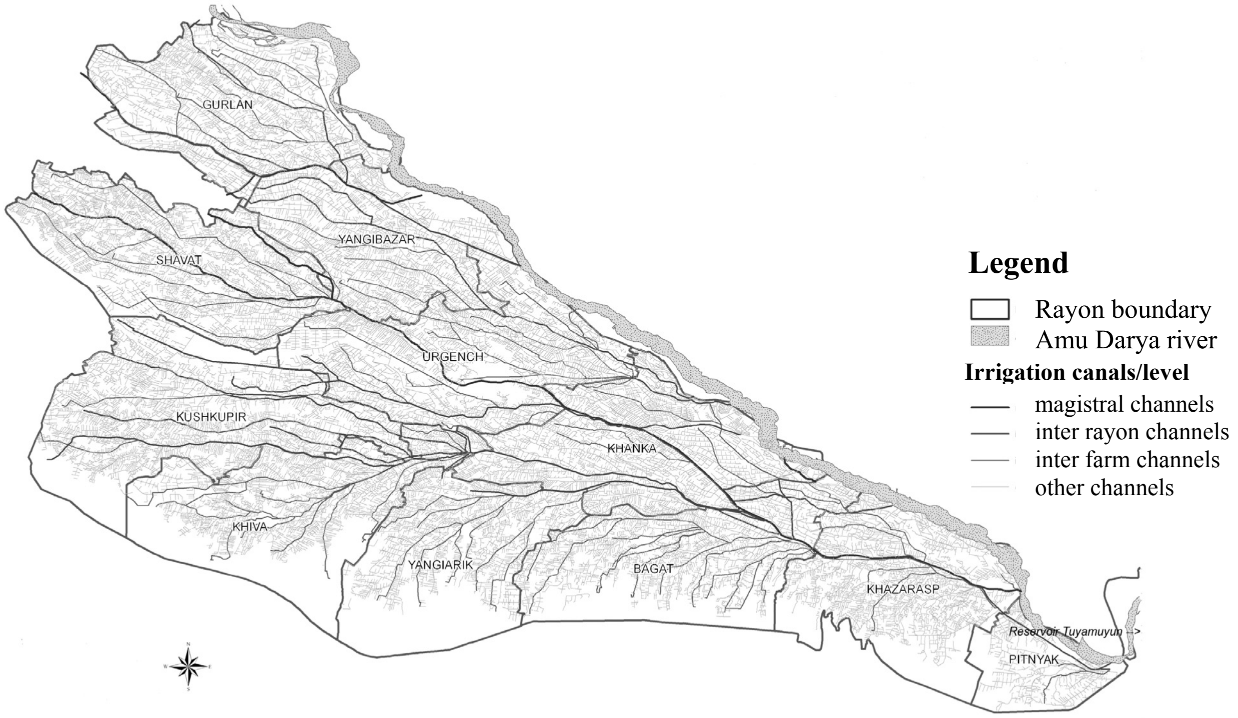

Figure 2.7 Irrigation system in Khorezm

Source: designed by GIS Center Khorezm, modified

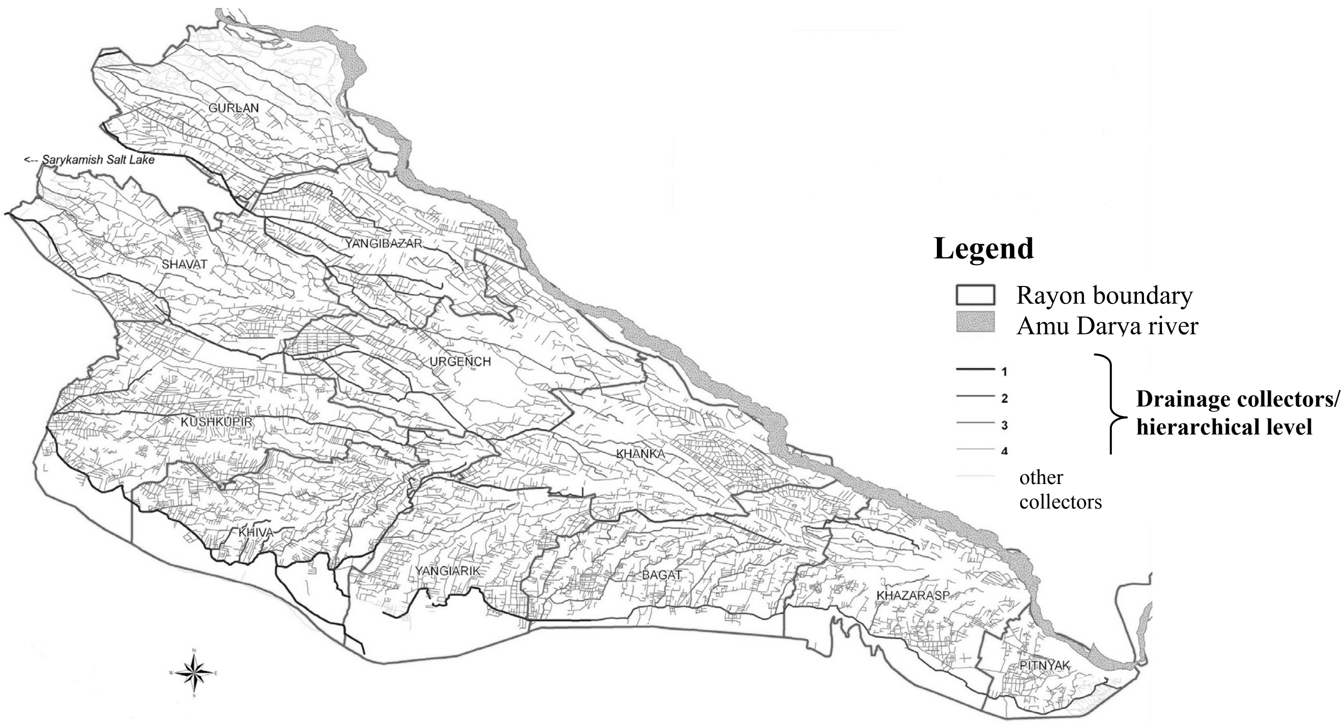

Figure 2.8 Drainage system in Khorezm

Source: designed by GIS Center Khorezm, modified

The drainage canals (collectors) in the Khorezm region consist of open drains. Like the irrigation system, the drainage system is built hierarchically (main, inter-farm, on-farm collectors) and has a combined total length of approximately 7,500 km (Figure 2.8).

The main collectors drain water into numerous lakes and depressions. The main saline depression is the Sarykamish Salt Lake outside of Khorezm, whose water level and salinity continue to rise. Only a small amount of water is diverted back to the river. Collector-drainage water is not treated at all.

As long as water is still freely available and long-term ownership is not clearly regulated, farm managers have no incentive to save water and conserve the environment. Besides the declining irrigation and drainage system maintenance, water logging has occurred and salinity and ground water levels have risen. The groundwater level in Khorezm, which is very shallow (approximately 120 cm-140 cm), is mainly determined by irrigation, drainage and leaching activities (GME, 2005). The average groundwater mineralization is 1 g/l to 3 g/l, with an average value of 1.75 g/l between 1990 and 2000 (Ibrakhimov, 2004). In certain areas and during some months the groundwater mineralization temporary increases to between 3 g/l and 10 g/l (GME, 2005; GME, 2001; Ibrakhimov, 2004). These temporary increases are due to water mismanagement, missing drainage, inefficient irrigation, fertilizer usage and salt leaching into the groundwater (Forkutsa, 2006; Akramkanov, 2005, Abdullaev, 2002). Some parts of Khorezm now prohibit groundwater use because of the increasing salinity. However, even in areas where groundwater use is allowed, it is not used extensively due to the high costs of pumping (Jalalov, no year specified). From the estimated available groundwater resources of about 5 million m^3 per day only 1.7 % is used, and this is mainly to supply drinking water to the urban and rural areas of Khorezm (UN, 2001).

2.4.5 Agriculture and land use

During the Soviet era the production of agricultural commodities, particularly of cotton, was expanded far into the country's dessert and marginal land with a large increase of irrigated area. One of the areas with the most intensive agricultural use is the Khorezm province (Rayon). In this province the industrial sector does not play any role of importance. The Khorezm region has 275,000 ha that are suitable for irrigation (FAO, 2003a; FAO, 2003b).

The surrounding deserts of Khorezm are sources of new land reclamation for cropping and irrigation. Currently the Amu Darya River provides irrigation water to 230,000-270,000 ha in Khorezm, of which more than 12 % have highly saline soils (FAO, 2003b). The irrigation water is used mainly for cotton, wheat, rice, and vegetable production. Irrigation on marginal land is also practiced and is not sustainable. Figure 2.9 shows the expansion of the irrigated area in Khorezm since 1982.

The region contributes to 15 % of the total national river water withdrawals. The water withdrawal for agriculture is estimated to be 94 % of the total regional water withdrawals. Only a small amount of water is utilized for industrial/municipal and household uses (JICA, 1999 and chapter 4.2.7).

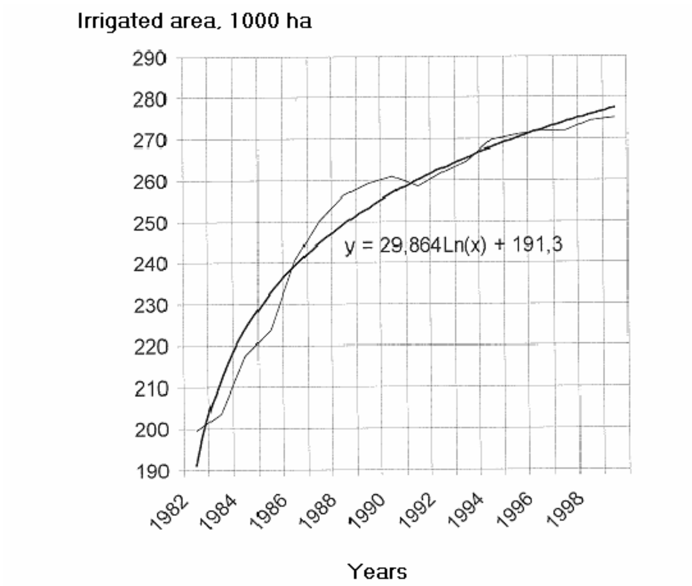

Figure 2.9 Irrigated area in Khorezm aiming at 275.000 ha in 2000
Source: Matjakubov, 2000 cited in Schäfer et al., 2001

The main crop in the Khorezm region is cotton, which occupied 40 % to 50 % of the total sown area between 1998-2003 and approximately 43 % in 2003. The other major crops in Khorezm are wheat and rice. Wheat occupied 14 to 22 % of the sown area in 1998-2003, and 15 % in 2003. Rice occupied 1-18 % of the cropping area in 1998-2003 and approximately 10 % in 2003 (OblStat 1998-2003). Furthermore, potato, vegetables, melons, fruits and grapes are also cultivated in Khorezm. The existing farming system in Khorezm consists mainly of private and Dekhan farms, as discussed in chapter 2.3, with different proportions of crop cultivations. Dekhan farms cultivate mainly vegetables, and to a lesser extent, maize, wheat and fodder crops. Private farms produce mainly cash crops such as cotton, wheat and rice.

State orders (governmentally imposed production quotas and price-fixing regulations) for cotton, wheat and rice still affect the production patterns of private farms in Uzbekistan in general and in Khorezm in particular. Cereal production, especially paddy rice, has increased significantly during recent years, primarily because rice is a staple food that is favored by the local population. It should be planted on heavy impermeable soils, but in Khorezm sand and sandy loamy soils are predominant, as described in chapter 2.4.3. Especially in drought years such as 2000 and 2001, the cropped area for rice decreased drastically due to its enormous irrigation requirements (Müller, 2006). Winter wheat was introduced in Khorezm after its independence as a part of promoting self-sufficiency in grain production. The expansion of the relatively salt-sensitive crop winter wheat, which is basically cropped after cotton, took place mainly at the expense of alfalfa, which had negative effects on the formerly handled crop rotation of alfalfa-cotton, causing a higher supply of nitrogen and humus content in the soil (UN, 2001; Schäfer et al, 2001).

The soil quality and land capability are determined on a 100-degree scale for irrigated land and is called 'bonitet'. This index can be used to conduct a comparative assessment of land quality and productivity. One point on this index is equal to a yielding capacity of 0.04 t/ha of *cotton*. This means that for the soils with the highest scores and, thus, the highest soil fertility, it is possible to gain 4 t/ha of cotton (FAO, 2003c).

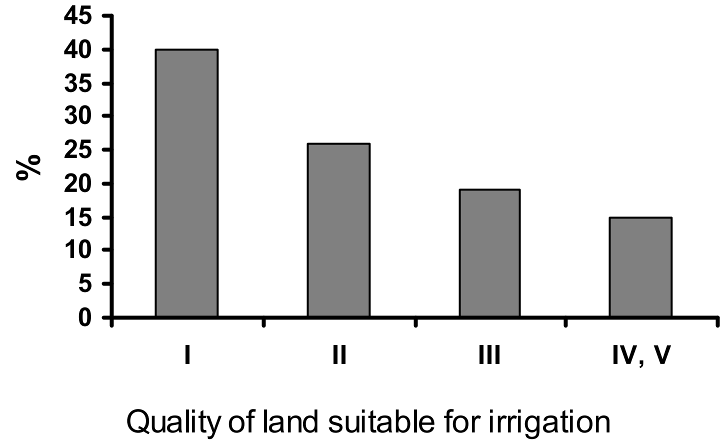

Figure 2.10 Land quality in Khorezm according to the bonitet-index
Notes:
The categories are defined as:
I Very good land, capable of producing 81-100 % of the potential, yield,
II Good land, capable of producing 61-80 % of the potential yield,
III Moderate quality land, capable of producing 41-60 % of the potential yield,
IV,V Poor land, capable of producing 40 % of the potential yield
Source: FAO, 2003b; EU, 1996

Figure 2.10 gives the quality of land suitability for cotton growth in the Khorezm region. The average bonitet-level for soils in Khorezm was 54 in the 1990s. This is equal to a cotton production of 2.16 t/ha. In 1972 this value was 79 points, which is equal to 3.16 t/ha of cotton. Giese et al., 1998 stated that a yield reduction from more than 4 t/ha in the 1980s to less than 3 t/ha towards the end of the 1990s was noticeable. Furthermore, we collected data on cotton yield for 1998-2005, and these data confirm the general tendency of a strong reduction in yield to less than 2.5-3 t/ha. In chapter 4.2.5 the actual cotton yields for 2003, which were only 1.5-1.9 t/ha, are discussed. This decrease in yield reduction is caused by the additional expansion of marginal land, but it is mainly a result of productivity losses due to the increasing salinity of the soils (Schäfer et al., 2001).

Khorezm has the highest rate of secondary or human-induced salinization on irrigated fields compared to all the provinces in Uzbekistan, and the rate is increasing (FAO, 2003b). The proportion of slight, moderate and high salinization of soils to the total salt affected area is 46.8 %, 41.1 % and 12.1 %, respectively. Water salinity is also increasing in Khorezm due to the intensified use of irrigation water by the upstream users and their return flows. Furthermore, the salt accumulation in the groundwater has increased (Ibrakhimov, 2007) due to soil leaching and saline irrigation water reaching the groundwater. Additionally, the groundwater table is rising, which intensifies the interaction between the groundwater, the root zone and the soil. This leads to increased salt accumulation in soils and eventually in the crops as well. The majority of the cultivated crops are very sensitive to increasing soil and water salinity. The result is that the crop yield is reduced, which in turn leads to declining revenues.

3 METHODOLOGY

The structure of agriculture and irrigation and the environmental and economic consequences that they have in Uzbekistan and Khorezm are pivotal problems. The efficiency of crops and water allocation are analyzed in this study in terms of agronomic, economic and hydrologic aspects and processes. These issues determine the composition and methodology of the hydrologic-agronomic-economic model described in detail in the following chapter. An overview of the general background of water management models and hydrologic-economic models currently in use and their main characteristics will be given. Finally, a detailed description of the Khorezmian water management model that includes basic formulas, features and interactions will be discussed.

3.1 Background: economic-hydrologic water management models

A wide range of models are available to study water resources. In general, they are dominated by hydrologic studies of flood/system control and water resource and quality management. However, many different models for reservoir operation, groundwater management, irrigation and drainage management, as well as the use of both surface and groundwater in conjunction, can be found. These water management models consider the quantity and quality of water, salt and soil. On the other hand, economic studies have focused on cost-benefit analyses for profit maximization or the optimization of irrigation, industrial, domestic net benefits, demand pattern and pricing or trading of water (McKinney et al., 1999).

This means that either the hydrologic or the economic component dominates the model, depending on the objectives and on the specific problems of the analysis. However, the sustainable and efficient management of water resources requires an interdisciplinary approach. Interdependencies between physical, economic, agronomic, sociologic and institutional aspects must be considered and incorporated into a holistic model. Thus, a combined economic and hydrologic study at the river basin level and its sublevels seems to be most appropriate to assess water management and policy issues (Young, 1996). These *economic-hydrologic models* integrate water resource behavior and economic components within a single numerical programming model. They consist of a hydrologic and an economic system. The economic components are driven by the hydrologic and agronomic system, which is based on physical parameters and principles. The hydrologic components and their operation, on the other hand, are driven by socio-economic, political and environmental objectives.

The two primary types of combined hydrologic-economic modeling techniques are *simulation* and *optimization*. Simulation models simulate water resource behavior using predefined sets of rules governing water allocations and infrastructure operations. Optimization models optimize and select allocations and infrastructure based on objective functions and accompanying constraints (McKinney et al., 1999). It is possible to assess water system responses using simulation models by changing demand patterns or population growth or by including extreme events such as droughts, floods, or climate change. Simulation models can also identify system failure components. Optimization models are generally based on an objective function that can be driven by hydrology-inferred or economic criteria such as optimal water allocation. In most cases these models also contain a simulation component to characterize the hydrologic system.

Other major differences in modeling water resources management are *short-term* and *long-term models*. Short-term models have modeling periods of one year or a single irrigation season, whereas long-term models use extended periods are mainly used to analyze long-term effects on quality and environmental patterns such as salt accumulation, groundwater or surface flow changes.

Furthermore, a differentiation between *loose* and *tight-coupled models* in integrated economic-hydrologic models is distinguished. In loose or even non-coupled models (also called the compartment approach) the connection between the economy and hydrology is very weak and only output data are transferred externally between the components. In tight- or strong-coupled models (also called holistic approaches) the components are directly connected into one single model based on the same unit of interaction (McKinney et al., 1999). These models are based on information transfer and on the interrelationship between the components that are calculated endogenously within the model. The different components of the system are interlinked and allow feedback between each other.

Furthermore, many integrated models for water resource management exist due to the different approaches described. These models vary in their spatial scale (basin wide, district, field level etc.), included components (drainage, groundwater, surface flows, salinity, institutional rules and incentives, water markets, benefits, etc.) or applied software. Recently, water resource management modelers have started to integrate decision support systems based on Geographical Information Systems (GIS) with a spatial representation of integrated economic, agronomic, institutional and hydrologic components.

The Water Management Model for Khorezm, described below, is characterized as an integrated hydrologic-agronomic-economic combined simulation-optimization model at the district level. It is a tightly coupled short-term model with a one-year time horizon coded in GAMS (General Algebraic Modeling System) and solved by a so-called piece-by-piece approach. The characteristics of the model and the modeling framework were chosen as they best fit the research objective of analyzing and improving water and crop allocation based on hydrologic, agronomic and economic systems. Furthermore, linking other risk and uncertainty management models in irrigated agriculture in Khorezm (Bobojonov, 2008), micro-economic analyses of farm restructuring in Khorezm (Djanibekov, 2008) or land and water use reforms in Uzbekistan using a general equilibrium approach (Müller, 2006) are possible, because all of these methods are based on the same modeling system (GAMS) and were applied to the Khorezm region within the “Economic and Ecological Restructuring of Water and Land Use in the Region Khorezm (Uzbekistan), a Pilot Project in Development Research” project. Additionally, a successful modeling framework for sustainable water resource management for different water basins, such as Mekong and Syr Darya (Cai, 1999), already existed that could serve as the basis for the Khorezm water management model.

3.2 The Khorezm water management model

3.2.1 Main purposes and elements of the model

The main questions of the study to be answered by the model are as follows:

- the identification of strategies and policies of efficient water and crop allocation among users, agricultural development and water resource demand management in Khorezm,
- the detection and determination of water supply and demand and the water availability and water use patterns in the region of Khorezm,
- the evaluation of economic and environmental consequences (costs, benefits and tradeoffs) of water use in the region and the consequences of water-based constraints on agricultural and economic development,
- the exploration of the impact of economic incentives, such as water prices, irrigation and management investment and the liberalization of the cotton market, on hydrology, water use and crop allocation.

The regional water allocation model is built up as a system of nonlinear difference equations. The components of the model and the interactions in the model are based on existing water resources, allocation and optimization theories and existing water resource models. Because the model will be a water management model for the Khorezm region, the scale will be at the regional level. In the Khorezm region the agricultural demand for irrigation water is of major importance, whereas other sectors are marginal (see chapter 2.4.5). For this reason, detailed irrigation and agronomic aspects are taken into account in the model. The allocation of water via irrigation canals to the field level will be of special consideration.

The model is composed of the following:

- the hydrologic components (water flow and balances, groundwater and drainage balances),
- economic components (production, price and profit functions for different crops and water uses, costs, welfare and water prices),
- agronomic components (crop parameters, yields, soil characteristics and evapotranspiration),
- irrigation management (water allocation and efficiencies) and
- institutional rules, policies and economic incentives (as scenario analyses).

Modeling sequences

The main steps in executing this study and developing the model are depicted in Figure 3.1. The first step was defining the problem, followed by deciding on available and applicable models to incorporate. Data collection, revision and compilation were carried out throughout the study and proved to be very difficult as to a situation of partly unpleasant and contradictory data. Secondary data were obtained with the help of models, such as CropWat and ClimWat, the climate database of the FAO (Allen et al., 1998; Smith, 1993). The next step was the development of a basic descriptive model with some main fixed parameters such as water inflow, cropping areas and yields. This type of model is of significance in the description of the de-facto situation in Khorezm. The outcome of this basic model provided information regarding the stability and reliability of the data used. The model was validated and verified followed by a plausibility control of the data, formulas, and system performance and the calibration of the model and for first analyses of economic, agronomic and hydrologic de-facto processes. By relaxing the fixed parameters it was possible to conduct a normative optimization model run. The normative model was utilized for scenarios runs outlined by the objectives of the study, such as water application change, technology change or economic and political incentives. The analysis of these scenarios and their interpretation, documentation, policy recommendation and feasibility filled out the study.

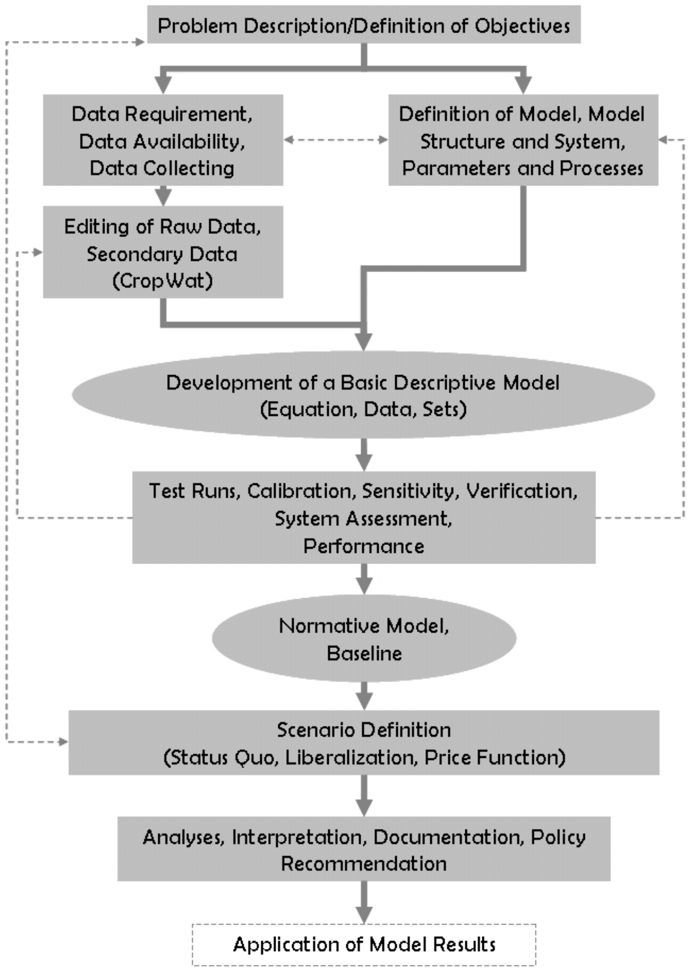

Figure 3.1 Execution and modeling steps of the study

3.2.2 Conceptual framework and components of the model

Water is discharged to the primary irrigation canals from the Amu Darya River (Figure 3.2) and the Tuyamuyun reservoir. It is then conveyed into Khorezm and distributed by a hierarchical canal network within the province. According to the model, the water is exogenously given to the region and then distributed to the districts. Within the districts the water is distributed for industrial/municipal consumption and to the agricultural demand sites. At the demand sites the water is allocated to a series of crops and crop fields, distributed according to their water requirements and profitability taking into consideration the different soil types and its hydraulic characteristics. The surface water (canal water), precipitation, re-used drainage water and groundwater (contribution by capillary rise and withdrawals by pumping) are considered to be potential sources for irrigation. Most of the water is consumed by the crops via transpiration and evaporation from the soil. The rest is percolated to the downward layer and to the groundwater, which is then drained, conveyed to evaporation ponds or re-used for irrigation. Due to high groundwater levels in Khorezm and the afflux of irrigation and drainage water within the canals, the influence of groundwater and groundwater exchange (percolation/seepage losses, capillary rise) is included within the modeling framework.

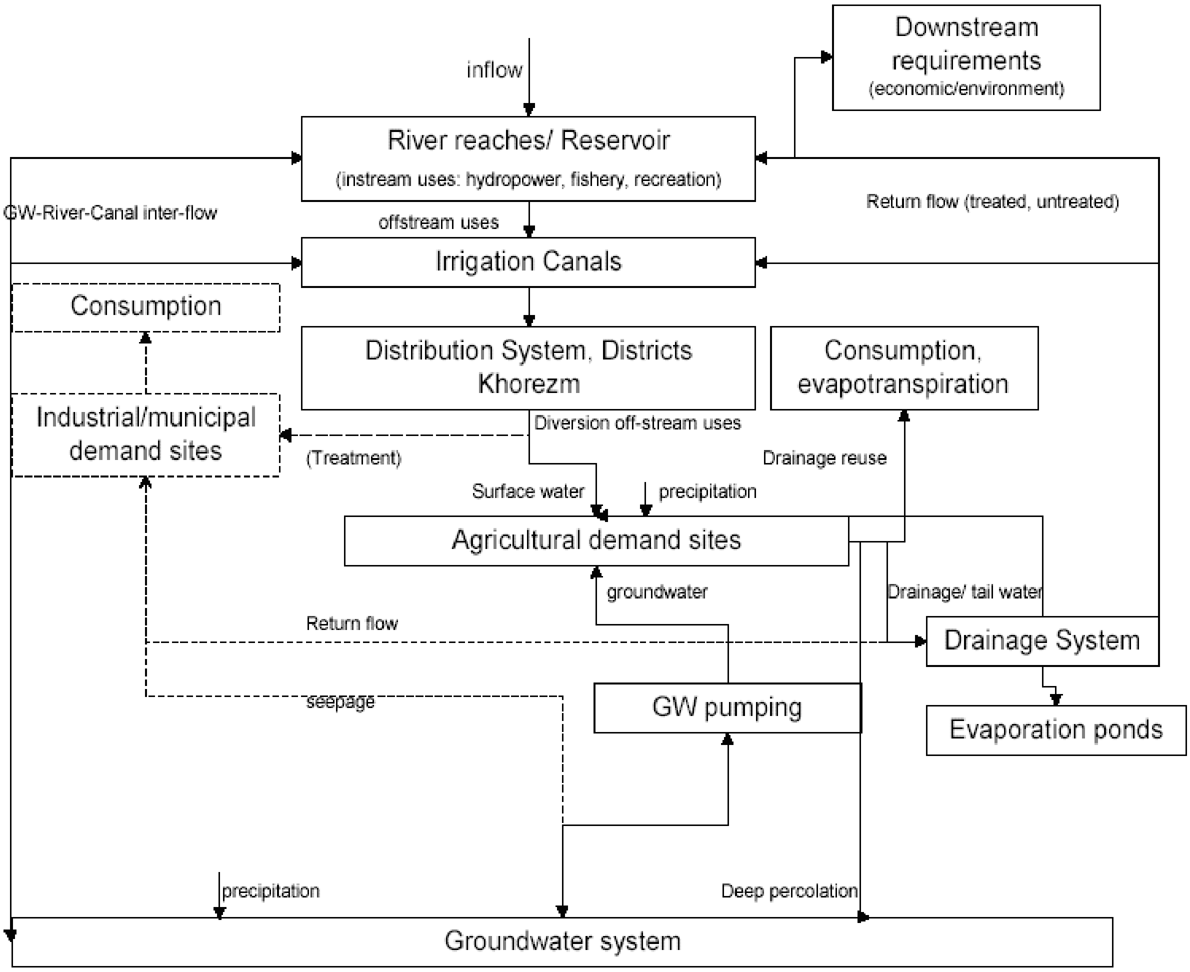

Figure 3.2 Schematic representation of the water distribution process in the Khorezm Water Management Model

Source: adapted from Daza and Peralta (1993), modified

For water allocation at the regional and field level, the efficiency of the water distribution system and the drainage system is taken into consideration. The determination of water allocation among crops and among different soil types is dependent on soil parameters, cropping pattern and crop characteristics. Water demand is determined endogenously within the model using empirically determined agronomic parameters for the production function. The water supply in the region, including the irrigated crop fields at each of the irrigation demand sites, is determined through hydrologic water balances (surface water, groundwater balance, drainage water and soil water).

Water supply and demand are integrated into an endogenous system. The valuation of production and water use costs, revenues and yields are determined in an economic objective function, which is constrained by hydrologic, agronomic, and institutional relations. Water allocation to districts and crops is determined by maximizing profits, which considers economic water use efficiency (*e-WUE*). Water-related policies and future programs will then be modeled as different scenarios.

The model consists of ten districts. It is assumed that every district consists of an evaporation pond and a groundwater reservoir. The model considers eight different crops (cotton, wheat, rice, other grain, alfalfa, vegetables, fruits, potatoes) and three main soil types (light, medium, heavy soils).

The model is written in the General Algebraic Modeling System (GAMS) (Brooke et al., 1988) language, which is a system for programming mathematical problems. GAMS allows for linkages with other models, which are developed within the project. The model covers a one-year time span and is subdivided into twelve monthly modeling periods.

3.2.3 Bio-physical components

The bio-physical components of the model are subdivided into hydrologic and crop and soil-water-related agronomic interactions. Hydrologic processes in the model include flows and balances of surface water, groundwater, drainage water and water within the root zone (soil water).

Water allocation

The following paragraph describes the water allocation within a demand site and the water allocation among crops. The water that is discharged from canals, rivers and the reservoir is allocated to different districts in Khorezm. Depending on the distribution efficiency, the water is then allocated for non-irrigation (municipal and industrial uses, *NIWD*) and irrigation purposes (*WCP*). The canal water for irrigation (and leaching), together with the groundwater pumping, accounts for the water that is available for a crop field (*WFLD*). However, the total effective water that a crop field receives (*WACP*) depends on the irrigation/application efficiency, which lowers the amount of water the field obtains (Figure 3.3 and equation (3.1), (3.2), (3.3)).

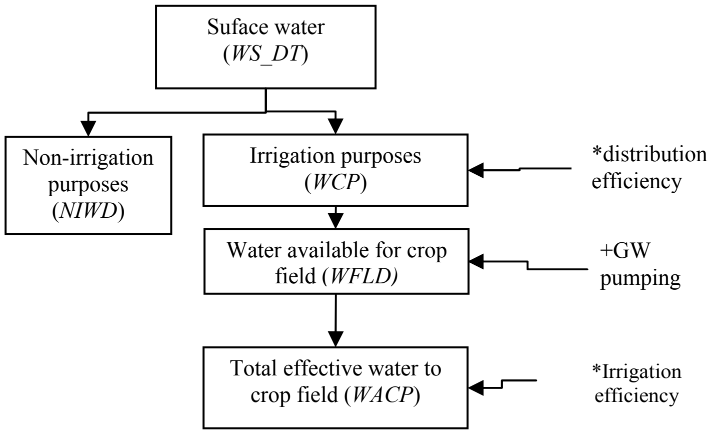

Figure 3.3 Surface water distribution

$$\sum_{soil}\sum_{c} WCP^{t}_{dt,soil,c} = WS\_DT^{t}_{dt} \cdot eff\_dstr_{dt} - NIWD^{t}_{dt} \quad (3.1)$$

$$WFLD^{t}_{dt,soil,c} = WCP^{t}_{dt,soil,c} + \sum_{gw\_dt} pump^{t}_{gw,dt,soil,c} \quad (3.2)$$

$$WACP^{t}_{dt,soil,c} = WFLD^{t}_{dt,soil,c} \cdot eff\_irr_{dt,soil,c} \quad (3.3)$$

WCP water at demand site for irrigation purposes per district, soil and crop type and month [10^6 m^3]
WS_DT total surface water per district and month [10^6 m^3]
eff_dstr distribution efficiency [-]
NIWD water for non irrigation purposes per district and month [10^6 m^3]
WFLD water available at crop field per district, soil and crop type and month [10^6 m^3]
pump pumped water from groundwater sources per aquifer, district, soil and crop type and month [10^6 m^3]
WACP effective water available for crops per district, soil and crop type and month [10^6 m^3]
eff_irr Irrigation/application efficiency [-]
for *WFLD, WCP* and *WACP:* $t \in$ *growth period*

following indices:

dt demand sites/districts (Khasarasp, Khanka, Urgench, Yangibazar, Gurlan, Bagat, Yangiarik, Khiva, Khushkupir, Shavat)
soil soil type (light, medium, heavy)
c crop type (cotton, wheat, rice, other grains, vegetables, fruit, alfalfa, potato)
t time period (months)
gw aquifer (per district)

Efficiencies

Distribution/network efficiency is defined as the ratio of water available at the crop field to the total water delivered from both surface and subsurface sources. Distribution efficiency depends mainly on canal properties (lining, material, leakages, and evaporation).

Israelsen (1932) is credited as the first person to engage in the calculation and examination of the efficiencies of irrigation. He defined efficiency as *"The ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period, over the water diverted from a river or other natural source into the farm or project canal or canals during the same period of time"*. Today, various definitions of efficiency at different scales, phases and crops exist (Wolff and Stein, 1999).

In the model, irrigation/application efficiency is defined as the ratio of the water that is effectively used by crops and soil to the total water applied to crop fields. This is applicable only with the assumption that irrigation efficiency is the same over all crop growth stages, within all crop fields, for all crop types and that there is no inclusion of reused water for irrigation in the calculation of irrigation efficiency.

Soil-water balance at root zone

The soil water content in the root zone depends on many factors, including the (surface) water application (WACP, see equation (3.3)) per area, the small quantity of rainfall within the Khorezm region (infiltrated effective rainfall, PE), the groundwater that contributes to crop water supply and is extracted by the roots from the groundwater zone via capillary rise (GC), the evapotranspiration output (*ETa*) and the deep percolation and surface runoff losses (Cai, 1999).

$$\begin{aligned}(z^{t}_{dt,soil,c} - z^{t-1}_{dt,soil,c}) \cdot rdpth_{c} &= WACP^{t}_{dt,soil,c} / ACP_{dt,soil,c} + GC^{t}_{dt,soil,c} \\ &\quad - ETa^{t}_{dt,soil,c} + PE^{t}_{dt,soil,c} - DP^{t}_{dt,soil,c}\end{aligned} \tag{3.4}$$

z	soil moisture per district, soil and crop type and month [cm^3/cm^3]
rdpth	root depth per crop [cm; 10^{-2} m]
ACP	cropped area per district, soil type and crop [ha]
GC	groundwater contribution via capillary rise per district, soil and crop type and month [10^{-3} m](equation (3.8))

ETa actual evapotranspiration per district, soil and crop type and month [10^{-3} m] (equation (3.12))
PE effective precipitation per district, soil and crop type and month [10^{-3} m] (equation (3.6), (3.7))
DP deep percolation per district, soil and crop type and month [10^{-3} m] (equation (3.5))

A visualization of the soil, surface and groundwater balances and flows can be seen in Figure 3.4.

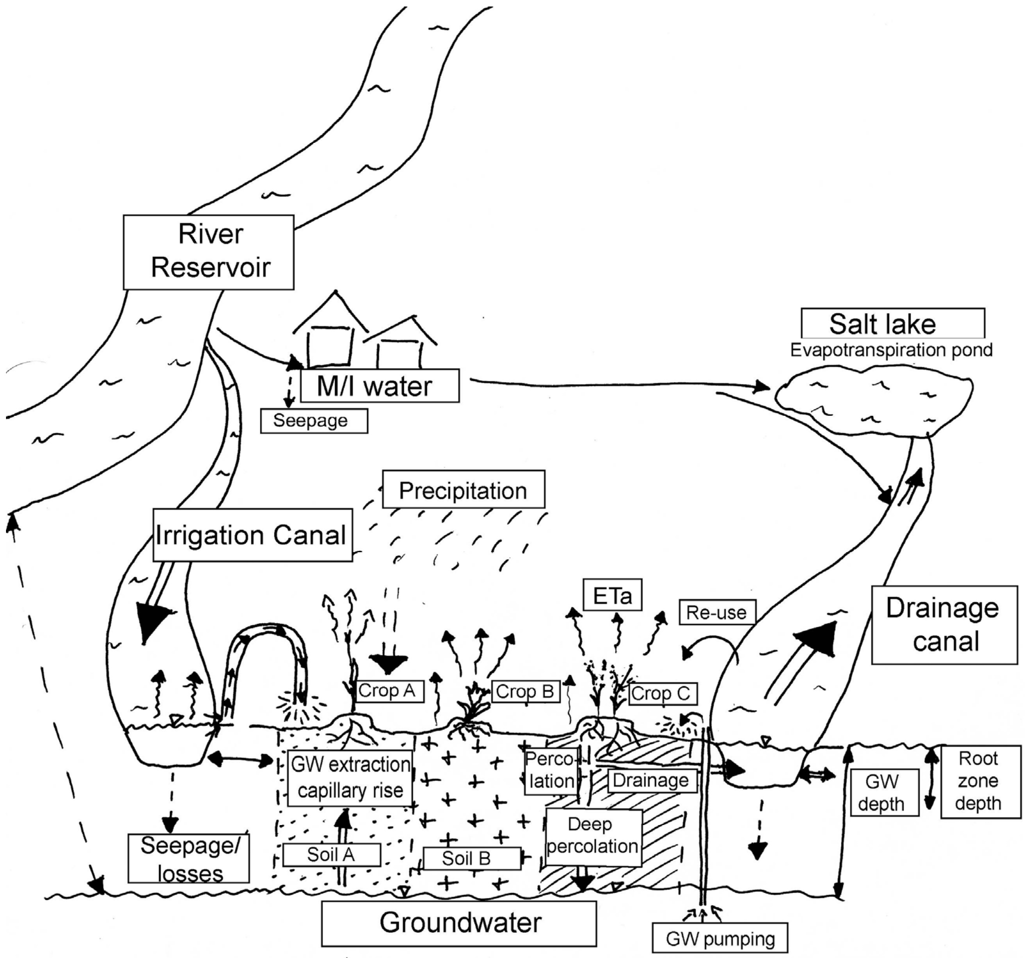

Figure 3.4 Schematic showing the surface and sub-surface water flows and soil water balance used in the model

Deep percolation

Deep percolation refers to the water that drains into soil layers, enters the groundwater or is transported out of the system via drainage canals. For this reason, it is not available for the crop. By definition, the percolated water contains irrigation and precipitation water not used by the crops.

$$DP_{dt,soil,c}^{t} = (rain_{dt}^{t} - PE_{dt,soil,c}^{t} + WFLD_{dt,soil,c}^{t} / ACP_{dt,soil,c} \cdot (1 - eff\_irr_{dt,soil,c})) \cdot (1 - r\_sr_{dt,soil,c}) \tag{3.5}$$

DP	deep percolation per district, soil and crop type and month [10^{-3} m]
rain	rainfall per district and month [10^{-3} m]
r_sr	ratio of surface runoff to total losses per district, soil and crop type [-]

In Khorezm, there is such a small amount of rainfall that we can assume almost all of the precipitated water is effectively used by the crops. Thus, the term *Rain-PE* can be neglected as a contributor of percolation. The soil water content in Khorezm might exceed field capacity due to high irrigation water supply and non-uniform water application, but not because of high precipitation.

In order to reach field capacity at the end of the field (which is the soil moisture or water content that is held by the soil without percolating due to gravity) one has to accept over-irrigation at begin of the furrow. The insufficient leveling of fields in Khorezm increases this tendency and results in relatively high rates of deep percolation and losses of available water for the crops.

Effective precipitation

Not all of the precipitation that falls on the soil surface can be used by crops. Some of the rain percolates below the root zone of the crop. Some of the rainfall does not infiltrate and becomes surface run-off. Only a small fraction called effective rainfall, which is the rainfall that is stored in the root zone, can be used by the crops. Factors that influence the effectiveness of rainfall are precipitation characteristics, soil properties, crop evapotranspiration rates, and irrigation management (Brouwer and Heibloem, 1986; USDA, 1993). As described in Dastane (1978), a wide range of definitions and estimation methods for effective rainfall are available. Effective rainfall depends basically on total rainfall and soil moisture as well as on other soil characteristics such as hydraulic conductivity, root depth, and reference crop evapotranspiration. In the model developed, the effective rainfall is the amount of precipitation that is infiltrated into the root zone and can be utilized by the crops. An estimate can be made using an empirical method developed by the Soil Conservation Service of the USDA (1967 and 1993). For simplification, an empirically derived method based on the USDA-SCS method and used by the CropWat program for calculating effective rainfall (PE) was used.

$$PE = rain/125 \cdot (125 - 0.2 \cdot rain) \qquad \text{(for rain<250 mm/a)} \qquad (3.6)$$

$$PE = 125 + 0.1 \cdot rain \qquad \text{(for rain>250 mm/a)} \qquad (3.7)$$

The amount of total rainfall (with <100 mm/y) and the absolute effective rainfall in Khorezm is low and does not occur during the crop period. Thus, rainfall does not contribute to additional water supply for crops.

Groundwater contribution to crop water supply

The contribution of capillary rise from the groundwater to soil water content is a major element of the soil-water balance in the root zone (equation (3.4)). It represents the movement of water from the groundwater table and plays a crucial role in crop water supply due to the extremely shallow groundwater levels in Khorezm (Ibrakhimov et al. 2007; Forkutsa et al., 2009). The calculation of capillary rise from the groundwater is based on the equation given by Eagleson (1978 and 2002) and cited in Cai (1999) for dry seasons:

$$GC^{t}_{dt,soil,c} = K_{dt,soil}\left[1 + \frac{1.5}{mm_{dt,soil} \cdot cc_{dt,soil} - 1}\right] \cdot \left[\frac{\varphi s_{dt,soil}}{\sum_{gw\_dt} hg^{m}_{dt,soil,c}}\right]^{mm_{dt,soil} \cdot cc_{dt,soil}} \qquad (3.8)$$

GC groundwater contribution via capillary rise per district, soil and crop type and month [10^{-3} m]
K hydraulic conductivity per district and soil type [10^{-2} m]
mm soil pore size distribution index per district and soil type [-]
cc soil pore disconnectedness index per district and soil type [-]
φs soil matrix potential per district and soil type [10^{-2} m]
hg groundwater table depth per district, soil and crop type and month [10^{-2} m]

Parameters such as hydraulic conductivity, soil connectivity, tortuosity and matrix potential are parameters relating to the soil. They describe the path and the speed at which water is flowing through the different soil types which in turn determine the capillary rise and the contribution to crop water supply. The values assumed for these variables are based on the different soil types and can be seen in Appendix C.

Groundwater balance

Groundwater is important when considering the crop water supply in Khorezm and is linked to the water balance of the root-zone in two ways. First, groundwater recharge comes from irrigation losses (percolation), and second, the groundwater influences the water balance (as well as the salt balance) in the root-zone via capillary rise. Deliberately shallow-held groundwater levels influence crop growth advantageously due to root zone extractions and capillary rise. However, capillary rise enhances salt accumulation in the root-zone and may negatively impact crop yield. To reach an appropriate balance between surface and groundwater resources taking the above-mentioned effects into account, the relationship between surface and groundwater systems needs to be considered. Within the integrated model, a “single-tank-model” is used to simulate the flows in aquifers (see Bear, 1977; described in Cai, 1999). Assuming that each district in Khorezm has one groundwater aquifer (AQA), the groundwater balance for the district includes the distribution losses from the canals (surface water leakages) and deep percolation in fields on the inflow side (DP), and pumping (pump) and groundwater contributions to root zones via capillary rise (GC) on the outflow side (Figure 3.5). The surface and subsurface water losses can be determined using the distribution and drainage efficiencies (eff_dstr, eff_drn).

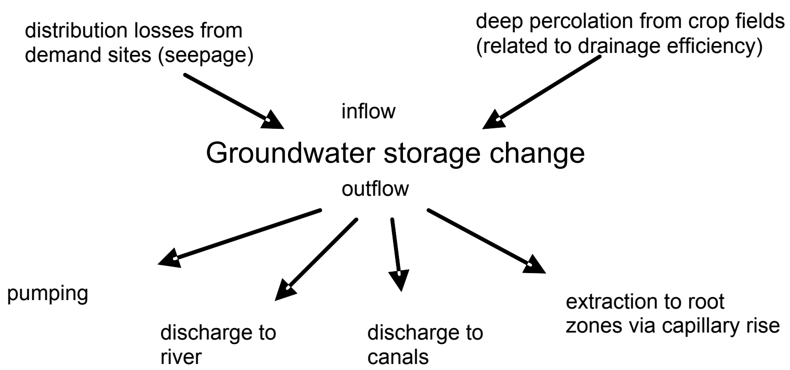

Figure 3.5 Groundwater balance

According to Cai (1999), the corresponding equation for the change in groundwater storage per district aquifer can be expressed as follows:

$$sy \cdot AQA \cdot (hg^{t} - hg^{t-1}) = \begin{cases} \sum_{dt} (WS\_DT_{dt}^{t} \cdot (1 - eff\_dstr_{dt}) \cdot (1 - eff\_drn_{dt}) \\ + \sum_{dt} \sum_{soil} \sum_{c} DP_{dt,soil,c}^{t} \cdot ACP_{dt,soil,c} \cdot (1 - eff\_drn_{dt}) \\ - \sum_{dt} \sum_{soil} \sum_{c} pump_{dt,soil,c}^{t} \\ - \sum_{dt} \sum_{soil} \sum_{c} GC_{dt,soil,c}^{t} \cdot ACP_{dt,soil,c} \\ - trans \cdot sy \cdot (hg^{t} - hg^{t-1}) \end{cases} \tag{3.9}$$

sy	groundwater storativity, aquifer specific yield coefficient per aquifer [cm^3/cm^3]
AQA	groundwater area (in horizontal direction) [ha]
hg	groundwater table depth per aquifer [10^{-2} m]
WS_DT	gross water supply to districts per district and month [10^6 m^3]
eff_dstr	distribution efficiency per district [-]
eff_drn	drainage efficiency, drainage over total irrigation water supply per district [-]
DP	deep percolation per district, soil and crop type and month [10^{-3} m]
ACP	irrigated crop area per district, soil and crop type [ha]
pump	groundwater pumping per aquifer, district, soil and crop type and month [10^6 m^3]
GC	groundwater contribution via capillary rise per district, soil and crop type and month [10^{-3} m]
trans	hydraulic conductivity in dependence of aquifer thickness per aquifer [10^{-2} m/day]

In this equation, *AQA* represents the horizontal area of the aquifer, *sy* is the aquifer storativity and describes the capacity of the aquifer to release groundwater from storage and *hg* is the depth of the groundwater table. The first term on right-hand side of the equation represents the distribution losses from the demand sites; whereas the second term represents the loss due to deep percolation into the groundwater through vertical drainage (some is lost through horizontal drainage into canals). The following paragraphs describe the pumping losses out of the aquifer, the groundwater contribution to crops by capillary rise and the discharge from the aquifer to the surface water system. The coefficient *trans* describes the dependency of hydraulic conductivity on the aquifer thickness.

Evapotranspiration

To determine the amount of crop water use and crop water productivity (the crop production function), several calculations are necessary. Accounting for the actual evapotranspiration (*ETa*) is the most relevant factor but also the most difficult to determine (Rappold, 2004). Evapotranspiration is the combination of the terms evaporation, which is the amount of water that is evaporated by the soil surface to the atmosphere, and transpiration, which is the amount of water that is transpired by crops and animals. To estimate the actual evapotranspiration, the concept of a reference crop evapotranspiration (*ETo*) was introduced by Doorenbros and Pruit (1975).

Reference crop evapotranspiration (ETo)

ETo is the evapotranspiration from a reference crop with the specific characteristics of grass, fully covering the soil and not deprived of water. It represents the evaporative demand of the atmosphere at a specific location and time of the year and is independent of crop type, crop development, management practices and soil factors. The value of *ETo* refers to the hypothetical evapotranspiration that can be achieved by a reference crop (grass) under given regional and climatologic conditions with no water shortages. The only factors that affect *ETo* are climatic parameters such as pressure, wind speed, temperature, solar radiation, and hours of daylight. This means that *ETo* is a climatic parameter and can be computed from weather data (Kassam and Smith, 2001).

The FAO Penman-Monteith method is widely used to calculate *ETo* (via the FAO CropWat program[8]). The climatic factors of the Khorezm region, including amongst others temperature, humidity, wind speed, and solar radiation, are incorporated into the calculation of the reference evapotranspiration (Allen et al., 1998).

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{3.10}$$

ETo	reference evapotranspiration for a reference crop per district and month (short grass) [10^{-3} m/day]
Rn	net radiation at the crop surface [10^6 J/m$^2\cdot$day]
G	soil heat flux density [10^6 J/m$^2\cdot$day]

8 CropWat is a water balance-based computer program to calculate crop water requirements and irrigation water requirements from climatic and crop data. It is also used in the development of irrigation schedules for different management conditions and the calculation of water supply schemes for varying cropping patterns.

T mean daily air temperature at 2 m height [K]
u_2 wind speed at 2 m height [m/s]
Es saturation vapor pressure [10^3 Pa]
Ea actual vapor pressure [10^3 Pa]
$e_s - e_a$ saturation vapor pressure deficit [10^3 Pa]
D slope of the vapor pressure curve [10^3 Pa/10^{-2} m]
G psychrometric constant [10^3 Pa/K]

The *ETo* is a the local evaporation potential of the atmosphere for a reference crop. It is not adapted to crop-specific characteristics. A crop-specific potential evapotranspiration value (*ETc*) was introduced by Doorenbos and Pruit (1975) to adjust the *ETo* term for a specific crop at given climatic conditions.

Crop-specific potential evapotranspiration (ETc)

ETc is defined as "the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions" (Allen et al., 1998).

To determine *ETc*, the *ETo* value is multiplied by the dimensionless crop factor (*kc*), which relates crop-specific evapotranspiration to the evapotranspiration of the standard (reference) crop according to equation (3.11).

$$ETc = kc \cdot ETo \tag{3.11}$$

kc crop coefficient relating *ETo* to *ETc* per crop and month [-]
ETo reference evapotranspiration per district and month [10^{-3}m/month] (equation (3.10))
ETc potential (maximum) crop-specific evapotranspiration per district and month [10^{-3}m/month]

Using equation (3.11), crop characteristics, local soil properties and climatic characteristics are incorporated into the *kc* coefficient to relate *ETo* to *ETc*. Crop characteristics and evaporation from the soil that influence evapotranspiration are included in the *kc* factor, such as crop height, vegetation and ground cover, albedo and canopy resistance. The *kc* factor varies between the different developmental stages of the crop, as the crop characteristics change over the growing period. *Kc* values are empirically determined. The basis of the *kc* values used in the model is described in chapter 4. The concept of the *kc* factor is standard and widely used all over the world (Kassam and Smith, 2001).

Figure 3.6 shows how to determine *ETo* and how to calculate *ETc*. In summary, potential evapotranspiration values (*ETo*) for a specific reference crop (grass) under standardized climatic and crop-specific conditions are determined using the Penman-Montheith method (equation (3.10)). To obtain a crop-specific value of evapotranspiration under standard conditions, the *kc* value is introduced (equation (3.11)). This value relates *ETo* to specific crop and climatic conditions.

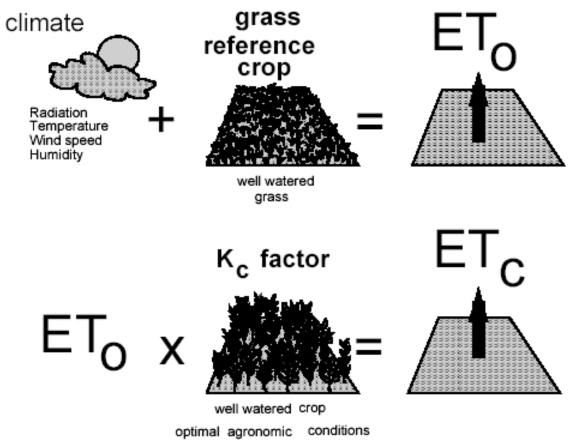

Figure 3.6 Procedure for calculating reference and crop-specific evapotranspiration under standard conditions

Source: Allen et al., 1998

The crop evapotranspiration (*ETc*) determined is valid for standard optimal agronomic conditions. The value of *ETo* is corrected for crop specific and climatic conditions (via the *kc* factor), but the values are still potential (maximum) evapotranspiration values. They are helpful for irrigation planning and determining crop water requirements under normal conditions but not for determining the *actual* crop evapotranspiration. Factors such as soil salinity, crop density, soil water content, land fertility and poor soil management may limit crop development and reduce evapotranspiration. These water and environmental stress factors require a modification of the *kc* factor and the implementation of an additional adjustment factor that incorporates these non-standard conditions.

Actual evapotranspiration (ETa)

Following the process described to determine evapotranspiration and the factors influencing evapotranspiration, the actual evapotranspiration (*ETa*) is consequently a function of *ETo* (and *ETc, kc*) and crop, soil and salinity specific coefficients. In the model used, the calculation of *ETa* is performed according to the work of Cai (1999), Jensen et al. (1971), Hanks (1985), Allen et al. (1998) and Prajamwong et al. (1997). These authors use a function of reference evapotranspiration and several correction factors, such as the soil moisture stress coefficient, the soil salinity coefficient, the soil water stress coefficient and the crop coefficient, that influence the actual evapotranspiration:

$$ETa^{t}_{dt,soil,c} = ETo^{t}_{dt} \cdot [kw^{t}_{dt,soil,c} \cdot (1 - ks^{t}_{dt,soil,c}) \cdot kct^{t}_{c} + (kc^{t}_{c} - kct^{t}_{c}) \cdot kap^{t}_{dt,soil,c}] \quad (3.12)$$

kw soil moisture stress for transpiration, transpiration reduction factor per district, soil and crop type and month [-] (equation (3.15))
ks soil salinity coefficient that influences evapotranspiration, salinity coefficient per district, soil and crop type and month [-] (equation (3.13))
kc crop evapotranspiration coefficient per crop and month [-] (equation (3.11), (3.14))
kct crop transpiration coefficient, transpiration component per crop and month [-] (equation (3.17))
kap coefficient of soil water stress effect for soil evaporation, evaporation coefficient per district, soil and crop type and month [-] (equation (3.16))

The coefficients relating *ETo* to *ETa* are described in following paragraph.

The salinity (ks) coefficient

The availability of soil water for root extraction and evapotranspiration can be diminished by salts in the soil water solution. Soil salinity is usually measured by the electrical conductivity of the saturated soil extract (ECe) and is expressed in deciSiemens per meter (ds/m). This technique is based on the principle that salt concentration changes as soil water content changes. Crop yields remain at a certain level until a specific threshold, called the threshold electrical conductivity of the saturated soil water extract (ECe threshold), is reached. If the average ECe of the root zone increases above this critical threshold level, yield begins to decrease linearly and is proportional to the increase in salinity. The slope (b) is the rate of decrease in yield with increasing salinity and has units of % reduction in yield per dS/m increase in ECe (Rhoades et al., 1992). Salt tolerance is crop-specific (Figure 3.7).

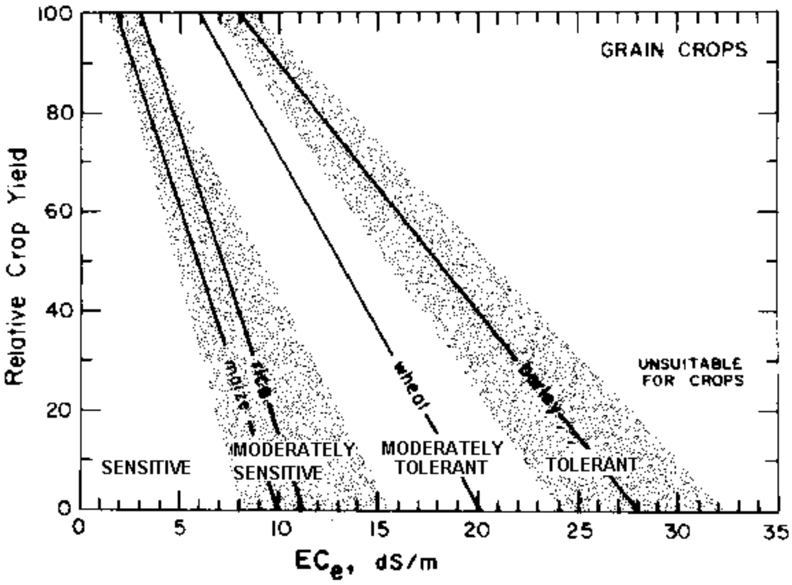

Figure 3.7 Salt tolerance of grain crops
Source: Rhoades et al., 1992

The soil salinity coefficient (*ks*) influences evapotranspiration and is estimated based on the salinity relationship in the root zone described by Rhoades et al. (1992).

$$ks^{t}_{dt,soil,c} = 1 - \frac{Ya}{Ym} = b^{t}_{c} \cdot (EC^{\,t}_{e\,dt,soil,c} - EC_{e\_threshold}{}^{t}_{c})/100$$

and (3.13)

$$ks^{t}_{dt,soil,c} = 0 \Rightarrow if \;\; EC^{\,t}_{e\,dt,soil,c} < EC_{e\_threshold}{}^{t}_{c}$$

Ya	actual crop yield per district, soil and crop type [t/ha]
Ym	maximum expected crop yield per district, soil and crop type [t/ha] (when ECe < ECe_threshold)
ECe	mean electrical conductivity of the saturation extract for the root [dS/m]
ECe_threshold	mean electrical conductivity of the saturation extract at the threshold ECe when crop yield first reduces below Ym [dS/m]
b	reduction in yield per increase in ECe per crop and month [dS/m]
t,dt,soil,c	time, district, soil type, crop- indices

The dual crop coefficient (kc)

Crop characteristics and evaporation from the soil are included in the *kc* factor, such as crop height, vegetation and ground cover, albedo and canopy resistance. In the dual crop coefficient, the effects of crop transpiration and soil evaporation are determined separately.

Kc consists of the *kw* coefficient, that describes crop transpiration and kap, that describes soil water evaporation.

$$kc_c^t = kw_{dt,soil,c}^t + kap_{dt,soil,c}^t \tag{3.14}$$

The kw coefficient

The coefficient that accounts for soil moisture stress as a result of reduction in crop transpiration consists of an empirically derived soil moisture relationship between field capacity and wilting point and is described in Cai (1999), who cited the work of Jensen et al. (1971) with the assumption that *kw* is "proportional to the logarithm of the percentage of the remaining available soil moisture" (Jensen et al., 1971).

$$kw_{dt,soil,c}^t = \ln\left[100 \cdot \left(\frac{z_{dt,soil,c}^t - zw_{soil}}{zs_{soil} - zw_{soil}}\right) + 1\right] / \ln(101) \tag{3.15}$$

zw soil moisture at wilting point per district and soil type [cm^3/cm^3]
zs soil moisture at field capacity per district and soil type [cm^3/cm^3]

The kap coefficient

The water stress coefficient that accounts for soil evaporation is described in Prajamwong et al. (1997) and is empirically derived.

$$kap_{dt,soil,c}^t = \left[\frac{z_{dt,soil,c}^t - 0.5 \cdot zw_{soil}}{zs_{soil} - 0.5 \cdot zw_{soil}}\right]^{0.5} \tag{3.16}$$

Both, kw and kap are valid for: $z_{dt,soil,c}^t \geq zw_{soil}\ and\ z_{dt,soil,c}^t \leq zs_{soil}$

The kct coefficient

The coefficient kct accounts for the change of the crop coefficient in dependency of the growing season. The coefficient was described by Hanks (1985).

Before crop emergence:

$$kct = 0 \quad \text{,and after crop emergence}$$

$$kct = kc \cdot 0.9 \tag{3.17}$$

Crop-water production function

Water stress for crops can be quantified using a relation between actual (*ETa*) and maximum evapotranspiration (*ETc*). In cases when crop water requirements are fully met from the available water supply, *ETa*=*ETc*. When the water supply for crops is insufficient, *ETa*<*ETc*. When this occurs, crop yields are reduced.

The relationship between crop water supply and crop yield is described by a correlation that was developed by the FAO (Doorenbos and Kassam, 1979). The FAO approach considers the relative crop yield loss (actual yield to maximum yield) as a linear function of water deficit. The water deficit is expressed as the ratio of actual evapotranspiration (*ETa*) to the maximum evapotranspiration (*ETc*). Using this approach, the impact of irrigation strategies on crop yield can be estimated because the irrigation strategies influence the soil moisture, which in turn determine the potential reduction in actual evapotranspiration. The FAO recommends the following relationship between relative yield decrease and relative evapotranspiration deficit, which is an empirically derived yield reduction factor, *ky* (Allen et al, 1998; Doorenbos and Kassam, 1979).

$$1 - Ya_{dt,soil,c} / Ym_{dt,soil,c} = \sum_{vegatation\,period} ky_c^t \cdot (1 - ETa_{dt,soil,c}^t / ETc_{dt,soil,c}^t) \qquad (3.18)$$

Ya	actual yield per district, soil and crop type [t/ha]
Ym	maximum/potential yield per district, soil and crop type [t/ha]
ky	yield response factor, seasonal yield response factor per crop and month [-]
ETa	actual evapotranspiration per district, soil and crop type and month [10^{-3}m/month]
ETc	crop reference evapotranspiration computed for optimal conditions [10^{-3}m/month]

The ky coefficient

The *ky* coefficient is the empirically derived yield response factor due to water stress caused by soil water shortage (soil moisture deficit). It relates the relative yield decrease (1-*Ya/Ym*) to the relative evapotranspiration deficit (1-*ETa*/*ETc*) and can be seen as the response of yield to water supply, or more precisely, to water deficit.

Crops have diverse water requirements and respond differently to water stress. Therefore, sensitivity to water stress varies from crop to crop and from one growth stage to another. As can be seen in Figure 3.8, crops such as alfalfa or sugarbeet (and, to some extent, cotton and wheat) have a *ky*<1 over their entire growth period. For such crops, the decrease in yield is proportionally less to the increase in water deficit (Doorenbos and Kassam, 1979a). For other crops such as maize and, to some extent, potato and tomato, *ky*>1, and the yield decrease is proportionally greater than the water deficit increase.

The decrease in yield due to water deficit for crops in the vegetative and ripening period is relatively small, whereas in the flowering and, to some extent, in the seed-filling periods, it is relatively high (Figure 3.9). For this reason, *ky* values are crop-specific and vary over the specific growth stages. The values of *ky* are based on experimental field data covering a wide range of growing conditions. Doorenbos and Kassam (1979) analyzed information on crop yield response to water and empirically derived the yield response factors *ky*(i) for water stress in a specified growth stage (i). Approximately 80–85% of the observed yield variation at different locations was explained by this relationship. Thus, the response factors *ky*(i) are recommended for the planning and the operation of irrigation systems (Allen et al., 1998).

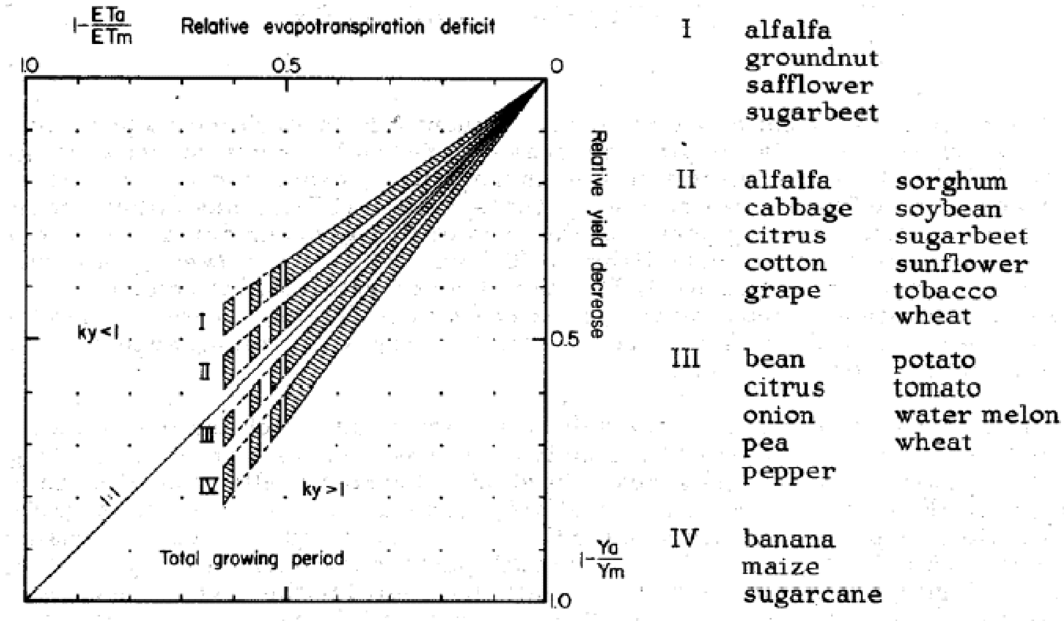

Figure 3.8 Relationship between relative yield and relative evapotranspiration for total growth period

Source: Doorenbos and Kassam, 1979a

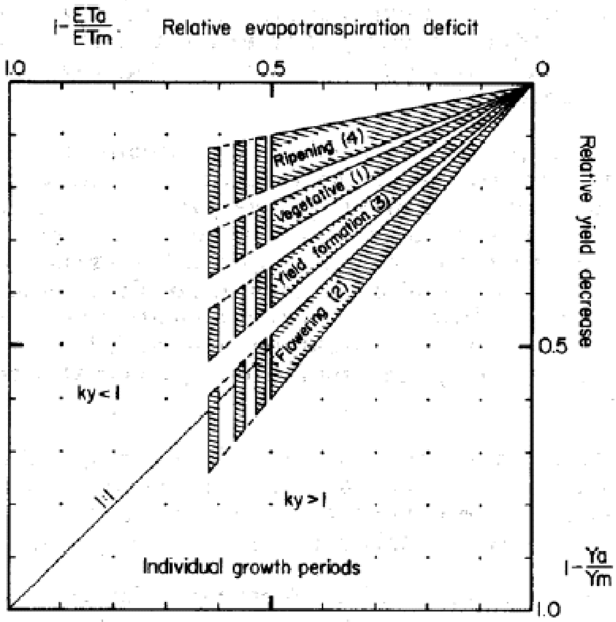

Figure 3.9 Relationship between relative yield and relative evapotranspiration for individual growth periods

Source: Doorenbos and Kassam, 1979a

3.2.4 Economic component

The operation of hydrologic-agronomic systems in integrated hydrologic-economic models is driven by socio-economic objectives, whereas the economic incentives are linked to the physical system. The objective of this model is to maximize the gross margins in irrigated agriculture specifically for the ten districts using physical, institutional and agro-political constraints. The objective function is expressed as follows:

$$\max obj = \sum_{dt} Aprft(dt) \tag{3.19}$$

Gross margins and water costs

The total gross margin from agricultural demand sites (Aprft) is equal to crop revenue (see equation (3.27)) minus the fixed variable cropping costs (otc), groundwater pumping costs (gct) and surface water supply costs (sct).

$$Aprft_{dt} = \sum_{soil}\sum_{cp}\begin{cases}(y\max_{dt,cp} \cdot mryld_{dt,soil,cp} \cdot ACP_{dt,soil,cp} \cdot cpp_{dt,soil,cp}) \\ -(acp_{dt,soil,cp} \cdot otc_{dt,cp}) \\ -(\sum_{m} pump_{gw,dt,soil,cp,m} \cdot gct_{dt}) \\ -(sct_{dt} \cdot swd_{dt})\end{cases} \tag{3.20}$$

obj	objective function [USD]	*otc*	other costs for crop cultivation [USD/ha]
Aprft	agricultural gross margin [USD]	*pump*	groundwater pumping [m^3]
ymax	max yield [t/ha]	*gct*	groundwater pumping costs per unit [USD/m^3]
mryld	min relative yield [-]	*swd*	surface water diversion to districts [m^3]
acp	irrigated crop area [ha]	*sct*	surface water price per unit [USD/m^3]
cpp	crop price [USD/t]		

Gross margins per crop, gross water costs and gross water application for a single crop/crop field and for all the districts is calculated as follows:

$$GM\_c_{dt,c} = Rv\_c_{dt,c} - WC\_c_{dt,c} - \sum_{s} acp_{dt,soil,c} \cdot otc_{dt,c} \tag{3.21}$$

Whereas the total gross margins are the sum of all the per crop gross margins:

$$GM\_all_{dt} = \sum_{c} GM\_c_{dt,c} \tag{3.22}$$

Total water costs and water costs per crop are a function of the surface and pumping water applied to the field and their supply costs:

$$WC\_c_{dt,c} = SW\_c_{dt,c} \cdot sct_{dt} + PW\_c_{dt,c} \cdot gct_{dt} \tag{3.23}$$

$$WC\_all_{dt} = SW\_all_{dt} \cdot sct_{dt} + PW\_all_{dt} \cdot gct_{dt} \tag{3.24}$$

The amount of surface water application depends on the water applied to the crop field and the distribution losses in the system:

$$SW\_c_{dt,c} = \sum_{t}\sum_{s} WCP^{t}_{dt,soil,c} \;\; / \, eff\_dstr \cdot (1 + leach) \tag{3.25}$$

$$SW\_all_{dt} = \sum_{t} WS\_DT^{t}_{dt} \tag{3.26}$$

The following terms are used in these equations:

GM_c, GM_all	gross margins for crops and districts [USD]	*SW_c, SW_all*	surface water applied to crops and districts [m^3]
Rv_c, Rv_all	revenue for crops and districts [USD]	*PW_c, PW_all*	pumped water applied to crops and districts [m^3]
WC_c, WC_all	water costs for crops and districts [USD]	*sct*	surface water price (costs) [USD/m^3]
WV_c, WV_all	value of water for crops and districts [-]	*WCP*	surface water applied to fields [m^3]
otc	other variable crop cultivation costs [USD/ha]	*acp*	cropped area [ha]
gct	groundwater pumping costs [USD/m^3]	*eff_dstr*	distribution efficiency [-]
WS_DT	gross water supply to	*dt,soil,*	district, soil type, crop-indices
leach	leaching fraction of water application [-]		

Revenues

Crop revenues are determined by calculating actual yields per calculated cropped area and the associated market prices (equation (3.27)). Finally, the actual yields are a product of the maximum potential yields per crop and the relative yields, which is an endogenously derived variable that includes the actual evapotranspiration (see equation

(3.12)) and yield response to water and crop coefficients for all crops in dependency of soil, climatic and crop characteristics. Thus, the main connection between agronomy and economy is found in this relationship, as actual evapotranspiration depends on climatic and soil moisture conditions, which in turn depend on hydrology and water management strategies.

$$Rv\_c_{dt,c} = \sum_{soil} ryld_{dt,c} \cdot Ym_{dt,soil,c} \cdot acp_{dt,soil,c} \cdot cpp_{dt,c} \quad , \tag{3.27}$$

ryld	relative cop yield per district, soil and crop type and month [-]
Ym	maximum potential yield per district, soil and crop type [t/ha]
cpp	cop selling prices per district and crop [USD/t]

Relative yield (*ryld*) is attained by conversion of the crop production function (equation (3.18)):

$$ryld^{t}_{dt,soil,c} = \sum_{vegetationperiod} 1 - ky^{t}_{c} \cdot (1 - \frac{ETa^{t}_{dt,soil,c}}{kc^{t}_{c} * ETo^{t}_{dt}}) = \frac{Ya_{dt,soil,c}}{Ym_{dt,soil,c}} \tag{3.28}$$

Economic water use efficiency

The economic water use efficiency (e-WUE) according to Zaffaroni and Schneiter (1998) and Copeland et al. (1993) is defined as the economic outcome (gross margin in irrigated agriculture) over the total water applied and not mistakable with the water use efficiency term used in bio-physics. Here the water use efficiency is a function of biomass yield over total water application. The e-WUE already includes this factor, as gross margin is a function of the crop yields. Furthermore, the crop prices and the productivity and cost effectiveness of the crop planted are implemented (see equation (3.20), (3.21), (3.27)). The e-WUE is an important indicator of the profitability of a crop in terms of water use and will be examined in more detail for single crops and districts in chapter 5.

$$e - WUE\_c_{dt,c} = GM\_c_{dt,c} / TW\_c_{dt,c} \tag{3.29}$$

$$e - WUE\_all_{dt} = GM\_all_{dt} / TW\_all_{dt} \tag{3.30}$$

TW_c, *TW_all*	total water applied to crops and districts [m^3]	*e-WUE_c* *e-Wue_all*	economic water use efficiency for single crops and for total Khorezm [-]

The total water applied to districts and crops is composed of surface water (*SW_c, SW_all*, see equation (3.25) and (3.26)) and a small amount of groundwater pumped (*pump*):

$$TW\_c_{dt,c} = SW\_c_{dt,c} + pump_{dt,c} \tag{3.31}$$

An important aim of this study is to apply economic incentives (such as subventions, cost calculations, prices and liberalization of the cotton sector) to find alternatives for efficient water and crop allocation. To determine whether these alternatives have an effect on the current system, the main economic task will be the analysis of economic incentives and their influences on benefits and costs, the hydrologic system operation, crop allocation and the water use in each scenario analysis.

Price-function

Thus far, sales prices for agricultural products have been exogenously provided to the model using fixed parameters according to actual surveyed market price data (see Appendix C). For scenarios with liberalized cotton and wheat markets or the introduction of water pricing mechanisms and released crop areas, it is important to implement an endogenous crop price function to analyze the effect of modified supply to the demand for agricultural products in an acreage-dependent manner (see chapter 8.3). Otherwise, corner solutions with high acreages of water-cost/price-efficient crops will arise that under consideration of optimal ecological water allocation seem reasonable. However, these solutions are not realistic because farmers strive to diversify their products and reduce the risk of decreasing prices for over-supplied crops. For this reason, the crop selling price will be endogenously calculated using a relationship between supplied goods and people's demand, and, related to that willingness and ability to pay for such goods. Supply is determined by the market. If farmers increase their production (and, thus, supply) the price will decrease. Thus, farmers will grow fewer crops, reduce the size the cropland or diversify crop cultivation until an equilibrium supply and demand is attained.

The price-function is implemented in the agricultural profit function (see equation (3.20)). Crop demand is a function of price and is characterized as follows:

$$D_{dt,c}(P) = a - B \cdot P_{dt,soil,c} \quad \text{and} \tag{3.32}$$

$$P_{dt,soil,c} = \frac{a}{B} - \frac{1}{B} \cdot D_{dt,c} \quad \text{and} \tag{3.33}$$

$$B = \eta \cdot \frac{D_{dt,c}^{t-1}}{P_{dt,soil,c}^{t-1}} \tag{3.34}$$

D/Dt-1	crop demand/demand last year	*A*	constant (y-intercept)
P/Pt-1	crop price/price last year	*B*	constant (slope)
η	price-elasticity		

Price elasticity η (of demand) is defined as the relative change in quantity of goods to a relative change in the price of those goods (Graf, 2002). Price elasticity was calculated for some agricultural products in Khorezm by Djanibekov (2008). The constant *a* can be derived from the production level in Khorezm in 2003 (see Appendix B).

4 DATA ANALYSIS AND CREDIBILITY CONTROL

The availability, quality and credibility of input data are major factors determining the quality and significance of a model. Various data were used for the integrated hydrologic-economic model presented. These data build a foundation for further model-relevant calculations, outcomes and analyses. For this reason it is necessary to monitor the credibility of all relevant data. The methods used to monitor data credibility are described below.

The modeling framework required multidisciplinary data on local hydrology, climatology, agronomy, economy, sociology, and crop and soil parameters. In addition to experimental data from the project, this study also used data from other studies and projects, secondary statistical data, empirically determined data, data from the literature and internet, official governmental scientific databases, and expert knowledge. A range of data types were used, including time series and single measurements, spatial and non-spatial data, country-level, district-level, and field-level data with high or low resolution, and qualitative and quantitative data. The basis year is 2003, but data collected between 1990 till 2004 were used when available, for example, in climatologic and groundwater analyses.

Large data sets are necessary to conduct such an integrated study. The data collections and measurements used and/or processed in this study were taken from studies within the Khorezm-Project, databases of the project and other institutions involved in agronomic-hydrologic-climatologic-economic investigations in Khorezm and Uzbekistan. Data on soil moisture, matrix potential, plant characteristics, precipitation, humidity, sunlight duration, groundwater table, aquifer yield coefficient, cropped areas, yields, prices and planting costs, irrigation efficiencies and salinity were included. The FAO CropWat program was used to determine the effective rainfall and reference evapotranspiration. The broad GIS-database of the project and the so-called hydromodule zones (MAWR, 1987) were used to obtain soil types in each district. The Russias Meteo Data Server (SMIS, 2003) contained climate data for the Meteo-Stations in the Khiva and Urgench districts. From the JICA-study (JICA, 1996), it was possible to calculate municipal and industrial (M&I) water use. The MAWR (2002) provided detailed measurements of groundwater level, groundwater salinity and drainage areas and Sokolov (1999) for groundwater pumping capacities. The Rosetta program (Schaap et al. 2001) and Eagleson (1978, 2002) delivered important soil-related data, including hydraulic conductivity, soil pore connectivity and tortuosity. Hydrologic data on water supply and distribution were extracted from Upradik (2001), SIC ICWC et al. (2004) and Oblwochos (2004). Oblwochos and Oblstat (1998-2007) also supplied several years of crop yield data and crop acreage data. Finally, FAO and Saniiri (Central Asian Research Institute of Irrigation) provided general information on crop parameters, such as crop coefficients, yield response factors, and root depth.

All data were crosschecked and tested for credibility and consistency. The fact that the project used an extensive database, an infrastructure to collect data, collaboration with local and national experts and many students working directly in the field (basic research) provided access to data that were otherwise unavailable. Nevertheless, problems were encountered with the reservoir operation data (subject to secrecy), and these data could not be implemented in the model. Information on water distribution, cropping areas and soil types differed between sources. Thus, the most reliable data and expert advice were used. For M&I water usage, no actual data were available. In this case, water use data from 1996 were extrapolated according to population growth and used to estimate piped water distribution.

In the following chapter, a description of the underlying hydrologic, economic and agronomic conditions and data within the area is given. These data are the basis for the model and are used for additional analyses.

4.1 Bio-physical data

4.1.1 Water distribution and supply

Annual water availability from 1989-2005 indicates that 2000 and 2001 were years of particular water scarcity, especially within the main vegetation period, due to an insufficient water supply from the Amu Darya River (see Figure 4.1). This affected crop yield, acreage and profits (Müller 2006). The years following 2001 showed an upward trend, but the water supply did not return to pre-2000 levels. The economic-hydrologic water management model presented here was calibrated based on data from the year 2003 (arrow). This year seems to be a characteristic year, representing a year with moderate water availability and having the most complete datasets available.

Furthermore, this year is comparable to another model from the Khorezm project using the same basis year (Djanibekov, 2008).

From 1988-2004 the maximum water supply reported was 5.3 km^3 in 1998, and the minimum reported was 2.04 km^3 in 2001. The average of this 16-year period was approximately 4.1 km^3. The water availability in 2003 was 4.13 km^3, which is roughly equal to the 16-year average. The range between the highest and lowest values during the 16-year period was between 50 to 121 % of the average. These values will be important in determining the scenario analysis of the modified water supply.

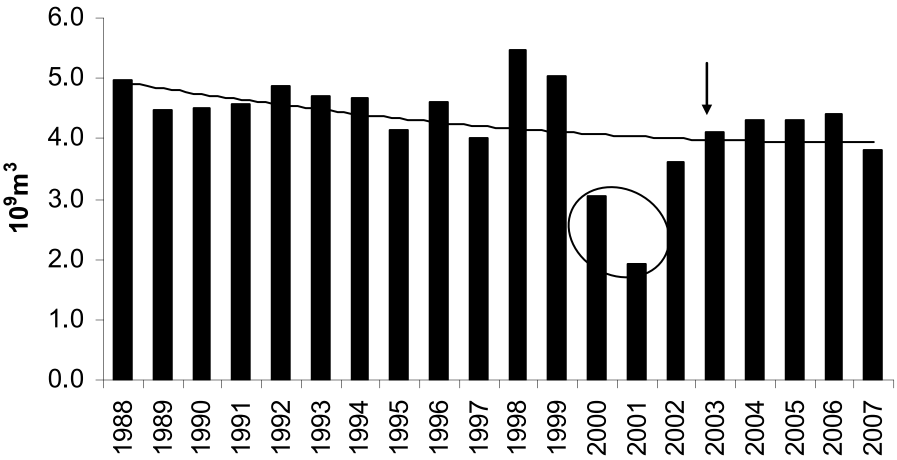

Figure 4.1 Water supply to Khorezm by year from 1988-2003 (10^9m^3 (=km^3))
Notes: Drought years are circled. The arrow indicates the 2003 data used in this study
Source: authors own presentation according to OblVodChoz (2004), Upradik 2001/2004, OblSelVodChos 2002, SIC ICWC 2005

The water distribution data from 2003 show that districts at the tail end of the irrigation system received less water than those at the beginning. The exception is in Kushkupir, where large amounts of leaching water from February to April contribute to a very high cumulative water supply (Figure 4.2).

The monthly water supply by district is characterized by high water input during the main crop growing period (June-September), with peaks in July and August. A relatively large amount of water is used from Oct-March for filling up the channel system (Jan-Feb), irrigating winter wheat and leaching salts out of the soil (Feb-March). In 2003, up to 25 % of the total water supply was used for leaching. For this reason, leaching was included as an additional component in the model.

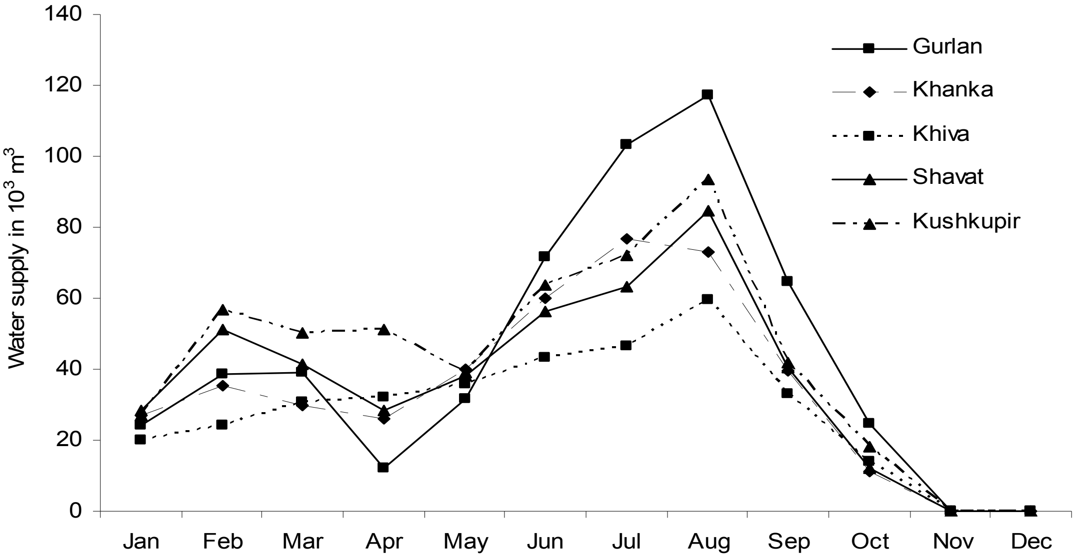

Figure 4.2 Total monthly water supply for selected Khorezm districts in 2003 (10^3 m^3)

Source: authors own presentation according to OblVodChoz (2003)

In this context, the water supply per irrigated area is of significance. Water allocation per hectare in single districts shows a relatively uniform distribution (Figure 4.3). The average water application ranges between 17.600 and 21.300 m^3/ha. In the Gurlan district, a large amount of rice was cultivated, which explains the higher water use in this district. The other districts are further from the river (Khiva, Yangiarik, Kushkupir) and show higher water supply per hectare. This could be caused by higher water losses within the irrigation canal system. In contrast, the Khasarasp, Khanka and Yangibazar canal networks are well extended and closely situated to the Amu Darya River. The decreased water use per hectare could be explained by a higher distribution efficiency and better utilization of water supply.

This distribution scheme is comparable with the data Müller (2006) used for his studies in 1999. They are directly dependent on the chosen cropping area data. The cropping-area data may not easily be applicable because several data sources with different values exist. The data from OblVodChoz (2004) seemed to be the most reliable, as additional details and area information on crop type were available. The underlying data on crop cultivation and irrigated area are presented in Figure 4.4. All data used in the model can be found in Appendix C.

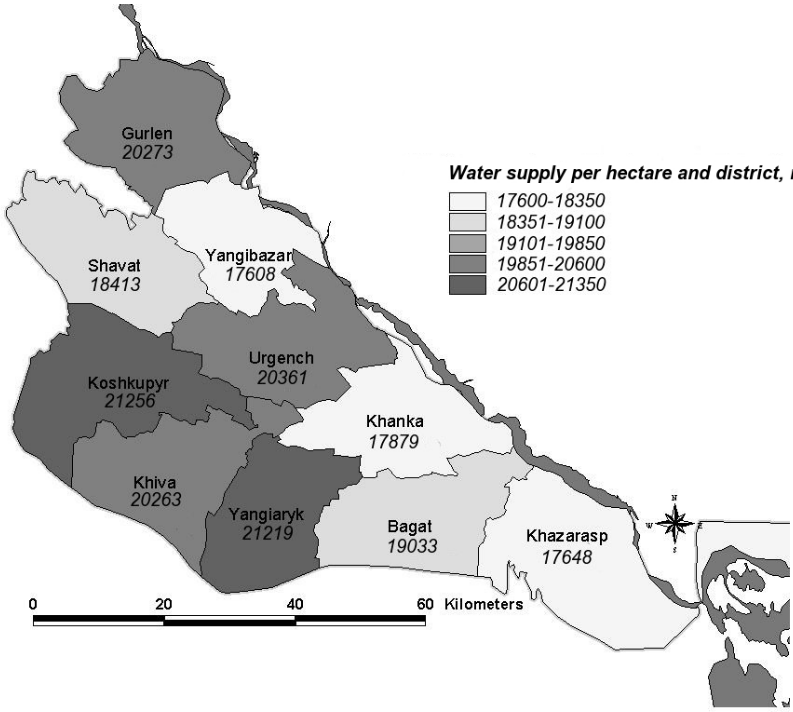

Figure 4.3 Irrigation water supply per hectare in 2003 at the district border (m^3/ha)

Source: authors own calculation, based on data from OblVodChoz (2003) and SoyuzNihiUzAshi, 1992

4.1.2 Soil types

To account for the different soil types in the dataset, the model differentiates between the hydro-module zones, which are a differentiation of soils based on soil texture and groundwater table levels. This classification system seemed to be most suitable for the model. The main soil types and related crop outcomes for those soil types can be considered without overloading the model. Furthermore, the groundwater level within the hydro-module zones classification is an important factor (especially for the Khorezm region) because the groundwater table (and balances) will also be considered in the model.

Light soils are considered to be sandy and sandy-loamy soils (clay fraction <35 %), whereas medium soils are moderately textured loamy soils. Heavy soils are the heavy loamy and loamy soils with homogeneous and heterogeneous texture and a minimum clay fraction of 45 % (SoyuzNihiUzAshi, 1992; for detailed information see Appendix C). Soil textural classes determine important parameters such as soil hydraulic conductivity, basic soil water characteristics (saturation, field capacity, permanent wilting point) and as a consequence soil moisture. These parameters have a strong influence on soil-water balance and crop yields. As shown in Figure 4.4, soils with light and moderately textured loamy fractions are dominant in Khorezm.

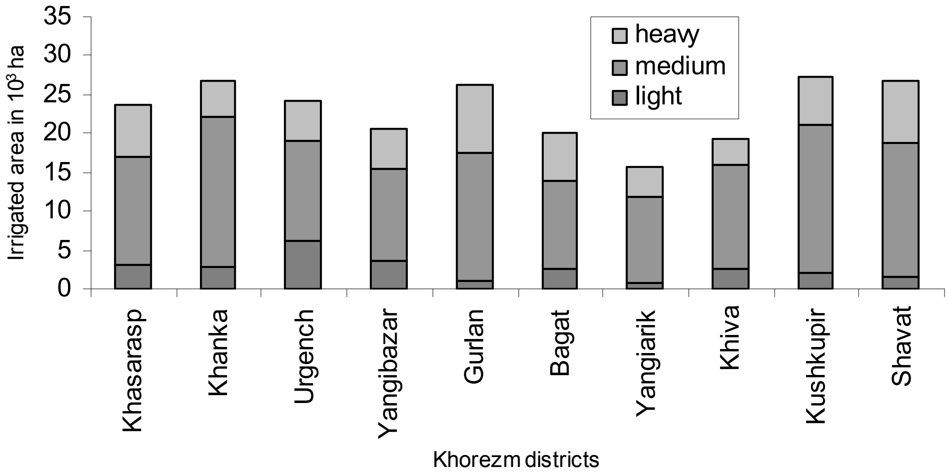

Figure 4.4 Soil areas under irrigation in Khorezm (10^3 ha)

Source: authors own presentation according to SoyuzNihiUzAshi, 1992

4.1.3 Groundwater level

The groundwater in Khorezm is relatively shallow. Leaching from February to April and intensive irrigation (with low efficiency) in the summer months cause the groundwater table to rise toward the surface. During the main irrigation period, from May to August, the groundwater is so shallow that the groundwater table limits the development of potential crop root length. Shallow groundwater is desired and to some extent consciously manipulated by farmers (water afflux in canals) because subsurface water can be reached and used by crop roots (Forkutsa, 2006). It represents a storage and additional water source throughout the season. The average level of the groundwater in 2003 is shown in Figure 4.5. The data set is taken from the Hydrological Melioration Expedition of the Khorezm Department of Land and Water Resources (GME, 2005; Ibrakhimov, 2004). Measurements of the groundwater level and salinity were collected in April, July and October from 2,000 wells that are equally distributed in Khorezm (Ibrakhimov, 2004). Using a linear interpolation method, the groundwater level was determined for the remaining months.

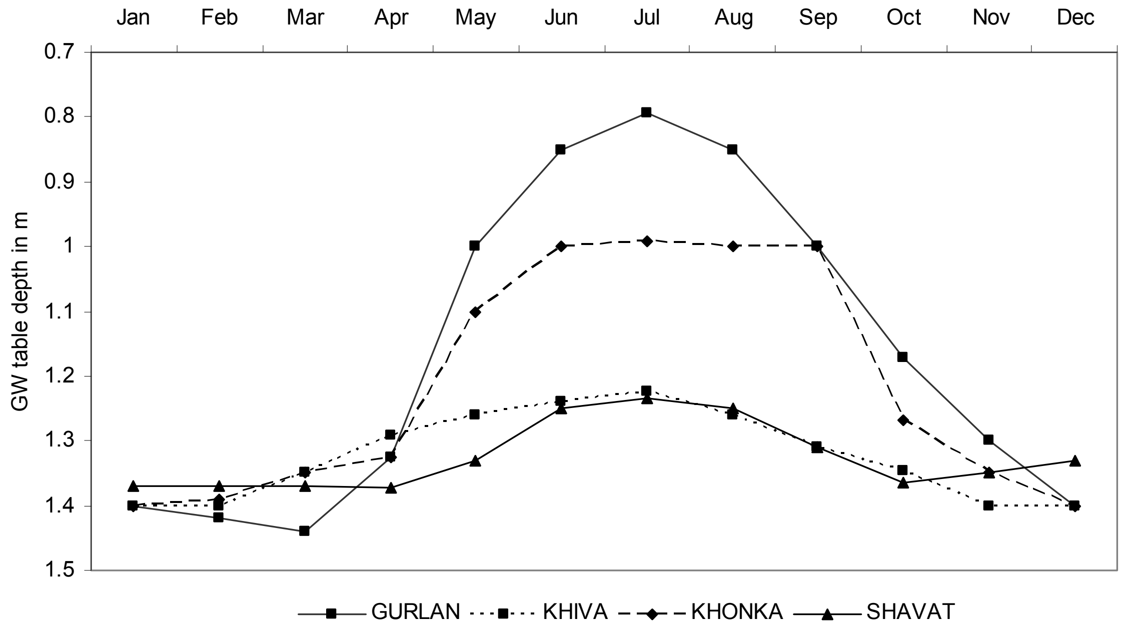

Figure 4.5 Groundwater table in Khorezm for selected districts in 2003 (m)

Source: authors own presentation according to GME, 2005; Ibrakhimov, 2004

For the hydrologic-economic model, a groundwater reservoir model was included to calculate the groundwater levels, the fluctuations and the contribution to crop water usage and soil moisture. For the model, boundaries on minimum and maximum groundwater levels must be implemented (see Table 4.1).

Table 4.1 Averaged minimum and maximum groundwater values by district from 1988-2004 (in m)

	min groundwater table below ground [m]	**max groundwater table below ground** [m]
Khasarasp	0.54	1.61
Khanka	0.52	1.85
Urgench	0.80	2.20
Yangibazar	0.55	1.85
Gurlan	0.50	1.78
Bagat	0.51	1.59
Yangiarik	0.52	1.55
Khiva	0.69	1.88
Kushkupir	0.69	1.93
Shavat	0.76	1.95

Source: according to data from GME, 2001; GME, 2005

These levels were obtained from a vast dataset containing the groundwater level and salinity data for several wells in the districts of Khorezm from 1988-2001 (GME, 2001) and from 2003-2004 (GME, 2005). At almost 50 cm deep, the minimum groundwater level is well near the surface and confirms the shallow groundwater levels in Khorezm.

4.1.4 Effective precipitation

The annual rainfall in Khorezm is approximately 94-97 mm (see chapter 2.4.2). Nevertheless, the effective precipitation is included in the calculation of irrigation water supply. The 2003 effective precipitation values for the three main climatic stations in Khorezm are given in Table 4.2. Between November and April, Khorezm registered rainfall with a peak in March and April, which is outside the main growing period.

As described in chapter 3.2.3, not all precipitation can be utilized by crops. Part of the precipitation percolates below the root zone, while some of the precipitation is lost as surface run-off. Only the rainfall that is stored in the root zone (not percolated or lost as run-off), can be used by the plants and is called effective rainfall. It is possible to determine the effective precipitation from rainfall (see equation (3.6), (3.7)) using the USDA Soil Conservation Service method (Dastane 1978; USDA 1967; USDA 1993). As shown in Table 4.2, the precipitation data from the three climate stations in Khiva, Urgench and Tujamujun were assigned to single crops and cropping periods. The amount of rainfall that can be effectively used for evapotranspiration processes is 96-98% of the total precipitation. The differences between climate stations are negligible, and the contribution to crop water supply during the main growing period is very small.

Table 4.2 Effective rainfall at the three main climate stations in Khorezm (in mm/month)

	effective rainfall [mm/month]		
	Tujamujun	Urgench	Khiva
Jan	10.9	11.5	11
Feb	9.8	10.2	10.2
Mar	19.4	16.3	15.9
Apr	18.1	11	9.5
May	4.8	11.3	11.9
Jun	2.9	2.9	2.8
Jul	0.1	1.6	1.2
Aug	0.2	2	2.5
Sep	2.6	1.6	1.9
Oct	3.8	6.2	4.4
Nov	9.3	8.6	9.4
Dec	12.4	12.3	11.9
total	94.3	95.5	92.6

Note: values calculated by CropWat program

4.2 Agro-economical crop data and efficiencies

4.2.1 Reference evapotranspiration

The term ‘reference evapotranspiration’ (ETo) refers to the potential evapotranspiration of a reference crop (grass) under given regional and climatologic conditions with no water shortages. It is affected by climatic parameters such as pressure, wind speed, temperature, radiation and sunlight hours and is calculated using the Penman-Monteith method (see equation (3.10), Allen et al., 1998, FAO CropWat). Reference evapotranspiration plays an important role in the model in the calculation of actual evapotranspiration, crop water demand and, finally, crop yields. Weather data from the three main climate stations in Khorezm were used.

The calculated ETo values in 2003 range from 1,166 to 1,515 mm/a, depending on the climate station in Khorezm. The values peak during the hot and dry summer months (see Figure 4.6 and Appendix C) and are comparable to the estimates of Conrad (2006), who reported values of 1,500 mm/a in Khorezm. Values of the FAO classification (FAO, 2000) also range between 1,000-1,500 mm/a for this region. Compared with precipitation data for the main growing season, a deficit in crop water supply is obvious and must be corrected with intensive irrigation.

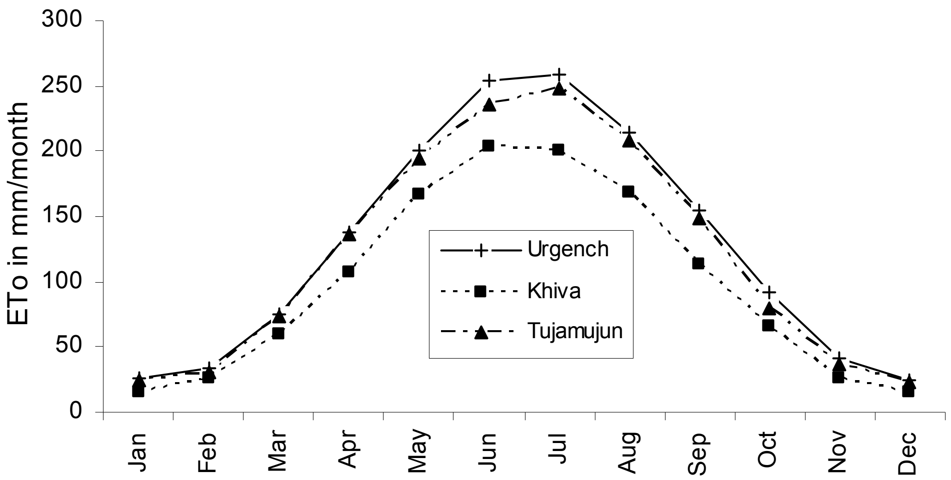

Figure 4.6 Reference evapotranspiration at the main climate stations in Khorezm (mm/month)

Note: values calculated by CropWat program

4.2.2 Kc-values

Reference evapotranspiration (ETo) is the basis for calculating the potential evapotranspiration of a specific crop (ETc). Kc values depend on specific crop characteristics and allow standard values of kc to be transferred between locations and between climates, which is the main reason for the global acceptance of the crop coefficient approach (Allen et al., 1998). Four primary characteristics distinguish a specified crop from the reference crop (grass) which are: crop height, albedo, canopy resistance and soil evaporation. During the growing season, changing crop characteristics affect the kc coefficient.

The determination of kc coefficients for crops grown in the Khorezm region was a difficult process because no standard values for the main crops in Khorezm exist. Furthermore, depending on the assumed duration, start and alternation of growing seasons, these values might vary by year. In the model, FAO standard values of kc (Allen et al., 1998), Forkutsa´s (2006) kc values for cotton in the Khiva district for the year 2003, and empirically determined values from Saniiri (2004) were used.

The monthly values listed in Table 4.3 are crop coefficients used in the model during the appropriate growing period for each crop. Depending on the beginning and the duration of the crop growing season, these values were adjusted to monthly values using CropWat.

Table 4.3 Crop coefficients for crops in Khorezm (kc), according to growing period

	cotton	**wheat**	**other grain**	**alfalfa**	**fruit**	**vegetab-les**	**rice**	**potato**
Jan		0.8						
Feb		0.87						
Mar		1.05		0.41	0.5			
Apr	0.35	1.15		0.72	0.58	0.7		0.5
May	0.4	0.97	0.36	0.95	0.76	0.76	1.05	0.55
Jun	0.87	0.4	0.95	0.95	0.9	0.96	1.13	1.05
Jul	1.2		1.1	0.95	0.9	1.05	1.2	1.15
Aug	1.2		0.86	0.95	0.9	1.05	1.2	0.96
Sep	0.99		0.38	0.94	0.8	1.01	0.95	0.75
Oct	0.71	0.35		0.63	0.7	0.97		
Nov		0.4						
Dec		0.6						

Source: according to Saniiri (2004); Forkutsa (2006); Allen et al., 1998

Table 4.4 contains information regarding the beginning, duration and end of the growth stages of the crops used in the model. The information was obtained from FAO (Allen et al., 1998; Doorenbos and Kassam, 1979), from Forkutsa´s work done in Khiva (2006), from Khorezmian farmer interviews (Djanibekov, 2003) and from Saniiri (2004). The latter differ for rice in the initial and mid-season stage.

Table 4.4 Crop stages and duration used in the model

	growing period	**stages** [days]				
		initial	develop-ment	mid season	late season	total
cotton	25.04-26.10	25	45	57	57	184
other grains	01.05-08.09	20	30	50	30	130
wheat	15.10-12.06	30	140	40	30	240
rice	01.05-28.09	30	30	60	30	150
potato	25.04-02.09	25	30	45	30	130
vegetables	10.04-12.10	30	50	60	50	190
fruits	15.03-16.10	20	65	80	50	215
alfalfa	20.03-31.10	10	30	150	35	225

4.2.3 Ky-values

The crop stages described are not only important for kc values, but also for crop sensitivity to water stress. Crops have different water requirements and respond differently to water stress. Thus, their sensitivity to water stress varies from one growth stage to another (see chapter 3.2.3). The response of crop yield to water supply or stress is quantified through the yield response to water factor, ky. This factor relates the decrease in relative yield (1-Ya/Ym) to the relative evapotranspiration deficit (1-ETa/ETc). Monthly data for ky values were obtained from the standard values of Doorenbos and Kassam (1979). These standard values were derived from broad and extensive field experiments. The data were crosschecked with local ky values provided by Saniiri (2004). In Table 4.5 the monthly values of yield response factors for the crops evaluated by the model are listed.

Table 4.5 Monthly yield response to water values (ky) for the crops evaluated by the model

	cotton[a]	**wheat**[a]	**other grain**	**alfalfa**[a]	**fruit**	**vege-tables**[a]	**rice**	**potato**
Jan		0.6						
Feb		0.6						
Mar		0.6		0.7	1			
Apr	0.2	0.5		0.73	1	0.8		0.45
May	0.4	0.45	0.45	0.92	1	0.8	0.6	0.45
Jun	0.4	0.4	0.7	1	1	0.4	1	0.6
Jul	0.5		1.3	1	1	0.6	1.2	0.8
Aug	0.5		0.9	0.9	1	1.2	0.5	0.8
Sep	0.4		0.5	0.8	1	1	1.2	0.7
Oct	0.2	0.2		0.7	1	0.8		
Nov		0.4						
Dec		0.6						

[a] Saniiri (2004)
Source: Doorenbos and Kassam (1979)

For the total growing period, the decrease in yield due to water stress is relatively small for crops such as cotton, alfalfa, potato and winter wheat (ky<1). In comparison, they are relatively large for crops like rice, other grains (mainly maize) and for some vegetables (ky>1). For the individual growth periods, water deficit has less impact on the crops in the initial phase and late season than during the mid-season (flowering and yield formation period). For most crops in Khorezm, this sensitive phase is in July and August, as can be seen in Table 4.5. This means that knowledge of yield response to water for individual crops is important in irrigation scheduling, operation, production planning and water application. The choice of crop and allocation of water plays an important role, especially under conditions of limited water supply. This means that water allocation during the most sensitive growth period is more important than equal allocation over the total growing period.

4.2.4 Efficiencies

Because gross water demand for irrigation is a complex function of precipitation, evapotranspiration, groundwater contribution, additional leaching water requirement and of efficiencies; efficiency levels are a central aspect for water use, allocation and distribution.

The efficiencies used in the model come from expert knowledge[9], OblVodChoz (2004) and GME (2001, 2005). The definition, calculation and discussion of the different efficiency approaches can be found in the methodology chapter (chapter 3.2.3). For the scenario analysis of different policies, the efficiency values in Table 4.6 were modified to some extent. Their influence on yields, production and operation costs will be explained in chapter 8.

Table 4.6 Efficiencies

distribution efficiency	*= 0.54-0.55 (water arriving the crop field/total water diverted from resources)*
irrigation (application) efficiency	*= 0.45-0.50 (water effectively used by crops/total water applied to fields)*
drainage ratio	*= 0.80-0.88 (initial drained area in % of total irrigation area)*

Source: according to OblVodChoz (2004); GME (2001, 2005) and expert interview

These values are comparable to other studies conducted in the Khorezm project and to values found in the literature. Hillel (1997) mentioned that the usual application efficiency is typically less than 50 % and frequently as low as 30 %. Forkusta´s (2006) application efficiencies for study fields in the Khiva district are in the range of 40-50 %, while Tischbein´s (2007) values are approximately 45 % for the 1,000 ha area in Khorezm.

9 B. Tischbein, personal communication on 16.03.05; discussion with representatives of BWO (Basin Water Organization) Amu Darya in May 2002 and representatives of OblVodChos (Mr. Makson Sabir) in Urgench (in 2003 with B. Tischbein)

4.2.5 Crop yield, cropped area, gross margins and productivity

Crop yield and productivity

Actual crop yields serve as a standard of comparison for relative yield values calculated by the model (see equation (3.28)). The correct calculation of yields is required to calculate gross margins of agricultural products and to evaluate economic scenarios. Furthermore, crop yields and cropping areas were fixed for the descriptive model (see chapter 5) to validate other model parameters.

The yield variability for cotton, wheat and rice was relatively small in 2003 among districts (Table 4.7).

Table 4.7 Actual crop yields in Khorezm in 2003 (in t/ha)

	cotton	**other grains**	**wheat**	**rice**	**vegetab-les**	**fruits**	**alfalfa**	**potato**
Khasarasp	1.69	3.70	3.25	4.04	18.72	7.47	8.18	7.05
Khanka	1.79	3.63	3.06	4.40	23.33	9.02	8.52	12.78
Urgench	1.52	3.70	3.37	4.20	13.28	10.98	6.62	6.71
Yangibazar	1.50	3.50	3.05	4.56	14.88	4.40	12.29	10.56
Gurlan	1.27	3.94	3.10	4.53	16.04	10.17	7.97	10.14
Bagat	1.62	3.95	3.21	4.56	19.22	8.03	5.48	12.84
Yangiarik	1.64	3.58	3.12	4.40	23.56	9.48	13.20	10.56
Khiva	1.82	2.99	2.69	4.10	18.70	9.39	12.15	12.40
Kushkupir	1.36	3.28	3.12	4.00	10.24	7.04	6.52	8.15
Shavat	1.61	3.14	2.89	3.99	19.58	13.35	12.15	19.23
total Khorezm	1.56	3.54	3.08	4.30	17.75	9.03	9.17	12.69

Source: OblStat (2004)

Acreage

As shown in Figure 4.7, crop cultivation in the Khorezm districts is relatively equal in distribution when considering crop type. The main crops are cotton, wheat and rice. The water supply in 2003 was sufficient for cropping rice. Rice cultivation was more prominent in districts close to the river, such as Khazarasp, Gurlan and Urgench. Continuous water flow to rice fields is easier when the water distribution distance to the fields is shorter. The high proportion of cotton and wheat is a consequence of the crop quotas set by the government for both crops.

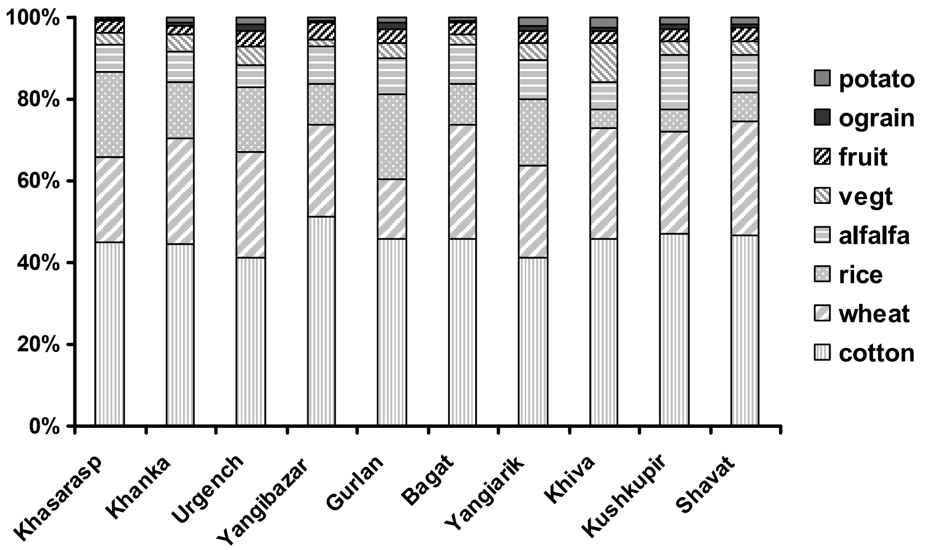

Figure 4.7 Acreage of main crops per district in 2003, cumulative share (in %)
Source: OblStat, 2004

The total acreage adds up to approximately 215,000 ha, without considering double cropping, with cotton and wheat having the highest acreage (see Table 4.8).

Table 4.8 Total cropped acreage per district and crop type in 2003 (in ha)

	cotton	other grains	wheat	rice	vege-tables	fruits	alfalfa	potato	sum
Khasarasp	10,456	108	4,901	4,913	730	668	1,491	67	23,334
Khanka	10,424	152	6,071	3,251	968	502	1,699	340	23,407
Urgench	9,245	352	5,867	3,549	1,091	845	1,214	355	22,518
Yangibazar	10,205	74	4,515	1,933	404	764	1,831	202	19,928
Gurlan	11,956	374	3,701	5,424	899	901	2,345	375	25,975
Bagat	8,817	111	5,384	1,944	503	548	1,795	133	19,235
Yangiarik	6,365	221	3,446	2,472	610	465	1,509	304	15,392
Khiva	7,642	122	4,547	771	1,645	476	1,086	421	16,710
Kushkupir	11,415	321	6,033	1,321	871	700	3,127	370	24,158
Shavat	11,198	238	6,778	1,653	756	812	2,294	363	24,092
total Khorezm	97,723	2,073	51,243	27,231	8,477	6,681	18,391	2,930	**214,749**

Source: OblStat, 2004

Gross margins and economic water use efficiency

Total gross margins per hectare in irrigated agriculture are shown in Figure 4.8.

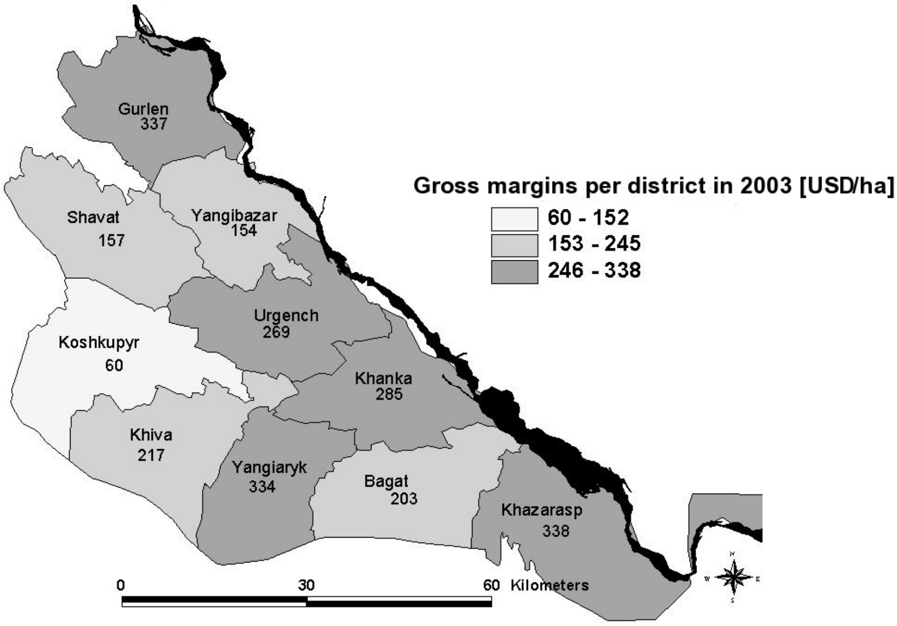

Figure 4.8 Gross margins in irrigated agriculture per hectare for districts in Khorezm, basis year 2003 (in USD/ha)

Source: authors own calculation, Data based on OblStat, 2004

In general, districts with direct connections to the river or districts at the beginning of the irrigation network have higher gross margins per ha than those at the end of the network and with no direct access to the river. The cultivation of rice with its high revenues is the main reason for the relatively high gross margins in districts like Khazarasp, Khanka, Urgench, Gurlan and Yangiarik (see Table 4.8).

In the model, gross margins are associated with the calculation of the economic water use efficiency (e-WUE). Here, e-WUE is the relationship between total gross margins (per ha) in irrigated agriculture and total water supply (per ha) (equation (3.29), (3.30) and chapter 3.2.4). The district ranking of e-WUE shows that Khasarasp, Khanka and Gurlan (all districts close to the river) rank highest due to relatively low water consumption (per cropped hectare) and high profits per hectare for rice production in this year. Shavat and Kushkupir, at the end of the irrigation system, showed high water consumption due to high water losses within the irrigation system and resultant lower yields and low gross margins (see Figure 4.9).

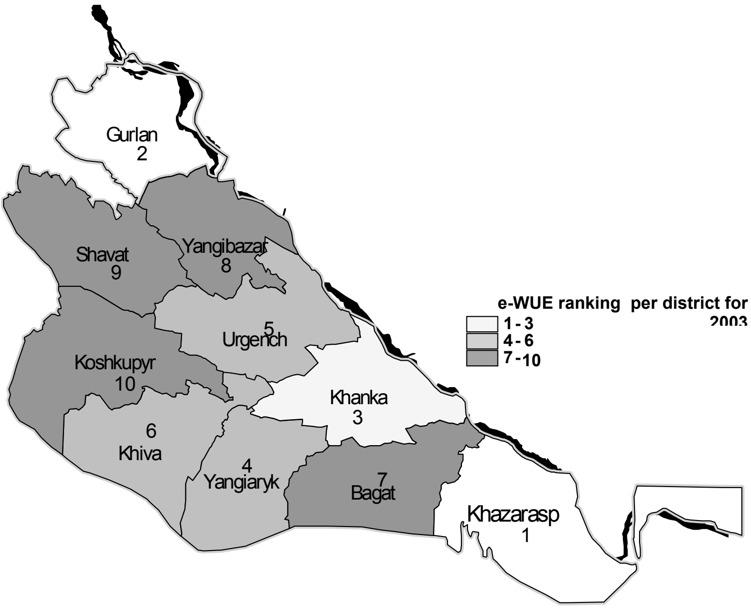

Figure 4.9 Economic water use efficiency (e-WUE) ranking for districts in Khorezm
Source: authors own calculation, basis year is 2003

4.2.6 Potential yield

The application and utilization of potential yield data for crops in Khorezm is necessary to calculate actual yields in the model (see equation (3.28)). Potential yield represents the maximum yield possible under given conditions including water availability, allocation and management improvements in the scenario analyses. The potential yield values for a given crop depend mainly on soil type and groundwater level, as the model determines hydrological consequences and changes. Other factors, such as fertilizer improvement and labor intensification, are not taken into consideration. Potential yield data are taken from MAWR (2001). They are valid for groundwater levels shallower than two meters, which is usually the case in Khorezm.

The described data were empirically determined, and a comparison of the maximum obtained crop yields in the districts of Khorezm shows that yields for most crops were far from potential yields even in years of good water supply. Thus, it was decided to crosscheck and adapt the selected data with actual yields. In some cases, data for potential yield was lacking for crops like fruits, vegetables and other grains. In these instances, an examination of actual yield for the past ten years was used to determine the maximum crop yield (plus 20%), which was used as the basis for potential yield for those crops (OblStat, 1998-2007). Furthermore, a correction of potential yield for rice and wheat was carried out because the empirically determined potential yield for both crops seemed too high for the Khorezm region. This is contrary to the situation for potato, where the maximum obtained yields are much higher than the potential values given by MAWR. For this reason, the potential yield was upgraded according to the maximum values for potato.

Table 4.9 Potential yields for crops and soil types in Khorezm (in t/ha)

	light soils	**medium soils**	**heavy soils**
cotton	2.7	3.2	2.55
other grains	4.8	5.0	4.60
wheat	5.5	6.0	5.20
rice	4.8	5.2	4.80
vegetables	26.0	29.0	25.00
fruits	11.0	13.5	10.00
alfalfa	22.1	24.6	20.90
potato	20.8	22.0	20.20

Source: according to MAWR (2001); OblStat (1998-2007)

4.2.7 Municipal and industrial water supply

In 2003, the industrial and domestic water supply in Khorezm averaged 107,000,000 m^3. This is approximately 2.5 % of Khorezm's total water supply. Indeed, no major industry exists in Khorezm, which explains the low value of municipal and industrial (M&I) water consumption. Due to the small amount of water, a complete provisioning of households and industry can be assumed, and a competition for water between industry/households and agriculture can be neglected. In addition, a sufficient drinking water supply is assumed, even in years with water shortages.

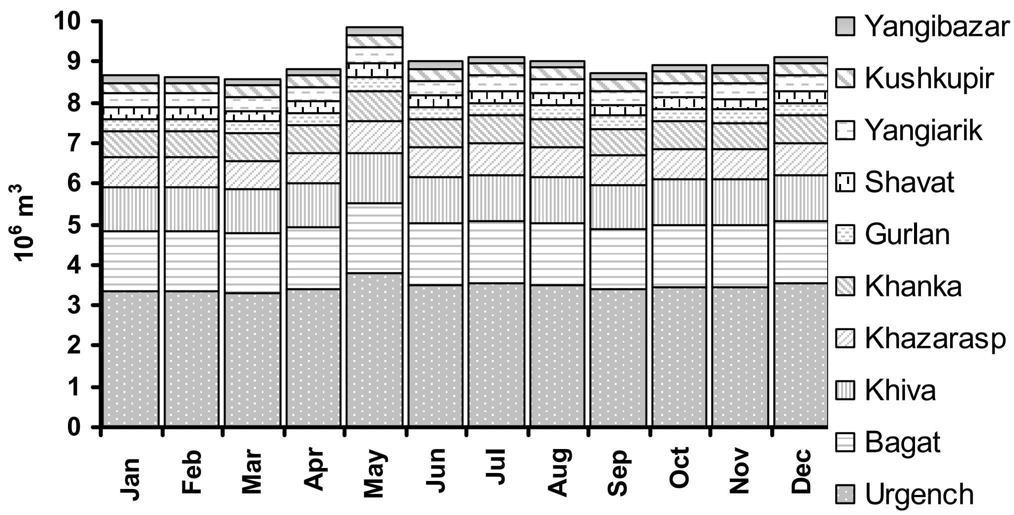

Figure 4.10 Monthly municipal and industrial water consumption in 2003 (in 10^6 m^3)
Source: authors own estimation based on Jica, 1996

The data used to determine M&I water is from JICA, 1996. Due to some missing data, M&I water consumption data from 1995 were interpolated taking of population development into consideration (OblStat, 2003) as well as trends in the piped water supply (Figure 4.10).

4.2.8 Other data

Additional data used in the model, such as pumping capacities, maximum and minimum yields, aquifer specific yield coefficient, hydraulic conductivity in aquifers, root depth and other soil related parameters, crop prices and costs, elasticities and salinity, are included in Appendix C.

5 MODEL VERIFICATION, CALIBRATION AND POSITIVE DESCRIPTIVE MODELING

According to Wehrheim (2003), complex models and the underlying data and parameters need to be verified and validated for homogeneity, consistency, and sensitivity. The terms “validation” and “verification” are often discussed in the literature but are very controversial and depend on personal preferences or definitions. In this study, validation and verification refer to the determination of the model behavior in comparison to real-world behavior. Thus, verification requires determining how well a model serves its intended purpose.

Therefore, verification “by construct” and “by result” can be performed (McCarl and Spreen, 1996). Verification by construct uses techniques that are employed in model construction and is motivated by real-world observations (functions, modules of software, equations, and values) to assure that the model was constructed properly. Verification by results compares the results of the model ex post with data and observations (McCarl and Apland, 1986). A well-verified model has passed both verification methods.

The verification of both methods, including the applied functions and procedures and model outcomes and behavior in comparison to real-world behavior, is included in chapter 5. The model is based on a successfully applied basin-wide integrated economic-hydrologic model for the Syr Darya River basin in Central Asia (Cai, 1999). The calculation of evapotranspiration, yield and of the resultant objective function is based on a widely used FAO crop water production model (CropWat, Allen et al., 1998). The required crop-specific parameters have been determined and measured in Uzbekistan. The data were compared with worldwide data collected from the literature. All other equations are based on experiments and well-established theory[10]. Soil parameters and boundaries are based on field measurements and were crosschecked with information from the literature[11]. The verification of input parameters and data (plausibility control) is discussed in chapter 4. During the verification process,

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[10] Groundwater tank model based on Bear, 1977; Groundwater contribution based on Eagleson 1978; effective rainfall based on USDA, 1969

[11] Soil moisture, groundwater table, permeability etc. according to Scheffer, Schachtschabel (1998); pumping capacity according to Sokolov (1999); for more details see chapter 3

calibration was also performed. The model calibration process involves modification and adjustment of the model input until the model output matches field conditions or observed data. Those modifications are only permissible if the data and boundaries are within realistic limits. Calibration for this model was based on the results and was performed manually. Manual calibration is very labor-intensive, but with the help of a pre-conducted sensitivity analysis (see chapter 6), good results were obtained.

The best way to validate model results and input data is to directly compare model outputs and inputs with observed or measured data from the study area. Consistency between the measurements and model outcomes in time and space is required. Unfortunately, this requirement cannot be fulfilled for most of the model input parameters and outcomes because no direct field data or measurement for comparison exists. For example, the direct measurement of groundwater fluxes, soil water balances or actual evapotranspiration is difficult and cannot cover the entire study area. Data for groundwater and other hydraulic values, such as deep percolation, groundwater extraction, water supply to districts, fields and crops, and cropping prices (variable costs), are difficult to access and often depend on estimates. Few measurements, if any, were taken for some soil, climatic and salinity parameters. When data are missing, alternative verification must be carried out using a comprehensive plausibility control.

In the following chapter a comparison of model outcomes with selected measurements, literature values, and simulation results from other studies is described. Additionally, the classification of parameters and variables within realistic dimensions and boundaries is performed.

5.1 Positive descriptive modeling

For model verification and plausibility control, a so-called positive model is first established to assess the model consistency with reality. A positive model analyzes "what is", in contrast to normative models that analyze "what should be" (see chapter 8). For the positive model, relevant input parameters, including water supply, cropping areas and yields, are taken from actual data observation in 2003 and fixed in the model. This method will be used to illustrate that the outputs, underlying formulas and data for water balances and crop production processes are within a realistic range. In later analyses, these fixed parameters will be relaxed to evaluate the impact of relevant parameters and to obtain a verified optimization model with appropriate constraints.

In the following paragraphs, verification and plausibility analyses of major hydrologic and agronomic model outcomes of the positive descriptive model, followed by an analysis of economic outcomes, is undertaken.

Evapotranspiration

The determination of actual evapotranspiration (ETa) is one of the most important calculations as crop growth, soil moisture and soil-water balance, as well as yields and corresponding agricultural profit and benefits rely on this result. Monthly ETa was determined for all ten districts, eight crops, and three soil types. The modeled ETa values range between 404 mm for wheat and other grains (fodder maize and sorghum) to 1,142 mm for vegetables and rice. The average ETa was 744 mm per year, of which approximately 700 mm occur within the growing period between April to October (see Table 5.1). Winter wheat, which grows in winter and spring, has the lowest evapotranspiration, as shown in the following figures. The low ETa for ”other grains” is due to the fact that maize cultivation occurs after winter wheat as a secondary crop. The cultivation period is very short, and the crop (plant matter, phylum) is harvested before ripening and is used as fodder. Due to high water consumption requirements and the irrigation method, rice has a high evapotranspiration rate. However, due to a relatively short growing period, the total ETa for the growing period in total is not exceptionally high.

Modeled values for monthly ETa are highest in June and July (see Table 5.1 and Figure 5.1) due to high evaporative demand driven by high radiation and low air humidity, as well as soil evaporation and high transpiration due to advanced crop growth. High values of ETa for alfalfa are attributable to the long growing period. The opposite is true for winter wheat grown between October and June under lower radiation and temperature conditions and, consequently, lower evaporation and transpiration rates.

Table 5.1 Actual evapotranspiration (ETa) values per crop type, averaged for Khorezm (in mm)

	ETa total[a][mm]	ETa total stdev [mm]	ETa min1 [mm]	ETa max1 [mm]	monthly ETa [mm]			
					May	June	July	August
cotton	762.2	96.4	560.0	976.7	69.6	172.1	188.0	155.1
wheat	509.2	52.7	421.8	621.0	151.5	66.4	-	-
rice	758.1	90.9	601.3	938.5	170.6	184.9	162.9	143.4
other grain	598.8	88.1	404.3	760.1	63.2	192.2	178.1	122.9
alfalfa	881.8	105.7	711.4	1,111.3	158.3	177.1	158.3	135.5
vegetable	866.9	132.6	652.3	1,141.6	120.5	174.8	169.8	149.4
fruit	813.7	89.9	675.7	1,014.2	130.9	181.3	155.0	117.6
potato	760.4	103.5	562.5	967.0	91.8	195.7	185.0	140.0

Notes: [a] Averaged for all districts and for whole vegetation period
stdev=standard deviation
min/max =minimum/maximum values

Source: author's own model results

Differences between crops (see Figure 5.1) are relatively high due to crop-specific properties such as crop development stages, plant height, leaf area, ground coverage and water management (Allen et al., 1998).

The differences in ETa between soil types are also not negligible (see Figure 5.2). Soil characteristics such as soil moisture, storage capacity, porosity and the matrix potential are all considered in the calculation of evapotranspiration (see equation (3.12)). A large range of ETa values for different soil and crop types in Khorezm demonstrate the importance of irrigation measures within this area, as evaporation and transpiration are far greater than that supplied by natural precipitation. This knowledge is necessary to implement proper irrigation management.

The range of model calculated ETa values for Khorezm in 2003 agrees with other existing studies. Conrad et al. (2004, 2006) calculated the actual evapotranspiration, based on remote sensing data for the growing period, to be 786 to 831 mm in 2004 and 701 to 833 mm in 2005 for cotton, depending on the method, and 877 mm to 1,046 mm for rice. Based on field observations by Forkutsa (2005; 2006), the calculated ETa values for cotton in district Khiva range from 160-640 mm, with an average of 450 mm during the 2003 growing period.

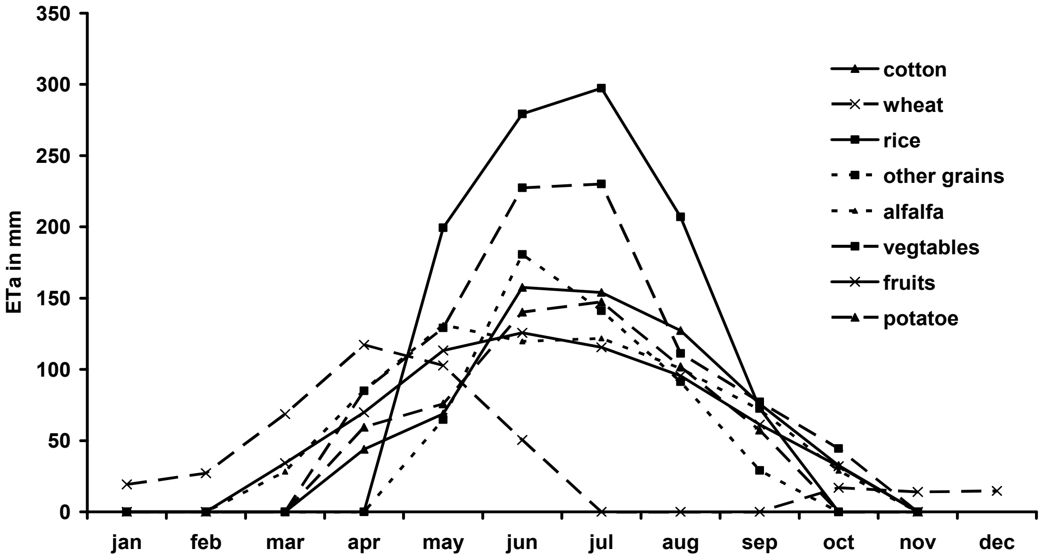


Figure 5.1 Calculated monthly Eta for the Gurlan district with medium soils (sandy-loamy) for different crop types (in mm)

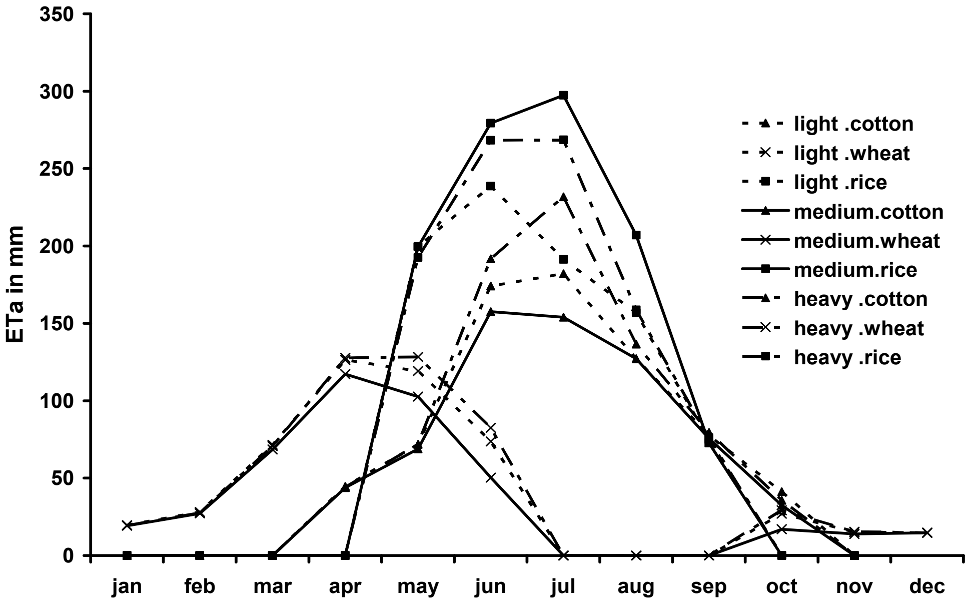


Figure 5.2 Calculated monthly ETa in the Gurlan district, for cotton, wheat and rice, for different soil types (in mm)

Notes: light, medium and heavy refer to soil types with the associated cultivated crops (cotton, wheat and rice)

Monthly and daily values of ETa for cotton and winter wheat are also comparable with those calculated by Conrad (2006), Forkutsa (2006) and Khamzina (2006). From April to mid-June, Conrad calculated ETa values for winter wheat in Yangibazar to be 346 mm and 274 mm. Our values of 389, 306 and 370 mm for light, medium and heavy soils, respectively, for the same district, crop and during the same period (see Table 5.2) are comparable.

Table 5.2 Comparison of ETa values in Khorezm for certain crops (in mm)

Author	Basic year	ETa [mm] winter wheat	ETa [mm] rice	ETa [mm] cotton
Conrad	2004[a]	288	1007-1046	786-831
	2005[b]		877-924	701-833
Forkutsa	2003[c]			641
Sommer				659-1056
our simulation	2003	509; 3541	758	762

Notes: [a] with beginning of April
[b] different arithmetic techniques
[c] Khiva district, for some tree species

Source: Conrad (2006); Forkutsa (2006); Sommer (2007)

Monthly cotton ETa values in 2003 for the Khiva district as reported by Forkutsa (2006) range from 71 mm in May, 69 mm in June, 128 mm in July and 122 mm in August. This is comparable with our modeled values of 58 mm in May, 135 mm in June, 132 mm in July and 111 mm in August for the same months, district, crop and soil type. Daily evapotranspiration values for cotton in Khiva of 1.9 mm/d in May to 4.5 mm/d in July and August also correspond very well to each other. Detailed information on daily ETa values for different crops in all districts can be found in Appendix D, Table D-1 and D-2.

Groundwater

To verify groundwater parameters, simulated values for all districts in Khorezm were compared with extrapolated and averaged groundwater data available for approximately 2,000 wells distributed within the Khorezm region. These data were provided by the "Hydrological Melioration Expedition of the Khorezm Department of Land and Water Resources". A detailed description and analysis of the network of groundwater observation wells in the Khorezm region can be found in the study by Ibrakhimov (2004).

Groundwater measurements were conducted three times per year in April, July, and October. Values in the remaining months were interpolated. The groundwater in Khorezm is relatively shallow and is maintained by intensive leaching and farmer manipulation by water afflux in canals. Data were also crosschecked with monthly groundwater measurements from a sub-unit of the Khorezm irrigation and drainage system (Tischbein, 2006). The characteristics of the groundwater curves are comparable. As shown in Figure 5.3, groundwater levels correspond well with the quasi-real measurements of groundwater values.

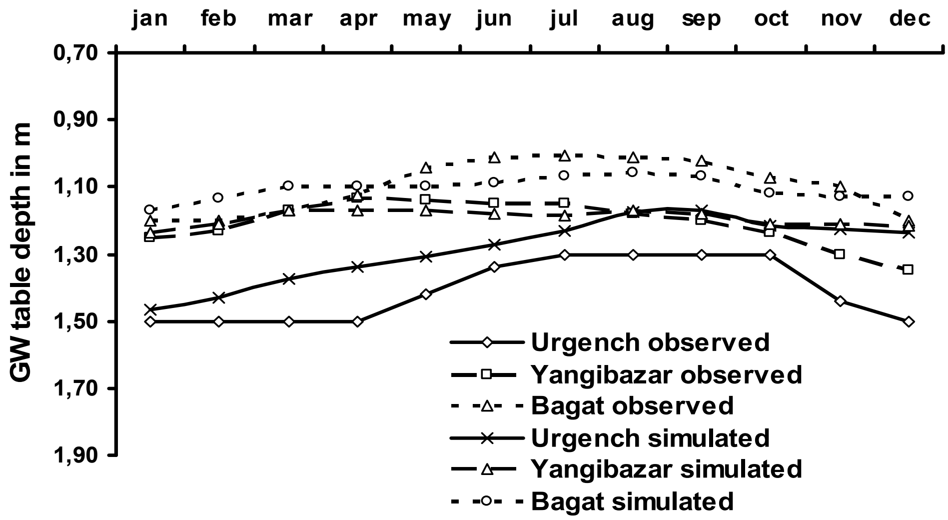


Figure 5.3 Groundwater simulation and verification

Notes: observed=observed values in April, July, October, rest interpolated groundwater data

simulated=with the model-simulated groundwater values

The use of a simple groundwater reservoir model provided by Bear (1977) and implemented by Cai (1999) seems to be an effective instrument to simulate groundwater balances involving pumping, extraction, percolation and discharge processes.

Drainage

The calculation of drainage disposal within the model takes into account that losses from irrigation water application to fields and from the distribution system (and non-irrigation water uses) to some extent recharge the groundwater, to a small portion is re-used and re-directed into the river, but for the most part, it is directed to drainage ponds and lakes. Most of the water is directed into the Sarikamish depression in the northwest of the region. Losses in the irrigation processes are taken into account in the model in the form of efficiencies. The verification of monthly drainage disposal was performed using data from 1990-2001. Unfortunately, data from 2003 were not available for this study. As shown in Figure 5.4, the simulated drainage course for 2003 in Khorezm is in a realistic range compared with data for 1998, which is a comparable year in terms of irrigation water distribution.

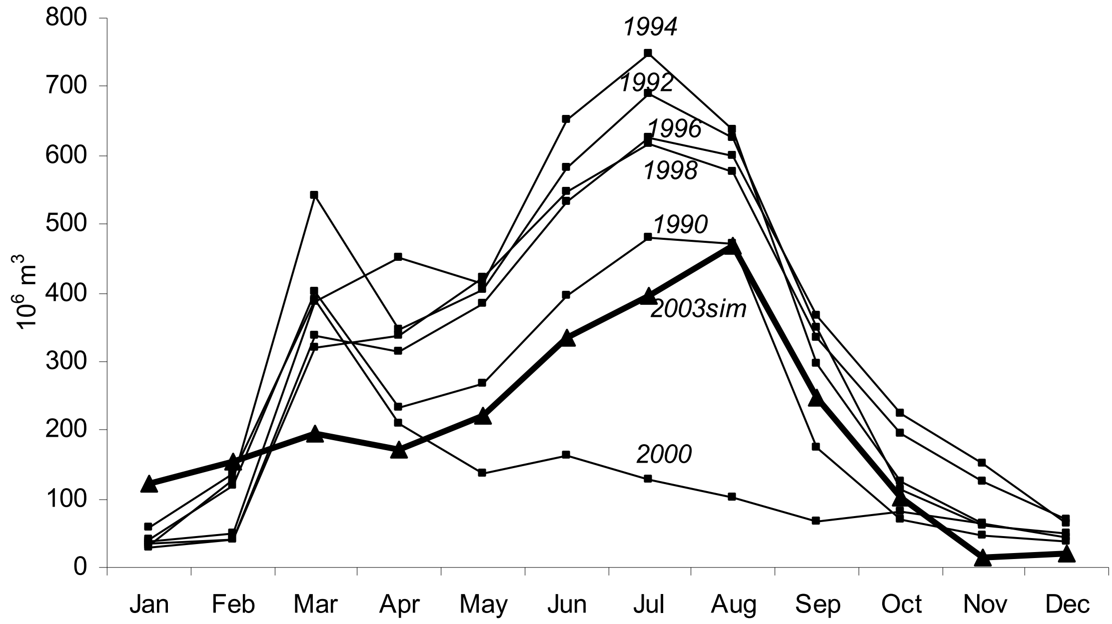


Figure 5.4 Total amount of drainage in Khorezm (in 10^6 m^3)
Notes: 2003sim, own model simulation for 2003
Source: GME (2001) Melioration Expedition and own simulation

The low amount of drainage water in 2000 stands out. This is caused by a drought during this period that also influenced the amount of drainage water. The relatively high amount of drainage in January, February and March of 2003 is due to high water supply for leaching (see Figure 4.2) during this year and also due to temperature conditions (when temperatures are above zero degree an early canal water flow for filling up the system is possible). Leaching is not only used for removing soil salinity, but also to recharge groundwater and soil water storage, which is used for crop growing processes later in the year.

The ratio of drainage water to the total applied irrigation water ranges in the model simulations from 50-72 % and is relatively stable around 60 %. The average simulated drainage disposal for 2003 is 59 % of the irrigation water (see Figure 5.5).

This value is comparable with the 55-65 % reported by Conrad (2006, p. 196) for his observations and calculations in 2004 and 2005. It is also comparable to the 67 % reported by Tischbein (2006) from observations in a sub-unit of the Khorezm irrigation and drainage system. Ibrakhimov et al. (2004) reported a drainage disposal of 70-75 % of the total irrigated water in Khorezm.

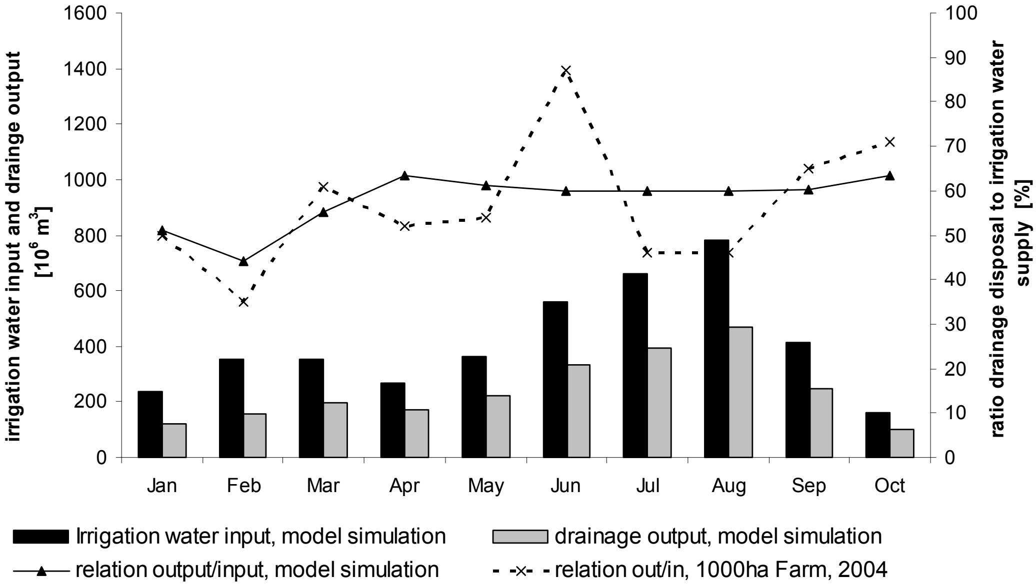


Figure 5.5 Total irrigation water input and drainage output (in 10^6 m^3) and ratio between drainage disposal and water supply (in %)

Notes: author's own simulation in comparison to values Tischbein (2006) measured for a 1000 ha farm in Khiva 2003/04

The relatively high drainage ratio in Khorezm is due to the high percolation and seepage losses within the unlined canals (only 11 % of the canals are lined, Ibrakhimov et al., 2007). Furthermore, drainage blocking (to raise the groundwater level and to increase the capillary rise) also contribute to high drainage ratios. Widespread rice cultivation in some parts of Khorezm with basin irrigation techniques and higher resultant drainage losses, as well as the low irrigation efficiencies at the field level due to non-sufficient field leveling (Conrad 2006; Forkutsa 2006; Ibrakhimov, 2004) further exacerbate high drainage ratios. Additional data on the simulated drainage for the ten Khorezm districts can be found in Appendix D.

Soil moisture

Soil moisture, defined as the ability of a soil to hold water or the water contained in the pore space of the unsaturated zone (US EPA, 2007) is an important factor for the determination of water balances within the model and for crop growth and yield. The soil moisture content is derived by balancing the effective precipitation, capillary rise, evapotranspiration, stress coefficients for transpiration and soil evaporation, infiltration and seepage losses of irrigation water, taking into account different soil types, crops and districts. This balance in turn influences groundwater, salinity, drainage balances, ETa and crop production (see equation (3.12)).

The simulated soil moisture is within the reported range of other simulations and measurements (see Figure 5.6). Averaged measurements of Forkutsa (2006) on sandy loamy cotton fields in the Khiva district are comparable with our simulation for crop, soil and district parameters and match the dynamic range of the data closely.

Sommer´s (2006) simulations with the CropSyst program have higher amplitude. The dynamic pattern is nevertheless comparable: in April/May and August due to irrigation water supply and dehydration, in June/July due to root water absorption. For heavy soils, only simulations of Sommer (2006) are available. The data are less similar because of the use of shorter (daily) time points and greater differences between field capacity and permanent wilting point in Sommer´s simulations (see Appendix D). Unfortunately, no comparable data were available for other districts or for other crops.

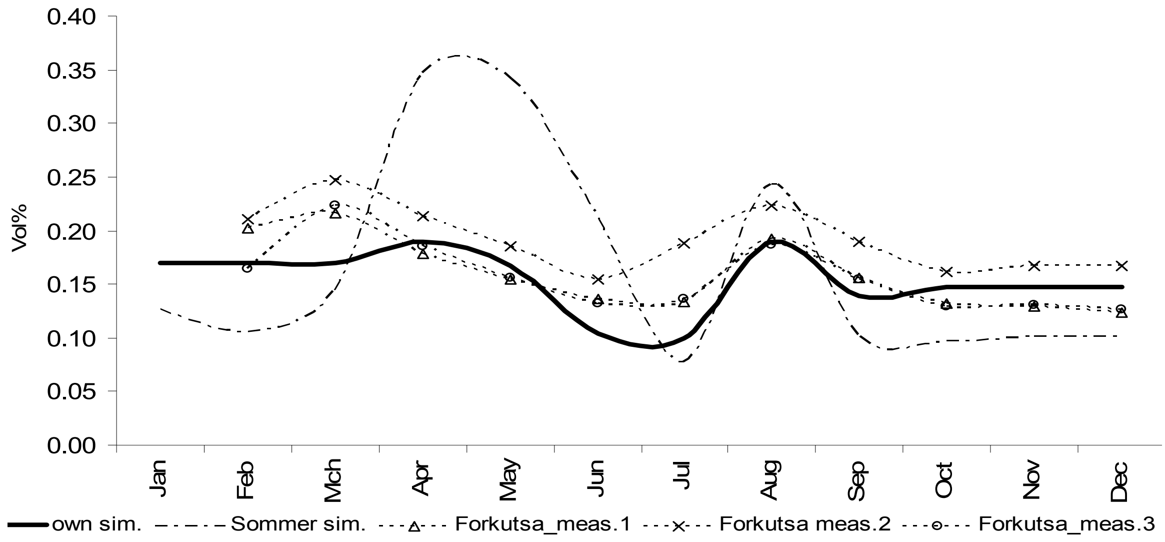


Figure 5.6 Soil moisture for soils under cotton cultivation: plausibility control, exemplified for the Khiva district

Notes:

own sim = author's own simulation for the Khiva district, light soils (sandy and sandy loamy) under cotton, for 2003,

Sommer sim = Sommer (2006), averaged, with CropSyst, for sandy+sandy loamy soils, cotton, 0-40 cm soil depth,

Forkutsa meas. =Forkutsa (2006), soil moisture measurements on sandy, sandy loamy fields in district Khiva; meas1=begin of the field, meas2=mid of field, meas3=end of the field, 20 cm soil depth, for 2003

Deep percolation

Percolation is the portion of infiltrated irrigation and precipitation water that leaves the root zone to the downward soil layer. Some of the percolation water is transferred to the drainage system, while the rest enters the groundwater (see equation (3.5)).

Water losses accompanying the intensive irrigation, mainly in cotton and especially in rice fields, recharge the groundwater (deep percolation). The consequence is a rising groundwater table and the establishment of shallow water tables (Willis 1996), which are common in Khorezm. A second consequence, mainly in dry climates, is salinization of soils (Zilberman, 1998) and groundwater (Soth et al., 1999). Forkutsa (2006) mentioned an attained cotton yield in cotton fields in Khorezm with no additional irrigation water supply due to a high groundwater level. That claim seems reasonable because the crop has the ability to use groundwater for growing processes. On the other hand, raising the groundwater leads to unsustainable salinization and elevated pesticide concentrations (Akramkhanov, 2005; Richards, 1954), which have not yet been examined in detail in the Khorezm area.

Percolation and deep percolation play an important role and is often by farmers manipulated in the Khorezm region. The examination of the amount of deep percolation and infiltration is very difficult because many factors are involved in the process of soil and groundwater balances (such as drainage, groundwater extraction, groundwater recharge and capillary rise). These factors can seldom be directly measured, especially in areas with high groundwater levels and where percolation and deep percolation are difficult to distinguish. For the Khorezm region, only one study on deep percolation was found (Forkutsa 2006).

As shown in Figure 5.7, the percolation values for the cotton in Khiva match data from Forkutsa´s (2006) cotton-growing study. The field values from this study were obtained using water balance calculations with the Hydrus-1d program (Simunek et al., 2005), as deep percolation to groundwater could not easily be measured directly. The relatively large downward water fluxes in August due to the high irrigation water contribution within this period are notable. In addition, large downward water fluxes can be observed in Forkutsa (2006)'s study and our simulation within the soil leaching period in April (due to high leaching water supply for this time on the fields). Forkutsa´s yearly percolation values range from 275 to 572 mm depending on the location within the field (begin and middle of the irrigated field). These values are comparable with our simulations for cotton-growing areas in Khorezm and Khiva. Our values range between 259 mm for heavy soils, 603 mm for medium soils and 407 mm for light soils in Khiva, and the fluxes in July to September are slightly higher than in the leaching period of February to April. Unfortunately, no additional data, calculations or measurements are available for other districts in Khorezm or for other crops. In literature the range of downward water fluxes for comparable dry and irrigated areas is as low as 100 mm and greater than 500 mm within the irrigation period (Stonestrom et al., 2003; Rockström et al. 1998; Pereira, 2005; Evans, nys.) and can be compared to our simulations.

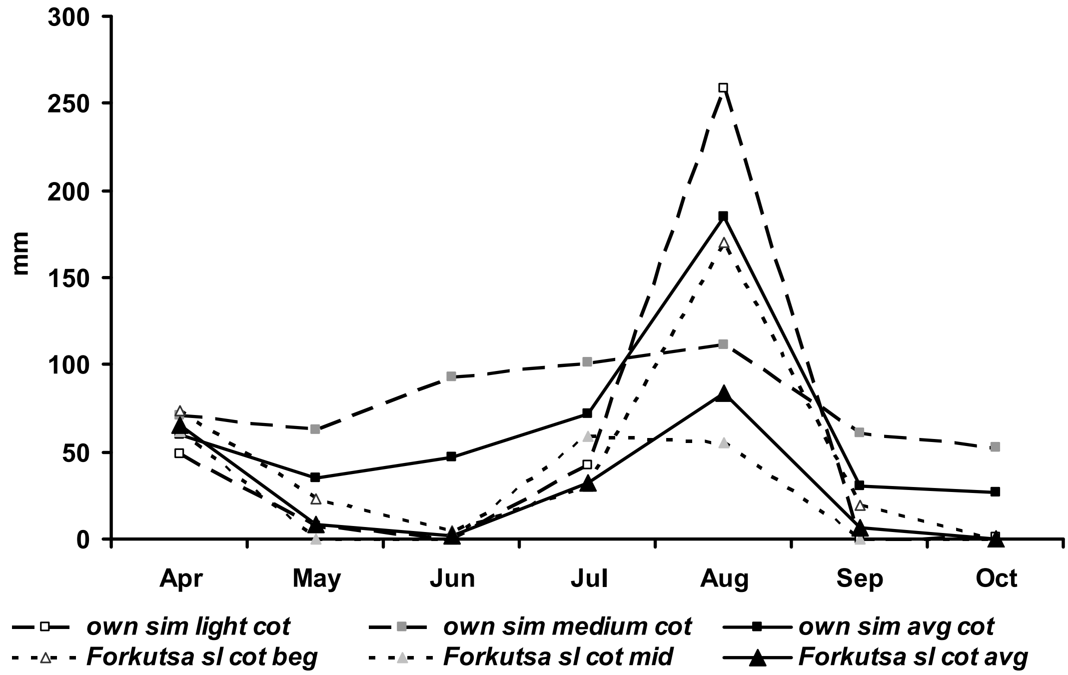


Figure 5.7 Downward water flux (deep percolation) in the Khiva district, plausibility control (in mm)

Notes:

comparison of deep percolation values for simulated data for cotton growing period April-October,

own sim light cot, own sim medium cot = own simulation for cotton fields in district Khiva on light and medium soils,

Own sim avg cot = average of light and medium soil on cotton fields in district Khiva, model simulation,

Forkutsa sl cot beg, meas sl cot mid = water balance calculations of Forkutsa (2006, p. 83) on sandy loamy fields in district Khiva, location: begin and mid of cotton field,

Forkutsa sl cot avg → water balance calculations of Forkutsa, average of sandy loamy cotton fields for begin and mid location in district Khiva

The average deep percolation ratios for all other districts can be seen in Figure 5.8. For all crops and soil types, the amount of deep percolation within the vegetation period for the ten districts in Khorezm is plotted.

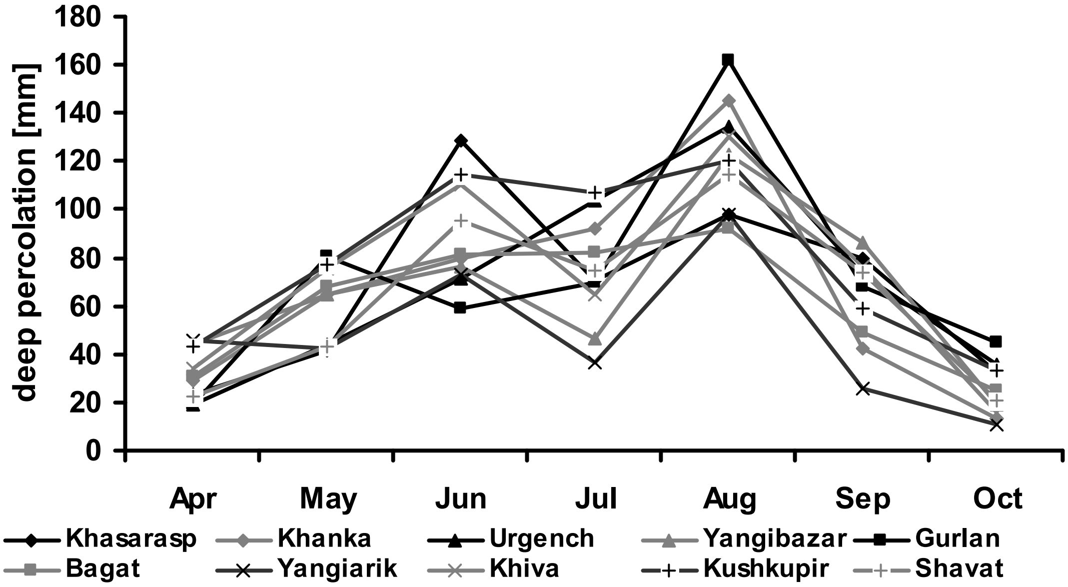


Figure 5.8 Deep percolation per Khorezm district (in mm)
Source: author's own simulations for 2003

The percolated quantity does not differ essentially by district, which reflects the tendency of surface water application to the districts (see chapter 4.1.1; i.e., for Gurlan higher than Kushkupir). The peaks in August and June are a consequence of the irrigation that basically takes place during these months. The progression curve for some districts depicts a more flat character due to slightly different crop cultivation schemes and modified irrigation patterns. Furthermore, different shares of soil types cause little differences in percolation quantities (e.g., districts with a higher amount of light soils denote a little higher percolation ratio due to soil hydraulic properties).

The fraction of water percolation to total water applied to the field's amounts to approximately 41-58 %, with an average of approximately 45 % in the growing period depending on crop and soil type. This value is comparable to Forkutsa´s calculated downward fluxes that range from 12-79 %[12]. Her most reliable value is approximately 46 %, which is slightly above the value of 40 % assumed by Tischbein (2007).

12 Forkutsa (2006), pp. 57 and 83; calculation for vegetation period April-October; 79 % value for groundwater level close to root level, and 12 % value for low irrigation water supply, not representative

5.2 Analyses descriptive model

Water supply to field level and crop water consumption

Based on the water supply situation in Khorezm in 2003 and on related water distribution efficiencies (see chapter 4.2.4), it is possible to determine crop water consumption and the water balances. As the output is determined, relevant parameters such as crop yield, cropped area and water supply in the deterministic model become fixed to enable the identification of crop water requirement by backward determination.

Of the nearly 4.1 km^3 irrigation water supply, approximately 55 % reaches the field. Some is used for leaching in January through March. In March, a small amount of water is used for the irrigation of wheat (0-20 %). In November and December, there is no additional water left for irrigation or leaching processes. Thus, for all crops and soil types, the averaged water supply applied to the field is approximately 8,300 m^3/ha, with some variation within the districts (see Figure 5.9).

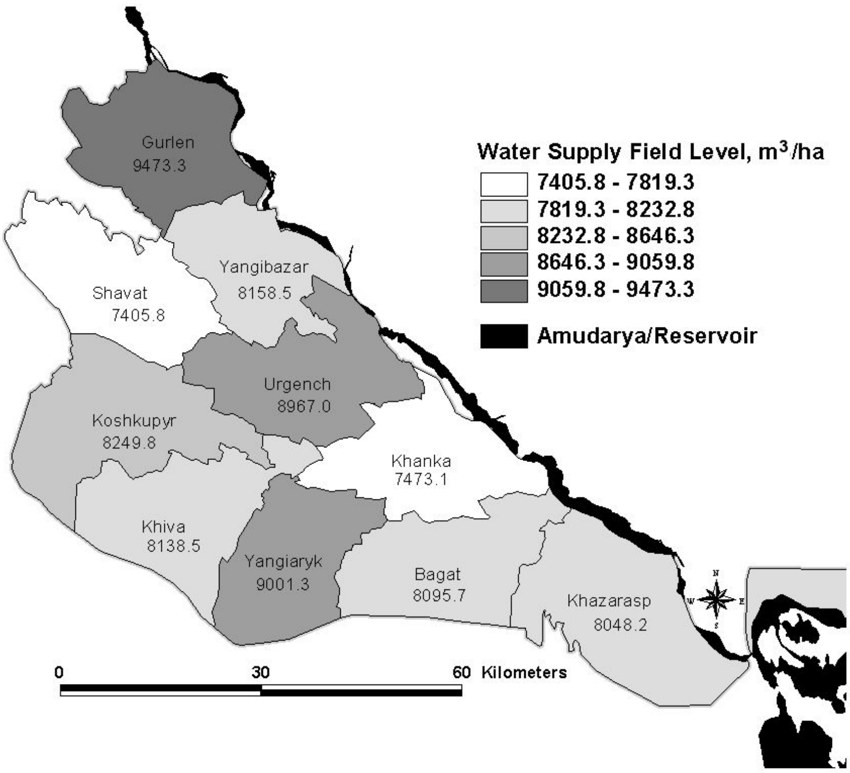


Figure 5.9 Water supply at field level, Khorezm, 2003 (in m^3/ha)

Notes:

author's own calculation based on overall irrigation water application, distribution/irrigation efficiencies, averaged for whole district and all assumed soil and crop types

Field level water supply reproduces the tendency of the district water supply situation in 2003 (see Figure 4.2). As the water availability that is put on the field depends only on surface water supply and distribution and application losses[13], the allocation of water at the field level in the different districts is comparable to Figure 4.2. Gurlan, Urgench and Yangiarik denote higher water availability at the field level. This may be due to the high district water supply for rice growing and also to the fact that the Gurlan and Urgench districts are close to the river and have their own river water entry points. As the figure shows, a general assumption of higher water supply for districts close to the river cannot be sustained. Müller (2006) noted this in his work covering the years 1998-2002. Political decisions may also play a role in the distribution of irrigation water (Veldwisch, 2007).

Monthly field water availability for irrigation purposes during the main growing period shows high water supply in July and August, as most of the crops (with the exception of winter wheat) are irrigated in these months (see Figure 5.10). The Gurlan district has the highest values of irrigation water application due to high rice cultivation.

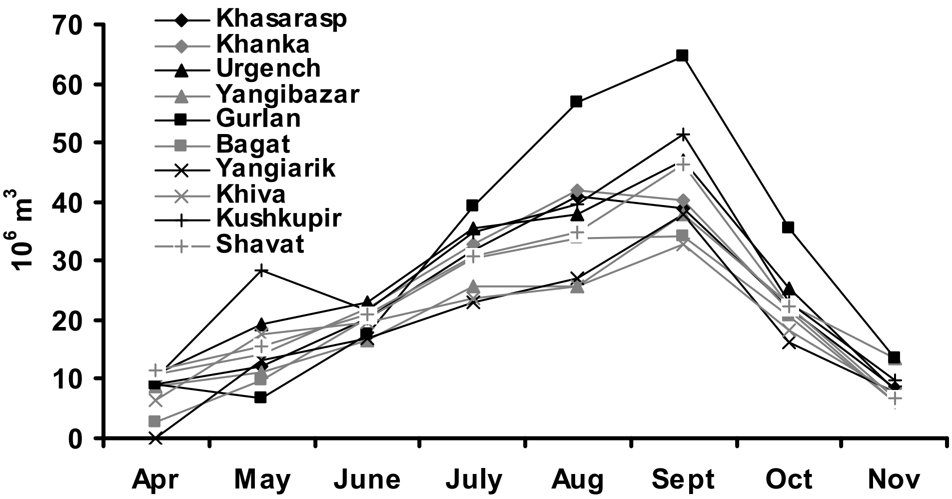


Figure 5.10 Monthly water supply at the field level per Khorezm district (in 10^6 m^3)
Source: author's own calculations for 2003

[13] And a small amount of groundwater pumping (2-3% of the total water supply)

The calculated water supply and for the different soil types averaged total range of crop water supply at the field level per hectare based on data for 2003 is shown in Table 5.3.

Table 5.3 Crop water supply at field level per hectare (in 10^3 m^3/ha)

Crop water supply 10^3 m^3/ha	**cotton**	**other grain**	**wheat**	**rice**	**vege-table**	**fruit**	**alfalfa**	**potato**
min. field water supply[a]	6.58	3.96	3.10	6.44	6.07	8.45	11.06	7.92
max. field water supply[b]	14.99	12.82	8.23	17.20	16.92	18.55	18.78	17.21
avg. field water supply	9.72	8.82	4.98	13.65	13.08	14.10	14.89	12.37

[a] minimum averaged water supply at the field level
[b] maximum averaged water supply at the field level

Source: own calculation, values refer to weighted averaged supply for different in dependency of soil type share and districts

As shown, the crop water supply per hectare at the field level seems to be very high (with the exception of rice) compared to the irrigation water norms from the Ministry of Land and Water Resources in Khorezm (see Table 5.3). These irrigation water norms are dependant on the crop that shall be irrigated and are based on a hydrological model developed during soviet times (OblVodChoz, 2002). In Table 5.4, the irrigation norms are listed for the single crops and districts in Khorezm.

Table 5.4 Field water demand/irrigation water norms (in 10^3 m^3/ha)

	cotton	**wheat**	**maize**	**rice**	**potato**	**vegetable**	**fruit**	**alfalfa**
Bagat	5.70	3.70	5.41	26.2	8.70	8.70	5.24	8.51
Gurlen	5.53	3.60	5.22	26.2	8.45	8.45	5.13	8.32
Kushkupir	5.36	3.53	5.03	26.2	8.21	8.21	5.05	8.10
Urgench	5.86	3.77	5.59	26.2	8.93	8.93	5.33	8.71
Khazarasp	5.95	3.79	5.70	26.2	9.06	9.06	5.36	8.85
Khanka	5.71	3.68	5.43	26.2	8.72	8.72	5.23	8.56
Khiva	5.51	3.62	5.19	26.2	8.42	8.42	5.15	8.26
Shavat	5.28	3.52	4.93	26.2	8.10	8.10	5.03	7.98
Yangiarik	5.44	3.57	5.12	26.2	8.33	8.33	5.10	8.20
Yangibazar	5.70	3.70	5.40	26.2	8.70	8.70	5.24	8.51
Khorezm avg.	5.61	3.65	5.31	26.2	8.57	8.57	5.19	8.41

Source: OblVodChoz, 2002

With the exception of rice, our calculated values exceed the values of OblVodChoz (2002). This tendency was already recognized by Müller (2006). Müller calculated the water supply for the period 1998-2001 and came to the conclusion that a general overuse of water for crop irrigation is occurring in Khorezm, with the exception of the drought years 2000/2001. Veldwisch (2008) also noted a general overuse of irrigation water compared to water norms in the Yangiarik district in 2005. This is contrary to direct measurements of field water supply in Khorezm (Forkutsa, 2006) that show a partial deficit water supply situation in two cotton fields in the Khiva district[14]. Tischbein (2007) also assumes a lower water supply at the field level but only at the tail end locations in Khorezm (more than 95 km from the Amu Darya). The situation depends on overall river/reservoir and district water supply situations for different years and on the location and scale. In addition, some fields and farmers will receive more or less water than others depending on their political and social contacts (Zavgorodnyaya 2006; Trevisani 2006) and on canal distances. As shown in Forkutsa´s work, field leveling causes irregular water supply for crops at different locations, even within a single field, where one end of the field presuppose higher water applications to assure sufficient water supply at the other end of the field. This questions the accuracy of the efficiencies published by the government. However, an overuse of water represents inefficient water management.

The surface water that is effectively used by the crop (see Table 5.5) depends on the amount of water that is directed to the field (field water application and effective precipitation), losses within the field due to drainage and evaporation and percolation to layers below the root zone. Furthermore, supplementary water that a crop root can use via capillary rise from groundwater and lower soil layers contributes to the crops total water use. It can be added to the surface water effectively used by crops, resulting in evapotranspiration processes (see chapter 3.2.3).

For the application efficiency, a value of approximately 42-47 % is assumed (defined as the ratio of the average depth of irrigation water stored in the root zone for crop consumptive use to the average depth applied). This value is derived from expert knowledge and soil water-balance calculations. For the 1,000-ha farm in Khiva, a value of approximately 45 % is derived (Tischbein 2005/2007). Forkutsa (2006) calculated an

[14] Forkutsa stated 800-4,000 m^3/ha for her cotton field study. In locations with shallow groundwater it is possible to subsist with lower water supply.

application efficiency of 40-50 % in her fields. Due to the introduction of the application efficiency term, the additional surface water losses at the field level will be described. In addition to the losses in the rest of the distribution system, the described percolation, drainage and soil evaporation processes and the capillary rise processes add up to the amount of water that a crop can effectively utilize for transpiration processes.

Table 5.5 Water effectively used by crops via transpiration (in 10^3 m^3/ha)

water effectively used by crops 10^3 m^3/ha	**cotton**	**other grain**	**wheat**	**rice**	**vege-table**	**fruit**	**alfalfa**	**potato**
minimum	2.06	3.89	1.19	2.90	2.73	3.40	3.60	4.13
maximum	5.40	6.36	3.70	7.16	9.06	8.35	7.48	6.40
average	3.81	4.99	2.07	4.99	5.06	5.44	5.71	5.18

Notes: Values refer to weighted averaged supply for different soil types and districts

As shown in Table 5.4 a general tendency of relatively low irrigation water utilization for wheat and, to some extent, for cotton becomes apparent when comparing with the data for field water supply (Table 5.3). For vegetables and fruits, the high surface applications are due to the relatively small fraction of allowable depletion of the difference between permanent wilting point and field capacity. This leads to rather frequent irrigation events for the crops with the above-mentioned losses, especially when surface irrigation methods are practiced (Tischbein, personal communication 2007). Furthermore, relatively high soil moisture within the rather small allowable depletion reduces the tendency of capillary rise.

Economic indicators:

After finalizing the verification, plausibility control and description of the main hydrologic and agronomic parameters for the descriptive model, it is possible to determine de facto economic parameters. These parameters include gross margins for main agricultural crops per district, economic water use efficiency, gross revenue and crop production costs. All other data relevant for the model are included in Appendix C.

Gross margin

Gross margin acts as an indicator of the profitability of crops as well as of districts (equation (3.20), (3.21), (3.22)). Table 5.6 show a calculated differentiation between gross margin with and without the introduction of a hypothetical water price. For the calculation of water costs for the districts and for single crops, total gross surface water and pumped water applied to fields, along with their costs, are included. The proportion of leaching is also included, as leaching is an important factor in crop-growing processes and soil preparation and must be reflected within economical analyses. In 2003, the reference year of the calculations, the share of water applied during the pre-season leaching was relatively high due to favorable climatic conditions initiating leaching in January and February (leaching normally begins in March). Approximately 20 % of the total water supply is leached within the first months of the year. A hypothetical water price for surface water of 0.003 USD/m3 was assumed and a groundwater pumping price of 0.005 USD/m3. The assumed water pricing has a relatively strong influence on gross margins, decreasing approximately 35 %, with a range of 22 % - 60 %, as compared to no water costs.

Table 5.6 Gross margins of crop production per district in 2003 (in 10^6 USD and USD/ha)

	Gross margin [10^6 USD]		**Gross margin** [USD/ha]	
	with water price (0.003 USD/m^3)	without water price	with water price (0.003 USD/m^3)	without water price
Khasarasp	3.72	4.97	157	210
Khanka	4.13	5.44	155	203
Urgench	2.79	4.2	116	174
Yangibazar	0.72	1.82	35	88
Gurlan	3.46	5.09	132	194
Bagat	1.67	2.73	83	136
Yangiarik	2.69	3.62	170	229
Khiva	2.67	3.7	139	192
Khushkupir	-0.65	0.83	-24	30
Shavat	1.88	3.17	70	119
Khorezm total	23.08	35.56	100	154

Source: own calculation, based on the descriptive model

A detailed analysis of changing water prices on gross margins shows the high impact, even with low water prices, on gross margins. At a water price of 0.009 USD/m^3, gross margins for Khorezm becoming negative (see Appendix D; Figure D.3). At this level, it is not worthwhile for farmers to cultivate crops because costs exceed returns. It should be noted that this analysis was conducted for the descriptive model with a fixed 2003 water supply. In the case of water pricing as an incentive to support water saving measures, this will have an effect on water demand and yields and in turn will change gross margins as well. Within the presented calculations, salinity terms are not yet included but will certainly reduce gross margins noticeably because salinity in groundwater and surface water affects evapotranspiration and crop growth conditions.

Another interesting point is the distribution of gross margin over single crops. As shown in Table 5.7, cotton and alfalfa show negative values. This means that even without the introduction of water pricing, costs for these crops exceed revenues. This observation is in agreement with the calculations of Djanibekov (2008) based on 2003 data. For alfalfa, this can be explained by the fact that alfalfa is mainly used internally within the farms and not as a revenue generator. For cotton, the state order for cotton production and the controlled but secured (lower) selling prices resulted in relatively low gross margins. Despite favorable production costs in 2003, it was not worthwhile for farmers to grow cotton, mainly due to low sales prices compared with world markets. Nevertheless, the fact that the government orders and buys a certain quantity of cotton at guaranteed prices while providing subsidized inputs (Müller 2006; Rudenko 2007) represents an enormous incentive for farmers to consider cotton production as a "safe" option. This compensates for the lower prices, although not necessarily in monetary terms. Depending on farmer's cotton-growing orders, pesticides, machinery and seeds will be provided and, therefore, government cotton prices cannot directly be compared with real market prices. Taking into consideration all the extra benefits of cotton growing, adding additional transport costs, custom duties and expenses for intermediate agents and institutions, the government-paid cotton prices almost match world market prices[15] as calculated by Rudenko (2007 and 2008).

[15] That also is kept artificially very low, i.a. because of the heavy subsidization of cotton production in almost all of the cotton producing countries

Table 5.7 Gross margin per crop without water pricing (in 10^6 USD)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**
Khasarasp	-0.222	0.571	3.615	0.018	-0.166	1.119	0.028	0.008
Khanka	0.004	0.590	2.740	0.025	-0.186	1.959	0.068	0.237
Urgench	-0.538	0.755	2.780	0.059	-0.149	1.044	0.214	0.032
Yangibazar	-0.638	0.434	1.721	0.011	-0.152	0.455	-0.108	0.096
Gurlan	-1.344	0.375	4.781	0.072	-0.265	1.122	0.184	0.163
Bagat	-0.321	0.605	1.731	0.022	-0.234	0.796	0.042	0.094
Yangiarik	-0.204	0.356	2.083	0.035	-0.116	1.248	0.076	0.145
Khiva	0.053	0.270	0.581	0.012	-0.091	2.517	0.075	0.278
Kushkupir	-1.060	0.623	0.956	0.041	-0.386	0.553	0.011	0.087
Shavat	-0.433	0.541	1.193	0.027	-0.193	1.230	0.321	0.486
Khorezm total	-4.703	5.12	22.181	0.322	-1.938	12.043	0.911	1.626

Source: author's own calculations, descriptive model

In contrast, high prices are being paid on the local market for rice and vegetables, but especially rice consume much more irrigation water. Their share in terms of area seems to be controlled mostly by administrative orders. It remains to be studied how the present cropping pattern would be affected by water prices. Water values and revenues per crop can be useful information for that decision, which is discussed below.

Revenue

Revenues are determined by produced yields and obtained market prices. In Table 5.8, revenues for the entire Khorezm area, all individual districts and observed crops are calculated and listed. As shown in the table, the highest revenues per crop can be obtained for rice and cotton. This depends mainly on high cropped areas for cotton (>45 %) and high selling prices of around 297 USD/t for rice. Regarding gross margins, alfalfa, maize, sorghum, barley, and beet have relatively small revenues. In fact, the production of these crops is used internally. Relatively high revenues for the districts close to the river (Khasarasp, Khanka, Urgench and Gurlan) are directly related to the cropping area and to high rice production in the Gurlan district, resulting in higher revenues for rice production.

Table 5.8 Revenues per crop, district and in total (in 10^6 USD)

	cotton	wheat	rice	other grain	alfalfa	vegetable	fruit	potato	Revenue per district [10^6 USD]	Cropped area [10^3 ha]
Khasarasp	3.84	1.63	5.89	0.04	0.09	1.45	0.30	0.05	13.27	23.7
Khanka	4.05	1.90	4.25	0.06	0.10	2.40	0.27	0.44	13.45	26.7
Urgench	3.05	2.02	4.43	0.13	0.06	1.54	0.56	0.24	12.01	24.1
Yangibazar	3.32	1.41	2.62	0.03	0.16	0.64	0.20	0.21	8.58	20.6
Gurlan	3.30	1.17	7.30	0.15	0.13	1.53	0.55	0.38	14.50	26.2
Bagat	3.10	1.76	2.63	0.04	0.07	1.02	0.26	0.17	9.07	20.2
Yangiarik	2.27	1.10	3.23	0.08	0.14	1.52	0.26	0.32	8.92	15.8
Khiva	3.02	1.25	0.94	0.04	0.09	3.26	0.27	0.52	9.38	19.2
Kushkupir	3.37	1.92	1.57	0.11	0.14	0.95	0.30	0.30	8.65	27.3
Shavat	3.91	2.00	1.96	0.08	0.20	1.57	0.65	0.70	11.06	26.7
Khorezm total	3.32	1.61	3.48	0.07	0.12	1.59	0.36	0.33	108.9	231

Source: author's calculations

Compared with official data from Oblstat (2003), both the cropping area (232,000 ha) and the total revenue of 109 Million USD[16] for crop production match our calculations.

Economic water use efficiency

Finally, the economic water use efficiency (e-WUE) is calculated with respect to water application to crop fields and water withdrawal to the entire districts (Table 5.9; Table 5.10). Depending on the economic water value, decisions regarding cropping patterns and areas, as well as water allocation and application, can be implemented.

The economic water use efficiency is established as the relationship between gross margins and the total water applied with respect to single crops and districts (see equation (3.29), (3.30)). In Table 5.9, the economic water use efficiency is listed in addition to data for the calculation of those values, such as gross margin and water application for single districts. As shown in the table, the total average water value for Khorezm is in the range of 0.009 USD/m^3 of applied water. For economic equilibrium, according to classical economic models, the water value should equal the full costs of water to maximize social welfare. However, for practical reasons, the water value is normally higher than the estimated full costs as a consequence of the difficulty in estimating costs of environmental externalities (Rogers, 1997). The assumed value of

[16] Assumed exchange rate US Dollar to Uzbek Soum in 2003 of avg. 973 Uzbek Soum

0.003 USD/m^3 of the full water costs used in the model is well below the calculated averaged water value of 0.009 USD/m^3. However, for some districts, such as Kushkupir and Yangibazar, the water value is close to or even below the assumed full water cost values. For first analyses, the assumed full water cost value should be within a realistic range, especially for Khorezm, because environmental consequences are relevant. The difference in the water use efficiency with and without water pricing, as displayed in Table 5.10, directly reflects the basis of water value calculation with and without water pricing and logically equals 0.003 USD/m^3.

Table 5.9 Economic water use efficiency, costs and gross margins in 2003

	Economic water use efficiency [USD/m^3]		**Water costs**	**Variable planting costs**	**Gross margins, without water price**	**Total water applied**
	with water price	without water price	[10^6 USD]	[10^6 USD]	[10^6 USD]	[10^6 m^3]
Khasarasp	0.009	0.012	1.24	8.30	4.97	411.8
Khanka	0.010	0.013	1.26	8.01	5.44	418.5
Urgench	0.006	0.009	1.38	7.81	4.20	458.5
Yangibazar	0.002	0.005	1.05	6.76	1.82	350.9
Gurlan	0.007	0.010	1.58	9.41	5.09	526.6
Bagat	0.005	0.007	1.10	6.33	2.73	366.1
Yangiarik	0.008	0.011	0.98	5.30	3.62	326.6
Khiva	0.008	0.011	1.02	5.69	3.70	338.6
Khushkupir	0	0.002	1.54	7.82	0.83	513.5
Shavat	0.004	0.007	1.33	7.89	3.17	443.6
Khorezm total	0.006	0.009	12.46	73.33	35.56	4,154.7

Source: author's own calculations based on the descriptive model

For the determination and the analysis of water use efficiencies, the examination of water values for single crops per district is significant. As shown in Table 5.10, the economic water use efficiency for vegetables, rice and potatoes is relatively high compared to the other crops. This is surprising, particularly for rice, as one would expect a lower value due to the high water utilization rate of rice. However, revenues for rice are much higher than for other crops, which means that it is worthwhile for farmers to grow rice in preferred areas with a sufficient water supply, such as in Gurlan. Similarly, for vegetables and potatoes, the correlation between gross margin and revenues is quite good, and additional water consumption for both crops is not as high as for rice.

Table 5.10 Economic water use efficiency per crop and district, without water pricing (in 10^3 USD/m^3)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**
Khasarasp	-1.0	12.0	42.0	7.0	-3.0	68.0	2.0	6.0
Khanka	0.02	8.0	31.0	6.0	-4.0	81.0	6.0	27.0
Urgench	-3.0	10.0	26.0	7.0	-4.0	37.0	8.0	4.0
Yangibazar	-4.0	10.0	31.0	7.0	-4.0	37.0	-5.0	18.0
Gurlan	-6.0	9.0	32.0	8.0	-5.0	37.0	6.0	15.0
Bagat	-2.0	15.0	43.0	17.0	-4.0	59.0	3.0	24.0
Yangiarik	-1.0	19.0	33.0	16.0	-3.0	76.0	6.0	25.0
Khiva	0.3	5.0	22.0	8.0	-2.0	72.0	6.0	19.0
Kushkupir	-5.0	9.0	22.0	7.0	-4.0	17.0	0.5	12.0
Shavat	-2.0	7.0	33.0	6.0	-2.0	52.0	16.0	55.0
Khorezm total	-2.4	10.4	31.5	8.9	-3.5	53.6	4.9	20.5

Source: author's own calculations

As described in chapter 3, 4 and 5, verification of the model variables and parameters matches very well with measurements and values from the literature. For this reason, the model can be characterized as plausible and coherent. After a successful verification and plausibility study of the model input (data, methodology, model formulation, see chapter 3 and 4) and output parameters (chapter 5), a sensitivity analysis is necessary to check the robustness of the model with respect to parameter changes and the influence of input parameter to output values. After implementing the sensitivity analysis, it will be possible to perform the main simulations and the scenario analyses.

6 SENSITIVITY ANALYSES

Sensitivity analyses are primarily used to test the strength of the model and the quality of the model definitions. They can also be used to determine the influence of input-factors on certain output variables (Saltelli, 2008) and in the ex ante identification of possible scenario analyses, making them useful for policy recommendations.

For this type of parameter impact analysis, a local sensitivity analysis was chosen because the implementation and execution is relatively simple, calculating efficiency is fast and sensitivity is explicitly assigned to one input-parameter (Huisman et al., 2004).

For the sensitivity analyses of the model, the following parameters were considered to be essential:

- natural inflow
- precipitation and effective rainfall
- reference crop evapotranspiration (ETo)
- irrigation/application efficiencies
- crop coefficients for transpiration, soil evaporation, yield response coefficient for water (ETo, kc, ky), and potential yields

Thus, relevant key hydrologic and agronomic parameters of the model, such as water, crop, climate, soil, and management, will be tested. The effects and characteristics of the analyses on major outcomes, including agricultural benefits, water withdrawals, cropped areas, crop share, and crop yields, will be described in following section. Unlike the following scenario analyses and the previous descriptive model (for validation purposes), the sensitivity analyses will be conducted with defixated (released) output variables (cropped area and yields) to receive the general reactions to the entire system and the model outcome. A step-by-step change of single input-parameters will be implemented simultaneously.

Various scenarios for sensitivity analyses for the different input-parameters were defined. All values (input and output) are given in relative numbers for better clarity and comparability and are shown in the tables below. For simplification, only the region-wide average values are shown. The percent change of the input-parameters varies between 10 % and 50 % according to high and low specific parameter levels.

6.1 Water supply

The water supply situation in 2003 combined with the underlying model input data can be defined as a medium water supply event (see Figure 4.1). For the sensitivity analyses, those values were changed by +50 % for very wet years with high water availability in Khorezm comparable to 1998 and -50 % for very dry years such as 2000/2001. The effect on agricultural benefits (revenues for cropping activities) is +17 % for wet years and -24 % for dry years. This is relatively high and is mainly caused by a significant extension of +35 % and a reduction of -28 % of the irrigated cropping area (Table 6.1). Furthermore, crop yields decreased in dry-year situations by -16 %. Interestingly the yield increase of +7 % in very wet years is relatively low.

Table 6.1 Sensitivity analysis for water inflow, all relative values

Relative inflow	**Agricultural revenues**	**Irrigated area**	**Crop yields**[a]
Dry (0.5)	0.76	0.72	0.84
Normal (1.00)	1.00	1.00	1.00
Wet (1.5)	1.17	1.35	1.07

Notes: [a] all illustrated crop yields are always conducted for medium soil, as they are dominant in Khorezm

For the rainfall scenario, both effective rainfall and total precipitation were decreased or increased to determine the influence of rainwater on crop growth and yield in Khorezm (Table 6.2). Consequently, the precipitation that reaches the crop root zone for crop growth and crop yield will be tested. As expected, even an increase of 50 % has a small impact on crop yields and the resultant agricultural benefits. The annual precipitation in Khorezm is less than 100 mm and is thus too low to contribute to the crop-growth processes. Furthermore, only a small share of approximately 30 mm of the total precipitation occurs in the main vegetation period between April and September. In addition, a significant increase in precipitation would not relieve the irrigation system significantly (e.g., by investigations into the runoff collection).

Table 6.2 Sensitivity analysis for precipitation and effective rainfall, all relative values

Precipitation and effective rainfall	Agricultural revenues	Irrigated area	Crop yields[a]
Low (0.5)	0.988	0.977	0.994
Normal (1.00)	1.000	1.000	1.000
High (1.5)	1.011	1.056	1.005

Notes: [a]crop yields for medium soils

6.2 Crop parameter

The system is very sensitive to a change of the parameter reference evapotranspiration (*ETo*). With an increase in the potential/maximum reference evapotranspiration (*ETo*), the crop water demand increases and cannot be fully fulfilled. Thus, the relation of *ETo* to *ETa* increases (more water would be necessary to converge *ETa* to *ETo*), which results in an increased water stress situation and, finally, a reduction in yield. In the opposite situation, with reduced *ETo*. The correlation between water stress and crop yield reduction is improved as the relation *ETo* to *ETa* is decreased. In that situation, a higher proportion of the (relatively decreased) crop water demand can be sufficiently covered by the given irrigation water supply.

Table 6.3 shows that with a 25 %[17] reduction of *ETo*, the irrigated area could be expanded by 38 %. Higher *ETo* values indicate that the irrigated area should be decreased by 16 %. While this change is less dramatic, it still shows that the *ETo* is very sensitive. Furthermore, with a reduced *ETo* and higher cropped area and higher crop yields, the agricultural revenues are +17 %. With increased *ETo* and lower cropped area and crop yield, revenue in agriculture is -13 %, respectively, which indicates sensitivity to *ETo* changes.

Table 6.3 Sensitivity analysis for reference crop Evapotranspiration (*ETo*), all relative values

Reference crop evapotranspiration *(ETo)*	Agricultural revenues	Irrigated area	Crop yields
Low (0.75)	1.17	1.38	1.09
Normal (1.00)	1.00	1.00	1.00
High (1.25)	0.87	0.84	0.93

[17] The relatively high increase/decrease of *ETo* by +/- 25 % is chosen for better comparability with other sensitivity analyses

Similarly, with the change of the crop parameters *kc* (crop coefficient for transpiration and soil evaporation) and potential yields the model outcome is very sensitive. Most notably, when the *kc* is decreased 20 %, the cropped area increases 30 %, and when the *kc* is increased 20 %, the area decreases 13 %.

A change of the parameter potential yield has a large influence on the agricultural benefits. Most notably, an increase of potential yields by 15 %, which could potentially be achieved with better crop genotypes, causes a significant increase in agricultural benefits by 26 % and an increased irrigated area of 17 % (Table 6.4).

In addition, a 10 % change of the crop yield response coefficient to water (*ky*) indicates a reasonable sensitivity of agricultural revenues. A 10 % decrease produces a 3 % increase in revenues while the same increase shows a 2 % decrease in revenue. Furthermore, for the same 10 % decrease or increase of *ky*, a 5 % increase and a 5 % decrease, respectively, is observed for crop yields.

Table 6.4 Sensitivity analysis for selected soil and crop parameter, all relative values

	Agricultural revenues	**Irrigated area**	**Crop yields**
Kc, crop coefficient			
Low (0.8)	1.13	1.30	1.06
Normal (1.00)	1.00	1.00	1.00
High (1.2)	0.89	0.87	0.94
Potential yield			
Low (0.85)	0.76	0.95	0.88
Normal (1.00)	1.00	1.00	1.00
High (1.15)	1.26	1.17	1.08
Ky, crop yield response coefficients			
Low (0.90)	1.03	1.014	1.05
Normal (1.00)	1.00	1.000	1.00
High (1.10)	0.98	0.985	0.95

Notes: Kc = crop coefficient for transpiration and soil evaporation
Potential yield=maximum obtainable yield in Khorezm region
Ky= crop yield response to water coefficient

6.3 Management parameter

A change of application/irrigation and distribution (network) efficiency by 15 % causes a change in revenues, cropping area and yields by approximately 2-6 % (Table 6.5). In order to simplify the sensitivity analyses for irrigation and distribution efficiencies, no investments or O&M costs are considered.

Table 6.5 Sensitivity analysis for water distribution efficiency parameter, all relative values

	Agricultural revenues	Irrigated area	Crop yields
Irrigation efficiency (eff_irr)			
Low (0.85)	0.94	0.94	0.97
Normal (1.00)	1.00	1.00	1.00
High (1.15)	1.05	1.07	1.02
Distribution efficiency (eff_dstr)			
Low (0.85)	0.95	0.95	0.97
Normal (1.00)	1.00	1.00	1.00
High (1.15)	1.05	1.06	1.02

To summarize, the acreage presented is highly sensitive to modifications in water supply, reference crop evapotranspiration (*ETo*) and evapotranspiration coefficient (*kc*) values. Agricultural revenues are highly sensitive to modifications of *kc*, *ETo*, potential yields and water supply. Crop yields are generally less sensitive than revenues and cropped areas. However, crop yields show an increased sensibility to water intake, yield response to water (*ky*), potential yields and efficiency. Precipitation parameter change shows no significant sensitivity for any of the considered outcomes, as precipitation in Khorezm is generally too low to contribute to crop water supply.

The reaction of the model is considered robust, because with parameter changes in either direction the model can be solved properly. The model was used to solve for output values in expected directions and ranges, which can then analyzed and closely examined with the help of scenario analyses.

Between sensitivity and scenario analysis, there is a somewhat smooth transition as in both cases a certain parameter change will be implemented and the reaction of the outcomes will be analyzed. Similar input parameters such as efficiencies or water intake will also be evaluated within the scenario analyses. The main difference between the two analyses is that for sensitivity analyses, the influence of an input parameter change to defixated output values will be considered, whereas for scenario analyses, a parameter change under ceteris paribus constraints and/or multiple parameter changes will be conducted.

7 DESCRIPTION OF SIMULATIONS AND SCENARIO ANALYSES

The descriptive model; the verification and plausibility control of the main parameters; data, formulas, the calibration; economic and hydrologic de facto analyses and sensitivity analyses were all introduced in earlier chapters. The normative optimization model will be described in this chapter. Scenario analyses are, similarly to the studies on sensitivity, analyses that describe the output of considered parameters according to a change in input parameters. Thus, in most cases, the two analyses cannot be clearly segregated from each other. A scenario analysis is thus, by definition, also a sensitivity analysis. However, in contrast to the sensitivity analyses, the scenario studies examine the impacts of different policies and politically, socially, economically or environmentally induced measures. The sensitivity analyses are used to verify the underlying model, model structure, data and causalities. For this reason both analyses are separated into chapters to take into account different policies and complete a more detailed reflection of not only the overall output parameter but also the soil and crop specific parameters and water balances.

The main purpose of the model simulations is the analysis of the effects of planned policies on agricultural, hydrologic, economic and agronomic outputs. The economical analyses that will be conducted address the following questions:

1. How will the irrigated area and crop allocation change under various hydrological conditions? How does it affect gross margins, revenues, cropping patterns and yields?
2. What is the economic water use efficiency for different crops and demand sites and how does it change under different water supply and management situations?
3. What influence on yields, benefits, cropping area, crop pattern, and hydrologic balances causes a change in water use efficiency?
4. How will the change of output prices for cotton influence cultivation, cropping area or crop type and how sensitive will the cropping area and crop prices are to the modification of cotton prices?
5. What will happen to water users, profit, demand, acreage, and to the water use efficiency if water prices are introduced?

6. How, and in what direction, will market liberalization for cotton production affect the entire cropping system?
7. Does the introduction of a demand- and supply-dependent crop price function influence cropping pattern, sales prices, acreage and other economical outputs such as revenues, gross margins and cost?

The selected scenarios were chosen in close coordination with the ZEF/UNESCO Khorezm project and include policies that are planned to be implemented in this arid region or appeared reasonable under the hydrologic conditions of the existing irrigation systems.

7.1 Scenario description

The scenarios and their different experiments were subdivided into tree blocks. *Scenario block 1* comprises analyses for situations under status quo conditions with acreage and cropping patterns similar to those found in 2003. Variable production cost and crop sales prices were kept constant on the basis of 2003 prices. The crop yields were calculated endogenously by the model in subject to described model methodology discussed in chapter 3. The endogenously calculated crop yield is the main distinguishing feature in contrast to the descriptive model, because there all the *input* parameters were fixed to 2003 levels to analyze, calibrate and validate the model intern processes and reactions. Scenario block 1 will analyze politically and environmentally induced measures via experiments such as the introduction of water pricing, water supply changes or management parameters under status quo. The objective is to identify the hydrologic, agronomic and economic effects and outcomes under the existing state procurement system with regulated cropping quotas for cotton and wheat. The focus is on analyzing what would have happened to the existing system if single variables were to change. Most important, the effect on the water balances will be demonstrated with the help of this scenario.

Scenario block 2 contains experiments with released acreage (abolition of the cotton quota system) but still with fixed actual 2003 variable cost and prices. This is to allow for analyses of more efficient crop and water allocation and acreage under the existing system. Experiments will again use the introduction of water pricing, water supply changes, improvements in the management parameter and the modification in cotton subsidization to see the effects of those measures on crop allocation and the resulting economical outcomes.

In *scenario block 3*, the introduction of a demand- and supply-dependant crop sales price function and the liberalization of the cotton sector and its consequences on crop allocation and economy will be evaluated. Due to the implementation of a price function, it shall be ensured that, as in reality, the most water- and economical effective crop (or crops) will not necessarily be planted at the whole area. Crop selection will be dependant on demand, and the willingness to pay the sales price for those crops will change over time. Thus, the supply of those crops will be modified. Another change within this scenario is the implementation of the liberalization of the cotton sector with modified production costs and cotton prices. Production costs will be higher due to the abolition of governmental subsidies. Cotton sales prices will be set up according to Central Asian and world market prices. The single experiments of block 3 are thus multiple scenarios as more than one parameter and variable will be changed simultaneously.

Within each of the three scenario blocks, some or all of the following experiments will be performed (Table 7.1):

1. Baseline scenario
2. Modified water supply
3. Modified irrigation management
4. Introduction of water pricing system
5. Abolishment of cotton quota system (released crop acreage) and modification of subsidization system for cotton[18].

[18] Not for block three, as it is already implemented

Table 7.1 Scenario characterization

Scenario	Scenario - Description	Experiments	Experiments - Description
1. Status quo	Actual 2003 conditions in terms of crop allocation, crop sales prices and costs	Baseline 1	Area fix/original, crop prices/costs fix/original, water supply original, no water pricing, efficiencies original
		Water supply	Exp1-1 = water supply -50 % Exp1-2 = water supply -25 % Exp1-3 = water supply +25 % Exp1-4 = water supply +50 %
		Efficiency	Exp1-5 =distribution efficiency 60 % Exp1-6 = distribution efficiency 65 % Exp1-7 = irrigation/application efficiency 50 % Exp1-8 = irrigation efficiency 60 % Exp1-9 = distribution efficiency 60 % and irrigation efficiency 50 %
		Water pricing	Water price=0.003 USD/m^3 Water price=0.006 USD/m^3 Water price=0.010 USD/m^3 Water price=0.025 USD/m^3 Water price=0.050 USD/m^3
2. Relaxed state- order system	relaxed crop allocation/acreage	Baseline 2 (Abolishment of cotton quota system)	Relaxed/defixed area, crop prices/costs fix/original, water supply original, no water pricing, efficiencies original
		Water supply	Water supply +50 % Water supply -50 %
		Modification of cotton subsidization	1.Cotton sales price 282 USD/t + variable cost 512 USD/ha (increased sales prices and total abolishment of subsidies) 2.Cotton sales price 282 USD/t + variable cost 388 USD/ha (increased sales prices under perpetuation of subsidies)
		Water pricing	Water price=0.006 USD/m^3 Water price=0.010 USD/m^3 Water price=0.025 USD/m^3
3. Introduction of price-function, cotton sector liberalization	Supply/demand and elasticity dependant crop sales price function, relaxed crop allocation, cotton sector liberalization	Baseline 3	Relaxed acreage, crop allocation, determined crop sales prices, variable cost original, efficiencies and water supply original, Cotton sales price 282 USD/t + variable cost 512 USD/ha
		Water supply	wsdt+50cppcalc= water supply +50 % wsdt-50cppcalc = water supply -50 %
		Water pricing	Exp3-1 Water price 0.006 USD/m^3, Crop sales price calculated Exp3-2 Water price 0.010 USD/m^3, Crop sales price calculated Exp3-3 Water price 0.025 USD/m^3, Crop sales price calculated Exp3-4 Water price 150 USD/ha, Crop sales price calculated

All experiments and their basis in Table 7.1 will be described in the following chapter.

7.1.1 Baseline (BL)

The baselines are used as a basis for the comparison of the effects and outcomes of the different experiments under the three scenario blocks. Consequently each scenario block has one baseline.

Baseline 1 reflects the actual 2003 situation in terms of cropped area, water supply, variable costs, selling prices and other input parameters such as climate and efficiencies. Thus, the baseline scenario describes a status quo situation under the existing state procurement system with given crop area and crop quantity restrictions as well as assignments for cotton and wheat and given fixed crop selling prices. Production inputs, such as diesel and fertilizer are still subsidized by the state.

In *Baseline 2* the status quo situation is modified for crop allocation. The acreage is unconfined/released while variable costs and selling prices remain the same as in 2003.

In *Baseline 3* a price function is implemented, leaving sales prices unrestrained. Furthermore, the governmental procurement system for cotton is abolished, and the acreage is unrestricted/released.

7.1.2 Water supply modification

The last period of water scarcity in the main vegetation time in 2008 showed the importance of the resource water in Khorezm. The increased demand of irrigation water in Khorezm due to the cropping of water-intensive crops and the high volume of leaching at the beginning of the year is one reason for the water shortages in the region of Khorezm and the downstream areas. Rising competition between upstream and downstream water users and between the riparian countries of the Amu Darya River[19] are further contributions to water shortages. The dramatic shrinking of the Aral Sea between 2006 and 2010 suggests that the Aral Sea is far beyond repair, and it is likely that the Large Aral Sea will be dried out in less than 10 years (ESA, 2009). Additionally climatic changes, such as temperature increases and the melting of the glaciers in the

[19] Higher water demand for irrigation and for hydropower generation e.g., in Tajikistan

watershed area of the Pamir Mountains, will account for an increase of evapotranspiration and an additional decrease in water quantity in the long-term. UNDP (2007) estimated that an increase of evapotranspiration caused by rising air temperatures will cause leaching and pre-irrigation to be increased by 5-10 %. Furthermore, the net irrigation will be increased by 10 %, which will be accompanied by increasing soil salinization and further land degradation. Novikov and Safarov (2002) and the Tajik Ministry of Water Economy estimate that the cotton water demand will increase an additional 22 % due to global warming, and this will cause another increase in irrigation water demand.

In reaction to this climatic development, the droughts in 2000, 2001 and 2008 and the higher probabilities of droughts respectively, the following scenario addresses the situation of a changed water supply and the effects on the water balances, the cropping system and the economic outcomes of the model. The water scarce situation will be of particular interest, but the effects of a situation with higher water availability than 2003 will also be analyzed because a temporary increase in the water quantity in short- and mid-term perspective is possible due to the melting glacier, resulting in supplemental water intake into the river system.

The following water supply experiments will be performed within each of the three scenario blocks (Table 7.1):

- *Experiment 1* describes a situation with a water supply decrease by using 50 % of the observed water values in 2003. This situation is comparable to the extreme drought year of 2001, where the water volume was 44 % of the value in 2003.
- *Experiment 2* describes a situation with a 25 % water volume decrease compared to the Baseline scenario (2003).
- *Experiment 3 and 4* describe a situation with 25 % and 50 % increase of water supply, respectively. These situations are comparable to the good water supply years of the 1990s, with water supply values 14 % - 38 % higher than in 2003.

7.1.3 Irrigation management modification

Irrigation and drainage management play a crucial role in meeting crop water demand and managing salinity in arid areas such as Khorezm. These measures are therefore prerequisites for the development of an agricultural economy and food security.

Irrigation scheduling according to time-dependent crop-specific requirements, the quality and quantity of water, water reuse, drainage, leaching and potential environmental impacts are of special interest in this area. However, soil characteristics, appropriate irrigation technology and channels of adequate hydraulic capacity and sufficient uniformity of the surface of irrigated fields are also important and should be considered. As described in chapter 2.4.4, the irrigation and drainage systems in Khorezm are in poor condition. The lack of sufficient maintenance of the channel system combined with the age of the channels cause leakages and seepage losses. Furthermore, channel construction technology and the absence of incentives for the careful use of water results in a very low water use efficiency that is still declining. UNDP (2007) noted that “in the current situation the operational life of the infrastructure will further decrease and may reach critical limits”.

As a result of this development, experiments and analyses concerning changed water use efficiencies will be performed. The effect of a further deterioration of the channel network as well as the effect of an improvement of the systems due to new technologies and better operation and management will also be analyzed.

To examine the effects of improved irrigation management, irrigation/field application and distribution efficiencies will be changed. The distribution efficiency is mainly dependant on canal properties and infiltration. A modification of the distribution efficiency to 60 % and 65 % of the original 54 % appears to be the most realistic (see Damis, 2008). A modification of the original 40-45 % application/irrigation efficiency to 50 % and 60 % will also be conducted. The application/irrigation efficiency is mainly dependant on soil, technology and crop properties. In the last experiment in this step, both, the irrigation and distribution efficiencies will be modified simultaneously to 60 % and 50 %, respectively.

7.1.4 Introduction of water pricing

Due to the expansion of irrigated agricultural cropping, water in Uzbekistan and the downstream area of the Amu Darya River in Khorezm is in high demand and is extremely valuable. The demand often reaches or even exceeds the available water resources. Additionally, a rising competition in water quality and quantity between riparian states, downstream and upstream users but also between farmers leads to a further aggravation of this situation. Most notably, the droughts in 2000, 2001 and 2008 in Uzbekistan demonstrated the importance and necessity of improved water management and a careful and sustainable management of irrigation water for all parties concerned.

The introduction of water prices or water price reforms has taken place in many countries all over the world (see Dinar and Subramanian, 1997; OECD, 1999; OECD, 2009). A long-term sustainable water management is, according to Gurria (2008) only possible if the water pricing is combined with other factors such as policies (e.g., decreasing farmer's support/subsidies and public financing) and if property rights are involved and ensured.

Indeed, Uzbekistan already adopted a water law in 1993 in which water saving and water rights and the need for water pricing is documented (FAO, 1997b). So far, no direct water pricing mechanisms have been introduced. In fact, the government bears the costs of the irrigation and drainage system[20] and due to the procurement system for crops such as cotton and wheat; this does not contribute to a productive and efficient usage of irrigation water. However, Uzbekistan is in the process of large-scale changes due to the farm- restructuring process (see chapter 2.3). The reconsolidation of land and the change from large collective farms to much smaller individual (private) farms with changed cropping patterns and water management practices has resulted in deficiencies in water allocation and distribution (Abdullayev, 2008). Furthermore, the newly established Water User Associations (WUA) has found it difficult to balance the general water supply and demand. Additionally, property rights for the land used by Uzbek farmers are still not clearly defined. It raises the question of whether water would be better managed and water wastage could be reduced if water was treated and priced as a commodity.

Water pricing would have a significant impact on the national and local agricultural structure. Farmers would be faced with reduced revenues and higher production costs that primarily were subsidized by the state. Water pricing could lead to a better financial support of the Water User Associations or public water suppliers and

[20] Members of Water User Associations (WUA) pay a small membership fee that should cover the expenses of the public water suppliers (BOBOJONOV, 2008). This amount of less than 0.0005 USD/m^3 (in 2005) could be considered as indirect water pricing. However, as it is so marginal and did not only include water distribution and operation costs, it will not be considered in detail.

reduce the dependency of the WUAs on the government. The obtained water charges could be re-invested into the improvement of the irrigation and drainage system and would thus lead to an improvement of water use efficiency, which in turn pays dividends to the farmers and the environment.

There are various water pricing approaches in agriculture, including volumetric pricing, non-volumetric pricing and water markets, and each of these approaches has several subgroups (Tsur et al., 2004). In volumetric pricing approaches, the water price is based on the volume of water that is consumed by the farmer. In non-volumetric pricing the area-based pricing method is primarily used. Using this approach, a fixed charge based on the irrigated area is being levied. Charges based on crop type or irrigation techniques are also possible. By using the complex system of water markets, individuals and companies could trade water at an equilibrium price (Easter and Liu, 2005).

Although volumetric pricing methods are more difficult to implement, these methods have the most water saving potential (Chohin-Kuper et al., 2003). Area-based pricing methods are much easier to implement, as the installation of flow-meters for volume-controlled pricing causes additional expenses and time (for e.g. the measurement and monitoring equipment). In the water pricing scenario, both, monetary water pricing method (based on volumetric water price per cubic meter of water use) and area-based water pricing are implemented. The effects on water demand, cropping system, the economical outcomes and the irrigated area will be reviewed. Based on the literature regarding developing and transitional countries with water deficits (Wegren, 1998; Cornish, 2004), the assumed water prices for volumetric pricing will be in the range of 25 USD/1000 m^3-50 USD/1000 m^3, and for the area-based water pricing, it will be 150 USD/ha. Corresponding to the recommendation of Lerman (in Wegren, 2004), who proposed a volumetric water price for Uzbekistan of 6.3 USD/1000 m^3, we will also analyze lower volumetric dependant water prices of 6 USD/1000 m^3 and 10 USD/1000 m^3.

7.1.5 Market liberalization

Abolition of the cotton quota system and modification of the cotton subsidization system

This scenario addresses the current state policy of fixing the price and the area the farmers have to cultivate for cotton. Because cotton is the main export product of Uzbekistan (45 % in 2004) and contributes to 25 % of the foreign exchange revenues and additional tax revenues, this policy is understandable (Gillson et al., 2004). Furthermore, the subsidies and guarantied prices for cotton lead to a reduced risk for farmers.

However, due to the governmental procurement system, the cotton producers obtain prices that are lower than market prices (Rudenko, 2008). The state's involvement in the agricultural sector hampers the development of true private farms due to the limited access to open markets, credits and inputs (FAO, 2003d). Furthermore, the intensive cultivation and, to some extent, monoculture of cotton in this arid area is leading to previously described problems such salinization and chemical contamination, waterlogging, high water consumption, the reduction of soil fertility and soil crustification. These problems result in a continuous reduction of cotton yields the last years (Guadagni et al., 2005). The quota system also has negative impacts on water use and management because farmers have to fulfill their quotas regardless of the suitability of the area and the availability of water (Abdullayev et al., 2009). Rudenko (2008) shows that the export of intermediate cotton products such as fiber prevents the further development of the local processing industry and the integration of the cotton sector into the remainder of the economy. Simultaneously, the government transfers many of the subsidies for the maintenance and operation of the irrigation system, including free irrigation water, a financing and credit system, write-offs and agricultural inputs such as fertilizer, machinery and energy, to lower the prices.

It should also be noted that subsidies, support, direct payments and quotas for the farmers in cotton-producing countries is standard. The subsidies in Europe (Spain, Portugal and Greece) and in the United States account for more than 100 % and 50 % respectively of the averaged world cotton prices in 2005/06 (USDA, 2005 and ICAC, 2007). These subsidies are the highest in the world and may be damaging, especially for the cotton production in developing countries, due to the distortion of competition.

China and other countries such as Turkey, Colombia, Mexico and Brazil provide direct income and price support. The impact of those incentives is that cotton prices are kept artificially low. According to the studies mentioned above, the world market prices of cotton would be approximately 10 %[21] higher if the subsidies were eliminated worldwide.

The situation just described reveals the controversy regarding subsidies and governmental intervention. It provides a certain guarantee and safety for the farmers but provides no incentives to reduce water consumption. Furthermore, the government intervention leads to huge governmental expenditures and negative externalities on the international cotton market, especially for developing countries.

WTO (2007) and the International Cotton Advisory Committee (ICAC, 2005) arranged agreements for a rapid and elaborate reduction of governmental measures and subsidies in the cotton sector. As a result the Uzbek "Cabinet of Ministers" and the President passed several regulations and decrees on the reduction of subsidies and demonopolization of Uzbeks ginning industry and cotton sector privatization (Askarov, 2005). In addition to the progression of farm restructuring in Uzbekistan, another step in the direction of policy transformation, market liberalization and privatization has thus been initiated.

The impact of the liberalization of the cotton market will be analyzed in the model for the Khorezm region. For this scenario, an elimination of the governmental procurement system is defined. There are several linkages between the explicit and implicit subsidies, taxes, credits, pricing and transfers back to agriculture that make it difficult to define the essential factors and changes for this scenario. Both input and output factors have to be changed. The state procurement price and the abolition of input subsidies for fertilizer, diesel, fuel and operation and maintenance costs for the irrigation canals have to be adjusted.

It is assumed that the price for raw cotton in a liberalized market situation is increased. Rudenko (2008) showed that the Uzbek and Khorezmian cotton-producing farmers received approximately 66 % of the export border price for cotton fiber in 2005. Because Uzbekistan is not exporting raw cotton directly but rather cotton fiber, the processing of raw cotton into cotton fiber with a current ginning efficiency of 32 % for

21 Ranging between a few % and up to 30 % higher

Uzbekistan has to be taken into account. Rudenko, 2008 showed in a study on the Cotton Value Chain that 3.125 tons of raw cotton yields approximately 1 ton of cotton fiber[22]. In addition, Guadagni et al., 2005 stated that the border price for raw cotton in 2003 could be approximately 28 % higher than the governmental price for raw cotton. This corresponds well with the 34 % cotton value chain analysis by Rudenko. Thus, a 30 % increase of the cotton price for the liberalization scenario appears to be realistic.

The second factor is the simultaneous change of production costs for cotton in the scenario of the abolition of the governmental subsidies. The costs for inputs such as fertilizer, energy and diesel fuels, seeds and water, as well as the operation and maintenance of the irrigation and drainage network, will increase for the farmers. Due to the absence of reliable, empirical data these estimates must be based on data from neighboring countries and other studies. Bobojonov (2008) indicates an increase of 36 % for fertilizer and 24 % for fuel and Djanibekov (2008) reported an increase of 28 % for cotton seeds and 20 % for pesticides in Kazakhstan in 2003. The change in production costs under a liberalized cotton scenario in this model is based on Rudenko´s (2008) calculations of an increase of 32 % for the total production costs, with fertilizer application being one of the major input factors in terms of expenses.

[22] With a changed ginning structure, which also is subsidized by the state, the efficiency would certainly change, too.

8 SCENARIO ANALYSES – RESULTS

8.1 Model results scenario block 1 - status quo scenario

The results of the three scenarios are considered separately for the sake of clarity. The effects to internal system processes, such as a decreasing water supply to the groundwater, drainage fluxes or to the soil water content, are explained in detail. The important outcomes for each scenario are then discussed and compared relative to their assets and drawbacks with respect to political, institutional, environmental and socio-economical settings.

8.1.1 Status quo – baseline 1

Baseline 1 considers status quo conditions, with acreage and cropping patterns found in 2003. The production cost and the crop sales prices are based on observed 2003 prices and were kept constant. The outcomes of the Baseline 1 scenario are included within the description of the water supply, water pricing and efficiency experiments described below and serve as a reference for comparison of the different experiments and underlying policies within scenario block 1.

The analyses of the status quo scenarios serve to answer the question "what would happen if" to water and soil balance processes, evapotranspiration and resultant yields. Scenarios for different water supply, modified efficiencies and implementation of water charges will be executed. The primary focus is on the hydrological and agronomical aspects, but fundamental economical outcomes should also be considered and will not detract from the analyses.

8.1.2 Status quo - water supply experiments

Gross margins

The influence of water supply on total gross margins is high. Simulations indicate a strong reduction in agricultural income of 47 % and 19 % for cases with 50 % and 25 % water supply decreases, respectively (Table 6.1). The added value in cases of a 25 % or 50 % water supply increase is +14 and +25 %, respectively. Because the crop acreage does not changed in the status quo Baseline 1 scenario, the increase in gross margins is a consequence of a reduced impact of water stress on yield occurring in the base year

2003. Although the increase is under-proportional (referring to water supply), we can conclude that there still exists a water stress situation in the Baseline 1 scenario for 2003. Even with a water supply increase, crop yields may only increase to a certain degree, but not reach potential yields.

Interestingly, the impacts of water scarcity in districts close to the river (d1-d6) are higher than of those farther away. A major reason for the larger influence of water scarcity in areas close to the river is that crops with high sensitivity to water stress are cultivated here (i.e., rice in Gurlan); therefore, the lower water availability has a stronger impact (stronger than the same reduced availability on less sensitive crops). Overall, the water quantity data show no significant relationship between obtained water volumes for a whole district and the distance to the river. In line with Conrad's (2006) investigations of the distance of a single field to the main canal, the character and the quality of secondary and tertiary channels play a more important role than district wide water allocation.

Table 8.1 Gross margins for cropping activities per district compared to Baseline 1 for different water supply experiments

Districts of Khorezm		Baseline 1 (BL1)	Exp1-1	Exp1-2	Exp1-3	Exp1-4
		Gross margin [10^6USD]	**Change to BL1, relative values** [%]			
Khazarasp	d1	8.84	-57	-24	18	31
Khanka	d2	9.24	-52	-22	15	26
Urgench	d3	9.09	-57	-24	16	27
Yangibazar	d4	6.33	-52	-22	17	29
Gurlan	d5	9.58	-65	-27	21	37
Bagat	d6	8.21	-33	-13	10	18
Yangiarik	d7	7.79	-38	-16	10	18
Khiva	d8	8.47	-36	-14	9	18
Kushkupir	d9	11.07	-35	-13	10	18
Shavat	d10	8.42	-46	-20	15	26
sum		*87.04*				
average			*-47*	*-19*	*14*	*25*

Notes: Exp1-1 = water supply -50 % to Baseline 1
Exp1-2 = water supply -25 % to Baseline 1
Exp1-3 = water supply +25 % to Baseline 1
Exp1-4 = water supply +50 % to Baseline 1

Source: model simulation results

Typically, the district-wide gross margins are the product of all obtained gross profit rates per crop, and here we present a second view on crop-specific gross margins. To illustrate the effect of water supply on gross margins per crop type, two scenarios for very low water supply (-50 %) and high water supply (+50 %) were chosen, as shown in Figure 8.1. Comparable with the descriptive model, also in the low water supply scenario the gross margins for cotton (and to a small extent for other grains as well) are negative due to relatively high costs, high cropping area, high water consumption and low revenues. An examination of the economic water use efficiency for cotton will confirm this conclusion. We should mention that the water supply scenarios are conducted under ceteris paribus conditions, meaning that all variables remain fixed, except the water supply. For this reason, the acreage for every crop is the same as in the Baseline 1 scenario. At low water supplies, the gross margins for vegetables are relatively high (particularly in Khiva). Due to high gross margins for alfalfa in Kushkupir, this district denotes the highest profit rate for low water supplies, even though there is no direct access to the river. At high water supplies, the gross margins for cotton and other grains are positive, but the gross margins for rice, alfalfa and vegetables contribute the most to this increase. Additionally, districts close to the river (except Yangibazar) generally have higher rice cropping areas and high gross margins due to sufficient water supply and high net sales.

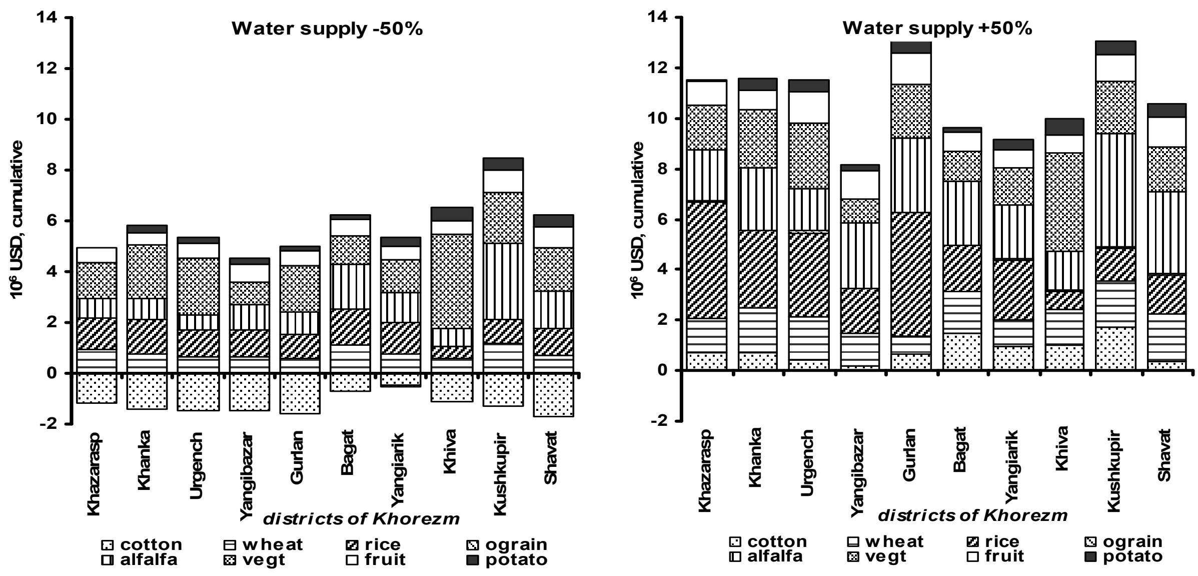


Figure 8.1 Gross margins per district for different water supply experiments (absolute values in 10^6 USD, cumulative)

Source: model simulation results

Revenue

Revenues and gross margins are undoubtedly linked with each other. To show the effect of water supply changes on crop and district-wide farmer incomes, the absolute revenues per crop and the revenue change for each crop per ha were compared to the Baseline 1 scenario as outlined in Figure 8.2. A strong increase in revenues for other grains per ha given a sufficient water supply (+50 %) is reflected in the values (bottom, right hand side). However, because the acreage of other grains is very low, the effect of that increase in revenues is relatively small, as seen by the absolute values (bottom, left hand side). For cotton, this situation is different. The change in revenues for cotton per ha given a high water supply has a relatively strong 40 % increase; additionally, because of the high cotton acreage, the impact on total revenues is strengthened. A major reason for this effect is the possibility of an increase in yields for cotton at high water supplies (Figure 8.3). The same is true for rice at high water levels.

Given low water supplies (-50 %), the situation is more complex (see Figure 8.2, at the head). Model simulations indicate that there are revenue losses for all crops. The absolute values for rice and cotton are highest because of a drastic decrease in rice yield (see Figure 8.3) and because of the huge cotton area affected.

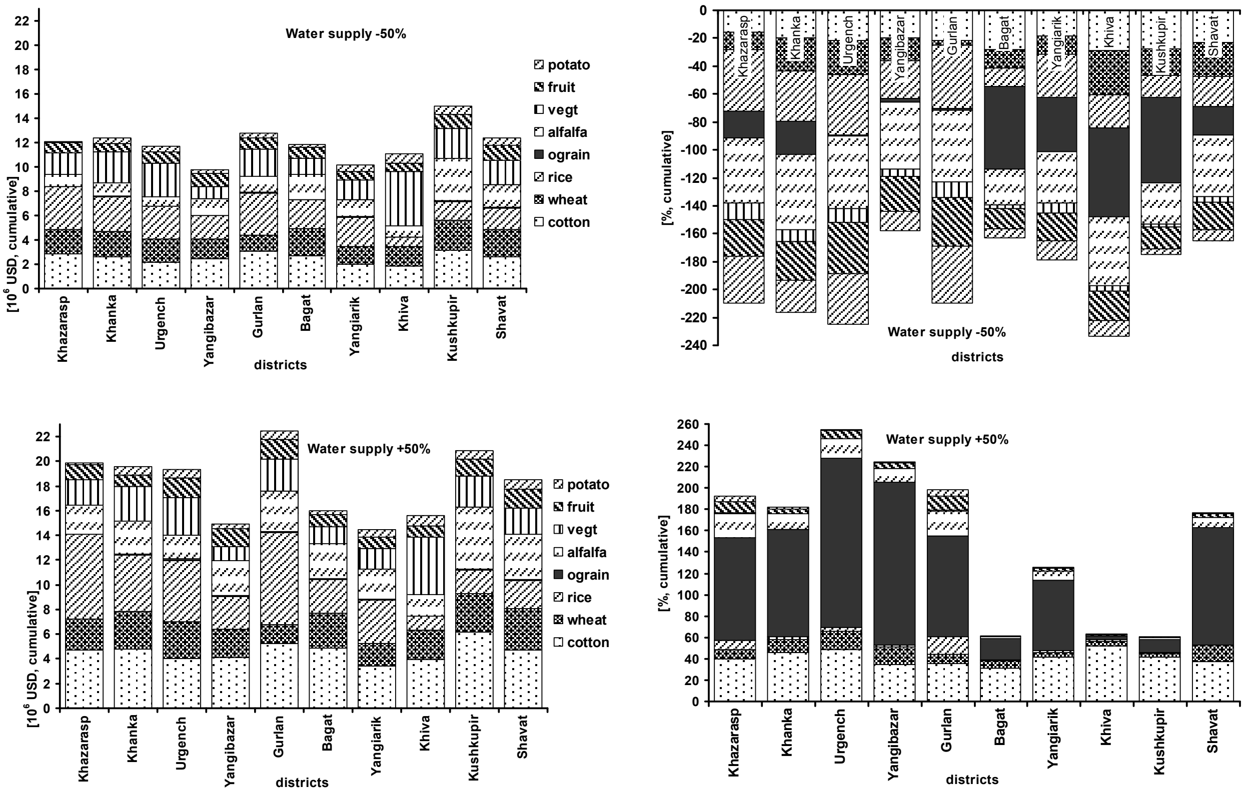


Figure 8.2 Left hand side: Revenues per crop and district (absolute values in 10^6 USD, cumulative),
Right hand side: crop per ha revenue change compared to BL1 scenario (in %, cumulative)

Source: model simulation results

Economic water use efficiency

As stated in chapter 5, the economic water use efficiency (e-WUE) is defined as the benefit of a unit of water to its users (UNESCO, 2003, 2006) and is established as the relationship between gross margins and the total water applied with respect to single crops and districts. With these values, it is possible to obtain an economical-ecological relationship for a single crop depending not only on monetary benefits but also on the water consumption needed to achieve those benefits. In Table 8.2, it is clearly shown that the water use efficiency for cotton and other grains is negative in most cases. Only when water supply reaches +25 % for other grains or +50 % for cotton will the e-WUE for both crops become positive. For other grains, the gross margins are relatively low due to small sales prices. The grains are normally grown by farmers as a byproduct of internal animal feeding (as second crop) and are not sold at the market. For cotton, the gross margins per hectare are relatively low because of high variable costs, low sales prices and relatively low yields per hectare due to relatively high water consumption with low water supplies. Other crops, such as vegetables (with the highest e-WUE), fruits, alfalfa, potatoes and wheat, present higher positive water use efficiencies and are more cost-benefit efficient from an economical-ecological perspective.

Table 8.2 Economic water use efficiency per crop and district for different water supply scenarios (in USD/m^3)

		cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	***total***
Baseline1	*Khazarasp*	-0.023	0.021	0.018	-0.005	0.034	0.048	0.037	0.032	*0.021*
	Khanka	-0.016	0.020	0.018	-0.001	0.031	0.046	0.035	0.031	*0.022*
	Urgench	-0.018	0.016	0.017	-0.009	0.028	0.044	0.031	0.028	*0.020*
	Yangibazar	-0.016	0.014	0.018	-0.009	0.028	0.041	0.031	0.029	*0.018*
	Gurlan	-0.010	0.013	0.016	-0.012	0.030	0.042	0.033	0.029	*0.018*
	Bagat	0.003	0.025	0.020	0.011	0.031	0.051	0.036	0.033	*0.022*
	Yangiarik	-0.001	0.021	0.020	0.006	0.033	0.049	0.037	0.033	*0.024*
	Khiva	-0.005	0.018	0.020	0.009	0.031	0.051	0.038	0.033	*0.025*
	Kushkupir	-0.001	0.020	0.020	0.010	0.032	0.051	0.038	0.033	*0.022*
	Shavat	-0.012	0.017	0.018	-0.002	0.029	0.044	0.034	0.030	*0.019*
Water supply -25%	*Khazarasp*	-0.044	0.023	0.017	-0.014	0.039	0.048	0.040	0.035	*0.020*
	Khanka	-0.038	0.018	0.017	-0.010	0.035	0.047	0.040	0.033	*0.021*
	Urgench	-0.047	0.016	0.015	-0.008	0.031	0.045	0.034	0.031	*0.019*
	Yangibazar	-0.039	0.015	0.017	-0.009	0.030	0.041	0.033	0.030	*0.018*
	Gurlan	-0.037	0.016	0.013	-0.011	0.033	0.044	0.034	0.030	*0.017*
	Bagat	-0.009	0.027	0.021	0.005	0.035	0.051	0.040	0.035	*0.024*
	Yangiarik	-0.023	0.025	0.019	-0.016	0.036	0.051	0.041	0.035	*0.025*
	Khiva	-0.030	0.018	0.020	-0.008	0.033	0.051	0.038	0.034	*0.027*
	Kushkupir	-0.015	0.022	0.021	-0.001	0.035	0.051	0.040	0.035	*0.023*
	Shavat	-0.043	0.015	0.017	-0.008	0.030	0.044	0.034	0.030	*0.019*
Water supply -50%	*Khazarasp*	-0.709	0.024	0.010	-0.015	0.050	0.054	0.045	0.032	*0.015*
	Khanka	-3.506	0.016	0.013	-0.009	0.039	0.049	0.039	0.032	*0.017*
	Urgench	-4.973	0.014	0.009	-0.008	0.032	0.046	0.033	0.026	*0.014*
	Yangibazar	-0.152	0.015	0.014	-0.008	0.033	0.045	0.035	0.030	*0.014*
	Gurlan	-0.124	0.016	0.006	-0.009	0.037	0.049	0.035	0.025	*0.011*
	Bagat	-0.044	0.031	0.020	-0.020	0.043	0.054	0.047	0.037	*0.025*
	Yangiarik	-0.047	0.029	0.017	-0.021	0.046	0.057	0.049	0.037	*0.024*
	Khiva	-0.118	0.018	0.016	-0.008	0.035	0.053	0.041	0.035	*0.026*
	Kushkupir	-0.070	0.021	0.020	-0.012	0.038	0.053	0.044	0.036	*0.022*
	Shavat	-0.352	0.014	0.015	-0.008	0.032	0.045	0.036	0.030	*0.016*
Water supply +25%	*Khazarasp*	-0.001	0.019	0.019	0.010	0.031	0.047	0.035	0.031	*0.021*
	Khanka	-0.001	0.019	0.018	0.009	0.028	0.046	0.034	0.030	*0.021*
	Urgench	-0.003	0.016	0.017	0.008	0.026	0.044	0.030	0.028	*0.019*
	Yangibazar	-0.005	0.013	0.017	0.008	0.026	0.041	0.030	0.028	*0.018*
	Gurlan	-0.001	0.012	0.016	0.002	0.029	0.043	0.033	0.029	*0.018*
	Bagat	0.006	0.023	0.019	0.011	0.031	0.052	0.036	0.033	*0.021*

Table 8.2 continued

		cotton	wheat	rice	other grain	alfalfa	vege-table	fruit	potato	*total*
	Yangiarik	0.005	0.018	0.019	0.010	0.030	0.052	0.035	0.032	*0.022*
	Khiva	0.003	0.017	0.019	0.009	0.030	0.050	0.037	0.032	*0.023*
	Kushkupir	0.004	0.019	0.020	0.009	0.030	0.050	0.036	0.032	*0.020*
	Shavat	-0.003	0.017	0.018	0.008	0.027	0.044	0.032	0.028	*0.018*
Water supply +50%	*Khazarasp*	0.006	0.018	0.018	0.011	0.030	0.047	0.034	0.030	*0.020*
	Khanka	0.004	0.018	0.018	0.009	0.027	0.046	0.033	0.030	*0.020*
	Urgench	0.003	0.015	0.016	0.008	0.026	0.044	0.030	0.028	*0.018*
	Yangibazar	0.001	0.013	0.016	0.008	0.025	0.041	0.029	0.028	*0.017*
	Gurlan	0.003	0.012	0.016	0.007	0.028	0.042	0.031	0.028	*0.018*
	Bagat	0.007	0.020	0.019	0.011	0.030	0.052	0.036	0.033	*0.019*
	Yangiarik	0.006	0.017	0.018	0.011	0.030	0.051	0.036	0.032	*0.020*
	Khiva	0.005	0.016	0.018	0.009	0.029	0.050	0.035	0.032	*0.021*
	Kushkupir	0.006	0.017	0.018	0.010	0.029	0.050	0.035	0.032	*0.019*
	Shavat	0.002	0.017	0.017	0.008	0.026	0.043	0.031	0.028	*0.017*

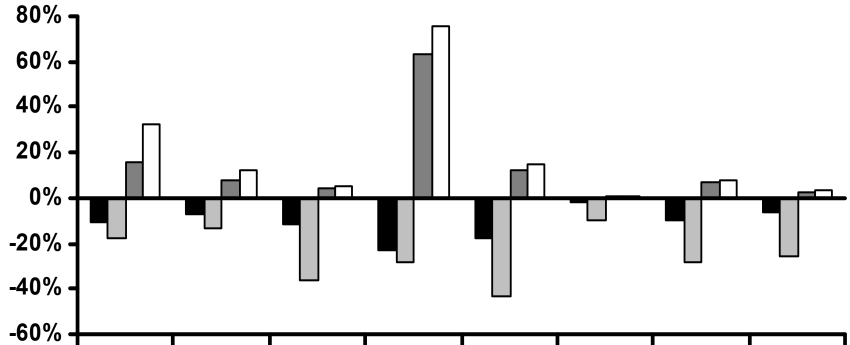
Source: model simulation results

Crop yields

Upon closer examination of the crop yield changes due to reduced water supply modifications, the model simulations indicate a strong decline in yields for rice and alfalfa (see Figure 8.3). For rice, this is expected because it is grown in Khorezm as paddy rice, which see drastic yield reductions in cases of a water deficit. The potential for increased yields in cases of additional water supply are seen mainly for cotton and grains[23]. Actual yields for the cash crop cotton show, that even at an average water supply (as in 2003), the observed cotton yield averages of 1.5-1.8 t/ha are quite low compared to the potential yields of around 3.5 t/ha. Therefore, it seems reasonable that the cropping areas for cotton were not always adequate. The cotton quota system is one major factor responsible for cotton cropping on marginal land. Salt stress due to non-effective leaching and salt accumulation, low efficiencies and political settings (the cotton quota system even on marginal land) amplify this effect. This effect will be examined in more detail in later scenarios. A potential enhancement of cotton yields is seen in all districts, mainly for medium soils, whereas alfalfa yields may increase with more water mainly in light soils[24].

[23] Here, mainly fodder maize is used as a secondary crop in crop rotation; the strong amplitude of grains is a consequence of the very low cropping area mainly on marginal land compared to the other crops.

[24] For more information on soils and crops, see Appendix E, Table E-1.



	cotton	wheat	rice	other grain	alfalfa	vegetab-les	fruit	potato
■ water supply -25%	-10%	-7%	-12%	-23%	-18%	-2%	-10%	-6%
□ water supply -50%	-18%	-13%	-36%	-29%	-43%	-10%	-28%	-25%
■ water supply +25%	15%	8%	4%	63%	12%	0%	7%	2%
□ water supply +50%	32%	13%	5%	76%	15%	1%	8%	3%

Figure 8.3 Crop yield modification per water supply experiments compared to Baseline 1 (in %)

Source: model simulation results

Evapotranspiration

Because crop yields are a function of crop-specific factors and evapotranspiration (see chapter 3), the change of actual evapotranspiration (*ETa*) under different water supply scenarios will be considered in more detail.

Under status quo conditions related to crop type and cropping area, model results show that the actual evapotranspiration for all crops per district is reduced by 9 % and 21 % for a water supply situation of -25 % and -50 %, respectively, compared to the Baseline 1 scenario (Table 8.3). This implies a water stress situation for the crops mainly during the peak transpiration time in the summer months between June and August (Figure 8.4), resulting in a reduction of crop yields. In situations with increased water supply, a further increase in evapotranspiration of 10 % and 16 % with water supplies of +25 and +50 % are possible, but not to the same extent as in “bad” water supply years.

Table 8.3 Change of actual evapotranspiration (*ETa*) per scenario and district compared to Baseline 1 (in %)

	Water supply -25%	Water supply -50%	Water supply +25%	Water supply +50%
Khazarasp	-9.5	-22.3	11.7	18.9
Khanka	-10.6	-23.1	13.9	18.5
Urgench	-10.6	-25.1	19.9	24.7
Yangibazar	-7.0	-18.4	17.2	20.9
Gurlan	-9.3	-22.2	10.2	18.4
Bagat	-7.5	-17.8	4.5	8.4
Yangiarik	-8.7	-18.9	8.0	13.2
Khiva	-12.7	-26.1	3.9	8.2
Kushkupir	-9.9	-21.0	2.8	8.6
Shavat	-7.8	-17.8	15.4	18.7
Total average	*-9.4*	*-21.3*	*10.7*	*15.9*

Source: model simulation results

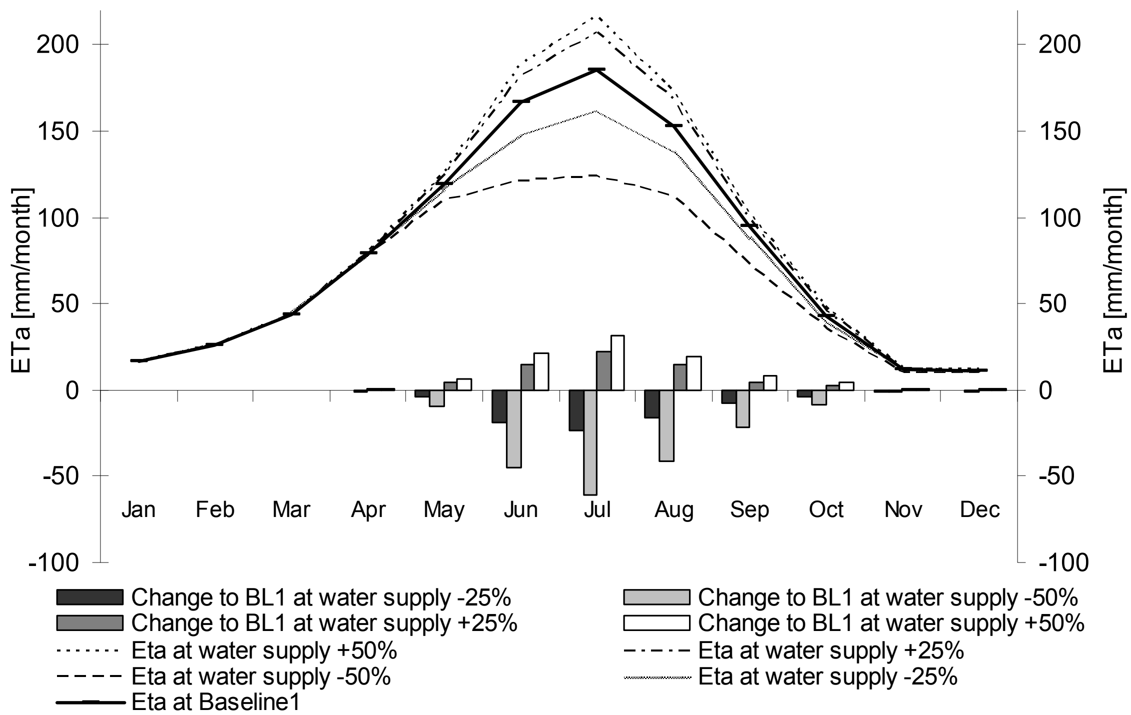


Figure 8.4 Actual evapotranspiration (*ETa*) and difference to the Baseline 1 (BL1) for modified water supply scenarios (absolute values (averaged over all crops and soil types) in mm/month).

Notes: absolute values for ETa are chosen to avoid overvaluation of changes in months with small ETa values

Source: model simulation results

The total evapotranspiration is defined as the sum of all crop- and soil-specific evaporation and transpiration values per district. Table 8.4 shows the crop-specific *ETa* changes compared to the Baseline 1 scenario for different water supply situations. A relatively uniform distribution of *ETa* change *per district* is seen in the table below, whereas the changes in *ETa per crop* vary significantly. In a high water supply situation, the effect on *ETa* is relatively high for cotton and other grains. As described previously, an increase in water supply for both crops can lead to an increase in yield. In low water supply situations, the *ETa* values are reduced for all crops. However, the values for vegetables and wheat have a smaller decline than those for the other crops. For wheat, this observation is due to the cropping period from October to June, which is outside the intensive transpiration period in the summer. As a result, the *ETa* values for wheat are generally much lower than for other crops, and a reduction in the water supply did not have a large influence on crop growth because there is enough water available in the reservoir and the Amu Darya River during the winter and spring. Other problems, such as the duration of the frost period, play a more important role for wheat.

Table 8.4 *ETa* change per crop and district for different water supply experiments compared to BL1 (relative values in %)

		Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*average*
Water supply -25%	cotton	-8.3	-10.8	-15.8	-10.7	-12.9	-18.2	-14.5	-17.2	-20.3	-16.1	*-14.5*
	wheat	-4.1	-8.0	-7.4	-7.1	-1.7	-3.3	-4.1	-12.8	-2.6	-9.8	*-6.1*
	rice	-9.5	-8.8	-8.8	-5.2	-8.0	-0.7	-7.2	-2.5	-1.1	-3.7	*-5.5*
	other grain	-13.1	-13.0	-0.6	-2.7	-6.6	-22.8	-17.0	-45.9	-35.9	-10.0	*-16.8*
	alfalfa	-17.5	-20.2	-26.3	-16.7	-19.7	-8.6	-10.9	-13.8	-11.2	-12.2	*-15.7*
	vegetable	-5.9	-4.7	-3.3	-1.0	-4.6	0.0	-2.4	-0.5	0.0	-0.8	*-2.3*
	fruit	-9.3	-11.1	-14.0	-9.0	-10.5	-5.5	-8.4	-8.3	-6.6	-8.5	*-9.1*
	potato	-9.2	-8.2	-8.5	-4.4	-10.4	-1.6	-5.2	-1.9	-1.6	-2.1	*-5.3*
	average	*-9.6*	*-10.6*	*-10.6*	*-7.1*	*-9.3*	*-7.6*	*-8.7*	*-12.9*	*-9.9*	*-7.9*	-9.4
Water supply -50%	cotton	-19.2	-21.3	-27.8	-24.2	-23.1	-27.6	-19.6	-28.5	-31.9	-24.4	*-24.8*
	wheat	-6.5	-12.3	-16.3	-9.2	-2.6	-8.1	-7.3	-18.5	-19.3	-13.1	*-11.3*
	rice	-23.2	-21.7	-23.0	-15.0	-22.3	-8.7	-18.5	-15.5	-9.5	-13.0	*-17.0*
	other grain	-17.1	-13.0	-0.6	-2.7	-6.6	-41.0	-23.6	-45.9	-44.3	-10.0	*-20.5*
	alfalfa	-36.5	-42.3	-45.9	-44.5	-38.1	-26.6	-33.0	-45.8	-31.1	-43.0	*-38.7*
	vegetable	-15.9	-13.5	-12.6	-7.7	-15.0	-4.2	-11.7	-8.6	-4.3	-6.3	*-10.0*
	fruit	-24.8	-30.5	-34.4	-26.4	-30.3	-17.5	-19.3	-28.4	-19.3	-21.8	*-25.3*
	potato	-35.8	-30.2	-40.2	-17.4	-40.0	-9.5	-18.0	-18.2	-7.9	-12.2	*-22.9*
	average	*-22.4*	*-23.1*	*-25.1*	*-18.4*	*-22.3*	*-17.9*	*-18.9*	*-26.2*	*-21.0*	*-18.0*	-21.3

Table 8.4 continued

		Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*average*
Water supply +25%	cotton	18.0	21.3	28.3	22.1	20.5	21.1	16.2	26.3	17.3	22.7	*21.4*
	wheat	2.7	5.9	15.1	12.2	3.7	2.8	1.6	2.8	1.3	13.9	*6.2*
	rice	5.5	1.7	1.8	0.3	6.0	0.4	0.9	0.5	0.2	0.3	*1.8*
	other grain	28.5	51.9	80.6	78.0	18.4	8.5	25.9	-0.5	1.8	65.5	*35.8*
	alfalfa	16.5	15.9	19.3	14.3	15.7	2.1	9.6	0.6	1.2	10.9	*10.6*
	vegetable	2.0	0.2	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	*0.4*
	fruit	10.0	9.0	10.4	7.4	8.4	0.7	6.1	0.3	0.5	5.5	*5.8*
	potato	4.9	2.6	1.9	1.7	5.0	0.2	1.7	0.4	0.4	1.6	*2.1*
	average	11.0	*13.6*	*19.7*	*17.0*	*10.0*	*4.5*	*7.8*	*3.8*	*2.9*	*15.1*	*10.6*
Water supply +50%	cotton	37.8	41.0	56.7	41.6	41.2	38.9	40.4	52.6	51.3	42.0	*44.3*
	wheat	6.7	11.6	20.2	18.5	4.7	6.6	4.5	5.0	3.6	19.5	*10.1*
	rice	6.2	2.2	2.2	0.8	9.0	0.6	1.2	0.9	0.6	0.7	*2.4*
	other grain	41.4	55.6	84.3	78.8	44.6	17.5	36.9	4.0	10.9	65.7	*44.0*
	alfalfa	24.6	19.0	19.6	15.5	22.4	2.5	12.3	1.7	1.8	12.3	*13.2*
	vegetable	2.0	0.2	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	*0.5*
	fruit	14.8	10.8	10.4	7.9	13.2	0.7	6.8	0.6	0.5	5.8	*7.1*
	potato	7.1	3.2	2.0	1.8	7.3	0.4	1.8	0.6	0.5	2.1	*2.7*
	average	17.6	*17.9*	*24.4*	*20.6*	*18.2*	*8.4*	*13.0*	*8.2*	*8.6*	*18.5*	*15.6*

Source: model simulation results

Vegetables, such as beans, carrots, tomatoes, melons and onions, seem to be better adapted to drought situations because of a fast expanding root system, relatively short growing periods and low crop yield reductions from irrigation deficits at late growing phases.

By examining the effect of *ETa* changes for different soil types, model simulation indicate that evapotranspiration levels signify a large influence of evaporation in low water supply (dehydration of soils) conditions. Additionally, there are only small differences among the different soil types, with the amplitude for light and heavy soils being greater than for medium soils (Table 8.5).

Table 8.5 Effect of water supply on *ETa* per soil type compared to BL1 in %

Soil type	**Water supply -25%**	**Water supply -50%**	**Water supply +25%**	**Water supply +50%**
light	-9.0	-22.6	7.6	10.9
medium	-7.8	-19.0	6.5	10.1
heavy	-9.3	-24.1	8.3	11.2

Source: model simulation results

Groundwater level and groundwater extraction

On closer examination of the effect of water supply changes on the agronomical system of Khorezm, the groundwater fluxes, balances and depth play a decisive role. In situations with high water supply, the model simulations show that the groundwater table increases after the leaching period (between February to April) and is about 15 cm (at +50 % water supply) closer to the surface at the beginning of the cropping period (Figure 8.5). Alternatively, the groundwater declines by about 17 cm in very low water supply situations. As a result, the depth of the groundwater table varies more than 30 cm between high and low water supply conditions. These values are based on an average for the Khorezm area; therefore, model simulations also indicate a variation of more than 42 cm at the district level.

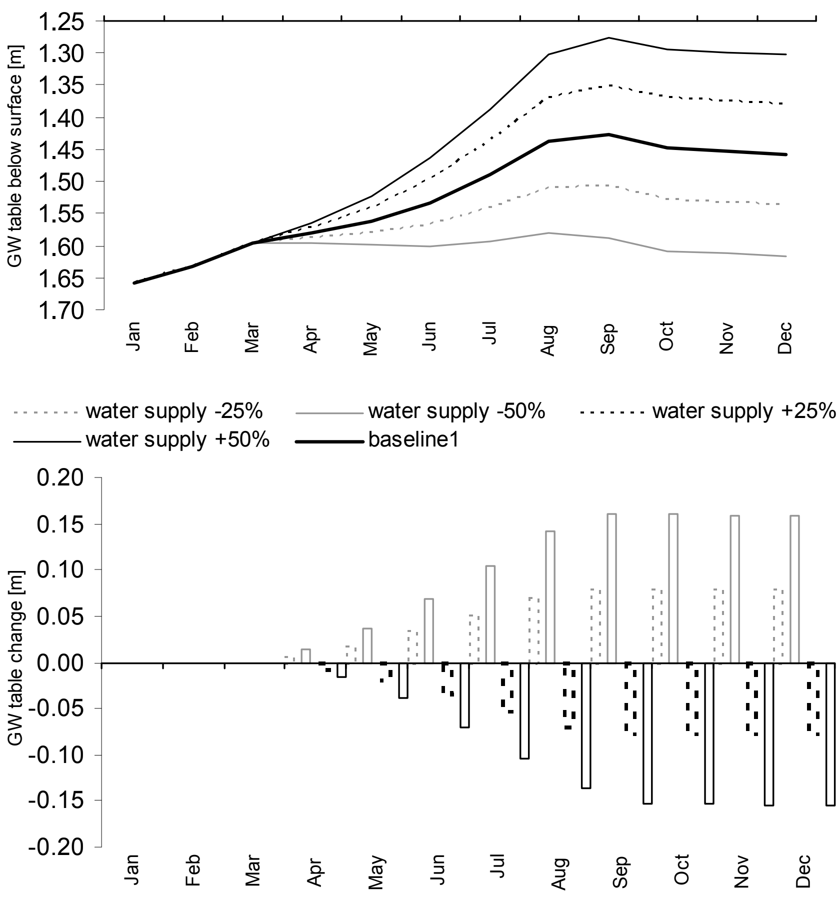


Figure 8.5 Groundwater table depth and GW table difference to Baseline 1 for different water supply experiments averaged over all districts (in m)

Source: model simulation results

The groundwater extraction increase compared to the Baseline 1 scenario (Table 8.6) is relatively high for light (sandy and sandy loamy) soils in low water supply situations. In situations of drought, low water supply or insufficient irrigation, crops are dependent on additional sources of water, such as the groundwater (via capillary rise and extension of rooting system). In good water supply situations, enough irrigation water is available for the crops and additional groundwater extraction is not necessary for crop growth. The groundwater extraction decreases by 5 % compared to the Baseline 1 scenario.

Table 8.6 Groundwater extraction change compared to Baseline1 in % for different water supply experiments (in %)

	Water supply -25%	Water supply -50%	Water supply +25%	Water supply +50%
change to BL1 [%]	7.7	15.7	-6.7	-5.6

Source: model simulation results

Percolation

In contrast to the groundwater outflow via extraction to the root zone, one factor that recharges groundwater is deep percolation. Both of these factors affect the groundwater storage balance.

As described in chapter 5, deep percolation is the water leaving the root zone downwards. Under the shallow groundwater conditions in Khorezm, percolation water enters the groundwater system or is transported out of the system via drainage canals (except the part that contributes to capillary rise) (equation (3.5)). For this reason it is not directly available for the crops. Downward water fluxes consist of irrigation and precipitation water not used by the crops.

As shown in Table 8.7, simulated deep percolation under modified water supply conditions shows a significant reduction of about 39% in deep percolation in drought situations compared to the Baseline 1. A rise in percolation of 22% is seen in situations of water surpluses. Logically, in times of water shortages, the available irrigation water is used by the crop, and less water is drained and percolated. In most cases, the change in deep percolation for light soils (and to a certain extent of heavy soils) is higher than of those for medium soils. Soil characteristics, such as lower storage capacity and higher hydraulic conductivity contribute to these results (see chapter 4). The reader is referred to Appendix E, Table E-2 for further information on changes in deep percolation for crop fields listed in different districts and depending on water supply.

Table 8.7 Deep percolation per soil type and district (changes compared to Baseline 1 for different water supply experiments, in %)

District	**Soil type**	***Water Supply Experiment***			
		Water supply -25%	**Water supply -50%**	**Water supply +25%**	**Water supply +50%**
Khazarasp	light	-29.7	-58.2	28.2	47.9
	medium	-15.0	-34.4	11.4	20.2
	heavy	-20.9	-47.4	24.5	33.6
Khanka	light	-29.4	-51.6	25.1	35.4
	medium	-15.5	-32.1	11.4	17.6
	heavy	-19.4	-43.0	17.8	22.4
Urgench	light	-22.8	-48.5	27.3	32.2
	medium	-16.5	-33.7	10.9	19.5
	heavy	-19.9	-42.5	22.1	23.3
Yangibazar	light	-14.8	-42.5	24.2	30.7
	medium	-11.5	-26.2	9.8	16.7
	heavy	-12.4	-33.5	17.2	20.7
Gurlan	light	-23.2	-50.8	22.1	39.2
	medium	-15.5	-37.4	11.3	23.3
	heavy	-17.2	-44.0	15.3	21.3
Bagat	light	-17.2	-44.0	7.4	16.2
	medium	-10.3	-25.0	6.9	12.3
	heavy	-14.3	-36.3	6.3	9.9
Yangiarik	light	-21.9	-56.1	21.5	28.9
	medium	-14.3	-33.3	10.7	17.1
	heavy	-19.7	-45.8	15.5	25.1
Khiva	light	-23.0	-51.6	5.3	11.9
	medium	-12.4	-29.1	5.7	12.4
	heavy	-14.3	-40.4	5.9	12.8
Kushkupir	light	-16.6	-41.3	5.3	12.3
	medium	-12.1	-25.4	6.9	13.6
	heavy	-15.3	-33.0	5.3	13.7
Shavat	light	-12.3	-36.0	20.9	28.4
	medium	-9.1	-22.3	11.0	16.5
	heavy	-10.4	-29.4	17.4	22.3
average		*-16.9*	*-39.2*	*14.4*	*21.9*

Source: model simulation results

8.1.3 Status quo - irrigation management and efficiency experiments

Different experiments were chosen for the analyses of modified irrigation management scenarios. For these experiments, the *distribution efficiency,* which is dependent on canal properties and operational mode, and *irrigation/field application efficiency*, which is dependent on irrigation method, discharge control, uniformity of field surface, soil characteristics and crop properties, will be changed. Modifications to 60 % and 65 % of the original 54 % for distribution efficiency and 50 % and 60 % of the original 40-45 % for irrigation efficiency seem to be most realistic (see Damis, 2008 and chapter 7.1.3). In a separate experiment, both, the distribution and irrigation efficiencies will be improved simultaneously (Exp. 1-9).

An increase in *distribution efficiency* can be achieved by changing the flow velocity, which is affected by canal maintenance and straightening, thereby decreasing percolation and evaporation. Additionally, changes in the canal lining or covering can decrease the porosity, water leakage and evaporation. Most of these measures are cost intensive, undesirable and difficult to accomplish. For instance, a certain amount of canal leakage may be ecologically worthwhile by enhancing leaching and elution of salts in the soil layer. On the other hand, seepage and percolation from canals contributes very little to leaching (effect is limited to the area at the canal); however, canal seepage recharges groundwater (and in the case where groundwater becomes shallow, there is enhancement of secondary soil salinization via the groundwater). Consequently, canal operation (i.e., sufficient irrigation scheduling, better coordination at the field and system levels), maintenance (i.e., cleaning, cutting and digging), reparation and plugging of the canal basement and walls are required and represent low cost measures that increase distribution efficiency, albeit a small change (approximately 5 %) from the assumed 54 % - 65 % (Exp1-5, Exp1-6).

An improvement in *irrigation efficiency* can be attained by changing the irrigation methods and technology, leveling the crop field and adjusting the crop irrigation scheduling and management. According to Goyne (2002), simple water and soil monitoring measures can improve efficiencies in cotton and grain fields by at least 10 %. For this reason, a modification of the original 40-45 % application/irrigation efficiency to 50 % and 60 % is conducted (Exp1-7, Exp.1-8).

Gross margins, revenue and water value

As shown in the model simulations, basically a positive effect on the overall gross margins can be attained by improving the *irrigation efficiency* at the field level. A 5 % increase in *irrigation efficiency* causes an increase of 9 % for total averaged gross margins (Table 8.8). A comparable increase of 10 % in gross margins can be achieved with a 10 % increase in efficiency of the distribution system (at a distribution efficiency level of 65 %). The results suggest that measures, especially at the field level, should be implemented to attain higher yields and benefits.

Similarly to the water supply scenarios, the efficiency scenarios show that the distribution of gross margins per crop is quite comparable (see Figure 8.6, exemplarily for irrigation efficiency of 60 %). Primarily rice, alfalfa and, to some extent, vegetables, wheat and fruit contribute to increased gross margins per district. Wheat and alfalfa denote the highest growth rates. In some districts, such as Yangibazar, Urgench and Gurlan, gross margins for cotton are still negative because of high production costs, high water consumption and relatively low revenues for extensive acreages.

Table 8.8 Agricultural gross margins per district compared to Baseline 1 for different efficiency experiments

Districts of Khorezm		**Gross margins** [10^6USD]	**Change to BL1, relative values** [%]				
		BL1	**Exp1-5**	**Exp1-6**	**Exp1-7**	**Exp1-8**	**Exp1-9**
Khazarasp	d1	8.84	7	12	7	19	14
Khanka	d2	9.24	6	11	7	16	12
Urgench	d3	9.09	8	13	8	19	14
Yangibazar	d4	6.33	7	12	7	19	14
Gurlan	d5	9.58	9	15	9	23	17
Bagat	d6	8.21	4	7	4	11	8
Yangiarik	d7	7.79	5	8	10	17	14
Khiva	d8	8.47	4	7	9	17	14
Kushkupir	d9	11.07	4	8	10	18	14
Shavat	d10	8.42	7	12	14	25	20
average			*6*	*10*	*9*	*18*	*14*

Notes: Exp1-5 = distribution efficiency 60%
Exp1-6 = distribution efficiency 65%
Exp1-7 = irrigation efficiency 50%
Exp1-8 = irrigation efficiency 60%
Exp1-9 = distribution efficiency 60% and irrigation efficiency 50%
BL1 = Baseline 1 scenario

Source: model simulation results

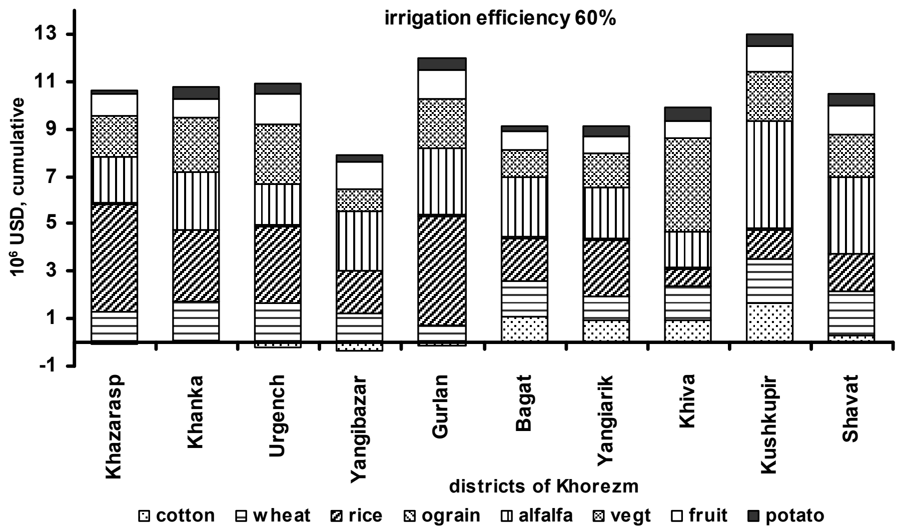


Figure 8.6 Cumulated gross margins per district and crop for `Irrigation Efficiency of 60 %´

Source: model simulation results

The main portion of the revenue per crop comes from cotton. However, in some districts, wheat, rice, alfalfa and vegetables also contribute to a higher share to the revenue. For other grains, revenue appears very low because of the very small acreage, but upon closer examination of the *per ha* change compared to Baseline 1, grains denote high upgrowth rates (see Figure 8.7). All data are showcased for an irrigation efficiency of 60 %. The revenue *per hectare* is highest for vegetables, followed by potato, fruit, alfalfa and rice. Cotton, wheat and other grains have lower per hectare revenues because of relatively low sales prices.

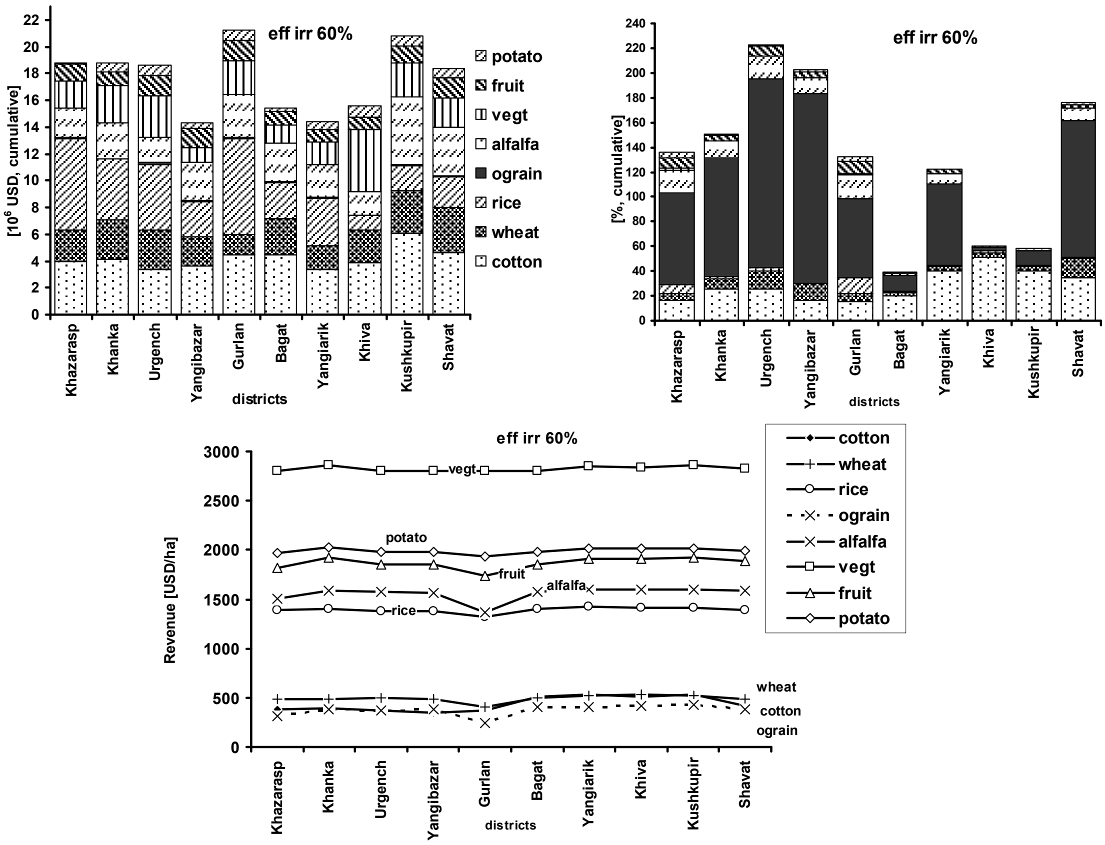


Figure 8.7 Left hand side: Revenues per crop and district (absolute values in 10^6 USD, cumulative),
Right hand side: crop per ha revenue change compared to BL1 scenario (in %, cumulative),
Bottom: Revenue/ha (in 10^6 USD)
Notes: eff irr 60%= scenario on irrigation efficiency of 60%
Source: model simulation results

The changes in the economic water use efficiency (e-WUE) per district for the different efficiency scenarios are relatively low. In all scenarios, the values range between 0.022-0.025 USD/m^3 (Table 8.9). The irrigation efficiency scenario with 60 % attains the highest values. However, cotton in Khazarasp, Urgench, Yangibazar and Gurlan still has negative values (even at higher efficiency levels) because of high production costs and low yields[25].

[25] For further information on e-WUE for district and crop type under status quo, see Table E-3 in Appendix E.

Table 8.9 Economic water use efficiency per crop and district for different efficiency experiments (in USD/m^3)

	Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*average*
						e-WUE (USD/m^3)					
BL1	0.021	0.022	0.020	0.018	0.018	0.022	0.024	0.025	0.022	0.019	*0.021*
Exp1-5	0.023	0.023	0.021	0.019	0.020	0.023	0.025	0.026	0.022	0.020	*0.022*
Exp1-6	0.024	0.024	0.022	0.020	0.021	0.024	0.026	0.027	0.023	0.021	*0.023*
Exp1-7	0.023	0.024	0.021	0.019	0.020	0.023	0.026	0.027	0.024	0.022	*0.023*
Exp1-8	0.026	0.026	0.023	0.021	0.022	0.025	0.028	0.029	0.025	0.024	*0.025*
Exp1-9	0.024	0.025	0.023	0.021	0.021	0.024	0.027	0.028	0.025	0.023	*0.024*
						change to Baseline 1 (%)					
Exp1-5	7	6	8	7	9	4	5	4	4	7	*6*
Exp1-6	12	11	13	12	15	7	8	7	8	12	*11*
Exp1-7	7	7	8	7	9	4	10	9	10	14	*8*
Exp1-8	19	16	19	19	23	11	17	17	18	25	*18*
Exp1-9	14	12	14	14	17	8	14	14	14	20	*14*

Notes: Exp1-5 = distribution efficiency 60%; Exp1-6 = distribution efficiency 65%; Exp1-9 = distribution efficiency 60% and irrigation efficiency 50%; Exp1-7 = irrigation efficiency 50%; Exp1-8 = irrigation efficiency 60%; BL1 = Baseline 1 scenario

Source: model simulation results

Evapotranspiration, yields and water application

As demonstrated in Table 8.10, the modeling results indicate that the actual evapotranspiration change is highest under the examined efficiency scenarios for an irrigation efficiency of 60 % as a result of more water availability at the field level. A smaller increase in the *ETa* and resultant lower yield increases (see Table 8.11) are noticeable for the districts Bagat, Khiva and Kushkupir. The main reason for this observation can be found in the lower, or nearly zero, increasing rates in the *ETa* for rice, vegetable, fruits and potatoes for increased efficiency levels, which is caused by lower water intake/supply rates for those crops compared to other crops.

Table 8.10 Actual evapotranspiration for different efficiency experiments compared to Baseline 1 (in %)

	Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*average*
Exp1-5	3	8	6	5	4	2	4	2	1	5	4
Exp1-6	5	10	15	10	7	3	6	3	2	12	7
Exp1-7	3	8	6	5	4	2	8	4	3	14	6
Exp1-8	12	15	21	18	12	5	13	8	8	19	13
Exp1-9	8	12	18	14	8	3	10	5	6	17	10

Notes: Exp1-5 = distribution efficiency 60%, Exp1-7 = irrigation efficiency 50%
Exp1-6 = distribution efficiency 65%, Exp1-8 = irrigation efficiency 60%
Exp1-9 = distribution efficiency 60% and irrigation efficiency 50%, BL1 = Baseline 1 scenario

Source: model simulation results

Closely connected to evapotranspiration are the resultant yields per crop. For example, Bagat, Khiva and Kushkupir show lower growth gradients than Khazarasp, Urgench or Gurlan. These latter three districts are at the beginning of the canal irrigation system, where total water application and water supplies are higher than for districts at the far end of the system, such as Khiva and Kushkupir.

Table 8.11 Yield per district, change compared to Baseline 1 for different efficiency experiments (in %)

	Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*
Exp1-5	3.5	11.0	7.8	6.2	5.2	1.6	4.8	1.6	1.2	5.4
Exp1-6	5.4	7.2	9.3	6.4	6.8	1.4	4.8	0.8	0.8	6.3
Exp1-7	2.8	5.1	5.0	3.6	4.0	0.9	5.3	0.9	0.9	7.2
Exp1-8	10.4	9.4	11.5	9.2	10.1	2.0	7.1	1.9	2.2	8.8
Exp1-9	7.3	8.3	10.6	7.9	7.8	1.5	6.4	1.0	1.7	8.3

Source: model simulation results

On closer examination of the *yield change per crop*, cotton, grains and alfalfa are important (Table 8.12). Their values are a consequence of a strong increase in water application for those crops (see Table 8.13).

Table 8.12 Yield change per crop compared to Baseline 1 for different efficiency experiments (in %)

	cotton	wheat	rice	other grain	alfalfa	vege-table	fruit	potato
Exp1-5	4.5	3.9	2.2	18.7	5.9	0.3	3.4	1.3
Exp1-6	9.2	5.8	3.4	39.4	10.0	0.4	5.7	1.9
Exp1-7	7.9	4.7	2.3	29.4	6.9	0.2	3.9	1.4
Exp1-8	22.3	9.9	4.5	69.6	13.7	0.4	7.2	2.6
Exp1-9	15.4	7.4	3.8	55.4	11.9	0.4	6.5	2.3

Source: model simulation results

As seen in Table 8.13, the water that finally reaches crops at the field level can be increased by 10 and 19 % as a result of changes in the distribution efficiency of 60 and 65 %, respectively. By changing the irrigation (application) efficiencies of 50 and 60 %, the amount of water increase slightly more to 15 % and 36 %, respectively. Simulation results show that even with relatively small changes in the efficiency it is possible to significantly increase the water supply situation at the field level. Furthermore, the values show that water and crop-specific system parameters, such as evapotranspiration and yields, which are mainly dependent on how much water reaches the field, are good comparable with the scenarios of changed water supply.

Table 8.13 Water application at field level for whole Khorezm region for different efficiency scenarios (absolute [10^6 m^3] and in %)

	Baseline 1	**Exp1-5**	**Exp1-6**	**Exp1-7**	**Exp1-8**	**Exp1-9**
total crop water application [10^6 m^3]	822	906	975	942	1,116	1,039
change to Baseline 1 [%]		10	19	15	36	26

Notes: Exp1-5 = distribution efficiency 60% Exp1-6 = distribution efficiency 65%
Exp1-7 = irrigation efficiency 50% Exp1-8 = irrigation efficiency 60%
Exp1-9 = distribution efficiency 60% and irrigation efficiency 50%

Source: model simulation results

Increases in the general water supply, along with improvements in the irrigation and distribution system, means more water reaches the field. In contrast to the water supply scenarios, a modification in the efficiencies has different impacts on the groundwater, drainage, capillary rise and soil water balances.

Drainage, groundwater and deep percolation

Due to the increased distribution and application efficiencies less water can infiltrate into the soil and recharge the groundwater by deep percolation; therefore, there were not significant changes in the deep percolation and groundwater under improved efficiency scenarios. The data for groundwater, groundwater table depth, drainage and groundwater extraction are presented below.

The groundwater table depth and change in depth compared to the Baseline 1 scenario is small, with a range of at most 3 cm for a distribution efficiency of 65 % (see Figure E.1 in Appendix E). One reason is that an improvement in the irrigation and distribution efficiency means less water is drained and percolated (see Table 8.14). However, more water is available for crop growth, meaning that crops can meet their water requirements using the additional available irrigation water instead of using ground- and soil-water extraction via capillary rise (Table 8.14). Percolation by loss from the irrigation network is an input to the groundwater system, whereas capillary rise is an output. Overall, the changes in groundwater level due to increased efficiency (reduced input) and lower capillary rise (reduced output) is small as a result of improved water supply in the root zone.

The drainage from sites during the main vegetation period was under improved irrigation efficiency approximately 4 % decreased. For improved distribution efficiencies, drainage decreased by 8 % because of lower leakage rates compared to the Baseline 1 scenario. Therefore, more water is available for crop growth. However, drainage is reduced, especially in the leaching period from January to March (Table 8.14), which has negative impacts on salt leaching and groundwater accumulation. At improved efficiencies mainly the leaching of the distribution and canal system because of reduced leakages is affected. Leaching at the field level is not heavily influenced (i.e., by activities such as laser leveling) because leaching proceeds outside the vegetation period, and here water is sufficiently available and provided only for this reason in most cases. An adjusted crop-soil-salinity model could be used to clarify how modified off-seasonal leaching affects soil-salt extraction or whether there may be additional leaching during the vegetation period.

Table 8.14 Surface drainage from demand sites for different efficiency experiments compared to Baseline 1 (in %)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	average
Exp1-5	-9	-11	-9	-4	-4	-4	-4	-4	-4	-4	0	0	*-5*
Exp1-6	-17	-20	-16	-7	-7	-8	-8	-8	-8	-7	1	1	*-9*
Exp1-7	-4	-1	-5	-5	-4	-4	-4	-4.5	-4	-4	1	1	*-3*
Exp1-8	-9	-11	-9	-4	-4	-4	-4	-4	-4	-4	0	0	*-8*
Exp1-9	-13	-12	-14	-9	-9	-9	-9	-9	-9	-9	1	1	*-8*

Notes: Exp1-5 = distribution efficiency 60% Exp1-6 = distribution efficiency 65%
Exp1-7 = irrigation efficiency 50% Exp1-8 = irrigation efficiency 60%
Exp1-9 = distribution efficiency 60% and irrigation efficiency 50%
Source: model simulation results

The other important factor that influences the groundwater balance is the water extraction from the groundwater. Groundwater extraction is reduced with improvements in irrigation and distribution efficiency (Table 8.15 and Table 8.16). Less groundwater is extracted as more irrigation water becomes available for crop growth and less water is needed from the groundwater and the soil via capillary rise. A decrease in groundwater extraction of 25 % is relatively high, given an improvement in irrigation efficiency to 60 %. This shows the importance of improving efficiency for soil and groundwater balances.

The reduction in groundwater extraction is slightly higher for light and heavy soils compared to medium soils, especially with an improvement in irrigation efficiency due to higher total extraction rates for those soil types, which is a consequence of soil hydrologic properties. In this situation, changes have a more significant effect on a percentage basis. The district-wide groundwater extraction changes are uniformly distributed. In Urgench, Yangiarik and Shavat, the extraction rates are slightly more reduced due to a larger proportion of light and heavy soils.

Table 8.15 Groundwater (GW) extraction change compared to Baseline 1 for different efficiency experiments, per soil type and per district (in %)

	Exp1-5	**Exp1-6**	**Exp1-7**	**Exp1-8**	**Exp1-9**
	GW extraction per soil type, in %				
change light soils	-9.9	-16.9	-11.5	-25.2	-20.6
change medium soils	-8.2	-14.2	-9.1	-21.3	-17.3
change heavy soils	-10.8	-19.4	-10.0	-24.6	-21.1
avg. change to BL1	*-10.1*	*-17.5*	*-10.8*	*-24.6*	*-20.4*
	Exp1-5	**Exp1-6**	**Exp1-7**	**Exp1-8**	**Exp1-9**
	GW extraction per district, change to BL1, in %				
Khazarasp	-8	-16	-6	-25	-19
Khanka	-12	-20	-11	-26	-22
Urgench	-14	-26	-12	-31	-28
Yangibazar	-12	-21	-10	-29	-24
Gurlan	-9	-16	-8	-21	-17
Bagat	-7	-12	-6	-14	-12
Yangiarik	-14	-21	-22	-30	-27
Khiva	-7	-11	-11	-21	-16
Kushkupir	-8	-12	-11	-21	-18
Shavat	-9	-19	-21	-31	-28
average	*-10*	*-17*	*-12*	-25	*-21*

Notes: GW extraction is not including groundwater pumping
Exp1-5 = distribution efficiency 60% Exp1-6 = distribution efficiency 65%
Exp1-7 = irrigation efficiency 50% Exp1-8 = irrigation efficiency 60%
Exp1-9 = distribution efficiency 60% and irrigation efficiency 50%
Source: model simulation results

The monthly extraction changes are as expected, with a reduction within the main irrigation and vegetation periods, particularly in July (Table 8.16).

Table 8.16 Monthly groundwater extraction change compared to Baseline 1 for different efficiency experiments (in %)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Groundwater Extraction, per month, change to BL1 in %											
Exp1-5	-0.4	-1.1	-1.7	-4.6	-11.5	-11.1	-12.5	-10.0	-9.6	-9.2	-8.6	-7.3
Exp1-6	-0.8	-1.9	-3.1	-8.5	-19.0	-19.7	-21.4	-17.5	-17.0	-15.1	-15.0	-12.9
Exp1-7	-0.2	-0.2	-0.6	-5.3	-13.5	-14.3	-13.4	-9.4	-12.3	-11.2	-10.8	-9.5
Exp1-8	-0.4	-0.5	-1.3	-15.5	-26.9	-28.3	-31.6	-22.2	-24.5	-21.3	-25.4	-22.5
Exp1-9	-0.6	-1.3	-2.3	-12.0	-22.3	-23.5	-26.6	-19.7	-20.3	-18.3	-18.9	-16.5

Source: model simulation results

8.1.4 Status quo - water pricing experiments

The water pricing scenario under status quo conditions contains experiments for volumetric water pricing of 3, 10, 25 and 50 USD/1000 m^3 of irrigation water. Water pricing analyses in this situation will identify the impacts of different water-pricing levels on costs and will be used to obtain gross margins for farmers under the observed situation for 2003. This scenario does not analyze optimal crop and water allocations because both factors are fixed[26] (water quantity, water usage, acreage, evapotranspiration and yields). The focus of these analyses is on the "what-if" analysis of the existing system and the economical effect of different water pricing levels.

According to Lerman (in Wegren, 1998), an expert recommendation for water pricing in Uzbekistan is about 6.33 US Dollar/1000 m^3. Additionally, Bobojonov´s (2008) research on water organization expenses for water in Khorezm determined a minimum price of 2.3 Uzbek Soums/m^3 (around 6.8 USD/1000m^3) to cover costs for operation and maintenance of the irrigation system (O&M)[27].

Compared to other parts of the world, this recommendation is very low. According to a detailed study on water charging in irrigated agriculture by the FAO, the average water price amounts to approximately 20 USD/1000m^3 in developing and emerging countries (Cornish et al., 2004), 50/1000m^3 in places such as Tunisia, Bulgaria and India and more than 250/1000m^3 in Israel. For this reason, several water prices within the described ranges and their impact on the local and district-wide economical outcomes will be determined.

The optimization parameter, agricultural profit (gross margin), can be decomposed into its constituent elements: revenues, variable costs and water costs (Table 8.17).

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[26] That research will be discussed in chapter 8.2 under the analysis of liberalization and free solved acreage, crop and water allocation.

[27] 2.3 UZS (Uzbek Soum) is equivalent to 0.0068 USD at an exchange rate of 340 USD for 1 Uzbek Soum in 2006

Table 8.17 Gross margin, costs and revenues for experiments with different levels of water pricing under status quo scenario block 1 (in 10^6 USD)

	Baseline 1	wp0.003	wp0.006	wp0.010	wp0.025	wp0.050	Baseline 1[a]	wp0.003	wp0.006	wp0.010	wp0.025	wp0.050	identical in all scenarios	identical in all scenarios
all in [10^6 USD]	Gross margin						Water costs						Rev-enue	Var. cost
Khazarasp	8.84	8.27	7.71	6.96	4.16	-0.36	0	0.56	1.12	1.87	4.68	9.19	17.14	8.30
Khanka	9.24	8.65	8.05	7.27	4.32	-0.43	0	0.59	1.18	1.97	4.92	9.67	17.25	8.01
Urgench	9.09	8.45	7.81	6.95	3.77	-1.34	0	0.64	1.28	2.13	5.31	10.43	16.90	7.81
Yangibazar	6.33	5.83	5.33	4.66	2.16	-1.87	0	0.50	1.00	1.67	4.17	8.20	13.09	6.76
Gurlan	9.58	8.85	8.11	7.13	3.46	-2.57	0	0.74	1.47	2.45	6.13	12.15	19.00	9.41
Bagat	8.21	7.70	7.20	6.53	4.03	0.12	0	0.50	1.01	1.68	4.18	8.09	14.54	6.33
Yangiarik	7.79	7.34	6.89	6.29	4.06	0.51	0	0.45	0.90	1.50	3.74	7.29	13.09	5.30
Khiva	8.47	8.00	7.53	6.91	4.58	0.87	0	0.47	0.94	1.56	3.89	7.60	14.16	5.69
Kushkupir	11.07	10.39	9.72	8.82	5.46	0.22	0	0.68	1.35	2.25	5.61	10.85	18.89	7.82
Shavat	8.42	7.83	7.23	6.43	3.47	-1.28	0	0.60	1.19	1.99	4.96	9.70	16.31	7.89
sum	*87.04*	*81.31*	*75.58*	*67.95*	*39.46*	*-6.13*	*0*	*5.73*	*11.45*	*19.09*	*47.58*	*93.17*	*160.36*	*73.33*

Notes: [a] Baseline 1= Baseline 1 scenario, status quo for 2003, no water price is assumed
wp0.0xx = status quo scenario with water price of 3, 6, 10, 25, 50 USD/1000m^3

Source: model simulation results

As expected, with increased water price, the gross margins per district and the total gross margins show a negative linear slope. Because revenues and variable costs due to constant crop allocation are stable, the linear decline in gross margins is caused by the rise in water costs.

At a water price of 50 USD/1000 m^3, gross margins in nearly all districts became negative because of high water consumption, especially in districts close to the river, resulting in high absolute water costs. A closer examination of the district-wide water price in which gross margins become zero shows values between 38 and 56 USD/1000 m^3, with an average of 47 USD/1000 m^3 (Table 8.18).

Table 8.18 Water price level per district in which gross margins became zero (in USD/1000 m^3)

Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*average*
48	48	43	38	39	51	53	56	51	43	*47*

Source: model simulation results

This result indicates low returns on sales for the produced crops already at a water price of 38 USD/1000 m^3. Even with a lower water price of 20 or 25 USD/1000 m^3, the returns on sales are so low that cropping does not make sense.

As Nazarkulov (2002) stated in his study on agricultural transformation in Uzbekistan, the total cost of water/water supply accounts for (depending on the chosen district in Uzbekistan) approximately 10 to 17 % of the total variable production cost. With the assumption of water costs of 15 % of the variable cost[28], the break-even-point of 6.04 USD/1000 m^3 would result in cost recovery for water costs (Table 8.19). This very low water price of 0.006 USD/m^3 seems to be indicated under the actual system and fits well with Lerman´s water price calculations and Bobojonov´s already stated water cost.

Table 8.19 Water cost-covering water price level per district and in total (in USD/1000 m^3)

Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*Khorezm*
6.7	6.0	5.5	6.0	5.8	5.6	5.2	5.4	5.2	5.9	*6.0*

Source: model simulation results

It should be emphasized that the analysis of water price was conducted for the status quo situation, with a given crop allocation and quantity. In situations where the farmer is free to decide on the crop type and quantity, the effect of water pricing on crop allocation will certainly be exposed. This analysis is conducted in the subsequent scenarios of block 2 and block 3.

8.1.5 Recapitulation scenario block 1

The status quo analyses of scenario block 1 showed a huge influence of modified water supply on the cropping system and the water and soil balances, mainly in cases of lower water supply. In this situation, the model simulations indicate a strong reduction in gross margins and yields for crops such as cotton, rice and alfalfa. The groundwater

[28] here, 15 % of 73.33 = 10.99

balances will be influenced mainly during low water supply because the crops need to seek alternative water sources (via capillary rise) that reduce the groundwater table.

With more water supply, crops such as vegetables, alfalfa and rice have a huge potential to become more profitable because of yield increases and a positive economical-ecological balance (comparable less water consumption with higher crop yields and financial gains). Cotton generally has negative values for economic water use efficiency. Additionally, cotton yields are low compared to the maximum possible yields for this area. Reasons for this include the huge expansion of cotton production even on marginal land and an insufficient water supply for this huge acreage. However, with increased water supply, it could be possible to increase yields and enhance the economical-ecological relationship to improve water use efficiency. However, other crops, such as vegetables, alfalfa and rice, will become more profitable under the given procurement system for cotton.

The positive effects on crop yield and water balances can basically be seen in cases where the *irrigation* efficiency (at the field application level) has improved. The general water supply increases -as does the amplitude, and improvements in the irrigation and distribution system means more water can reach the field.

Analyses of water pricing under the given situation showed that even at water prices of around 38-52 USD/1000 m^3, overall gross margins become zero, and at lower water prices of 20-25 USD/1000 m^3, it is still not worthwhile/profitable for farmers to crop. Consequently, water prices must be much lower than 20 USD/1000 m^3; a price of 6 USD/1000 m^3 seems to be most reasonable.

8.2 Model results scenario block 2– released state order system and free decision of crop allocation

The second scenario block concentrates on the analysis of the management of water and crop allocation and its economical effects in situations with released acreage. Unlike the first scenario under status quo conditions, the second scenario focuses on effective crop allocation. For this purpose and comparable with scenario block 1, all parameters, such as variable cost, sales price, water supply and efficiencies, will be kept constant. Only the cropping area will be released to determine what would happen under the given situation if the governmental crop quota system were released and crop allocation became only a function of optimal and efficient water allocation and an optimal economical relation of costs and prices and was not dictated by a fixed quota system. Here we examine the effects of modified water supply, abolishment of the substitution system for cotton and the introduction of a water price under released acreage on crop allocation and economical outcomes.

8.2.1 Baseline 2-released acreage

This scenario relaxes the cropping area and allows for the free selection of crops in terms of quantity and crop type. More economical and hydrological crop allocation will be demonstrated with respect to gross margins, revenues and variable costs, crop allocation and cropped area.

The simulation results indicate that the total gross margins increased by approximately 21 % (Table 8.20) compared to Baseline 1.

Table 8.20 Gross margin, costs and revenues for Baseline 2 (in 10^6 USD), and changes to Baseline 1 (in %)

	Gross margin			Revenue			Variable cost		
	[10^6 USD]		[%]	[10^6 USD]		[%]	[10^6 USD]		[%]
	Baseline 2	**Baseline 1**	**Comparison BL2 to BL1**	**Baseline 2**	**Baseline 1**	**Comparison BL2 to BL1**	**Baseline 2**	**Baseline 1**	**Comparison BL2 to BL1**
Khazarasp	10.54	8.84	*19*	15.3	17.14	*-11*	4.7	8.30	*-43*
Khanka	11.22	9.24	*21*	15.7	17.25	*-9*	4.5	8.01	*-44*
Urgench	11.06	9.09	*22*	15.7	16.90	*-7*	4.7	7.81	*-40*
Yangibazar	8.10	6.33	*28*	11.6	13.09	*-12*	3.5	6.76	*-49*
Gurlan	11.60	9.58	*21*	17.0	19.00	*-10*	5.4	9.41	*-43*
Bagat	9.67	8.21	*18*	13.8	14.54	*-5*	4.2	6.33	*-34*
Yangiarik	8.97	7.79	*15*	12.5	13.09	*-4*	3.6	5.30	*-33*
Khiva	10.32	8.47	*22*	14.0	14.16	*-1*	3.7	5.69	*-35*
Kushkupir	13.34	11.07	*21*	18.0	18.89	*-5*	4.7	7.82	*-40*
Shavat	10.63	8.42	*26*	15.0	16.31	*-8*	4.4	7.89	*-45*
sum	*105.45*	*87.04*	*21*	*148.7*	*160.36*	*-7*	*43.2*	*73.33*	*-41*

Notes: Baseline 1 = status quo scenario
Baseline 2 =released state order system; like status quo with released acreage and crop quota

Source: model simulation results

Major reason for this effect is a 41 % decrease in production costs, which is attributed to a decrease in the cultivated cropping area and a modification to more water effective and benefiting crops in monetary terms. The 7 % decrease in revenues is relatively moderate and caused by a general decrease in acreage. However, the cost savings and reallocation of crops compensate for this effect.

As seen in Table 8.21, the shares on gross margin are very high for alfalfa, rice, vegetables, wheat and fruit. This general increase in the gross margins compared to the status quo (Baseline 1) is mainly due to an increase in acreage and additional gains in gross margins (of around 18-20 %) for crops like alfalfa, vegetables, fruit and potato[29]. In terms of irrigation water consumption, crops such as wheat, with around 3600 m^3/ha, and fruit, maize and cotton (~5000 m^3/ha) are most efficient[30]. However, considering additional economical aspects such as production costs and sales prices, wheat and other crops (vegetables, fruit, potato and rice) that have higher water consumption but better cost/benefit relations become more attractive.

For districts like Shavat and Yangibazar, the increase in gross margins is 26–28 % and caused by the huge acreage of cotton and resultant losses in gross margins in the status quo situation (see Table 8.21, for Baseline 1). On the contrary, in districts with less cotton acreage in the status quo, such as Yangiarik, we see a smaller increase in gross margins because the Baseline 1 situation is less negative. In Baseline 2, the cotton area is drastically reduced and thus, losses in gross margins for cotton.

Further examination of acreage illustrates the correlation between gross margins (and its linked variables like revenues and costs), crop variety and the cropped area. As seen in Table 8.22, the total cropped area is reduced by 28 to 40 % because of a reduction in cotton acreage. As a result of the negative gross margins for cotton due to the state quota and bad cost/benefit relations under the status quo (Baseline 1), the cotton area with released acreage is under Baseline 2 diminished by 92 % (see Table 8.23). However, the acreage for other crops, such as vegetable, alfalfa, fruit, wheat and potato, has expanded by 20 % compared to the status quo[31].

29 The quotient of rice for the gross margins is approx. 24 Million USD, which seems very high, but the change compared to Baseline 1 and 2 with 4.5 % is relatively low, as the acreage would not be expanded.

30 Vegetables, potatoes and alfalfa are ~8000 m^3/ha, rice is ~26000 m^3/ha.

31 The maximum crop area is used in the model as an upper boundary.

Table 8.21 Gross margin per crop for all Khorezm districts (in 10^6 USD)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	***sum total***
				Gross margin, Baseline 2 [10^6 USD]					
Khazarasp	0.00	1.38	4.11	0.00	1.93	2.03	0.99	0.10	*10.54*
Khanka	0.00	1.40	3.15	0.00	2.46	2.80	0.83	0.57	*11.22*
Urgench	0.01	1.39	2.96	0.00	1.74	3.08	1.31	0.58	*11.06*
Yangibazar	0.01	0.94	1.87	0.00	2.61	1.14	1.20	0.33	*8.10*
Gurlan	0.12	0.77	3.31	0.00	3.00	2.51	1.32	0.57	*11.60*
Bagat	0.28	1.67	2.19	0.01	2.94	1.42	0.94	0.22	*9.67*
Yangiarik	0.03	1.14	2.58	0.00	2.20	1.76	0.76	0.51	*8.97*
Khiva	0.02	1.44	0.86	0.00	1.73	4.71	0.83	0.72	*10.32*
Kushkupir	0.26	2.03	1.52	0.00	5.12	2.52	1.26	0.64	*13.34*
Shavat	0.02	1.29	1.79	0.00	3.42	2.16	1.34	0.61	*10.63*
Baseline 2 total	***0.75***	***13.46***	***24.33***	***0.01***	***27.16***	***24.12***	***10.77***	***4.85***	***105.45***
				Gross margin, Baseline 1 [10^6 USD]					
Khazarasp	-0.653	1.210	4.022	-0.002	1.629	1.696	0.845	0.089	*8.84*
Khanka	-0.775	1.414	2.976	-0.001	2.091	2.332	0.721	0.482	*9.24*
Urgench	-0.873	1.270	3.135	-0.019	1.407	2.564	1.112	0.489	*9.09*
Yangibazar	-0.877	0.953	1.765	-0.004	2.220	0.951	1.044	0.280	*6.33*
Gurlan	-0.754	0.628	3.827	-0.020	2.273	2.090	1.062	0.479	*9.58*
Bagat	0.322	1.449	1.792	0.018	2.470	1.182	0.789	0.186	*8.21*
Yangiarik	-0.057	0.999	2.300	0.010	1.968	1.465	0.677	0.433	*7.79*
Khiva	-0.371	1.336	0.711	0.024	1.535	3.922	0.710	0.603	*8.47*
Kushkupir	-0.092	1.759	1.239	0.057	4.421	2.096	1.058	0.529	*11.07*
Shavat	-0.906	1.434	1.521	-0.004	2.919	1.800	1.158	0.502	*8.42*
Baseline 1 total	***-5.04***	***12.45***	***23.29***	***0.06***	***22.93***	***20.10***	***9.18***	***4.07***	***87.04***

Source: model simulation results

Table 8.22 Acreage per district for Baseline 1 and Baseline 2 scenarios (in ha)

	Baseline 2	**Baseline 1**	**Change Baseline 2 to Baseline 1**
	Acreage [ha]		[%]
Khazarasp	14,623	23,333	*-37.3*
Khanka	14,925	23,407	*-36.2*
Urgench	14,828	22,518	*-34.1*
Yangibazar	11,900	19,928	*-40.3*
Gurlan	16,259	25,974	*-37.4*
Bagat	14,214	19,234	*-26.1*
Yangiarik	11,122	15,392	*-27.7*
Khiva	11,935	16,709	*-28.6*
Kushkupir	16,630	24,156	*-31.2*
Shavat	15,610	24,094	*-35.2*
sum	***142,046***	***214,745***	***-33.9***

Source: model simulation results

In this context, the resultant share of crops over the total area is very interesting. In the observed situation in 2003, nearly 50 % of the area is cropped by cotton, followed by wheat and rice at approximately 25 and 13 %, respectively. All other crops are marginal. However, for the Baseline 2 scenario with released acreage, wheat, rice and alfalfa have 43, 20 and 16 % of the area, respectively, followed by vegetables and fruits with 7 and 6 %. Cotton is only cropped on 6 % of the total area.

Table 8.23 Acreage per crop for Khorezm, Baseline 1 and Baseline 2

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	***sum***
Baseline 2 [ha]	8,774	61,492	27,911	98	22,069	10,171	8,016	3,515	*142,046*
Share of total area BL2 [%]	6	43	20	0	16	7	6	2	*100*
Baseline 1 [ha]	97,722	51,242	27,231	2,074	18,391	8,476	6,680	2,929	*214,745*
Share of total area BL1 [%]	46	24	13	1	9	4	3	1	*100*
change Baseline 2 to Baseline 1 [%]	***-91.0***	***20.0***	***2.5***	***-95.3***	***20.0***	***20.0***	***20.0***	***20.0***	***-33.9***

Source: model simulation results

8.2.2 Water supply

The following experiments will illustrate how crop allocation, economical outputs and crop acreage are affected under released crop area and modified water supply. Here, Baseline 2 shall be compared with the results of a water quantity modification of +50 and -50% of the observed water supply in 2003. The experiments will provide insight into the crop allocation of scenario block 2 if water supply is changed. Crop acreage, gross margins, revenues and variable costs shall be analyzed and described.

In situations with increased water supply of 50 %, modeling results indicate that the overall acreage will increase by approximately 33 % compared to the Baseline 2 situation. If the water supply decreases (by 50 %), a 23 % reduction of cropped area can be expected, as seen in Table 8.24. Gurlan, in particular, shows high impacts from water supply modifications, especially in situations with higher water supply. Rice, for example, is an economically beneficial crop, and if enough water is available (particularly in Gurlan, a district directly connected to the river), rice plantations will be very profitable in wet years and have positive impacts on revenues, acreage and gross margins.

Table 8.24 Cropped area per district compared of Baseline 2 with experiments of modified water supply

	acreage per district [ha]			change wsdt+50% to Baseline 2 [%]	change wsdt-50% to Baseline 2 [%]
	Baseline 2	wsdt+50%	Wsdt-50%		
Khazarasp	14,623	20,348	10,337	*39*	*-29*
Khanka	14,925	18,701	11,498	*25*	*-23*
Urgench	14,828	18,660	11,338	*26*	*-24*
Yangibazar	11,900	14,899	9,260	*25*	*-22*
Gurlan	16,259	24,783	11,047	*52*	*-32*
Bagat	14,214	19,478	11,106	*37*	*-22*
Yangiarik	11,122	15,105	8,112	*36*	*-27*
Khiva	11,935	14,809	9,723	*24*	*-19*
Kushkupir	16,630	23,336	13,320	*40*	*-20*
Shavat	15,610	18,864	13,205	*21*	*-15*
sum	*142,046*	*188,984*	*108,946*	*33*	*-23*

Notes: wsdt+50% = water supply +50% of observed
wsdt-50% = water supply -50% of observed

Source: model simulation results

This trend in rice cultivation is evident by the 17% rise in acreage shown in Table 8.25.

Table 8.25 Crop allocation and share of crop area relative to total area for experiments with modified water supply under scenario block 2 for Khorezm (in ha and %)

	cotton	wheat	rice	other grain	alfalfa	vegetable	fruits	potato	*sum*
crop area, Baseline 2 [ha]	8,774	61,492	27,911	98	22,069	10,171	8,016	3,515	*142,046*
share of crop area to total area BL2 *[%]*	*6.2*	*43.3*	*19.6*	*0.1*	*15.5*	*7.2*	*5.6*	*2.5*	*100*
crop area, wsdt+50% [ha]	50,187	61,490	32,677	858	22,069	10,171	8,016	3,515	*188,984*
share of crop area to total area wsdt+50% *[%]*	*26.6*	*32.5*	*17.3*	*0.5*	*11.7*	*5.4*	*4.2*	*1.9*	*100*
crop area, wsdt-50% [ha]	916	61,490	2,852	3	22,069	10,171	8,016	3,429	*108,946*
share of crop area to total area wsdt-50% *[%]*	*0.8*	*56.4*	*2.6*	*0.0*	*20.3*	*9.3*	*7.4*	*3.1*	*100*

Source: model simulation results

Conversely, in dry years, the rice area is reduced by 97 %. Similar trends are seen for cotton. If enough water is available, the area for cotton is increased; however, if water supply is reduced, a drastic reduction in the cotton area (by approx. 90 %) can be seen. The change for all other considered crops is marginal[32]. However, the cropping of all other considered crops is still beneficial enough that they are planted even in reduced water supply conditions.

In this context, the composition of crops compared to the total cropped area in dry and wet years is very interesting. In situations with less water supply, wheat (with a lower irrigation water consumption) is dominant, followed by alfalfa, vegetables and fruits; in situations with additional water supply, a trend toward crops with high water consumption and those that are economically profitable, such as rice, cotton, (wheat) and alfalfa, is noticeable.

All of the considered parameters are related to each other, and the development of acreage under different water supply scenarios is analogous to the revenue. Total revenues increased by about 26 % with an increased water supply of 50 % compared to the Baseline 2 scenario. Once again the Gurlan district (and to some extent Khasarasp) had the highest increase due to vast profits from rice (see Table 8.26). In addition to rice, large profits can be made with alfalfa, wheat, vegetables and cotton. Much lower gains are seen for fruits and potatoes because the total allowed area is too small. Districts with a low rice (and alfalfa) contingent, such as Khiva, had the lowest revenue increases, where vegetables are the most beneficial crop but do not get reach the profit levels of rice.

Modeling results indicate that a revenue reduction of 30% can be seen in situations with low water supply. A reduction in crop production is seen for all crops. However, a decline in rice production during the dry years is primarily responsible because not enough water is available. As expected, the revenue decrease is highest for districts with typically high rice production, such as Gurlan and Khasarasp. As seen in Table 8.26, cotton production is also drastically reduced for the same reason. The most gains can be generated in low water supply situations by using less water-demanding crops, such as wheat, alfalfa, vegetables and, to some extent, fruits and potatoes.

32 Crops like vegetables, fruit, alfalfa and potatoes are already cropped until set boundaries. An increase of area due to model intern sets is not possible. The upper bounds were set to avoid unrealistic high cropping of the most effective crop over the possible area.

Table 8.26 Revenues per crop and district for modified water supply (in 10^6 USD) and comparison to Baseline 2 (in %)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	**total**	**change to Baseline 2**
	revenues per crop and district for wsdt+50% [10^6 USD]									[%]
Khazarasp	2.2	2.9	8.2	0.0	2.7	2.5	1.5	0.2	*20.0*	*31.2*
Khanka	1.8	3.5	5.5	0.0	3.2	3.3	1.2	0.8	*19.4*	*23.6*
Urgench	1.6	3.4	6.0	0.0	2.3	3.7	1.9	0.8	*19.7*	*25.3*
Yangibazar	1.7	2.6	3.3	0.0	3.3	1.4	1.7	0.5	*14.4*	*24.8*
Gurlan	3.6	1.8	8.5	0.0	3.7	3.0	1.8	0.9	*23.4*	*37.5*
Bagat	4.1	3.3	3.3	0.0	3.4	1.7	1.2	0.3	*17.2*	*24.4*
Yangiarik	2.4	2.1	4.2	0.0	2.9	2.1	1.1	0.7	*15.6*	*24.2*
Khiva	2.4	2.9	1.3	0.0	2.1	5.6	1.1	1.0	*16.4*	*17.0*
Kushkupir	4.7	3.8	2.3	0.1	6.0	3.0	1.6	0.9	*22.3*	*24.0*
Shavat	2.0	3.9	2.8	0.0	4.4	2.6	1.8	0.9	*18.3*	*22.1*
sum	*26.5*	*30.1*	*45.3*	*0.3*	*33.9*	*28.8*	*14.9*	*7.0*	***186.7***	**25.6**
	revenues per crop and district for wsdt-50% [10^6 USD]									[%]
Khazarasp	0.0	2.6	1.1	0.0	2.4	2.4	1.4	0.2	*10.1*	*-34.1*
Khanka	0.0	2.6	0.0	0.0	2.9	3.3	1.1	0.8	*10.8*	*-31.5*
Urgench	0.0	2.4	0.1	0.0	2.0	3.7	1.8	0.8	*10.8*	*-31.2*
Yangibazar	0.0	1.9	0.0	0.0	2.8	1.4	1.6	0.5	*8.1*	*-29.7*
Gurlan	0.4	1.7	0.3	0.0	3.5	3.0	1.8	0.8	*11.4*	*-33.0*
Bagat	0.0	2.7	1.5	0.0	2.8	1.7	1.1	0.3	*10.1*	*-26.9*
Yangiarik	0.0	1.9	0.7	0.0	2.4	2.1	1.0	0.7	*8.7*	*-30.5*
Khiva	0.0	1.9	0.0	0.0	1.3	5.5	0.9	0.8	*10.4*	*-26.1*
Kushkupir	0.0	2.9	0.0	0.0	4.9	3.0	1.5	0.9	*13.1*	*-27.4*
Shavat	0.0	2.6	0.0	0.0	3.2	2.6	1.6	0.8	*10.8*	*-27.8*
sum	*0.4*	*23.2*	*3.7*	*0.0*	*28.1*	*28.5*	*13.6*	*6.6*	***104.2***	**-29.9**
Baseline 2	*4.2*	*26.7*	*37.3*	*0.0*	*30.9*	*28.7*	*14.0*	*6.9*	*148.7*	

Source: model simulation results

Inversely proportional is the development of variable costs under modified water supply. With an increase of water supply by 50 %, the crop acreage shifts into higher water demanding and economically beneficial crops, such as rice and cotton. Simultaneously, the production costs for these crops are higher, and as the acreage increases, the variable costs also increase by approximately 43 % compared to the Baseline 2. Gurlan and Khasarasp suffer a loss (but also high gross margins) due to expanded rice cropping, as seen in Table 8.27.

In situations with a decreased water supply of 50 %, the production costs decreased by about 34 % compared to the Baseline 2 because of a reduction in the cropping area and a change in crop production toward less water-demanding but high-productive crops, such as wheat.

Table 8.27 Variable cost per crop and district for modified water supply (in 10^6 USD) and comparison to Baseline 2 (in %)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege table**	**fruit**	**potato**	**sum per district**	**change to BL2**
	Variable cost per crop and district for wsdt+50% [10^6 USD]									[%]
Khazarasp	1.9	1.3	2.7	0.0	0.3	0.4	0.3	0.0	7.0	*48.0*
Khanka	1.3	1.6	1.8	0.0	0.3	0.5	0.2	0.2	6.0	*33.1*
Urgench	1.2	1.5	2.0	0.0	0.2	0.6	0.4	0.2	6.2	*33.0*
Yangibazar	1.3	1.2	1.1	0.0	0.4	0.2	0.4	0.1	4.6	*34.1*
Gurlan	3.2	1.0	3.0	0.0	0.5	0.5	0.4	0.3	8.9	*64.0*
Bagat	2.7	1.4	1.1	0.0	0.4	0.3	0.3	0.1	6.2	*48.9*
Yangiarik	1.7	0.9	1.4	0.0	0.3	0.3	0.2	0.2	5.1	*43.1*
Khiva	1.6	1.2	0.4	0.0	0.2	0.9	0.2	0.3	4.8	*29.9*
Kushkupir	3.2	1.6	0.7	0.1	0.6	0.5	0.3	0.3	7.2	*54.6*
Shavat	1.4	1.7	0.9	0.0	0.5	0.4	0.4	0.3	5.6	*29.0*
sum per crop	*19.5*	*13.2*	*15.2*	*0.2*	*3.7*	*4.6*	*3.3*	*2.0*	***61.6***	***42.7***
	Variable cost per crop and district for wsdt-50% [10^6 USD]									[%]
Khazarasp	0.0	1.3	0.4	0.0	0.3	0.4	0.3	0.0	2.8	-41.8
Khanka	0.0	1.6	0.0	0.0	0.3	0.5	0.2	0.2	2.9	-35.3
Urgench	0.0	1.5	0.0	0.0	0.2	0.6	0.4	0.2	3.1	-34.4
Yangibazar	0.0	1.2	0.0	0.0	0.4	0.2	0.4	0.1	2.3	-34.3
Gurlan	0.4	1.0	0.1	0.0	0.5	0.5	0.4	0.3	3.1	-42.8
Bagat	0.0	1.4	0.5	0.0	0.4	0.3	0.3	0.1	2.9	-30.9
Yangiarik	0.0	0.9	0.2	0.0	0.3	0.3	0.2	0.2	2.2	-38.1
Khiva	0.0	1.2	0.0	0.0	0.2	0.9	0.2	0.2	2.8	-25.5
Kushkupir	0.0	1.6	0.0	0.0	0.6	0.5	0.3	0.3	3.3	-30.1
Shavat	0.0	1.7	0.0	0.0	0.5	0.4	0.4	0.3	3.3	-24.9
sum per crop	*0.4*	*13.2*	*1.3*	*0.0*	*3.7*	*4.6*	*3.3*	*2.0*	***28.5***	***-34.1***

Source: model simulation results

The gross margins resulting from the difference between revenues and costs in cases of modified water supply can be seen in Table 8.28. The overall gross margins increased by 19 % with additional water supply because of the extension of rice, alfalfa, vegetables and wheat production. Unsurprisingly, the districts of Gurlan and Khasarasp attained the highest growth due to the huge intensification of rice cropping. A tendency toward higher gross margins can be seen for all districts closer to the river.

At a water supply of -50 % of the original, the reduction in gross margins is relatively high at 28 %. Heavy losses in yields due to the water deficit were recorded for all crops[33]. In those situations, a shift toward less water-demanding crops, such as wheat, and toward crops with higher value added in economic terms, such as vegetables, fruit and alfalfa, can be seen. Furthermore, the loss of gross margins due to less water

33 For this, see also detailed information on the water supply experiments of the Baseline 1 (status quo) scenario.

supply is relatively equally distributed in all districts, independent of river closeness or distance.

Table 8.28 Gross margin per crop and district for modified water supply (in 10^6 US Dollar) and comparison to Baseline 2 (in %)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	**sum**	**change to Baseline 2**
	Gross margins per crop and district for wsdt+50% [10^6 USD]									[%]
Khazarasp	0.3	1.6	5.5	0.0	2.4	2.1	1.1	0.1	*13.0*	*23.7*
Khanka	0.5	2.0	3.7	0.0	2.9	2.8	0.9	0.6	*13.4*	*19.8*
Urgench	0.4	1.9	4.0	0.0	2.0	3.1	1.5	0.6	*13.5*	*22.1*
Yangibazar	0.4	1.4	2.2	0.0	3.0	1.1	1.3	0.3	*9.8*	*20.8*
Gurlan	0.4	0.9	5.5	0.0	3.2	2.5	1.4	0.6	*14.5*	*25.1*
Bagat	1.3	1.9	2.2	0.0	3.0	1.4	1.0	0.2	*11.0*	*13.8*
Yangiarik	0.7	1.2	2.8	0.0	2.6	1.8	0.8	0.5	*10.5*	*16.7*
Khiva	0.9	1.7	0.9	0.0	1.9	4.7	0.9	0.7	*11.6*	*12.3*
Kushkupir	1.5	2.2	1.5	0.1	5.4	2.5	1.3	0.6	*15.1*	*13.3*
Shavat	0.6	2.1	1.9	0.0	3.9	2.2	1.4	0.6	*12.7*	*19.2*
sum	*7.0*	*16.9*	*30.1*	*0.1*	*30.2*	*24.2*	*11.6*	*5.0*	***125.1***	***18.6***
	Gross margins per crop and district for wsdt-50% [10^6 USD]									[%]
Khazarasp	0.0	1.3	0.7	0.0	2.1	2.1	1.1	0.1	*7.3*	*-30.7*
Khanka	0.0	1.1	0.0	0.0	2.5	2.8	0.9	0.6	*7.9*	*-30.0*
Urgench	0.0	0.9	0.1	0.0	1.8	3.1	1.4	0.6	*7.8*	*-29.8*
Yangibazar	0.0	0.8	0.0	0.0	2.4	1.1	1.2	0.3	*5.9*	*-27.8*
Gurlan	0.1	0.7	0.2	0.0	3.0	2.5	1.3	0.6	*8.3*	*-28.4*
Bagat	0.0	1.4	1.0	0.0	2.4	1.4	0.8	0.2	*7.2*	*-25.2*
Yangiarik	0.0	1.0	0.5	0.0	2.1	1.7	0.7	0.5	*6.5*	*-27.4*
Khiva	0.0	0.7	0.0	0.0	1.1	4.6	0.7	0.6	*7.6*	*-26.3*
Kushkupir	0.0	1.3	0.0	0.0	4.2	2.5	1.1	0.6	*9.8*	*-26.5*
Shavat	0.0	0.9	0.0	0.0	2.7	2.2	1.2	0.6	*7.5*	*-29.0*
sum	*0.1*	*10.0*	*2.4*	*0.0*	*24.3*	*23.9*	*10.4*	*4.7*	***75.8***	***-28.1***

Source: model simulation results

8.2.3 Abolishment of the substitution system for cotton

The next two experiments under scenario block 2 were conducted to test crop allocation and the related economical outcome under the abolishment of the cotton quota system and the abandonment of the subsidization system for cotton in Khorezm. For this purpose, the acreage is released; all other parameters, such as prices and costs, are comparable to the status quo situation, with the exception of those for cotton. In experiment one (Lib_1), the cotton sales price and the variable costs for cotton will be changed as described in chapter 7[34], which are based on a situation where the Uzbek

[34] Cotton sales price 282 USD/t + variable cost 512 USD/ha

cotton market would be liberalized and the state order system for cotton[35] would be abolished. The second liberalization experiment (Lib_2) under scenario block 2 will test the reaction of the model to the successive implementation of a cotton market liberalization while maintaining the subsidies for cotton production[36] but allowing the full transfer of bordering prices/Central Asian market prices for cotton[37].

Table 8.29 shows the resultant irrigated area under the two liberalization experiments in comparison to the Baseline 2 scenario. In Lib_1 with modified production costs and sales prices, the acreage in all districts does not change significantly compared to Baseline 2. One reason for this is that with increased sales prices, the costs of cotton production will also increase due to the abolishment of subsidies by the government, and the additional revenues do not prevail costs, meaning that it is still not worthwhile for farmers to crop cotton as long as other products, such as vegetables, wheat, rice or alfalfa, are more economically efficient[38]. A second situation was examined where only sales prices were adapted and costs were still reduced by subsidization (Lib_2). Here, the total acreage increased by 30% (mainly induced by a sharp increase of cotton area), but the district-wide increases are not uniformly distributed.

Table 8.29 Irrigated area per district compared to Baseline 2 with experiments under liberalization of cotton sector

	acreage per district [ha]			**change Lib_1 to Baseline 2** [%]	**change Lib_2 to Baseline 2** [%]
	Baseline 2	**Lib_1**	**Lib_2**		
Khazarasp	14,623	14,623	20,881	0.0	43
Khanka	14,925	14,924	18,134	-0.0	21
Urgench	14,828	14,841	17,164	0.1	16
Yangibazar	11,900	11,904	13,972	0.0	17
Gurlan	16,259	16,117	22,537	-0.9	39
Bagat	14,214	14,357	20,821	1.0	46
Yangiarik	11,122	11,184	16,031	0.6	44
Khiva	11,935	11,780	13,308	-1.3	12
Kushkupir	16,630	16,692	24,548	0.4	48
Shavat	15,610	15,550	17,967	-0.4	15
sum	*142,046*	*141,971*	*185,363*	*-0.1*	*30*

Notes: Lib_1 = Cotton sales price 282 USD/t + variable cost 512 USD/ha
Lib_2 = Cotton sales price 282 USD/t + variable cost 388 USD/ha

Source: model simulation results

35 Subsidies, fixed production quota and reduced but secured sales prices for cotton
36 Reduced prices for seed, machinery and diesel will be reflected in lower variable cost.
37 Cotton sales price 282 USD/t + variable cost 388 USD/ha
38 This effect can be seen per crop in Table 8.30: share of crop area Lib_1 to total area Lib_1 [%].

As seen in Table 8.30, the difference between Baseline 2 and Lib_1 is (also on a crop wise consideration) marginal. However, the changes in acreage between Lib_2 and BL2 are significant and caused by a large increase in cotton area, which is partly at the expense of rice cropping. The cropping of all other crops was not be influenced by the increase in sales prices for cotton (Lib_2)[39]. As in the previous experiments with released acreage, the maximum allowed cropping area for vegetables, alfalfa, potatoes and fruit is already attained, and a further expansion is not allowed. However, even with higher sales prices for cotton, the cropping of vegetables, fruits and alfalfa is still economically efficient. Additionally, with higher sales prices and constant costs (de facto subsidies by the government), the expansion of cotton is economically (in monetary terms) and hydrologically (in terms of water use efficiency if enough water is available as in the base situation of 2003) effective and worthwhile for farmers.

Table 8.30 Crop allocation, share of crop area to total area and comparison with Baseline 2 for cotton sector liberalization under scenario block 2 for Khorezm (in ha and %)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vegetable**	**fruits**	**potato**	**sum**
crop area, Baseline 2 [ha]	8,774	61,492	27,911	98	22,069	10,171	8,016	3,515	*142,046*
share of crop area to total area in Baseline 2 [%]	6	43	20	0	16	7	6	2	*100*
crop area, Lib_1 [ha]	8,795	61,490	27,802	112	22,069	10,171	8,016	3515	*141,971*
share of crop area Lib_1 to total area Lib_1 [%]	6	43	20	0	16	7	6	2	*100*
crop area change lib_1 to Baseline 2 [%]	0.2	0.0	-0.4	14.7	0.0	0.0	0.0	0.0	-0.1
crop area, Lib_2 [ha]	58,352	61,490	21,746	3	22,069	10,171	8,016	3,515	*185,363*
share of crop area Lib_2 to total area Lib_2 [%]	31	33	12	0	12	5	4	2	*100*
crop area change lib_2 to Baseline 2 [%]	565	0	-22	-97	0	0	0	0	*30*

Source: model simulation results

39 The percent decrease of other grains seems high, at -97 %, but is marginal in absolute values.

The expansion of the irrigated area for cotton in experiment *Lib_2* is reflected in a 600% increase in revenue (see Table 8.31), but it is accompanied by a decrease in revenue for rice of -18 %. Revenues for cotton in experiment *Lib_1* increased by 37 % and are a result of the fact that the sales prices in experiment Lib_1 increased to 282 USD/t, and the (small) increase in cropped area for cotton.

Table 8.31 also shows the variable costs for both liberalization experiments. In experiment Lib_1 with increased sales prices and abolishment of the state subsidies, the modification of the production cost by 32 % is reflected in the impact on variable costs for cotton, which changed by 32 %. The increase in sales prices and maintenance of subsidies used in experiment Lib_2 show a strong increase in the total variable cost that is a consequence of the increase in the cotton irrigated area. This interrelation is reflected in identical growth rates for costs and area (see Table 8.31 and Table 8.30 for Lib_2).

The gross margins are shown in Table 8.31. A 3 % increase in the gross margins for Lib_2 was seen compared to BL2. Indeed, the change in gross margins for cotton was more than 700 %, but the increase in absolute values for gross margins is accompanied by a very high total variable cost for cotton for Lib_2 because of the expansion of acreage for cotton. In addition, in both liberalization experiments with modified subsidies, the total absolute gross margins are compensated for by a relatively high reduction in gross margins for rice.

Table 8.31 Gross margin, revenue, and variable cost per crop for cotton market liberalization experiments under scenario block 2 (in 10^6 USD) and compared to Baseline 2 (in %)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruits**	**potato**	***sum***
					Gross margin per crop				
Lib_1 [10^6USD]	1.2	13.4	24.3	0.0	27.0	24.1	10.7	4.9	105.6
Lib_2 [10^6USD]	6.5	14.1	20.4	0.0	27.4	24.1	11.1	4.9	108.6
change lib_1 to BL2 [%]	*56.3*	*-0.6*	*0.0*	*-11.8*	*-0.5*	*0.0*	*-0.2*	*0.1*	*0.2*
change lib_2 to BL2 [%]	*761*	*5.1*	*-16.1*	*-100.5*	*0.9*	*0.0*	*3.1*	*1.2*	*3.0*
					Revenues per crop				
Lib_1 [10^6USD]	5.7	26.6	37.2	0.0	30.8	28.7	14.0	6.9	149.9
Lib_2 [10^6USD]	29.1	27.4	30.5	0.0	31.1	28.7	14.4	6.9	168.1
change lib_1 to BL2 [%]	*37*	*-0.3*	*-0.1*	*6.6*	*-0.4*	*0.0*	*-0.2*	*0.0*	*0.8*
change lib_2 to BL2 [%]	*600*	*2.6*	*-18*	*-98*	*0.8*	*0.0*	*2.4*	*0.8*	*13.1*
					Variable cost per crop				
Lib_1 [10^6USD]	4.5	13.2	12.9	0.0	3.7	4.6	3.3	2.0	44.3
Lib_2 [10^6USD]	22.6	13.2	10.1	0.0	3.7	4.6	3.3	2.0	59.6
change lib_1 to BL2 [%]	*32.3*	*0.0*	*-0.4*	*14.7*	*0.0*	*0.0*	*0.0*	*0.0*	*2.4*
change lib_2 to BL2 [%]	*565*	*0.0*	*-22.1*	*-96.9*	*0.0*	*0.0*	*0.0*	*0.0*	*37.9*

Source: model simulation results

8.2.4 Water pricing under baseline 2

The following section provides a short analysis on water pricing under the given Baseline 2 scenario, with liberalization of the cotton sector for a modified, more efficient crop allocation (in comparison to the status quo Baseline 1) situation. For clarity, the focus shall be on the description of the effects of different water pricing levels on the economical outcomes. The previously determined crop allocation of Baseline 2-liberalization will be the basis of this analysis[40].

Again, three levels of water pricing were chosen: 6, 10 and 25 USD/1000 m^3 of water. As crop allocation is already predetermined, only the influence of water prices on gross margins, water costs and water cost-covering shall be considered.

[40] The liberalization experiment of Baseline 2 as basis of the water pricing analysis is chosen to permit a direct comparison to the Baseline 3 scenario under liberalization.

As a result of increased water cost due to water pricing, the total gross margins decreased (Table 8.32) by 11, 18 and 46 % at water pricing levels of 6, 10 and 25 USD/1000 m^3, respectively. In the case of a water price of 25 USD/1000 m^3, the costs for water add up to more than the total variable production costs. As a result of high water consumption for rice cultivation, the cost for water is highest in Gurlan.

Table 8.32 Gross margin, costs and revenues for experiments with different levels of water pricing under scenario block 2 with liberalization of the cotton sector (in 10^6 USD)

	Gross margin				**Water costs**				**Revenue**[a]	**Variable cost**[a]	**Water supply at district border**
	Lib_1	**wp0.006**	**wp0.010**	**wp0.025**	**Lib_1**	**wp0.006**	**wp0.010**	**wp0.025**	**all scenarios**	**all scenarios**	**all scenarios**
	[10^6 USD]										[10^6 m^3]
Khazarasp	10.5	9.4	8.6	5.8	x	-1.1	-1.9	-4.8	15.3	-4.7	411.8
Khanka	11.2	10.0	9.2	6.2	x	-1.2	-2.0	-5.0	15.7	-4.5	418.5
Urgench	11.1	9.8	8.9	5.6	x	-1.3	-2.2	-5.4	15.7	-4.7	458.5
Yangibazar	8.1	7.1	6.4	3.8	x	-1.0	-1.7	-4.3	11.6	-3.5	350.9
Gurlan	11.6	10.1	9.1	5.4	x	-1.5	-2.5	-6.2	17.2	-5.6	526.6
Bagat	9.7	8.7	8.0	5.5	x	-1.0	-1.7	-4.2	14.2	-4.5	366.1
Yangiarik	9.0	8.1	7.5	5.2	x	-0.9	-1.5	-3.8	12.6	-3.7	326.6
Khiva	10.3	9.4	8.7	6.4	x	-1.0	-1.6	-4.0	14.1	-3.8	338.6
Kushkupir	13.4	12.0	11.1	7.7	x	-1.4	-2.3	-5.7	18.3	-4.9	513.5
Shavat	10.6	9.4	8.6	5.6	x	-1.2	-2.0	-5.1	15.0	-4.4	443.6
sum	*105.6*	*94.0*	*86.2*	*57.2*	*x*	*-11.7*	*-19.4*	*-48.4*	*149.9*	*-44.3*	*4,154.7*
difference to Lib_1 [%]		*-11.0*	*-18.4*	*-45.8*							
% share of corresponding gross margin						*12.5*	*22.5*	*84.6*			

Notes: Lib_1 = Baseline 2 scenario with liberalization of cotton sector
wp0.0xx = water price experiment with levels of 0.006, 0.010 and 0.025 USD/m^3
[a] identical for all scenarios

Source: model simulation results

The share of water costs for the total gross margins at the pricing level of 25 USD/1000 m^3 is more than 84 % of the total gross margins that can be attained. Even at lower water pricing levels of 10 or 6 USD/1000 m^3, the share of water costs to gross margins amounts to 23 and 13 %, respectively.

Because of the increased gross margins under liberalization in Baseline 2 (due to cultivation of more economically and ecologically effective crops), the water price level for which gross margins become zero increased to 55 USD/1000 m^3 compared to 47 USD/1000 m^3 seen in the status quo calculation of Basline1 with water pricing (Table 8.33).

Table 8.33 Water price level per district in which gross margins became zero (in USD/1000 m^3)

Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*sum*
55	56	55	48	47	58	59	65	59	53	55

Source: model simulation results

However, even with this slight increase, water pricing that is comparable to other developing economies (i.e., 25 USD/1000 m^3) is still too high for farmers in Khorezm because of low gross profit margins. A water pricing level under 10 USD/1000 m^3 water is recommended for Khorezm.

8.2.5 Recapitulation scenario block 2

The experiments under block 2 showed that, with released acreage, the more effective crop allocation in terms of crop quantity and crop type will change significantly. The results also illustrate that this allocation is determined by the relationship between more economical (in terms of cost and benefits) and water efficient crops (in terms of water consumption). Simulation results showed that cotton production was drastically reduced, and the available area for vegetables, fruits, alfalfa and potatoes increased compared to the status quo situation (BL1). The total acreage is decreased as a result of an abstraction of marginal and ineffective land under cotton. In situations with additional water supply, more rice (especially in districts close to the river) is cropped and the total acreage increased. The cotton area did not extend because of ineffective cost/benefit relations and relatively high water consumption. With less water supply, the rice acreage decreased drastically and is associated with a reduction in the total area and gross margins. The proportion of wheat production increased in situations with less water supply because it is less water demanding.

With the liberalization of the cotton market and the abolishment of cotton subsidies, the situation does not significantly change; the cost and water consumption for cotton is still too high, and sales prices are too low to balance out the high production costs. If subsidies remained (or cost will be reduced) and bordering prices for cotton could directly pass to farmers, it may be worthwhile to grow cotton.

Regarding water consumption and water effectiveness, wheat and, to some extent, potatoes and alfalfa are more water use efficient. If we consider economical efficiency, (ratio of input cost/output benefit), vegetables, fruits, potatoes, alfalfa and, if enough water is available, rice are most effective and should be cropped.

The analysis on water pricing under scenario block 2 showed that, even with increased gross margins due to modified and more efficient crop allocation and cultivation, a water pricing level of more than 10 USD/1000 m^3 is not accomplishable because of relatively low gross profit margins in Khorezm. At a higher water price level, crop cultivation is not beneficial.

However, the results of scenario block 2 with released acreage also showed that the crop allocation is only controlled by this hydrologic-economic efficiency optimization factor, and the most effective crops were cropped over the entire area up to set boundaries. Modified acreage and crop production, dependent on supply and demand and willingness to pay for a certain product, will result in changed crop prices. These are not yet included in the optimization and production function. The results and weaknesses shown here illustrate that this demand- and supply-dependent price factor should taken into account for the next set of experiments under scenario block 3. Nevertheless, this analysis was very important and showed the effect of more efficient crop allocation considering both, water demand and the cost/price effectiveness of the crops.

8.3 Model results scenario block 3– introduction of a price-function and liberalization of cotton sector

The analysis of the previous scenarios addressed the inspection of water and the cropping system in Khorezm under observed conditions in terms of cropping pattern and acreage (Baseline 1 and its experiments), and sales prices and production costs with released acreage (Baseline 2 and its experiments). The following scenario block 3 addresses the situation with modified governmental procurement system for cotton and the implementation of a price function. The scenario shall provide information on more effective crop allocation and acreage, variable sales prices dependent on the market situation for certain crops in Khorezm and the resultant economical impact. For this reason, it is necessary to first release the crop area and then the sales prices for agricultural products in the following experiments. According to chapter 3.2.4, an endogenously calculated crop price will be determined to account for the variable crop sales prices that depend on demand and supply and the willingness to pay for a product[41]. Thereby, both, sales prices and supply/acreage will be modified internally.

8.3.1 Baseline 3

For the price function scenario with the abolishment of the state order for cotton, the production costs of cotton increased by 32 %. Because cotton is exported and not traded on local markets, a 30 % higher cotton price is assumed (see chapter 7.1.5). The acreage is released and a price function is implemented. The resultant scenario (Baseline 3) will be the basis of comparison with other price function scenarios under scenario block 3 by modifying the water supply and introducing a water price.

Unlike the scenarios under status quo conditions (with observed acreage and existent state order system, Baseline 1), where the effects of changes in water supply and water management on soil and water balances and crop-parameters were considered in more detail, the focus of the following experiments will be on the economical output to understand the effect of price mechanisms, crop allocation and liberalization of the cotton sector on agricultural profits, gross margins and revenues for changes in cropping pattern, areas, crop pricing and allocation.

Revenues, cropping area, variable costs and gross margins under released state order system

Due to the implementation of endogenously determined and demand-dependent crop sales prices, crop allocation is not only dependent on optimal water use and cost-price

41 With the exception of cotton, as no trade on local market is taking place; bordering prices are assumed.

relations for single crops (as already shown in Baseline 2), but it is also dependent on cropping acreage and the resulting demand and supply controlled variable crop prices. If only a few crops (here in the model mainly for optimal water allocation and maximal profits) are grown in expanded areas and the supply on local markets increases, the resultant decreased demand will cause lower prices for those crops until an equilibrium of demand and supply under optimal prices and cropping areas is reached.

Under a liberalized scenario in Khorezm, the model simulations indicate a decline of total acreage of 57 % compared to the base situation (BL1, Table 8.34). The percent change in area for all crops would decrease, but primarily it would decrease for potato, vegetables and wheat. Overall, the area for crops produced in huge quantities, such as cotton, wheat and rice, will decrease. The marginal and/or unproductive land is taken out of the production system. It can be used as a starting point to consider ecological measures (for alternative uses like tree plantation, ponds or other ecological utilizations).

Table 8.34 Comparison of absolute and relative changes in acreage per district and crop between Baseline 1 and Baseline 3 scenarios

	Baseline 3	*Khazarasp*	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*average/sum*
cotton	absolute area [ha]	4,913	5,352	3,909	4,325	4,481	3,900	2,842	3,792	4,310	5,061	42,886
	relative change to BL1 [%]	*-53*	*-49*	*-58*	*-58*	*-63*	*-56*	*-55*	*-50*	*-62*	*-55*	*-56*
	absolute change [ha]	-5,543	-5,071	-5,336	-5,880	-7,475	-4,917	-3,522	-3,850	-7,105	-6,138	-54,836
wheat	absolute area [ha]	1,718	1,550	1,700	1,228	1,174	1,506	926	1,203	2,476	1,669	15,150
	relative change to BL1 [%]	*-65*	*-74*	*-71*	*-73*	*-68*	*-72*	*-73*	*-74*	*-59*	*-75*	*-70*
	absolute change [ha]	-3,183	-4,520	-4,167	-3,287	-2,527	-3,878	-2,520	-3,345	-3,556	-5,109	-36,092
rice	absolute area [ha]	2,686	1,802	1,940	895	3,161	1,107	968	512	1,020	805	14,897
	relative change to BL1 [%]	*-45*	*-45*	*-45*	*-54*	*-42*	*-43*	*-61*	*-34*	*-23*	*-51*	*-44*
	absolute change [ha]	-2,226	-1,449	-1,609	-1,038	-2,263	-837	-1,504	-259	-301	-849	-12,334

Table 8.34 continued

	Baseline 3	*Khazarasp*	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*average/sum*
other grain	absolute area [ha]	12	22	48	12	130	144	37	61	196	27	690
	relative change to BL1 [%]	*-89*	*-85*	*-86*	*-84*	*-65*	*30*	*-83*	*-50*	*-39*	*-89*	*-64*
	absolute change [ha]	-97	-130	-304	-62	-244	33	-184	-61	-125	-211	-1,384
alfalfa	absolute area [ha]	716	683	759	481	1,761	1,688	2,056	1,474	1,647	916	12,182
	relative change to BL1 [%]	*-52*	*-60*	*-37*	*-74*	*-25*	*-6*	*36*	*36*	*-47*	*-60*	*-29*
	absolute change [ha]	-774	-1,017	-455	-1,350	-584	-107	546	388	-1,479	-1,378	-6,209
vege-table	absolute area [ha]	110	397	164	62	237	144	133	177	368	239	2,033
	relative change to BL1 [%]	*-85*	*-59*	*-85*	*-85*	*-74*	*-71*	*-78*	*-89*	*-58*	*-68*	*-75*
	absolute change [ha]	-620	-572	-927	-342	-661	-358	-477	-1467	-503	-518	-6,443
fruit	absolute area [ha]	395	279	509	182	467	370	285	220	952	534	4,193
	relative change to BL1 [%]	*-41*	*-44*	*-40*	*-76*	*-48*	*-33*	*-39*	*-54*	*36*	*-34*	*-37*
	absolute change [ha]	-273	-223	-336	-582	-434	-178	-180	-255	252	-278	-2,487
potato	absolute area [ha]	3	112	11	13	49	53	35	47	30	114	467
	relative change to BL1 [%]	*-96*	*-67*	*-97*	*-93*	*-87*	*-60*	*-89*	*-89*	*-92*	*-68*	*-84*
	absolute change [ha]	-64	-228	-344	-189	-326	-80	-269	-374	-340	-248	-2,462

Notes: BL1= Baseline 1 scenario (status quo) with fixed area
Baseline 3 scenario with liberalization of the cotton sector, released area and price-function

Source: model simulation results

The reduction in acreage is observed in all soil types, but it is approximately 77 % higher for light soils and 70 % for heavy soils (Table 8.35)[42]. These results are in

[42] Compared to the *Baseline 2* scenario, with already released acreage but without price function, the reduction in crop area is -35 %, as all other parameter are constant due to the price effect. The reduction in area can mainly be seen for wheat, rice, alfalfa, vegetables and, to some extent, fruit and potatoes, whereas the cotton area is increased (see Table E-4 of Appendix E). On closer examination of gross margins, mainly alfalfa and vegetables suffer huge losses, whereas cotton can increase its gross margin compared to Baseline 2.

line with the fact that medium soils tend to be most advantageous under conditions of irrigated agriculture[43].

Table 8.35 Comparison of absolute and relative changes in acreage per soil type between the Baseline 1 scenario and the Baseline 3 scenario

Soil type	**relative change** [%]	**absolute change** [ha]
light	*-77.1*	-18,735
medium	*-48.0*	-65,491
heavy	*-70.3*	-38,021
average	*-65.1*	
sum		-122,247

Source: model simulation results

This tendency is caused by an increase of 48 to 84% in sales prices for all provided crops in Khorezm (Table 8.36).

Table 8.36 Comparison of absolute prices (in USD/t) and relative changes in crop prices per district between Baseline 1 and Baseline 3 scenarios

Crop prices BL3 [USD/t]	**Cotton**[a]	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**
Khazarasp	282	181	454	216	105	159	251	378
Khanka	282	190	476	202	113	165	258	325
Urgench	282	186	428	176	105	157	243	301
Yangibazar	282	188	468	236	112	162	254	329
Gurlan	282	187	433	182	105	157	245	316
Bagat	282	172	398	126	85	150	233	299
Yangiarik	282	182	426	175	105	156	243	306
Khiva	282	169	428	182	103	156	243	312
Kushkupir	282	165	398	138	86	149	230	289
Shavat	282	189	471	204	114	163	257	323
average	**282**	**181**	**438**	**184**	**103**	**157**	**246**	**318**
Comparison BL1 and BL3 relative change [%]								
Khazarasp	*30*	*77*	*55*	*116*	*50*	*50*	*57*	*110*
Khanka	*30*	*86*	*63*	*102*	*62*	*55*	*61*	*81*
Urgench	*30*	*82*	*47*	*76*	*50*	*48*	*52*	*67*
Yangibazar	*30*	*84*	*60*	*136*	*60*	*53*	*59*	*83*
Gurlan	*30*	*83*	*48*	*82*	*50*	*48*	*53*	*75*
Bagat	*30*	*69*	*36*	*26*	*22*	*42*	*46*	*66*
Yangiarik	*30*	*78*	*46*	*75*	*50*	*47*	*52*	*70*
Khiva	*30*	*66*	*47*	*82*	*47*	*47*	*52*	*73*
Kushkupir	*30*	*62*	*36*	*38*	*22*	*41*	*44*	*61*
Shavat	*30*	*86*	*61*	*104*	*62*	*53*	*60*	*80*
average	***30***	***77***	***50***	***84***	***48***	***48***	***54***	***77***

Notes: [a] sales prices for cotton are fixed as it is exported and not traded on local markets BL3=Baseline 3

Source: model simulation results

[43] Light soils have disadvantages: low storage capacity and high permeability requiring either techniques like sprinklers or small units in the fields with furrows and basins. Heavy soils are also not optimal, as they have only medium storage capacity and in many cases drainage problems.

The prices for these crops increased in the model simulations due to area and supply reductions[44]. Increases in sales prices for crops such as potato, grains and wheat are higher than those for alfalfa, vegetables, fruit and rice because the latter (mainly vegetables and fruits) are more water efficient and have a better cost-benefit relationship and are preferred for cropping[45]. Crop supply is higher compared to potatoes, grains and wheat, whereas the demand for those crops is increased (see also Baseline 2).

The total agricultural gross margins per district in Khorezm are, compared to the Baseline 1 scenario under 2003 conditions, heterogeneously. For districts like Bagat, Yangiarik, Khiva and Kushkupir, the absolute values are relatively low and are lower than those for the Baseline 1 scenario (Table 8.37). The results are primarily a function of the change in gross margins for *cotton*; which were mostly negative in the Baseline 1 scenario (see Figure 8.1). Due to the abolishment of the governmental cotton quota system and the increase in sales prices for cotton, the revenues for cotton increased in the price function scenario (BL3). For most of the other crops, the gross margins decrease in the price function scenario (compared to BL1) due to higher sales prices, decreased acreage, and less production. The total gross margins are dependent on the relation between changes in gross margins for cotton and for all other crops; in some cases, this change is negative or slightly positive for districts, such as Khanka, Gurlan or Shavat because the acreage of cotton is higher (see Table 8.34, absolute area) than in other districts.

Upon closer examination of gross margins per crop in the price function scenario, we see that cotton, wheat, rice and, to some extent, fruit and vegetables have a huge share of the gross margins because of the relationship between acreage and sales and production-costs. For rice, this is true in districts close to the river, where rice is a beneficial crop in good water supply years.

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[44] Or vice versa, as they are mutually dependent.

[45] As demonstrated in the first scenarios under status quo conditions (Baseline 1).

Table 8.37 Gross margins (absolute values and absolute changes in 10^6 USD) for Baseline 1 scenario and Baseline 3 scenario

	cotton	wheat	rice	other grains	alfalfa	vege-table	fruit	potato	*sum*
Baseline 3, Gross margins [10^6 USD]									
Khazarasp	1.72	0.86	4.03	0.01	0.53	0.31	0.61	0.01	*8.07*
Khanka	1.72	1.20	3.37	0.01	0.84	1.34	0.77	0.36	*9.63*
Urgench	1.37	1.32	3.23	0.02	0.74	0.57	1.33	0.03	*8.63*
Yangibazar	1.46	0.95	1.67	0.01	0.95	0.25	0.50	0.04	*5.83*
Gurlan	1.33	0.89	5.34	0.06	1.24	0.76	1.15	0.15	*10.94*
Bagat	1.42	0.93	1.35	0.00	0.62	0.45	0.62	0.15	*5.53*
Yangiarik	1.04	0.77	1.61	0.02	1.32	0.52	0.75	0.10	*6.14*
Khiva	1.39	0.74	0.75	0.04	0.87	0.68	0.56	0.14	*5.17*
Kushkupir	1.51	1.18	1.14	0.00	0.73	0.31	0.27	0.09	*5.22*
Shavat	1.73	1.32	1.50	0.02	1.48	0.98	1.50	0.37	*8.90*
average	*1.47*	*1.02*	*2.40*	*0.02*	*0.93*	*0.62*	*0.81*	*0.15*	
sum	14.68	10.15	23.99	0.19	9.31	6.19	8.08	1.45	***74.03***
Baseline 1, Gross margins [10^6 USD]									
Khazarasp	-0.65	1.21	4.02	0.00	1.63	1.70	0.85	0.09	*8.84*
Khanka	-0.78	1.41	2.98	0.00	2.09	2.33	0.72	0.48	*9.24*
Urgench	-0.87	1.27	3.14	-0.02	1.41	2.56	1.11	0.49	*9.09*
Yangibazar	-0.88	0.95	1.76	0.00	2.22	0.95	1.04	0.28	*6.33*
Gurlan	-0.75	0.63	3.83	-0.02	2.27	2.09	1.06	0.48	*9.58*
Bagat	0.32	1.45	1.79	0.02	2.47	1.18	0.79	0.19	*8.21*
Yangiarik	-0.06	1.00	2.30	0.01	1.97	1.46	0.68	0.43	*7.79*
Khiva	-0.37	1.34	0.71	0.02	1.53	3.92	0.71	0.60	*8.47*
Kushkupir	-0.09	1.76	1.24	0.06	4.42	2.10	1.06	0.53	*11.07*
Shavat	-0.91	1.43	1.52	0.00	2.92	1.80	1.16	0.50	*8.42*
average	*-0.50*	*1.25*	*2.33*	*0.01*	*2.29*	*2.01*	*0.92*	*0.41*	
sum	-5.04	12.45	23.29	0.06	22.93	20.10	9.18	4.07	***87.04***
Change between BL3 and BL1 [10^6 USD]									
Khazarasp	2.37	-0.35	0.01	0.01	-1.10	-1.39	-0.23	-0.08	*-0.77*
Khanka	2.50	-0.21	0.40	0.01	-1.25	-0.99	0.05	-0.12	*0.39*
Urgench	2.24	0.05	0.10	0.04	-0.66	-1.99	0.22	-0.46	*-0.46*
Yangibazar	2.33	-0.01	-0.10	0.01	-1.27	-0.70	-0.54	-0.24	*-0.50*
Gurlan	2.09	0.26	1.52	0.08	-1.03	-1.33	0.09	-0.33	*1.35*
Bagat	1.10	-0.52	-0.44	-0.02	-1.85	-0.73	-0.17	-0.03	*-2.68*
Yangiarik	1.10	-0.23	-0.69	0.01	-0.65	-0.95	0.08	-0.33	*-1.66*
Khiva	1.76	-0.59	0.04	0.01	-0.67	-3.24	-0.15	-0.46	*-3.30*
Kushkupir	1.60	-0.58	-0.10	-0.06	-3.69	-1.78	-0.79	-0.44	*-5.85*
Shavat	2.63	-0.12	-0.02	0.02	-1.44	-0.82	0.34	-0.14	*0.47*
average	*2.0*	*-0.2*	*0.1*	*0.0*	*-1.4*	*-1.4*	*-0.1*	*-0.3*	
sum	19.71	-2.30	0.70	0.13	-13.62	-13.91	-1.10	-2.62	***-13.00***

Notes: Baseline 1 (BL1): baseline scenario with 2003 conditions in terms of acreage, variable production costs and sales prices, state order system
Baseline 3 (BL3): price function scenario with defixed area, released state order system, price function

Source: model simulation results

As shown in Table 8.38, total revenues for all districts and crops are positive and are a result of high revenues obtained for cotton, rice, and, to some extent, wheat and alfalfa. Compared to the Baseline 1 scenario, total revenues decreased (between 19 to 51 %). Cotton revenues turn out to be higher than for the Baseline 1 scenario (and for some districts, for fruit and rice as well), with the exception of Kushkupir, Gurlan and Bagat. All other crop revenues declined compared to the Baseline 1. These results are primarily due to the reduction in cropping area that could not be compensated for by higher sales prices and the quantities and types of crops that were grown. Unlike in Baseline 2, the crop allocation is not only dependent on water consumption and economical efficiency (cots/benefit relation) of the crop, but also on demand and supply and modified sales prices. As a result, also crops with lower economical (in monetary terms) and ecological efficiency (water consumption) are cropped because the willingness to pay for a certain crop will influence the prices and the supply. The outcome is that revenues for those less beneficial crops decline and are lower than in Baseline 2 without the price function.

With the abolition of substitutions for cotton production in the price function scenario, the production costs per ha for cotton increased (see chapter 7), but as a result of a reduction in cotton area the total costs decreased compared to the Baseline 1 scenario (see Table 8.38).

For all other crops, the variable production costs per hectare are constant compared to the Baseline 1 scenario because the variable costs for inputs, such as fertilizer, diesel, seed and labor remain the same. The total production costs per district decreased because the acreage decreased under the price function scenario (BL3). Therefore, we can conclude that the production cost change between Baseline 1 and Baseline 3 is a result of cropping area changes and both changes (area and costs) must be logically the same as precisely seen in Table 8.34.

Table 8.38 Revenues and production costs of the Baseline 3 scenario, and comparison of revenue and production costs between the Baseline 1 scenario and Baseline 3 scenario (in 10^6 USD and %)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	**sum**
				Revenue, Baseline 3 [10^6 USD]					
Khazarasp	4.23	1.23	5.27	0.01	0.65	0.36	0.77	0.01	**12.53**
Khanka	4.46	1.54	4.21	0.02	0.96	1.52	0.88	0.42	**14.01**
Urgench	3.37	1.69	4.13	0.03	0.87	0.64	1.54	0.04	**12.32**
Yangibazar	3.67	1.21	2.08	0.01	1.03	0.28	0.58	0.05	**8.92**
Gurlan	3.63	1.14	6.81	0.09	1.54	0.87	1.34	0.18	**15.60**

Table 8.38. continued

	cotton	wheat	rice	other grain	alfalfa	vege-table	fruit	potato	sum
Bagat	3.41	1.25	1.87	0.02	0.90	0.51	0.77	0.19	**8.92**
Yangiarik	2.50	0.97	2.06	0.03	1.66	0.58	0.87	0.12	**8.79**
Khiva	3.33	1.00	0.98	0.05	1.12	0.76	0.65	0.17	**8.06**
Kushkupir	3.71	1.71	1.61	0.04	1.01	0.48	0.66	0.10	**9.32**
Shavat	4.32	1.67	1.88	0.02	1.63	1.09	1.72	0.43	**12.77**
sum	*36.64*	*13.41*	*30.90*	*0.33*	*11.37*	*7.11*	*9.78*	*1.72*	
change between revenue BL1 to BL3 [%]									
Khazarasp	*24*	*-46*	*-16*	*-60*	*-66*	*-82*	*-31*	*-90*	***-27***
Khanka	*37*	*-43*	*-6*	*-44*	*-60*	*-45*	*-4*	*-38*	***-19***
Urgench	*24*	*-33*	*-14*	*-36*	*-46*	*-79*	*6*	*-94*	***-27***
Yangibazar	*19*	*-37*	*-22*	*1*	*-59*	*-75*	*-57*	*-87*	***-32***
Gurlan	*-7*	*-20*	*7*	*63*	*-42*	*-65*	*-6*	*-74*	***-18***
Bagat	*-9*	*-52*	*-31*	*-38*	*-68*	*-64*	*-24*	*-30*	***-39***
Yangiarik	*3*	*-44*	*-40*	*-44*	*-25*	*-67*	*1*	*-80*	***-33***
Khiva	*28*	*-57*	*-8*	*1*	*-35*	*-84*	*-28*	*-80*	***-43***
Kushkupir	*-14*	*-44*	*-13*	*-69*	*-80*	*-81*	*-51*	*-86*	***-51***
Shavat	*26*	*-42*	*-18*	*-43*	*-51*	*-49*	*15*	*-39*	***-22***
Production costs BL3 [10^6 USD]									
Khazarasp	2.52	0.37	1.25	0.00	0.12	0.05	0.16	0.00	**4.47**
Khanka	2.74	0.33	0.84	0.00	0.12	0.18	0.11	0.06	**4.39**
Urgench	2.00	0.37	0.90	0.01	0.13	0.07	0.21	0.01	**3.69**
Yangibazar	2.21	0.26	0.42	0.00	0.08	0.03	0.07	0.01	**3.09**
Gurlan	2.29	0.25	1.47	0.03	0.30	0.11	0.19	0.03	**4.66**
Bagat	2.00	0.32	0.51	0.03	0.29	0.07	0.15	0.03	**3.39**
Yangiarik	1.46	0.20	0.45	0.01	0.35	0.06	0.12	0.02	**2.65**
Khiva	1.94	0.26	0.24	0.01	0.25	0.08	0.09	0.03	**2.90**
Kushkupir	2.21	0.53	0.47	0.04	0.28	0.17	0.39	0.02	**4.10**
Shavat	2.59	0.36	0.37	0.01	0.15	0.11	0.22	0.07	**3.87**
sum	*21.96*	*3.26*	*6.91*	*0.14*	*2.06*	*0.92*	*1.70*	*0.27*	
change between production costs BL1 to BL3 [%]									
Khazarasp	*-38*	*-65*	*-45*	*-89*	*-52*	*-85*	*-41*	*-96*	***-46***
Khanka	*-32*	*-74*	*-45*	*-85*	*-60*	*-59*	*-44*	*-67*	***-45***
Urgench	*-44*	*-71*	*-45*	*-86*	*-37*	*-85*	*-40*	*-97*	***-53***
Yangibazar	*-44*	*-73*	*-54*	*-84*	*-74*	*-85*	*-76*	*-93*	***-54***
Gurlan	*-51*	*-68*	*-42*	*-65*	*-25*	*-74*	*-48*	*-87*	***-50***
Bagat	*-42*	*-72*	*-43*	*30*	*-6*	*-71*	*-33*	*-60*	***-46***
Yangiarik	*-41*	*-73*	*-61*	*-83*	*36*	*-78*	*-39*	*-89*	***-50***
Khiva	*-35*	*-74*	*-34*	*-50*	*36*	*-89*	*-54*	*-89*	***-49***
Kushkupir	*-50*	*-59*	*-23*	*-39*	*-47*	*-58*	*36*	*-92*	***-48***
Shavat	*-40*	*-75*	*-51*	*-89*	*-60*	*-68*	*-34*	*-68*	***-51***
avg	*-42*	*-70*	*-44*	*-64*	*-29*	*-75*	*-37*	*-84*	

Source: model simulation results

In conclusion, model results indicate that the liberalization of cotton production in Uzbekistan/Khorezm and the introduction of a price-function into the model caused sales prices for all crop to become significantly higher. However, unproductive agricultural areas are taken out of the production simultaneously.

The gross margins for cotton increased compared to partly negative values seen in the Baseline 1 scenario. In the Khanka, Gurlan and Shavat districts, the gross margins increase compared to the Baseline 1 because of high acreages and revenues for cotton, and in Gurlan for rice. A general trend favoring districts close to the river cannot be confirmed as long as sufficient water allocation and canal distribution is warranted.

The modeling results indicate that the liberalization in cotton production and the implementation of a price function would lead to higher production costs and higher sales prices. Due to modified price regulations, supply, demand and the resulting sales prices will change the whole crop allocation. Subsequently, less efficient crops, such as cotton, become more attractive because the supply of other crops will decrease due to high sales prices. In cooperation with the Water User Associations (WUA) and the management of common resources, such as machinery-parks, it would be possible to reduce costs and use manpower more effectively to reduce the costs for the individual farmer.

8.3.2 Price function scenario- water supply experiments

The effect of modified water supply under liberalization and after introduction of a price function will be described in the following paragraphs. Different levels of water supply have significant impacts on crop allocation, gross margins and sales prices for crops. Here, an increase and decrease in water supply by 50 % compared to the observed situation in 2003 will be examined.

Crop allocation and cropping area

A 53% increase in total cropped area is seen with increased water supply. This can be attributed to a sharp rise in crops such as rice, vegetables and fruits (Table 8.39), which are water demanding but very beneficial in terms of sales revenues. The percent increase for other grains (maize, barley etc.) is more than 240 %, but their influence in absolute values is still limited due to the relatively small area of not more than 1.2 % of the total area. The total acreage for cotton is 45,000 ha, followed by rice, wheat and alfalfa (see Table 8.40).

Interestingly, with decreased water supply, the total cropping area increased by 17 % compared to BL3, which is not necessarily expected because lower water supply usually means less area can be sufficiently cropped. This same rationale can be applied to all other crops, with the exception of cotton and wheat in some districts (see Table 8.39). In these areas, cotton acreage is increasing and is a major influence for the total cropped area. The total acreage of cotton is 58 % of the total area (see Table 8.40). The constant sales price for cotton and beneficial revenues in the model help explain these results. Even with less water and lower yields, it is worthwhile for farmers to grow cotton for export in the price function scenario because sales prices are in BL3 increased and constant for cotton.

Table 8.39 Crop Area, comparison between Baseline 3 scenario and experiments with modified water supply

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	**total**
total area Baseline 3[a] [ha]	42,886	15,150	14,897	690	12,182	2,033	4,193	467	92,498
area change, wsdt+50cppcalc[b] [%]	*4.6*	*68.2*	*123.4*	*150.0*	*67.6*	*123.0*	*154.1*	*7.2*	*52.9*
area change, wsdt-50cppcalc[c] [%]	*46.0*	*15.8*	*-24.5*	*-47.5*	*-8.2*	*-16.6*	*-17.4*	*-10.7*	*17.3*

[a] Baseline 3= price function scenario
[b] wsdt+50cppcalc = scenario with water supply +50%
[c] wsdt-50cppcalc = scenario with water supply -50%

Source: model simulation results

Table 8.40 Total cropped area per district and crop in ha for experiments with water supply +50% and -50%

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**	**total per district**
				Area wsdt+50cppcalc [ha]					
Khazarasp	4,788	4,725	5,802	34	1,208	310	1,143	3	*18,013*
Khanka	5,046	2,001	2,406	104	1,755	498	1,168	125	*13,103*
Urgench	3,976	1,740	3,611	169	1,321	496	1,644	12	*12,969*
Yangibazar	4,346	2,399	1,915	50	1,805	246	845	15	*11,620*
Gurlan	4,410	1,480	7,716	497	2,839	757	1,973	51	*19,722*
Bagat	4,456	4,333	3,235	160	1,786	454	1,153	54	*15,632*
Yangiarik	2,944	1,197	2,640	149	2,995	477	363	36	*10,803*
Khiva	3,775	1,849	1,612	234	2,072	594	766	49	*10,951*
Kushkupir	6,000	4,061	2,954	194	1,996	439	983	31	*16,656*
Shavat	5,133	1,698	1,383	135	2,636	263	617	127	*11,991*
total area per crop	*44,874*	*25,484*	*33,274*	*1,726*	*20,413*	*4,534*	*10,654*	*501*	*141,459*
% of total area	*31.7*	*18.0*	*23.5*	*1.2*	*14.4*	*3.2*	*7.5*	*0.4*	
				Area wsdt-50cppcalc [ha]					
Khazarasp	7,906	1,511	2,077	11	594	106	437	3	*12,644*
Khanka	9,104	2,180	1,498	18	918	333	281	101	*14,433*
Urgench	5,917	2,442	1,424	33	1,027	146	499	10	*11,498*
Yangibazar	6,889	1,654	738	12	1,200	64	190	12	*10,759*
Gurlan	6,965	1,539	2,326	99	1,575	258	470	45	*13,276*
Bagat	4,665	1,518	718	43	709	150	255	46	*8,103*
Yangiarik	3,311	1,030	811	40	1,312	131	406	32	*7,073*
Khiva	5,185	1,292	345	52	1,168	171	205	40	*8,458*
Kushkupir	4,662	1,700	642	38	789	106	212	27	*8,177*
Shavat	8,012	2,671	668	17	1,891	229	508	102	*14,097*
total area per crop	*62,616*	*17,538*	*11,247*	*362*	*11,182*	*1,695*	*3,462*	*417*	*108,519*
% of total area	*57.7*	*16.2*	*10.4*	*0.3*	*10.3*	*1.6*	*3.2*	*0.4*	

Source: model simulation results

Crop sales prices

As expected, crop sales prices are lower when water supply increases (Table 8.41). An opposite effect can be seen for the price function scenario with reduced water supply of 50 %. Apart from other grains, which are characterized by low acreage, the increase in sales prices for rice was 22 %. The acreage of the high water demanding crop rice will decrease in situations with water deficit and consumer demand and willingness to pay will rise.

With an increase in water supply of 50 %, the price for other grains and alfalfa/clover in Khorezm will decrease between 29 and 19 %. Grains for fodder are produced as a byproduct/second crop and are not that important for the local market (especially in humid years) because they are always produced (mainly for self-utilization of fodder crops by the farmers who have both, crops and livestock). In dry years, the water supply for first and/or cash crops is often insufficient, however, livestock must be fed; therefore, farmers are willing to pay more for fodder crops.

Table 8.41 Crop sales prices for experiments with water supply +50% and -50%; total per crop (in USD/t and in %) compared to Baseline 3

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**
Sales price wsdt+50cppcalc [USD/t]								
Khazarasp	282	162	397	157	81	148	227	358
Khanka	282	167	397	113	84	150	233	296
Urgench	282	176	397	123	87	150	232	290
Yangibazar	282	166	398	155	82	148	230	303
Gurlan	282	166	396	122	82	148	228	303
Bagat	282	166	373	103	78	145	221	296
Yangiarik	282	166	397	129	86	151	234	296
Khiva	282	166	396	134	82	148	230	299
Kushkupir	282	165	377	123	78	145	222	287
Shavat	282	177	396	124	89	151	234	296
Sales price wsdt+50cppcalc, change to Baseline 3 [%]								
Khazarasp	0	-10	-13	-27	-23	-7	-10	-5
Khanka	0	-12	-17	-44	-26	-9	-10	-9
Urgench	0	-5	-7	-30	-18	-4	-5	-4
Yangibazar	0	-12	-15	-34	-26	-9	-10	-8
Gurlan	0	-11	-8	-33	-22	-6	-7	-4
Bagat	0	-4	-6	-18	-8	-4	-5	-1
Yangiarik	0	-9	-7	-26	-19	-3	-4	-3
Khiva	0	-2	-7	-26	-20	-5	-6	-4
Kushkupir	0	0	-5	-11	-9	-3	-3	-1
Shavat	0	-6	-16	-39	-22	-7	-9	-8
average	*0*	*-7*	*-10*	*-29*	*-19*	*-6*	*-7*	*-5*
Sales price wsdt-50cppcalc [USD/t]								
Khazarasp	282	195	539	268	117	172	274	408
Khanka	282	200	552	248	120	177	278	355
Urgench	282	198	545	250	118	175	276	345
Yangibazar	282	197	546	278	118	175	276	358
Gurlan	282	195	544	249	119	175	273	355
Bagat	282	192	505	213	113	168	264	338
Yangiarik	282	191	495	220	115	167	267	332
Khiva	282	200	558	255	119	175	277	355
Kushkupir	282	189	485	221	115	165	260	321
Shavat	282	202	552	252	124	177	279	355
Sales price wsdt-50cppcalc, change to Baseline 3 [%]								
Khazarasp	0	8	19	24	11	8	9	8
Khanka	0	5	16	23	6	7	8	9
Urgench	0	6	27	42	13	12	13	14
Yangibazar	0	5	17	18	5	8	8	9
Gurlan	0	5	25	37	13	11	12	12
Bagat	0	12	27	69	33	12	13	13

Table 8.41. continued

	cotton	wheat	rice	other grain	alfalfa	vege-table	fruit	potato
Yangiarik	0	5	16	26	9	7	10	8
Khiva	0	18	30	40	15	13	14	14
Kushkupir	0	14	22	60	34	10	13	11
Shavat	0	6	17	24	9	9	9	10
average	*0*	*8*	*22*	*36*	*15*	*10*	*11*	*11*

Source: model simulation results

Gross margins, revenues and costs

As seen in Table 8.42, revenues for the price function scenario with reduced water quantity is decreased by approximately 4 % in all districts and for all crops. This is particularly the case for rice and other grains, which have an 11 and 17 % reduction, respectively. Gurlan, which is the main rice producing district, is most strongly affected. The reduction in cropped area and the production of lower quantities as a consequence of less water availability could not be compensated for with a higher sales price.

Simulations with increased water availability indicate that revenues increased by only 0.3 %. This small increase is primarily caused by an enhancement in wheat and rice production. Interestingly, Bagat, Yangiarik, Khiva and Kushkupir had decreases in total gross margins because crop sales prices and resulting revenues declined. Even an increase in the cropping area could not compensate for the lower earnings due to a decline in prices.

Table 8.42 Changes in revenue per district and crop with water supply +50 % and water supply-50 % compared to Baseline 3 scenario (in %)

	Cotton[a]	wheat	rice	other grain	alfalfa	vege-table	fruit	potato	Total[b]
				Revenue wsdt+50%cppcalc, change to BL3 [%]					
Khazarasp	**0.0**	**0.8**	**2.1**	**-4.0**	**-5.2**	**0.3**	**0.5**	**0.6**	***0.7***
Khanka	**0.0**	**2.2**	**4.2**	**-1.5**	**-3.5**	**0.9**	**1.2**	**1.6**	***1.5***
Urgench	0.0	1.1	0.6	-6.5	-3.1	0.2	0.2	0.4	*0.2*
Yangibazar	0.0	1.8	3.2	-0.4	-4.2	0.6	0.9	1.2	*0.6*
Gurlan	0.0	1.7	0.9	-6.9	-4.6	0.2	0.2	0.5	*0.0*
Bagat	0.0	0.2	-0.3	-8.4	-3.2	-0.1	-0.2	0.1	*-0.4*
Yangiarik	0.0	1.0	0.5	-4.8	-3.4	0.1	0.2	0.3	*-0.4*
Khiva	0.0	0.0	0.6	-4.0	-4.8	0.1	0.1	0.4	*-0.6*
Kushkupir	0.0	0.0	-0.2	-4.5	-3.2	-0.1	-0.2	0.0	*-0.4*
Shavat	0.0	1.6	3.7	0.6	-1.6	0.7	1.0	1.4	*0.8*
average	*0.0*	*1.0*	*1.5*	*-4.1*	*-3.7*	*0.3*	*0.4*	*0.7*	
total average									***0.3***

Table 8.42 continued

	Cotton[a]	wheat	rice	other grain	alfalfa	vege-table	fruit	potato	Total[b]
Revenue wsdt-50%cppcalc, change to BL3 [%]									
Khazarasp	0.0	-2.4	-11.0	-10.9	-1.2	-1.8	-2.5	-2.1	*-5.2*
Khanka	0.0	-2.2	-11.8	-25.5	-1.5	-2.2	-2.7	-3.8	*-4.5*
Urgench	0.0	-2.3	-13.3	-24.7	-1.6	-2.5	-3.2	-4.5	*-5.5*
Yangibazar	0.0	-1.7	-11.2	-13.8	-1.0	-2.1	-2.6	-3.4	*-3.2*
Gurlan	0.0	-1.6	-13.0	-22.2	-1.7	-2.4	-2.8	-3.8	*-6.5*
Bagat	0.0	-2.4	-7.5	-4.9	3.1	-1.4	-1.9	-2.6	*-1.9*
Yangiarik	0.0	-1.4	-5.5	-10.0	-0.8	-1.0	-2.0	-1.9	*-1.9*
Khiva	0.0	-4.2	-16.1	-24.0	-1.6	-2.6	-3.4	-4.3	*-3.5*
Kushkupir	0.0	-2.1	-4.9	-3.7	2.6	-0.9	-1.3	-1.9	*-1.1*
Shavat	0.0	-2.7	-12.3	-25.2	-2.8	-2.6	-3.0	-4.0	*-3.3*
average	*0.0*	*-2.3*	*-10.7*	*-16.5*	*-0.7*	*-2.0*	*-2.5*	*-3.2*	
total average									***-4.0***

[a] as sales prices for cotton is fixed → revenues keep unchanged
[b] change of total per crop summed district revenue
Source: model simulation results

Production costs were also examined. The variable costs (in USD/ha) are not influenced by a change in sales price or water supply. Therefore, the total variable cost a farmer has to pay is dependent on the area he wants to cultivate with a certain crop[46]. From this, it follows that the percent *change* in total production costs per crop and district is exactly the same as the percent area *change per crop and district* (see Table 8.40). The absolute costs in both water supply scenarios are higher than for the price function Baseline 3 scenario because the area in both cases increased along with the crop quantity (see Table E.4 of Appendix E).

Gross margins, which are a result of revenues minus costs, declined in both water supply scenarios (see equation (3.20), (3.21), (3.22)). In situations with more water, a decline of about 23 % can be expected due to the reduction of crop prices (see Table 8.41) and an increment of variable costs due to acreage expansion (see Table 8.40). In these situations, the gross margin reduction for rice, fruit and, to some extent, wheat and vegetables is responsible for the total gross margin decrease (see Table 8.44). The relatively high reductions (43%) in Bagat and Kushkupir are caused by a sharp loss of gross margins for rice and wheat in Bagat and rice and vegetables in Kushkupir.

In situations with less water, a 17% reduction in gross margins can be expected (see Table 8.43). Indeed, crop sales prices rose, but crop quantity and revenues

46 Production costs (USD)= cropping area (ha)·var. costs (USD/ha).

were reduced (see Table 8.42). This effect is primarily caused by a huge decrease in cotton of about 61 %.

Table 8.43 Gross margins, total per district in 10^6 USD and change per district and crop between experiments with water supply +50% and water supply -50% compared to Baseline 3 scenario (in %)

	Gross margin [10^6 USD]			**Gross margin change to Baseline 3** [%]	
	Baseline 3	**wsdt+50% cppcalc**	**wsdt-50% cppcalc**	**wsdt+50% cppcalc**	**wsdt-50% cppcalc**
Khazarasp	8.07	5.65	6.22	-30.0	-22.9
Khanka	9.63	9.00	7.08	-6.5	-26.4
Urgench	8.63	7.10	6.97	-17.7	-19.2
Yangibazar	5.83	4.56	4.08	-21.7	-29.9
Gurlan	10.94	7.70	8.99	-29.6	-17.8
Bagat	5.53	3.13	5.38	-43.3	-2.7
Yangiarik	6.14	4.85	5.86	-21.0	-4.6
Khiva	5.17	3.94	4.30	-23.9	-16.8
Kushkupir	5.22	2.97	5.87	-43.1	12.6
Shavat	8.90	8.32	6.67	-6.4	-25.0
Sum/avg	*74.03*	*57.22*	*61.42*	*-22.7*	*-17.0*

Source: model simulation results

Table 8.44 Gross margin changes per crop compared to Baseline 3 (in % and 10^6 USD)

	cotton	**wheat**	**rice**	**other grain**	**alfalfa**	**vege-table**	**fruit**	**potato**
				wsdt+50%cppcalc				
GM[a]**,** 10^6 USD	13.66	8.07	15.98	-0.04	7.51	5.09	5.50	1.45
GM, change to BL3 [%][1]	*-7*	*-23*	*-40*	[b]	*-19*	*-22*	*-34*	*-0.3*
				GM for wsdt+50%cppcalc, change to BL3 [10^6 USD]				
Khazarasp	0.06	-0.64	-1.34	0.00	-0.12	-0.09	-0.30	0.000
Khanka	0.16	-0.06	-0.10	-0.02	-0.21	-0.03	-0.35	-0.001
Urgench	-0.03	0.01	-0.75	-0.03	-0.12	-0.15	-0.46	0.000
Yangibazar	-0.01	-0.23	-0.41	-0.01	-0.27	-0.08	-0.26	0.000
Gurlan	0.04	-0.05	-2.05	-0.08	-0.25	-0.23	-0.61	-0.001
Bagat	-0.28	-0.61	-0.99	-0.01	-0.05	-0.14	-0.32	0.000
Yangiarik	-0.05	-0.05	-0.76	-0.02	-0.22	-0.15	-0.03	0.000
Khiva	0.01	-0.14	-0.50	-0.04	-0.15	-0.19	-0.22	-0.001
Kushkupir	-0.87	-0.34	-0.90	0.00	-0.09	-0.03	-0.01	0.000
Shavat	-0.04	0.02	-0.20	-0.02	-0.32	0.00	-0.02	-0.001

Table 8.44 continued

	cotton	wheat	rice	other grain	alfalfa	vege-table	fruit	potato
				wsdt-50%cppcalc				
GM, 10^6 USD	4.59	9.33	22.21	0.19	9.39	6.19	8.11	1.42
GM, change to BL3 [%][1]	*-61*	*-8*	*-6*	[b]	*3*	*2*	*8*	*-1.8*
				GM per district for wsdt-50%cppcalc, change to BL3 [10^6 USD]				
Khazarasp	-1.53	0.02	-0.30	0.00	0.01	0.00	-0.04	0.000
Khanka	-1.92	-0.17	-0.36	0.00	-0.05	0.00	-0.02	-0.010
Urgench	-1.03	-0.20	-0.31	-0.01	-0.06	-0.01	-0.05	-0.001
Yangibazar	-1.31	-0.11	-0.16	0.00	-0.13	-0.01	-0.02	-0.001
Gurlan	-1.27	-0.10	-0.50	-0.01	0.01	-0.03	-0.04	-0.004
Bagat	-0.39	-0.03	0.04	0.02	0.19	-0.01	0.03	-0.001
Yangiarik	-0.24	-0.04	-0.04	0.00	0.11	-0.01	-0.07	-0.001
Khiva	-0.71	-0.06	-0.08	-0.01	0.03	-0.02	-0.02	-0.003
Kushkupir	-0.18	0.13	0.10	0.03	0.17	0.11	0.29	0.000
Shavat	-1.51	-0.26	-0.17	0.00	-0.21	-0.02	-0.04	-0.010

[a] GM=gross margin
[b] because of partly negative values, percent change for other grains cannot be determined
Source: model simulation results

To summarize, the model simulations indicate that increasing the water supply will cause crop sales prices to decrease due to increased acreage and crop supply. Simultaneously, total revenues will be increased because of higher crop quantity, but total variable costs will decrease; in sum, the gross margins at that level of water supply will decrease.

In situations with lower water supply, crop sales prices will increase at slightly enlarged acreage (mainly caused by an increase of acreage for cotton). Crop revenues will decrease because of higher prices, but crop yields at that water supply level will decline. Total costs increase to the same degree as acreage. In sum, the total gross margins decrease slightly as crop prices increase, but costs rise while total crop quantity (due to lower yields) falls.

8.3.3 Price function scenario - water pricing experiments

As described for the water pricing analysis under status quo conditions of 2003 (Baseline 1), it is important to conduct water pricing experiments for situations with a relaxed state order system and free farmer decisions on crop type and quantity (and demand and supply controlled crop sales pricing). Here, the effect of water pricing on economically and environmentally efficient crop allocation can be identified. As described in the water pricing experiments of scenario block 2 (see chapter 8.2.4), the focus will be on the effects of different water pricing levels on the economical outcomes. The crop allocation of Baseline 3 will be the basis of the analysis.

For the water pricing analysis under the liberalization and price function scenario, several experiments were chosen. First, depending on the pricing method for water prices, the volumetric pricing will be analyzed. Second, an additional experiment on area-based water pricing will be conducted to determine the feasibility and effects of both methods based on economical outcomes, such as gross margins and costs (see chapter 7.1.4).

For volumetric water pricing, the three different levels were chosen: 6, 10, and 25 USD/1000 m^3. All other higher values are not enforceable and realistic as the status quo experiments of scenario block 1 and the water pricing experiments of block 2 already show that at those values gross margins became negative.

For reasons of clarity, only one value was chosen for the area-based water pricing. In literature (Cornish et al., 2004), the average amount of volumetric water pricing in developing and transition countries with water deficits is around 150 USD/ha. Table 8.45 provides an overview of the experiments and the parameters within the price function scenario with water pricing.

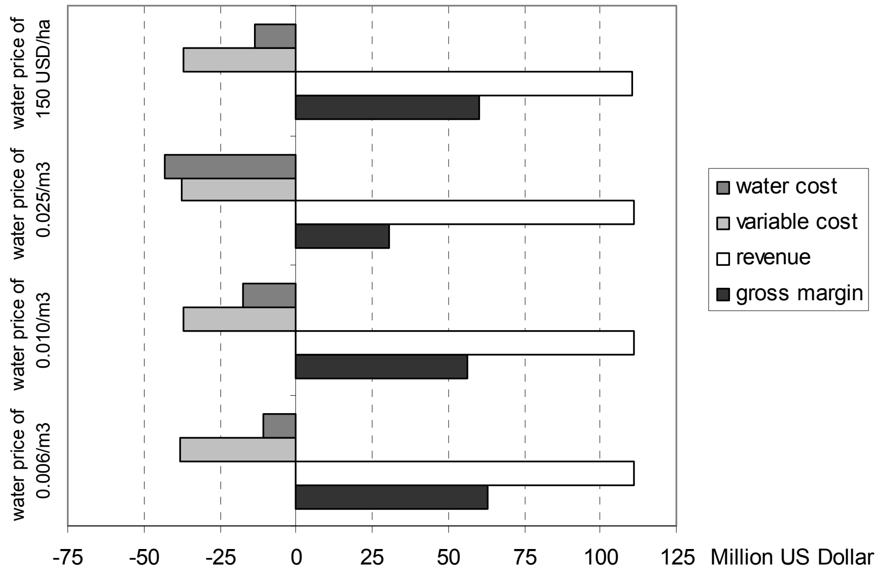
Table 8.45 Water pricing experiments under liberalization and price function (parameter description)

	Parameter Description:
Exp3-1	water price 0.006 USD/m^3, crop sales price calculated, relaxed area
Exp3-2	water price 0.010 USD/m^3, crop sales price calculated, relaxed area
Exp3-3	water price 0.025 USD/m^3, crop sales price calculated, relaxed area
Exp3-4	water price 150 USD/ha, crop sales price calculated, relaxed area

Source: model presentation

Water pricing under liberalization and implementation of a price function had a very high impact on additional costs and gross margins. As seen in Figure 8.8, gross margins in the water pricing experiments decreased severely. At water pricing of 6, 10 and 25 USD/1000 m^3, the gross margins decreased by 15, 24 and 59 %, respectively, compared to the gross margin of Baseline 3. The overall gross margins of Baseline 3 are already lower compared to Baseline 2 due to modified sales prices and demand/supply controlled crop allocation (with economic/ecologic effective water allocation) (see Table 8.32), which means the effect of water pricing on gross margins in this situation is even stronger.

Compared to the volumetric water price, a value between 8 to 10 USD/1000 m^3 matches closely with the outcomes of an area-based water pricing of 150 USD/ha under the determined crop allocation, crop quantity and sales prices.



all in 10^6 USD	water price of 0.006/m3	water price of 0.010/m3	water price of 0.025/m3	water price of 150 USD/ha
water cost	-10.5	-17.5	-43.3	-13.6
variable cost	-37.9	-37.3	-37.3	-36.8
revenue	111.2	111.2	111.1	110.7
gross margin	62.8	56.4	30.4	60.3

Figure 8.8 Gross margin, revenue, variable costs and water costs for different water pricing scenarios under liberalization for Khorezm

Source: model simulation results

Table 8.46 Water costs for different water pricing scenarios under liberalization per district (10^6 USD)

	Baseline 3	**Exp3-1 wp0.006 cppdefix**	**Exp3-2 wp0.010 cppdefix**	**Exp3-3 wp0.025 cppdefix**	**Exp3-4 wp150 USD/ha cppdefix**
			Water cost [10^6 USD]		
Khazarasp	0.0	-1.0	-1.7	-4.3	-1.6
Khanka	0.0	-1.1	-1.8	-4.4	-1.4
Urgench	0.0	-1.2	-1.9	-4.8	-1.3
Yangibazar	0.0	-0.9	-1.6	-3.8	-1.1
Gurlan	0.0	-1.4	-2.3	-5.7	-1.7
Bagat	0.0	-0.9	-1.5	-3.8	-1.3
Yangiarik	0.0	-0.8	-1.4	-3.5	-1.1
Khiva	0.0	-0.9	-1.4	-3.6	-1.1
Kushkupir	0.0	-1.2	-2.0	-5.1	-1.6
Shavat	0.0	-1.1	-1.8	-4.4	-1.3
sum	*0.0*	*-10.5*	*-17.5*	*-43.3*	*-13.6*

Notes: wp = water price (in USD/m^3 or USD/ha)
cppdefix = crop sales price determined in the model
Baseline 3 = base scenario under liberalization and price function without water pricing

Source: model simulation results

As seen in Table 8.46, water costs are highest for Gurlan and Kushkupir because of the higher water consumption due to extended rice cultivation in Gurlan and high acreage, crop production and water usage in Kushkupir. The costs are lowest in Yangiarik, Khiva and Yangibazar because of less acreage and cultivation of fewer water demanding crops (see Table 8.34).

Unfortunately, there is not sufficient information available on the de facto costs for water and water supply (i.e., operation and maintenance cost for the irrigation system)[47] such that a real cost could not be compared with the de facto water consumption in Khorezm to obtain a realistic water price. Therefore, the only possibility under this situation is an analysis on the effect of several water prices on gross margins from the farmers' perspective and their potential to pay those prices. The examination of a water price at which the total gross margins become zero or even negative can serve as a rough guide. The water pricing experiments under the Baseline 3 scenario show, that even at a water price of 43 USD/m^3, overall gross margins become zero. This implies that it is not worthwhile for farmers to cultivate crops at this level because the cost would exceed any possible gains. Even at lower water price levels, those gains would be

47 With the exception of the assumed 0.006 USD/1000m^3 by Bobojonov, 2008.

marginal or very low. Table 8.47 shows a direct comparison of the effect for all water pricing experiments in all scenario blocks. Block 3, with pricing of 43 USD/1000 m^3, is lowest because of the modified sales prices and non economic/ecologic optimal crop allocation situations. Based on these results, a very low water price of maximum 6 USD/1000 m^3 is recommended.

Table 8.47 Water price level per district and scenario block in which gross margins became zero (in USD/1000 m^3)

	Khazarasp	*Khanka*	*Urgench*	*Yangibazar*	*Gurlan*	*Bagat*	*Yangiarik*	*Khiva*	*Kushkupir*	*Shavat*	*sum*
Wp_BL1	48	48	43	38	39	51	53	56	51	43	47
Wp_BL2	55	56	55	48	47	58	59	65	59	53	55
Wp_BL3	48	54	47	38	48	36	45	36	26	50	43

Notes: Wp_BL1, BL2, BL3 = water price experiments under scenario block 1, 2, 3
Source: model simulation results

8.3.4 Decomposition

The experiments of scenario block 3 (and partly of block 2) were multivariable scenarios. Several factors were modified to test a certain effect. In the following decomposition analysis, the optimization parameter “agricultural profit/gross margin” shall be decomposed into its single indicators to quantify the different structural effects on the overall outcome. For this purpose, the optimization parameters of the scenarios with a stepwise modification of only one single parameter were compared. The analysis allowed for complexity and more transparency in the model (Büringer, 2008; Mayer, 2006). The following indicators are relevant for the analysis:

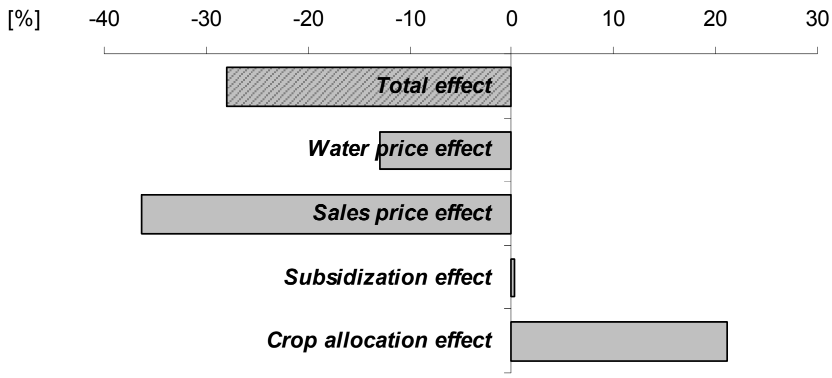
- *Crop allocation effect* (due to the relaxation of acreage and abolishment of the state order system)
- *Subsidization effect* (abolishment of subsidies for cotton and implementation of border prices for cotton)
- *Sales price effect* (due to implementation of an internally determined price function for all other crops, with the exception of cotton)
- *Water price effect* (implementation of a water price of 6 USD/m^3)

The total effect of the optimization parameter for the multivariable scenario accounts for about -28 %. Figure 8.9 shows that this total effect is fragmented into its single effects. The effect of supply- and demand-dependent sales prices due to the implementation of a price function have a -36 % influence on the total gross margins and indirectly to crop allocation. Not surprisingly, this effect is negative because crop allocation is oriented on consumers demand and willingness to pay and not only driven by ecological aspects (crop water consumption) and cost/benefit relations (yields, variable cost,…). The impact of relaxation of the cropping area and abolition of the cotton and wheat quota system was 21 %. The free decision on crop allocation and crop type by farmers according to economical and ecological aspects resulted in the cultivation of more effective crops in terms of water consumption, yields, acreage (on productive land) and positive cost/benefit relations. The effect from the abolition of the cotton subsidization system was marginal at 0.2 % because sales prices for cotton, according to world market prices, increased; however, production costs also increased (due to the abolition of governmental subsidies) and the cost/benefit relation was low, meaning additional cotton production was not worthwhile[48].

The decomposition was conducted for the experiments under Baseline 3 with released acreage, abolition of the cotton and wheat quota system and the free decision of farmers on crop type and quantity. Therefore, cotton production is already reduced due to liberalization, and the possible abolition of the cotton subsidization system does not play a crucial role.

The effect of a water price, even at 6 USD/m^3, was -13 %. Not surprisingly, water prices are reflected in additional costs for farmers and have a negative impact on gross margins as long as no direct improvement in the irrigation/drainage system and the operation system is reflected in increased water supply, which would result in increased yields and revenues. However, for a water price of only 6 USD/m^3, these measures could not sufficiently be implemented, but higher prices are not affordable for farmers due to relatively low gross profit margins.

[48] As long as substitution will be continued, this situation is certainly much more efficient for farmers; see experiment Baseline 2_ lib2.



[all in percent]	Crop allocation effect	Subsidization effect	Sales price effect	Water price effect	Total effect
□ Impact on optimization parameter	21.2	0.2	-36.3	-13.0	-27.9

Figure 8.9 Decomposition and effect of structural parameters on the optimization output (in %)

Source: authors own results

8.3.5 Recapitulation scenario block 3

The introduction of a supply- and demand-dependent price function in the scenarios of block 3 was important to show crop allocation and economical outcomes under more realistic circumstances. Scenario block 2 focused on the determination of a hypothetically optimal and more efficient crop allocation according to model-based agronomical, economical and hydrological parameters. The focus under block 3 is a realistic crop allocation under implementation of additional relevant factors, such as consideration of the market situation (demand and supply) and the liberalization of the cotton sector.

The experiments under scenario block 3 indicate a general reduction in gross margins and acreage and an increase in sales prices (of 50-70 %) for the considered crops. Additionally, crop quantity and crop allocation changed significantly compared to Baseline 2. Due to modified prices in Baseline 3, not only will the most efficient crop be cultivated, but dependant on water supply, cost/benefit relations and demand also “second best options” (in this case crops) will be cropped, which has significant impacts on inter alia crop allocation, water consumption, revenues, and gross margins.

The total amount of basic crops that are produced in huge quantities, such as cotton, wheat and rice, will decrease. However, compared to the Baseline 2 situation, the cultivation of cotton in Baseline 3 increased (but still does not approach the values of the status quo situation) as a reaction to high sales prices for other products and decreased demand or reduced willingness to pay for those crops. Therefore, market equilibrium and the resulting allocation are regulated in a completely different form if only ecological aspects are to be considered.

In situations with decreased water supply, cotton production also increased (compared to BL2), whereas rice cultivation (due to high water consumption but less water availability) decrease. As a result, prices and demand for rice will increase. Additionally, the share of wheat, which is the crop with the lowest water consumption rate, is favorable in situations with less water availability. The same occurs for fodder crops that are essential, particularly in dry years. As a result of less water availability and reduced yields, the demand and crop sales prices will increase in dry years. In contrast, the situations with additional water supply. Sales prices will be reduced due to augmented supply. The modeling results indicate that all considered crops, especially rice, could be cultivated.

Finally, the introduction of a water price under scenarios block 3 shows the same reaction as in block 1 and 2. Due to low gross profit margins for crops in Khorezm, the implementation of a water price has significant impact on additional costs and revenues. Even at a very low water price of 6 USD/1000 m^3, the effect is immense. At a level of 43 USD/1000m^3, overall gross margins become zero. This leads to the recommendation of a very low price for water as long as gross profit margins in Khorezm are low.

9 CONCLUSION AND OUTLOOK

In this chapter the results of the research and the outcomes of the three scenarios and their different experiments and its underlying policies will be summarized. Based on the results, various recommendations and the feasibility of implication of those recommendations will be described and analyzed.

The last section of the chapter gives an overall conclusion of the research and discusses the benefits of the modeling and modeling framework, research limitations and further research.

9.1 Research conclusions, policy recommendations and implications

The results of the three scenarios and their related experiments showed several significant factors, of which the most important will be described in the following section. The following four main categories will be discussed:

- Optimal crop allocation.
- Water balances, water supply and water efficiency.
- Abolition of cotton subsidization.
- Water pricing.

9.1.1 Optimal crop allocation under released acreage and cotton quota system

Results

The effect of a relaxation of acreage and the state order system for cotton and wheat combined with the free choice of farmers on crop type and quantity decision has a positive effect on revenues and gross margins. Due to the flexibility of farming activities and crop allocation, it is likely that more farmers will choose to cultivate crops that can be traded on local markets and crops with a good relationship between water consumption and cost/revenues, resulting in high economic water use efficiency. Examples of these crops include vegetables, rice and alfalfa and, to a lesser extent, fruits, wheat, and potatoes. The cultivation of wheat and rice is significantly influenced by water availability (high for rice and low for wheat). These results correspond well with the findings of Djanibekov, 2008.

Model results indicate that the cultivation of cotton is with abolishing of the state order system not longer attractive for farmers. The state order system causes the sales prices to be relatively low but the costs for growing cotton to be very high. Thus, e-WUE for cotton is very low or even negative. If subsidies by the government were to be omitted, those costs will increase, and the incentive for cultivate cotton will decline even further. Additionally, the relatively high water consumption and decreasing yields due to cultivation on marginal land and/or saline soils did not increase the attractiveness of cotton.

The second essential result of this scenario analyses is the major reduction of acreage in general. This is mainly induced by a strong reduction of cotton cultivation, and it is most apparent in situations with lower water supplies. Unproductive and marginal land is removed from the system. Thus, the overall yield could be increased as more water is available for less area, and more effective crops (in terms of water consumption and economic cost/revenue relation) can be cropped.

Policy recommendations and implementation

The model results suggest that the region could benefit from a general reduction of the total cropped area by diminishing unproductive and marginal land. It would result in a reduction of cotton cultivation and simultaneously produce a shift in crop allocation to more economically and ecologically efficient crops and crops tradable on local markets. The general reduction of acreage, mainly due to a drastic reduction of cotton area, would benefit ecology, alternative crop allocation and water availability.

However, the structures for the intensive cultivation, processing and commercialization of cotton in Khorezm still exist in the form of machinery parks, farm workers and the high knowledge of farmers regarding cotton cultivation, especially in this region. If maintaining the expanded and intensive cotton cultivation policy, the government has to account for water shortages that, according to expert knowledge, will continue to occur and even be exacerbated in the future due to climatic changes and the increased extraction of Amu Darya river water by upstream riparian. Beside reduced water supply, decreased cotton yields in Khorezm can be seen over the past years. This situation is not going to change as long as marginal land is used and soil salinity continues to increase in soil. The third problem of cotton cultivation perpetuation is the reduced availability of productive land for the cultivation of crops that are more economically and ecologically efficient and locally utilizable.

If the expanded cotton cultivation in Khorezm is favored by the government, it can only be sustained by a further perpetuation of the subsidization system, as shown by the experiments on the liberalization of the cotton sector (chapter 9.1.3). It then becomes a question of whether the continuation of cotton production under impeding conditions, declining yields, possible water shortages and additional costs for the subsidization system can be offset by the foreign exchange proceeds[49].

Following Rudenko (2008), a practicable recommendation would be a stepwise reduction of the cotton cultivation and subsidization that would finally give the local population the ability to grow and sell more diversified and desirable crops to feed the increasing number of local inhabitants and livestock and to increase their ability to cope with modified water supply. Diverse crop cultivation is also good for both, soil properties and for risk management for the farmer. By reorganizing the agricultural system in Khorezm from extensive cotton production to the diversified cultivation of crops such as vegetables, fodder and fruits (and rice, if water availability is sufficient), the proportion of semi-subsistence could be increased, and due to the labor-intensive crop cultivation of vegetables, the employment rates of the rural population could be maintained.

The extension of wheat cultivation appears to be appropriate due to its low water consumption and the possibility of double cropping. However, wheat is not favored by the local population, and the attractiveness of rice is still much higher. In this case, information campaigns could certainly be helpful. However, rice cultivation in years with additional water available, especially in districts close to the river, is possible-especially because a possible diminishment of cotton cultivation will leave more crop area and make additional water available. The implementation of new, resistant, less water-consuming rice phenotypes as well as an introduction of water-saving strategies would be advisable.

[49] Macro-economical calculations taking into account the described circumstances would be helpful in the final decision on cotton policy by the government

9.1.2 Water balances, water supply and efficiency

Results

The influence of water supply on water balances, crop allocation and yields is naturally very high. A large influence of modified water supply on the entire cropping system and the water and soil balances can be detected (mainly in cases of low water supply). Crops such as cotton, rice and alfalfa showed a strong reduction of gross margins and yields in the simulations. With additional water supply, crops such as vegetables, alfalfa, fodder crops, rice and wheat have a large potential to become more profitable as a result of yield increases and a positive economic-ecologic balance.

Furthermore, the scenarios and experiments showed a large influence of groundwater on crop water supply. The groundwater balances will be primarily affected in cases of low water supply because in these cases, the crops need to seek alternative water sources via capillary rise, which ultimately causes a strong reduction in the groundwater table. When irrigation and precipitation water supply is not enough, groundwater must be used. Studies have shown that even with zero water supplies it is possible for some crops to exist by capillary rise out of the groundwater and by reaching the groundwater with the roots, especially when the groundwater is very shallow, as is the case in major parts of Khorezm (Forkutsa, 2006 and Figure 4.5). The resulting groundwater fluctuation and amplitude during the year, especially between the vegetation and non-vegetation period, can be up to 30 cm-40 cm. The fact that leaching is performed at the beginning of the year to elute salt out of the soils and to enhance soil properties is adding to these groundwater fluctuations. This leaching is absolutely essential in Khorezm to wash out the soils and to contribute to groundwater replenishment and refill soil moisture at the beginning of the vegetation period. Furthermore, the tremendous seepage losses of the irrigation system and the resulting low efficiencies also contribute to groundwater replenishment and leaching of the saline soils, which are both generally very positive effects.

Altogether, water supply scenarios demonstrate a huge effect on crop allocation, water and soil balances, and yields and gross margins with modified water quantities. However, even with a possible (but difficult to obtain) alteration of the general water supply, an increase in water would be depleted due to low distribution and irrigation/application efficiency. As a result, direct efforts towards the improvement of the irrigation and water management system appear to be more effective and easier to implement. Several measures exist to improve the distribution and irrigation efficiencies, the cropping system and water supply management in Khorezm. They will be discussed and checked for feasibility and practicability in the following paragraphs.

Options, impacts and implementation of efficiency improvement measures

Multiple possibilities exist for increasing water use efficiency. Water savings and/or improvement of the economic water use efficiency (e-WUE) at the field level could be obtained by utilizing less water-intensive and more salt-tolerant crops as well as crop combinations and double cropping. Crop rotation and base leveling for better and more uniform water distribution within the fields are also possible solutions. In addition, a reduction of conveyance losses at the farm level due to on-farm channel improvement, irrigation scheduling according to variable and site-specific requirements (instead of norms), and improving the current irrigation and cropping techniques could all improve the water use efficiency. Current irrigation techniques could be improved by the introduction of modern irrigation techniques such as surge flow, alternate furrow, drip-, double-side and sprinkler irrigation, while cropping techniques could be improved by introducing mulching and zero-tillage, hydrogel or the planting of shelterbelts. Furthermore, the on-farm drainage system is open and requires desilting, reconstruction and repair (UNDP, 2007). An additional task would be to gather information from each farm regarding soil and crop characteristics and on-farm flow rates and use this information to determine water applications.

Improvements at the district level could be attained by the reconstruction and repair of inter-farm and main channels, intake structures, hydro-mechanic equipment, and pumping stations as well as the treatment and reuse of drainage water. Due to a complete desilting of the Tuyamujun reservoir, the total amount of water could be increased, and as a result, more water could be stored for water-scarce vegetation months. Admittedly, this measure is hardly feasible and operable and is very cost intensive.

According to Vlek et al. (2001), canal lining, which has been completed for some canals in Khorezm, is also very cost intensive, and the efficiency improvements are in a range of about one percent. Thus, this engineering measure does not appear to be an immediate and practicable option of water saving in Khorezm.

In addition, a further expansion of double cropping in Khorezm, such as winter wheat with rice, winter wheat with vegetables with short-growing periods like onions, melons and beets and winter wheat with maize or cotton, appears to be a advantageous measure. However, it involves supplemental annual costs such as seed purchase, maintenance, harvest costs and fertilizer expenditure. Another issue is the unpredictability of the beginning and end of the frost period as well as its duration. According to Damis (2008), only a small percentage of cropping area in Khorezm could adopt this technique because social and economic factors make it unfeasible.

A reasonable crop *rotation* such as cotton with sorghum would certainly improve soil quality and diversification, but economically continuous cotton cropping would result in much higher commodity prices, as the demand for cotton is higher than the demand for sorghum. Furthermore, the state procurement system for cotton and wheat, which is still in effect, induces more farmers to cultivate those crops. Similar to the possible reduction of cropping area to reduce the amount of irrigation water, this measure is certainly very advantageous but an improvement of e-WUE is not indicated.

It is also possible to crop less water-intensive but more salt-tolerant crops in Khorezm. Particularly noteworthy are cotton, wheat, and garden beet[50], in contrast to rice, fruit trees, clover and, to some extent, potatoes. The use of aerobic rice instead of flooded rice would reduce the amount of irrigation water but would still be less productive. For this reason, a general reduction of rice-cropping areas in dry years is advisable.

The application of hydrogel, granules for holding soil moisture, is a promising water-retaining mechanism, especially in arid areas. Hydrogels act as a reservoir and can absorb approximately 400 times of their own weight in water. However, they are cost-intensive, and the water holding capacity is decreased in irrigation water containing dissolved salt (Jhurry, 1997).

Another possibility to increase the supply of irrigation water is to re-use drainage water. However, this is associated with high costs for treatment infrastructure.

[50] cotton and wheat are already intensively cropped in Khorezm

An additional task could be the implementation of measures for controlled drainage as a further development of the current drainage blocking system. Controlled drainage would consider the temporal requirements of the groundwater level. Water table management with controlled drainage[51] would reduce the drainage water leaving the crop fields; the water level in surrounding fields would rise. Additionally controlled drainage could favor locations with rather low salt content in the groundwater to avoid increased salinity of the groundwater in certain areas.

All of the measures described to reduce water demand and/or supply show that possibilities are available but are associated with immense costs or financial losses for farmers or high subsidies from the government. Government purchases and capital investments in the water sector are still declining and, at the same time, costs for electricity (e.g. for pumping stations) and equipment are rising (UNDP, 2007).

The most suitable measure for improving water use efficiencies for local conditions in Khorezm seems to be the perpetuation and extension of gravity irrigation such double-furrow and surge-flow irrigation (Damis, 2008) and measures on controlled drainage. Sprinkler and drip irrigation appear to be cost-intensive and, due to the high salinization in Khorezm, impracticable.

In addition to gravity irrigation, a consistent base leveling using laser and the introduction of soil moisture-increasing crop techniques, such as mulching, no-tilling techniques, and the planting of shelterbelts, appears to be advisable. These techniques are easy to implement, and implementation costs are relatively low. Land leveling by lasers has been proven to be a good method of increasing water use efficiency and yields. Land irregularities are eliminated, and scarce water resources can be utilized more efficiently and distributed more equally (Assif et al., 2003). According to Bobojonov (2008), 70 % of the cropped area in the region is unevenly leveled. Laser leveling could save around 25 % water, and soil and crop properties could be improved, which would cause increased yields (Ergamberdiev et al., 2008).

[51] by installation of control structure, such as a flashboard riser

9.1.3 Abolition of cotton subsidization and transfer of bordering prices for cotton

Results

The results of the different scenarios demonstrate that after relaxation of the acreage and the increased freedom of farmers to decide how and how much to crop (chapter 9.1.1), the effect of the liberalization of the cotton sector would result in a drastic decrease in cotton cultivation. Indeed, the sales prices for cotton would increase, and thus, so would the income for the farmers. However, the production cost to produce one unit of cotton would be increased as well, due to the abolition of the governmental subsidies. The positive effect on income for cotton sales would fully compensate for the abolition of governmental subsidies.

Due to the free decision of farmers, other higher-value adding crops such as vegetables, fruit, fodder crops and rice, if enough water is available, would be cultivated. With the cultivation and marketing of those crops, the overall gross margins could be increased, and the loss of income by the reduction of cotton cultivation could be compensated.

Only in cases of continued governmental subsidies would the further cultivation of cotton be feasible. In this case, variable costs for cotton production must still be subsidized by the state and any additional higher income as a result of increased sales prices for cotton (bordering/world market prices) would benefit the farmers directly. However, sales price increases for cotton must take into account deductions of costs for vendors, processing, taxes, interest payments, administration, ginning, suppliers, etc, and the prices may not increase enough to bring the production and cultivation of cotton up to the current level, which is created by subsidies and fixed but secured governmental prices (Rudenko, 2008). Furthermore, according to Bobojonov (2008) the abolition of secured but, indeed, lower sales prices for cotton would cause an increased risk for the farmers, as world market prices for cotton fluctuate and the consistent higher prices is not assured.

Discussion and implementation

The perpetuation of the current system of cotton quotas and subsidization by the government creates considerable advantages for the state and farmers and thus, illuminate the continuing system of the expanded cotton cultivation. The export of cotton and cotton fiber is a very important source of foreign exchange earnings for the Uzbek government. Due to marketing and the pre- and post-cotton-processing industry, including ginneries, cotton oil, the cotton oil cake-extracting industry, the laundry soap industry, the textile industry and the machine industry, the cotton cultivation constitutes a large share of the Uzbek economy. Additional public revenues such as taxes, savings and agricultural tariffs and duties, as well as an increase in the employment rate, can be attained by the state and could be reinvested into the import of various goods and services. Another reason for continuing the current cotton policy is the absence of sufficient alternatives. The dominance of the agricultural sector and the high share of agriculture in the GDP (Müller, 2006), combined with the missing sectoral differentiation (secondary and tertiary sector) and the lack of urban agglomerations and infrastructure in Uzbekistan leads to missing employment alternatives for the rural population-especially in Khorezm, where almost 78 % of the population live in rural areas (chapter 2.4.1).

Also for farmers, the cultivation of cotton has several advantages. They attain input subsidies for the cropping of cotton and additional grants for the cultivation of other crops, such as reduced seed prices or discounted credits. Furthermore, the general acceptance of the requested quantity of cotton for a guaranteed price represents an essential factor of risk minimization for farmers. Moreover, the extensive knowledge of cotton cultivation and irrigation schemes and the necessary machinery is still present, all of which represent supplemental benefits. As the cotton production is relatively labor-intensive, employment rates could be sustained, which is an important aspect in predominantly rural areas. The continuation of subsidization of the cotton sector seems reasonable, especially if losses in tariffs and credits would be taken into account[52].

Many cotton-producing countries in the world act similarly regarding subsidization and special concessions. However, the reduction and, ultimately, the total abolition of subsidies is expected (chapter 7.1.5).

If the continued system of high cotton production and export remains favored by the government, it would only be possible with subsidies. Without subsidies, the

52 This analysis could not be performed here; for this purpose, a macroeconomic analysis of the liberalization in the cotton sector is necessary.

farmers would grow more value-adding crops. If the reduction or abolition of the current cotton order system is favored in Uzbekistan, as indicated by the scenarios, this would only be possible through a step-wise reduction of the state order and cotton subsidies and would eventually require a policy of promoting other crops, as has already been done for wheat. A modification of the current state order system with reduced orders or free choice of the farmers regarding whether or not to grow cotton for a reduced but assured price (production quota instead of crop-area quota) seems to be the most advantageous. With this system, the farmers have the right to choose what and how much to crop while simultaneously maintaining the possibility of reducing the cropping risk. Additionally a general positive effect of diversification and the innovation potential of farmers can be expected.

9.1.4 Water pricing

Results

The introduction of water pricing, even at extremely low levels, resulted in both scenarios, status quo situation and scenario with relaxed state order for cotton in a sharp decline of income for farmers. Comparatively low gross profit margins in Khorezm inhibit the introduction of water pricing under the current system of subsidies and production quota. These findings are consistent with Bobojonov (2008). However, even with liberalization of the cotton market, pricing water seems to become very difficult because income and welfare of farmers due to alternative crop allocation and higher sales prices could be increased, but the growth rate of gross margins is relatively low, and high losses due to additional costs for water pricing would thus eliminate additional income.

Implementation of a water price

The scenarios showed that the introduction of a water price of more than approximately 6 USD/1000 m^3-10 USD/1000 m^3 is not feasible because otherwise the crop cultivation is no longer worthwhile for farmers. The results demonstrate that an introduction of a water price is a very sensible topic and needs careful implementation. A stepwise introduction of a water charge with simultaneous reductions of subsidies for inputs in cotton production seems to be appropriate to avoid overcharges of the farmers. Water pricing could lead to a better financial support of the Water User Associations (WUAs) or public water suppliers and reduce the dependency of WUAs on the government. The WUAs could re-invest the attained water charges into the improvement of the irrigation and drainage system. This could lead to an improvement of water use efficiency, which in turn pays off for both the farmers and the environment. However, even with such a low water price, only the true cost for the operation and maintenance of the irrigation system could be paid, not to mention additional investments.

To improve the sensibility of the farmers for the cultivation of less water-demanding crops, an introduction of a pricing method that depends on the crop type and vegetation period seems to be advisable and affordable. Alternatively, the introduction of a block-rate, bonus or quota-system could be considered. In this scenario, a certain supply of water could be delivered to farmers for free, and the farmer would be charged for any additional water consumed (remaining quotas could be traded on the local market). However, the problem is the current absence of a reliable method of measuring the volume of water consumed and the high costs of installing the technology to accurately make such measurements. A mixture between area-based charging and crop-type-based water pricing seems to be the most advantageous. The crop-type-based charging provides incentives for farmers to save water. Applying a higher water price for water-demanding crops would discourage the irrigation of those crops. This would give the government the possibility of directing the crop cultivation into favored crops (Chohin-Kuper et al., 2003).

As long as gross profit margins in Khorezm are low, charging for water in extreme situations, as in years with reduced water supply, must be conducted depending on the discharge within the river and the storage capacity of the reservoir.

9.1.5 Recapitulation

All of the results show that a liberalization of the cotton sector and the abolition of subsidies are possible and would lead to a completely modified and ecologically more efficient and sustainable crop allocation. This would lead to additional positive effects on the income and revenues of the farmers. Furthermore, the introduction of a water price on a very low level would be desirable for resource conservation and the environmental awareness of the water consumers. However, the discussion showed that a perpetuation of the present system with quotas and subsidies for cotton is indeed reasonable for both farmers and state, but under the aspect of sustainability, a change out of the system must be implemented.

Converting to a long-term sustainable water management is only possible if the water pricing is combined with other factors, such as policies (e.g. decrement of farmer's support/subsidies and public financing) and if property rights for farmers are assured (Gurria, 2008). According to Thomas et al. (2000), improving incomes and living standards is only possible by improving the quality of the legal systems, improving access to education, protecting the environment, managing global risks, and improving the quality of governance by the increased participation and transparency of institutions, combating of corruption and bureaucratic harassment. Thus, solid macroeconomic policies and the application of appropriate market-oriented microeconomic principles are basic elements. All of these factors must be considered in order for a sustainable reconstruction of the system to be possible.

9.2 Overall conclusion and outlook

As outlined in the introduction of this study, efficient and sustainable water and crop management are essential for the agricultural sector, the growing population, the environment of Khorezm and the downstream water users. In the water-scarce region of Khorezm, intensive irrigation agriculture is the major water user. It is characterized by its low efficiency and the deterioration of ecology due to an exploitative and inefficient use of the water and soil resources combined with the missing diversification of crops. The subsidization and cotton quota system of the government, along with missing property rights and the lack of water-saving incentives, promoted high water demand and social, economic and ecologic problems.

To determine a more economically and ecologically efficient strategy of crop and water management and allocation, an understanding of the basic hydrologic and agronomic characteristics and balances is of special importance. Thus, the determination of important factors for more efficient water and crop management in Khorezm was one objective of the study. It is also important to analyze the effects of modified social, technological, environmental and institutional conditions. The analyses described were required in preparation for the modeling. The objective was to build up an integrated and interdisciplinary model with plenty of experimental, empirical, and statistical data with different spatial and temporal resolutions. The model is a simplified framework to represent complex bio-physical and economic processes. The results from the model simulations are based on the way the model tries to capture reality. Thus, the detailed collection and verification of data and model accuracy was another objective of the study.

The development of an integrated hydrologic, agronomic and economic model for the Khorezm region turned out to be a suitable tool to analyze political incentives on the basis of water, climatic and crop-specific parameters. The validation of the model and the various results showed that the model and modeling framework could serve as a tool to provide information on both the underlying hydrologic and agronomic processes and as a decision support facility to evaluate the effects of political incentives on the regional water distribution, crop allocation and economic outcomes.

9.3 Limitations and further research

Some limitations and assumptions in formulating, solving and analyzing the model, as well as limits inherent in the modeling structure and underlying data and scenarios, became apparent. The acquiring and investigation of reliable data turned out to be a challenging task because the availability and reliability of sufficient and coherent data can be problematic in Uzbekistan and Khorezm.

As described in chapter 4, for some groundwater, crop, soil and water-related characteristics, there were no direct measurements or reference values available. In these cases, assumptions or literature values were used. The application of adapted regional data would make the processes more precise.

More recent and detailed data on groundwater fluctuations show deeper groundwater levels of 2 m-2.3 m below the surface in Khorezm in December/January on a daily resolution. Because of the lack of those data at the calibration phase, they could not be used in the model. The shallow groundwater situation in Khorezm, which leads to capillary rise, is of special interest, the possible impacts of deeper groundwater should be investigated in future research. However, the described groundwater depression will certainly have no large impact in the main vegetation period.

The economic basis of the model included the applied prices and costs. They were assumed to be constant throughout the year; however, this could be changed in further research. If information on water supply costs or for instance the costs to install and operate volume meter becomes available, a more in-depth analysis on the effects of water pricing could be performed. This is also true for the information on costs that are necessary for certain technical, institutional and political modifications, such as the investment costs to improve the irrigation efficiency or opportunity costs if the cotton sector were to be liberalized. It should then be possible to offset gains and implementation and maintaining costs to obtain a more realistic view of the costs and the macro-economical benefits that those measures would imply.

Furthermore, a possible extension of the various actors involved in the agricultural sector of Khorezm could be interesting. The de-aggregation can provide information on farmer's income and crop allocation even at smaller levels. The connection with an already successfully implemented model ("KhoRASM", Djanibekov, 2008) for the Khorezm region with differentiation of the agricultural actors and a detailed modulation of supply and demand would be recommend for further research.

The aggregation of certain crops into one single crop type, such as for vegetables, fruits and other grains, is difficult because the same parameters (yield response to water, growth period, salinity or potential yield) have to be considered for all crops in one aggregate. Due to the different characteristics of the single crops (especially for vegetables), this could be problematic and could affect the results. It would be recommended to reduce the quantity of crops in the model and de-aggregate the groups, reconsidering tomatoes, onions, berries or melons as single crops. Furthermore, the different irrigation strategy for rice is not directly comparable to those of the other crops and should be improved[53].

No direct information on multiple cropping is included in this study. Furthermore, the investment into the drainage system and drainage disposal will certainly be more important in the future and could be analyzed with the help of this model. Additionally, the extension of the salinity aspects in soil, surface water, drainage and groundwater is not yet included but could provide further information on the effect

[53] due to permanent downward movement of water, capillary rise should be close to zero

of salt in water and soil, the possibility of treatment and, eventually, the implementation of salt-taxes and their impacts.

The temporal extension of the model to analyze long-term perspectives could be used in future research. However, due to the implementation of several indices and multidimensionality, the calculation capacity was not sufficient, and it was thus not feasible to include here. The same is true for the extension of the spatial resolution of the model and/or the implementation of a node-link network to release water supply and receive information on hydrological fluxes. Eventually, a splitting of the model could solve the problem of capacity and computation time. However, it must be emphasized that a further extension of the model will increase the model dimensionality and reduce clarity and reliability.

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11 APPENDICES

11.1 Appendix A - business operation in agriculture

Table A.1

Main characteristics of organization and legal form of business operation in agriculture

Form of business operation	Definition	Conditions of establishing	Land provision
Agricultural cooperative (shirkat)	An independent economic agent with the rights of legal entity established on shareholding base and predominantly family (collective) contract, voluntary association of citizens to produce agricultural commodities	Established by founders on voluntary base. Family (cooperative) contract is predominant form of arranging production activity in agricultural cooperative (shirkat)	Agricultural land into permanent possession for production of agricultural commodities
Farm	An independent economic agent with the rights of legal entity based on joint activity of members of farm involved into agricultural commodities production with using land plots provided to it for long term lease.	Established on a contest base, predominantly on those lands and territories where there is no excess of labor resources. Farm specialized in cattle breeding is established when cattle has not less than 30 conditional heads. For farms specialized in plant growing minimal size of land plots provided for leasing to grow cotton and grain makes 10 hectares, for gardening, wine-growing, vegetable-growing and other crops - 1 hectare.	Reserve lands, lands from a special republican fund, lands in farms with insufficient labor resources and lands of new irrigation. Lands of loss-making or low profitable agricultural enterprises. Lands of agricultural co-operatives (shirkats) (on decision of district Khokim).
Dehkan farm	Family small scale farm, producing and selling agricultural production based on personal labor of family members on attached to a house plot of land provided to the head of family for life long heritable possession	On voluntary base. District Khokim makes decision (based on Board's decision of agricultural cooperative) on establishing dehkan farm with taking into account conclusion of district commission on considering issues of providing land plots	Attached to a house land plot including area occupied with buildings and back yards provided for life long inheritable possession up to 0.35 hectare on irrigated lands and up to 0.5 hectare on non-irrigated (dry) lands, and in steppe and desert zone – to 1 hectare on non-irrigated (dry) lands.

Source: CER (2004)

11.2 Appendix B – economic data used in the model

Table B.1 Crop price elasticity of demand per crop and district, factor b

	cotton	ograin	wheat	rice	vegt	fruit	alfalfa	potato
Khasarasp	-40.7	-0.2	-45.2	-34.2	-15.9	-14.3	-58.7	-0.1
Khanka	-42.9	-0.7	-57.4	-27.9	-68.1	-16.5	-87.2	-5.2
Urgench	-32.4	-1.2	-62.5	-26.4	-28.5	-28.5	-79	-0.5
Yangibazar	-35.3	-0.3	-44.8	-13.6	-12.5	-10.8	-93.8	-0.6
Gurlan	-34.9	-3.2	-42.3	-43.7	-38.6	-24.9	-139.5	-2.1
Bagat	-32.9	-1	-45.7	-11.9	-22.8	-14.2	-84.8	-2.2
Yangiarik	-24	-1.1	-35.7	-13.1	-25.6	-16.1	-150.9	-1.5
Khiva	-32.1	-1.7	-36.5	-6.3	-33.8	-11.9	-101.5	-2
Kushkupir	-35.7	-1.3	-62.4	-10.2	-21.2	-12.1	-95	-1.3
Shavat	-41.5	-1	-62.4	-12.4	-48.8	-32	-149.3	-5.3

Note: factor b of b=elasticity η·production/price

Source: derived from Djanibekov, 2008 and WATSIM database (von Lampe, 1999; Uni Bonn 2004)

Table B.2 Crop price elasticity of demand per crop and district, factor α

	cotton	ograin	wheat	rice	vegt	fruit	alfalfa	potato
Khasarasp	26,490	80	14,962	27,141	4,774	6,673	12,329	70
Khanka	27,930	223	18,998	22,116	20,462	7,679	18,319	2,995
Urgench	21,076	401	20,706	20,957	8,576	13,264	16,592	282
Yangibazar	22,974	118	14,852	10,815	3,762	5,019	19,702	354
Gurlan	22,706	1,078	13,998	34,651	11,612	11,586	29,294	1,236
Bagat	21,386	324	15,130	9,426	6,843	6,600	17,800	1,277
Yangiarik	15,618	366	11,833	10,410	7,707	7,494	31,688	864
Khiva	20,865	580	12,085	4,995	10,170	5,559	21,313	1,168
Kushkupir	23,235	450	20,652	8,103	6,368	5,638	19,941	732
Shavat	27,013	326	20,660	9,825	14,656	14,905	31,346	3,052

Note: factor α of α=production-b·price

Table B.3 Crop price elasticity of demand, factor η

cotton	-0.5
wheat	-0.445
ograin	-0.42
alfalfa	-0.5
vegetable	-0.545
fruit	-0.524
rice	-0.582
potato	-0.452

Note: η of b=elasticity η · production/price

Source: derived from Djanibekov, 2008 and WATSIM database (von Lampe, 1999; Uni Bonn 2004)

11.3 Appendix C – bio-physical data used in the model

Table C.2 Distribution of soil types in each rayon in Khorezm region according to hydromodule zones

Rayons	Soil type			
	VII	VIII	IX	Others
Urgench	52%	12%	29%	7%
Yangibazar	42%	19%	36%	3%
Bagat	43%	19%	38%	1%
Shavat	9%	29%	57%	5%
Khazarasp	65%	17%	17%	0%
Khiva	24%	20%	44%	12%
Khanka	45%	26%	24%	5%
Gurlen	29%	29%	32%	10%
Yangiarik	23%	30%	43%	4%
Kushkupir	17%	34%	41%	8%
Khorezm region	35%	23%	36%	6%

Sandy and sandy-loamy soils (with GW table 1–2 m), of thin and intermediate layer thickness, loamy and clayey;
Light and moderately textured loamy soils, homogeneous and heavy-textured loamy becoming lighter further down;
Heavy loamy and loamy soils, with homogeneous and heterogeneous texture.

Source: ObSelVodChoz (Department of agriculture and water resources in Khorezm region), 2004 and SayuzNihi UzASHI (1992)

Table C.3 Reference evapotranspiration (*ETo*), based on Cropwat FAO Penman-Monteith method (in mm/month)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Khasarasp	25.1	30.8	73.2	135.6	195	236.4	247.7	208	148.5	80	36.9	23.6
Khanka	25.6	32.5	73.9	136.8	197.9	245.6	253.4	211.1	151.5	86.2	38.9	24.3
Urgench	26	34.2	74.7	138	200.9	254.7	259.2	214.2	154.5	92.4	40.8	25.1
Yangibazar	26	34.2	74.7	138	200.9	254.7	259.2	214.2	154.5	92.4	40.8	25.1
Gurlan	26	34.2	74.7	138	200.9	254.7	259.2	214.2	154.5	92.4	40.8	25.1
Bagat	20.2	28.1	66.7	121.7	180.7	219.8	224.1	188.3	131.1	72.5	31.5	19.1
Yangiarik	15.2	25.5	60.1	107.7	166.5	203.1	200.6	168.6	113.7	65.1	26.1	14.6
Khiva	15.2	25.5	60.1	107.7	166.5	203.1	200.6	168.6	113.7	65.1	26.1	14.6
Kushkupir	15.2	25.5	60.1	107.7	166.5	203.1	200.6	168.6	113.7	65.1	26.1	14.6
Shavat	20.6	29.8	67.4	122.9	183.7	228.9	229.9	191.4	134.1	78.7	33.5	19.8

Table C.4 Precipitation of districts in Khorezm (in mm/month)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Khasarasp	11.1	10	20	18.7	4.8	2.9	0.1	0.2	2.6	3.8	9.5	12.7
Khanka	11.7	10.4	16.7	11.2	11.5	2.9	1.6	2	1.6	6.3	8.7	12.6
Urgench	11.7	10.4	16.7	11.2	11.5	2.9	1.6	2	1.6	6.3	8.7	12.6
Yangibazar	11.7	10.4	16.7	11.2	11.5	2.9	1.6	2	1.6	6.3	8.7	12.6

Table C. 4 continued

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gurlan	11.7	10.4	16.7	11.2	11.5	2.9	1.6	2	1.6	6.3	8.7	12.6
Bagat	11.1	10	20	18.7	4.8	2.9	0.1	0.2	2.6	3.8	9.5	12.7
Yangiarik	11.2	10.4	16.3	9.6	12.1	2.8	1.2	2.5	1.9	4.4	9.5	12.1
Khiva	11.2	10.4	16.3	9.6	12.1	2.8	1.2	2.5	1.9	4.4	9.5	12.1
Kushkupir	11.2	10.4	16.3	9.6	12.1	2.8	1.2	2.5	1.9	4.4	9.5	12.1
Shavat	11.5	10.4	16.5	10.4	11.8	2.9	1.4	2.3	1.8	5.4	9.1	12.4

Table C.5 Total irrigated area in hectare per soil for 2003 (in ha)

District/soil type	light	medium	heavy
Khasarasp	2966	14029	6720
Khanka	2779	19372	4569
Urgench	6090	13070	4910
Yangibazar	3689	11686	5235
Gurlan	1084	16460	8676
Bagat	2500	11471	6189
Yangiarik	886	11027	3908
Khiva	2518	13416	3287
Kushkupir	1992	19212	6086
Shavat	1576	17094	8040

Source: according to Oblstat 2001-2005

Table C.6 Municipal and industrial water uses (in 10^6 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Khasarasp	0.72	0.72	0.71	0.74	0.82	0.75	0.76	0.75	0.73	0.74	0.74	0.76
Khanka	0.66	0.66	0.65	0.67	0.75	0.68	0.69	0.69	0.66	0.68	0.68	0.69
Urgench	3.35	3.34	3.31	3.41	3.81	3.48	3.53	3.49	3.38	3.46	3.45	3.53
Yangibazar	0.16	0.16	0.16	0.16	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.17
Gurlan	0.30	0.30	0.30	0.31	0.34	0.31	0.32	0.31	0.30	0.31	0.31	0.32
Bagat	1.49	1.49	1.48	1.52	1.70	1.55	1.57	1.56	1.51	1.54	1.54	1.57
Yangiarik	0.35	0.35	0.35	0.36	0.40	0.36	0.37	0.36	0.35	0.36	0.36	0.37
Khiva	1.07	1.07	1.06	1.09	1.22	1.12	1.13	1.12	1.08	1.11	1.11	1.13
Kushkupir	0.27	0.27	0.27	0.28	0.31	0.28	0.29	0.28	0.27	0.28	0.28	0.29
Shavat	0.28	0.28	0.28	0.28	0.32	0.29	0.29	0.29	0.28	0.29	0.29	0.29

Source: authors own calculation according to JICA, 1996

Table C.7 *Ky(s)* coefficient, seasonal crop response coefficients

cotton	0.85
wheat	1.15
ograin	1.25
alfalfa	1.1
vegt	1
fruit	1.1
rice	2
potato	1.1

Source: according to Doorenbos and Kassam (1979)

Table C.8 Groundwater table depth in 2003, averaged 5-days values (in cm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Khasarasp	155.4	129.3	114.9	113.4	111.2	105.2	92.5	86.4	95.2	118.6	146.5	161.6
Khanka	187.5	136.7	128.4	137.2	124.7	106.7	87.4	79.3	104.5	157.6	193.5	215.3
Urgench	211.7	169.7	149.5	155.8	149.1	128	122	112.1	129	173	202.1	224.3
Yangibazar	191.6	145.5	122.4	131.9	137.6	122.7	111	109.2	120.6	155.5	191.1	217.2
Gurlan	173.1	112.6	108	143.2	122.5	84	80.4	74.4	94.4	151.7	184.6	206.3
Bagat	157.1	129.1	120.1	110.8	104.9	96.6	87.6	83.5	92.9	118.9	148.3	176.1
Yangiarik	149.2	94.9	98.2	102.1	96.3	90.1	76.5	71.7	90	128.5	155.8	193.5
Khiva	197.6	163.9	146.5	134.9	133.2	122.2	109.5	105.1	124.1	150.3	180.4	205.1
Kushkupir	201	174.8	153.5	137.5	146	135.7	119.6	111.4	122.9	142.8	163.1	185.6
Shavat	212.7	158.3	128.6	140.8	135	124.7	114.1	108	122	162.5	193.6	217.6

Source: according to GME, 2001-2005

Table C.9 Aquifer specific parameter: groundwater pumping capacity (in 10^6 m^3) (*pump_cp*); initial aquifer depth to the base level (in m) (*hg00*); aquifer specific yield coefficient (*sy*)

	groundwater pumping	initial groundwater table	aquifer specific yield
Khasarasp	3.6	1.4	0.35
Khanka	3.6	1.6	0.35
Urgench	3.9	1.9	0.35
Yangibazar	3.2	1.8	0.35
Gurlan	3.9	1.6	0.35
Bagat	3.1	1.4	0.35
Yangiarik	2.4	1.4	0.35
Khiva	2.6	1.9	0.35
Kushkupir	4.1	1.9	0.35
Shavat	3.8	1.9	0.35

Note: the volume of water per unit volume of aquifer that can be extracted by pumping, http://www.kgs.ukans.edu/HighPlains/atlas/apgengw.htm

Source: according to Sokolv, 1999 ($34.2 \cdot 10^6$ m^3 in 1995 for whole Khorezm) and in dependency crop acreage per district, according to GME, 2001; GME, 2005

trans: hydraulic conductivity in aquifers in cm/d; a constant of proportionality that describes how easily water flows through the medium

trans(gw)=0.00010

Table C.10 Initial root depth (in cm)

cotton	140
rice	160
wheat	140
ograin	130
alfalfa	120
vegt	100
fruit	140
potato	60

Source: according to: http://www.fao.org/ag/agl/aglw/cropwater, Forkutsa (2006), Tischbein, 2008 (personal communication), Saniiri (2004), reduced due to shallow groundwater in Khorezm

Table C.11 Soil related parameter: soils pore connectivity index (*cc*); soil connectivity and turtuosity parameter (*mm*); effective saturated hydraulic conductivity (*khs*)

Khorezm	cc[a]	mm[b]	smp[c]	Khs[d]
Light soil	3.5	0.45	20	250
Medium soil	4.2	0.50	25	150
Heavy soil	7.3	0.55	80	80

[a] soils pore connectivity index permeability index, dimensionless, according to Eagleson 2002, p.181, table 6.2
[b] soil connectivity and turtuosity parameter pore size distribution index, dimensionless, according to Forkutsa (2006), Cai (1999), Rosetta neural network model (2002)
[c] saturated soil matric potential in cm suction, according to Eagleson 2002, Cai 1999, Khamzina 2006
[d] effective saturated hydraulic conductivity in cm per month, according to Eagleson 2002, Rosetta neural network model (2002), Cai 1999

Table C.12 Saturated soil moisture at field capacity, pF 2; soil moisture at wilting point, pf 4.2; initial soil moisture, *z0*

	Zs, pF 2[a]			Zw, pF 4.2[b]		
	light	medium	heavy	light	medium	heavy
Khasarasp	0.22	0.33	0.35	0.1	0.15	0.17
Khanka	0.22	0.33	0.35	0.1	0.15	0.17
Urgench	0.22	0.33	0.35	0.1	0.15	0.17
Yangibazar	0.22	0.33	0.34	0.1	0.15	0.17
Gurlan	0.22	0.33	0.35	0.1	0.15	0.17
Bagat	0.2	0.3	0.35	0.09	0.13	0.17
Yangiarik	0.2	0.3	0.35	0.09	0.13	0.17
Khiva	0.2	0.25	0.36	0.09	0.13	0.17
Kushkupir	0.2	0.3	0.35	0.09	0.13	0.17
Shavat	0.2	0.3	0.35	0.09	0.13	0.17

[a] pF2
[b] pF4.2
All values in $cm^3 \cdot cm^{-3}$and

Source: according to: Forkutsa 2006; Khamzina, 2006; Cai, 1999 and Scheffer and Schachtschabel (1998), p.189, fig 5.4-4

Table C.13 Crop price (in USD/t) (cpp) and variable crop planting cost (in USD/ha) (otc)

	cotton	ograin	wheat	rice	vegt	fruit	alfalfa	potato
cpp	217	100	102	292	106	160	70	180
otc	512	201	215	464	451	406	169	580

Source: according to Djanibekov, 2008

Table C.14 Salinity coefficients; salinity effecting coefficient-slope and threshold of electrical conductivity

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						b, salinity effecting coefficient-slope						
cotton				5.2	5.2	5.2	5.2	5.2	5.2	5.2		
wheat	7.1	7.1	7.1	7.1	7.1	7.1				7.1	7.1	7.1
ograin					12	12	12	12	12			

Table C.14 continued

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
alfalfa			7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3		
vegt				7.3	7.3	7.3	7.3	7.3	7.3	7.3		
fruit			14	14	14	14	14	14	14	14		
rice				11.8	11.8	11.8	11.8	11.8	11.8			
potato				12	12	12	12	12	12			
ctd, threshold of electrical conductivity in saturating extract of soil[a]												
cotton				7.7	7.7	7.7	7.7	7.7	7.7	7.7		
wheat	6	6	6	6	6	6				6	6	6
ograin					1.7	1.7	1.7	1.7	1.7	1.7		
alfalfa			2	2	2	2	2	2	2	2		
vegt				2	2	2	2	2	2	2		
fruit			1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8		
rice				3	3	3	3	3	3			
potato				1.7	1.7	1.7	1.7	1.7	1.7			

Notes: [a] rate of decrease in yield with increase in salinity, %reduction in yield per dS/m increase in ECe threshold, percentage decrement value per unit increase of salinity in excessive of the threshold
[a] ECe threshold in deci siemens per meter or m mho per cm

Source: All values according to Maas and Hoffmann 1977, Maas 1999, http://www.ussl.ars.usda.gov/salt_tol_db.htm, http://www.fao.org/docrep/T0667E/t0667e00.htm (Salt Tolerance Database)

Table C.15 Water supply to demand site by month (in 10^6 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Khasarasp	26.5	37.8	30.5	22.3	37	57.5	74.2	70.6	39.8	15.6
Khanka	27.1	35.4	29.8	26.1	40	59.9	76.5	73.2	39.5	11
Urgench	26	31	44.7	34.9	41.9	64.8	68.9	85.3	46	15
Yangibazar	13	23.1	35.7	20.4	30.2	46.9	46.9	68.9	41.3	24.5
Gurlan	24.1	38.5	39	12.1	31.9	71.6	103.1	117.3	64.5	24.5
Bagat	24.3	30	29	18.1	37	55.2	61.5	62.2	37.6	11.2
Yangiarik	21.5	24.3	22.6	24	31	41.7	48.9	68.7	29.5	14.4
Khiva	20.2	24.3	30.7	31.9	35.6	43.3	46.5	59.4	32.9	13.8
Kushkupir	27.1	56.9	50.3	51.4	39.1	63.6	71.9	93.3	42	17.9
Shavat	28.2	51	41.2	28.5	38.1	56.1	63.1	84.5	40.7	12.2

Source: according to OblVodChos 2003

11.4 Appendix D – Data validation

Table D.16 Comparison of monthly and daily *ETa* values (in mm)

	ETa [mm]	May	June	July	August
FORKUTSA (2006)	monthly	71	69	128	122
	daily	2.3	2.3	4.1	3.9
Authors own simulations	monthly	58	135	132	111
	daily	1.9	4.5	4.2	3.6

Notes: all values for district Khiva, cotton growing and sandy loamy field, year 2003

Table D.17 Daily *Eta* values in mm per crop type (in mm)

Crop	daily *ETa* [mm]			
	May	June	July	August
Cotton	2.3	5.7	6.1	5.0
Wheat	5.1	2.2	-	-
Rice	5.7	6.2	5.3	4.6
OthGrain	2.1	6.4	5.7	4.0
Alfalfa	5.3	5.9	5.1	4.4
Vegetable	4.0	5.8	5.5	4.8
Fruit	4.4	6.0	5.0	3.8
Potatoe	3.1	6.5	6.0	4.5

Notes: all values are averaged over all districts

Source: authors own calculations

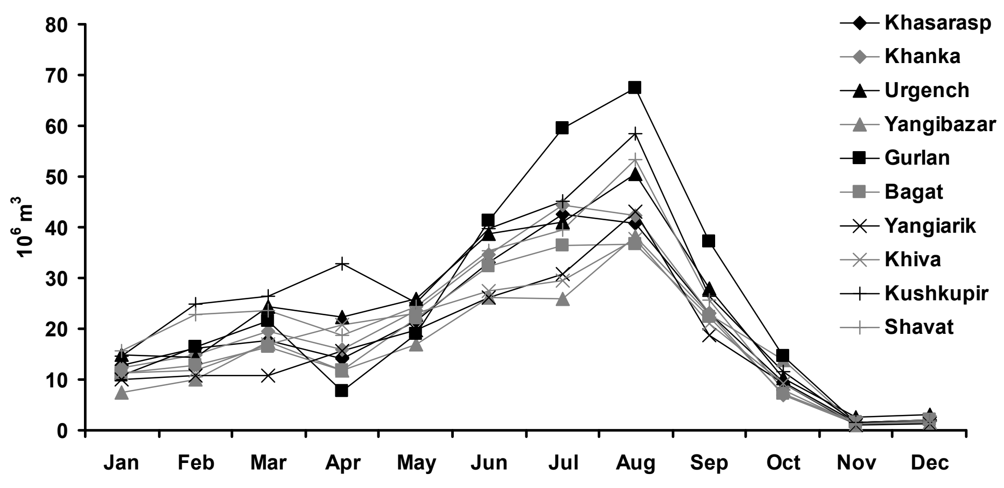

Figure D.1 Drainage per district and month (in 10^6 m^3)

Source: authors own simulations

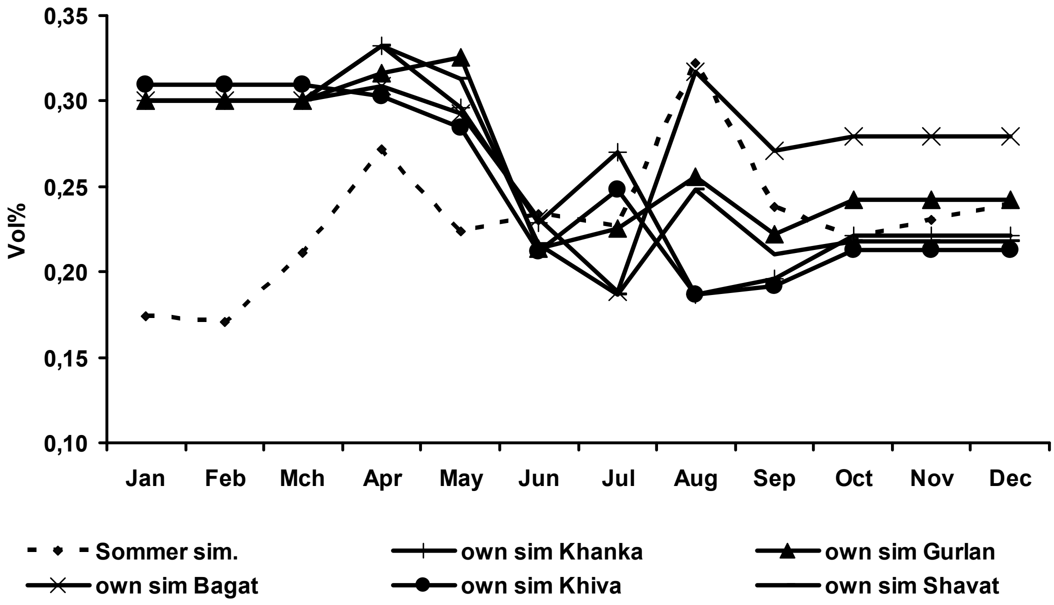

Figure D.2 Plausibility control, comparison of soil moisture, for heavy/loamy soils under cotton cultivation

Notes: authors own sim: different districts, heavy soils, cotton
sim Sommer (2006): cropsyst, loamy soils, 0-40 cm, cotton

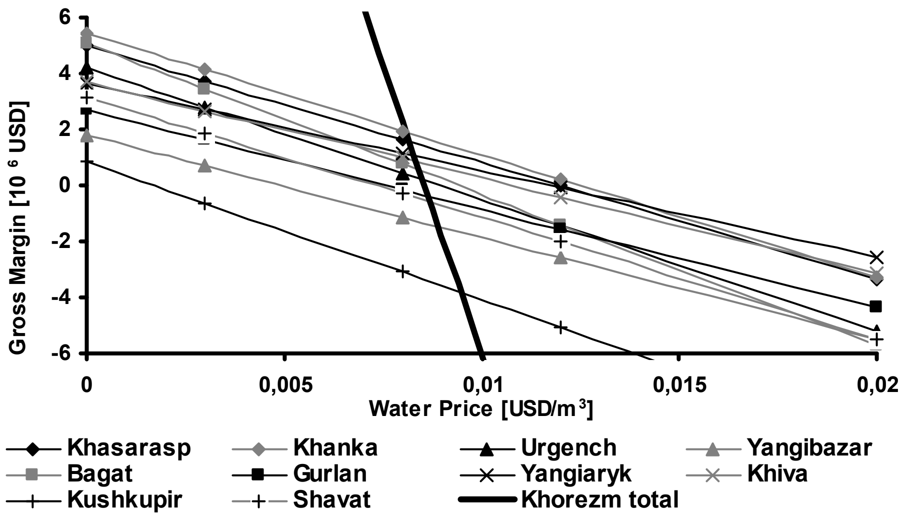

Figure D.3 Effect of changed water prices on gross margins, descriptive model

11.5 Appendix E – simulation results

Table E.18 Yield per crop und soil type, status quo scenario with modified water supply, comparison to Baseline1 (in %)

	cotton	wheat	rice	other grain	alfalfa	vegt	fruit	potato	*avg*
				water supply -25%					
d1 light	-4	-1	-26	-26	-17	-8	-12	-15	*-14*
d1 medium	-5	-12	-14	0	-24	0	-10	-3	*-9*
d1 heavy	-8	-2	-23	-28	-17	-9	-9	-14	*-14*
d2 light	-4	-1	-24	-30	-28	-8	-15	-14	*-15*
d2 medium	-9	-20	-11	-27	-19	0	-10	-2	*-12*
d2 heavy	-10	-7	-20	-3	-22	-7	-13	-12	*-12*
d3 light	-7	-2	-24	-3	-27	-6	-14	-14	*-12*
d3 medium	-11	-14	-14	0	-32	0	-10	-2	*-10*
d3 heavy	-14	-9	-18	0	-30	-4	-23	-12	*-14*
d4 light	-3	-2	-14	-13	-15	-2	-11	-9	*-9*
d4 medium	-16	-19	-7	0	-14	0	-7	-1	*-8*
d4 heavy	-3	-3	-12	0	-28	-1	-13	-5	*-8*
d5 light	-5	-2	-21	-28	-17	-6	-9	-14	*-13*
d5 medium	-17	-2	-14	0	-31	0	-10	-7	*-10*
d5 heavy	-6	-3	-21	0	-19	-7	-17	-14	*-11*
d6 light	-7	-5	-1	-28	-13	0	-8	-3	*-8*
d6 medium	-22	-5	0	-41	-3	0	0	-1	*-9*
d6 heavy	-12	-1	-3	-21	-13	0	-10	-2	*-8*
d7 light	-6	-7	-18	-6	-12	-4	-10	-8	*-9*
d7 medium	-16	-7	-7	-39	-13	0	-8	-1	*-11*
d7 heavy	-11	-1	-19	-31	-11	-4	-10	-8	*-12*
d8 light	-10	-15	-6	-56	-22	0	-14	-5	*-16*
d8 medium	-24	-20	0	-65	-8	0	0	-1	*-15*
d8 heavy	-1	-10	-9	-61	-16	-1	-13	0	*-14*
d9 light	-11	-4	-1	-38	-15	0	-10	-4	*-10*
d9 medium	-18	-5	-2	-46	-8	0	-1	-1	*-10*
d9 heavy	-16	0	-4	-60	-15	0	-11	0	*-13*
d10 light	-4	-1	-9	-20	-16	-1	-10	-6	*-8*
d10 medium	-14	-21	-4	-26	-11	0	-7	0	*-10*
d10 heavy	-15	-13	-10	0	-15	-1	-12	-1	*-8*
avg	*-10*	*-7*	*-12*	*-23*	*-18*	*-2*	*-10*	*-6*	
				water supply -50%					
d1 light	-8	-2	-63	-32	-32	-22	-29	-42	*-29*
d1 medium	-17	-18	-37	0	-52	-7	-26	-25	*-23*
d1 heavy	-18	-3	-55	-39	-39	-19	-29	-55	*-32*
d2 light	-8	-2	-57	-30	-39	-19	-38	-36	*-29*
d2 medium	-23	-28	-31	-27	-56	-6	-25	-16	*-26*
d2 heavy	-16	-14	-50	-3	-46	-16	-41	-49	*-29*
d3 light	-11	-3	-63	-3	-50	-18	-40	-46	*-29*
d3 medium	-28	-31	-34	0	-51	-6	-34	-22	*-26*
d3 heavy	-18	-22	-49	0	-54	-13	-41	-65	*-33*
d4 light	-9	-3	-41	-13	-48	-12	-34	-27	*-23*
d4 medium	-24	-23	-22	0	-44	-3	-19	-7	*-18*
d4 heavy	-18	-4	-31	0	-59	-9	-36	-24	*-22*
d5 light	-9	-2	-59	-28	-29	-21	-32	-41	*-28*
d5 medium	-25	-3	-40	0	-54	-9	-35	-33	*-25*
d5 heavy	-16	-4	-57	0	-46	-16	-36	-62	*-30*
d6 light	-11	-7	-24	-48	-33	-6	-25	-16	*-21*
d6 medium	-36	-19	-8	-62	-21	0	-8	-1	*-19*
d6 heavy	-16	-2	-22	-54	-35	-6	-25	-14	*-22*
d7 light	-8	-7	-46	-24	-35	-15	-25	-26	*-23*
d7 medium	-19	-17	-26	-39	-36	-5	-20	-9	*-21*
d7 heavy	-17	-1	-44	-42	-39	-15	-20	-25	*-25*
d8 light	-14	-16	-39	-56	-53	-13	-37	-33	*-33*
d8 medium	-35	-38	-18	-65	-48	-1	-15	-5	*-28*
d8 heavy	-11	-10	-39	-61	-50	-12	-43	-22	*-31*
d9 light	-14	-20	-24	-55	-40	-7	-26	-17	*-25*
d9 medium	-29	-15	-13	-62	-26	-1	-12	-2	*-20*
d9 heavy	-27	-33	-21	-60	-37	-5	-26	-8	*-27*
d10 light	-6	-1	-36	-20	-49	-9	-28	-22	*-21*
d10 medium	-26	-29	-19	-26	-39	-2	-16	-3	*-20*
d10 heavy	-16	-14	-27	0	-57	-7	-29	-16	*-21*
avg	*-18*	*-13*	*-36*	*-29*	*-43*	*-10*	*-28*	*-25*	

Table E.18 continued

	cotton	wheat	rice	other grain	alfalfa	vegt	fruit	potato	*avg*
				water supply +25%					
d1 light	7	2	15	29	23	2	15	7	*13*
d1 medium	23	6	1	114	14	0	5	0	*20*
d1 heavy	12	2	22	19	20	4	15	10	*13*
d2 light	9	6	5	53	24	1	16	6	*15*
d2 medium	25	8	0	96	10	0	1	0	*18*
d2 heavy	12	7	6	118	21	0	15	3	*23*
d3 light	15	21	6	126	27	0	16	5	*27*
d3 medium	20	5	0	163	12	0	3	0	*25*
d3 heavy	23	33	5	152	28	0	18	1	*32*
d4 light	13	13	2	104	23	0	14	4	*22*
d4 medium	12	8	0	166	8	0	0	0	*24*
d4 heavy	20	26	0	154	18	0	12	1	*29*
d5 light	14	1	17	7	21	4	12	7	*10*
d5 medium	14	10	8	44	16	0	8	1	*13*
d5 heavy	16	3	18	54	18	2	9	9	*16*
d6 light	14	5	1	17	3	0	0	0	*5*
d6 medium	20	3	1	10	0	0	0	0	*4*
d6 heavy	14	1	1	8	4	0	2	1	*4*
d7 light	6	3	3	31	13	0	9	4	*8*
d7 medium	28	2	1	62	4	0	0	0	*12*
d7 heavy	4	1	3	25	16	0	12	2	*8*
d8 light	3	6	0	2	2	0	0	1	*2*
d8 medium	34	1	1	-4	0	0	0	0	*4*
d8 heavy	19	3	2	0	0	0	1	0	*3*
d9 light	5	1	1	5	2	0	0	0	*2*
d9 medium	29	2	0	1	1	0	0	0	*4*
d9 heavy	2	2	1	2	1	0	2	1	*1*
d10 light	14	17	0	87	18	0	9	4	*19*
d10 medium	14	4	0	100	7	0	0	1	*16*
d10 heavy	18	35	2	156	13	0	9	1	*29*
avg	*15*	*8*	*4*	*63*	*12*	*0*	*7*	*2*	
				water supply +50%					
d1 light	11	11	17	40	38	2	23	10	*19*
d1 medium	55	10	2	160	17	0	5	0	*31*
d1 heavy	23	3	24	34	31	4	24	14	*20*
d2 light	13	17	7	61	29	1	18	7	*19*
d2 medium	56	12	1	104	10	0	1	0	*23*
d2 heavy	21	14	6	120	26	0	19	4	*26*
d3 light	22	35	7	137	28	0	16	6	*31*
d3 medium	66	6	2	168	12	0	3	0	*32*
d3 heavy	27	38	5	157	28	0	18	1	*34*
d4 light	19	26	3	109	26	0	14	5	*25*
d4 medium	42	10	1	167	8	0	0	0	*28*
d4 heavy	25	35	1	153	20	0	14	1	*31*
d5 light	22	2	26	51	30	5	18	10	*21*
d5 medium	41	10	13	98	23	0	12	2	*25*
d5 heavy	25	6	24	94	25	4	15	13	*26*
d6 light	32	11	1	35	3	0	0	0	*10*
d6 medium	34	7	1	16	0	0	0	0	*7*
d6 heavy	24	5	2	22	5	0	2	1	*8*
d7 light	22	6	3	55	17	0	9	4	*14*
d7 medium	50	3	1	79	5	0	0	0	*17*
d7 heavy	22	7	4	34	20	0	14	2	*13*
d8 light	23	9	2	11	2	0	0	1	*6*
d8 medium	62	3	2	3	0	0	0	0	*9*
d8 heavy	26	6	2	3	3	0	2	1	*5*
d9 light	34	4	2	21	2	0	0	0	*8*
d9 medium	44	2	1	12	1	0	0	0	*8*
d9 heavy	34	6	1	12	3	0	2	1	*7*
d10 light	19	29	2	92	20	0	9	4	*22*
d10 medium	43	7	0	97	7	0	0	1	*19*
d10 heavy	22	41	2	155	15	0	10	1	*31*
avg	*32*	*13*	*5*	*76*	*15*	*1*	*8*	*3*	

Table E.19 Change of deep percolation per hectare, district and crop type compared to BL1 for different water supply scenarios (in %)

		cotton	wheat	rice	other grain	alfalfa	vegetable	fruit	potato
Water supply -25	Khazarasp	-9	-18	-23	-16	-34	-12	-22	-22
	Khanka	-22	-14	-20	-17	-36	-12	-26	-17
	Urgench	-36	-16	-18	8	-38	-7	-26	-18
	Yangibazar	-20	-28	-10	3	-26	-2	-17	-11
	Gurlan	-30	-23	-16	-2	-32	-11	-18	-20
	Bagat	-44	-16	-5	-43	-23	0	-18	-8
	Yangiarik	-47	-24	-18	-42	-23	-8	-21	-14
	Khiva	-38	-30	-5	-67	-24	-1	-14	-7
	Kushkupir	-46	-10	-5	-57	-22	-1	-16	-7
	Shavat	-44	-19	-8	-17	-19	-2	-15	-4
	avg	*-34*	*-20*	*-13*	*-25*	*-28*	*-5*	*-19*	*-13*
Water supply -50	Khazarasp	-34	-24	-44	-11	-65	-33	-49	-55
	Khanka	-47	-19	-40	-9	-64	-25	-50	-46
	Urgench	-61	-30	-38	14	-62	-21	-50	-52
	Yangibazar	-51	-32	-28	11	-63	-19	-44	-28
	Gurlan	-50	-25	-40	9	-61	-31	-50	-57
	Bagat	-59	-31	-25	-68	-53	-12	-44	-26
	Yangiarik	-57	-35	-43	-51	-63	-31	-49	-39
	Khiva	-62	-42	-29	-66	-64	-17	-45	-30
	Kushkupir	-69	-42	-24	-67	-50	-11	-39	-18
	Shavat	-63	-25	-26	-14	-59	-12	-35	-19
	avg	*-55*	*-31*	*-34*	*-25*	*-60*	*-21*	*-45*	*-37*
Water suply +25	Khazarasp	58	12	17	77	41	4	25	13
	Khanka	70	16	4	138	37	0	22	8
	Urgench	82	36	5	178	36	0	19	5
	Yangibazar	63	32	2	185	29	-1	15	6
	Gurlan	75	25	17	36	26	4	14	9
	Bagat	62	17	7	18	7	-1	2	2
	Yangiarik	65	20	8	91	29	-4	22	7
	Khiva	73	12	4	-2	5	1	5	3
	Kushkupir	46	11	2	4	7	1	6	5
	Shavat	67	31	2	140	25	0	14	9
	avg	*66*	*21*	*7*	*86*	*24*	*0*	*14*	*7*
Water supply +50	Khazarasp	132	36	23	110	67	3	42	21
	Khanka	137	41	10	140	48	0	30	12
	Urgench	163	56	11	194	38	-1	20	6
	Yangibazar	120	56	9	188	36	-1	20	7
	Gurlan	163	18	27	96	44	6	29	13
	Bagat	142	45	9	49	8	-3	1	2
	Yangiarik	182	44	13	130	36	-5	21	7
	Khiva	155	24	10	6	11	1	11	5
	Kushkupir	143	24	10	22	10	0	7	5
	Shavat	131	50	5	144	32	0	19	13
	avg	*147*	*39*	*13*	*108*	*33*	*0*	*20*	*9*

Table E.20 Economic water use efficiency per crop and district for different efficiency experiments under status quo scenario (in USD/m^3)

		cotton	wheat	rice	ograin	alfalfa	vegetable	fruit	potato
effdstr05_acpfix	Khazarasp	-0.026	0.020	0.017	-0.008	0.033	0.045	0.035	0.030
	Khanka	-0.024	0.018	0.017	-0.009	0.029	0.043	0.033	0.029
	Urgench	-0.029	0.015	0.015	-0.008	0.027	0.040	0.029	0.026
	Yangibazar	-0.020	0.013	0.016	-0.008	0.027	0.038	0.029	0.027
	Gurlan	-0.012	0.012	0.014	-0.012	0.030	0.040	0.032	0.027
	Bagat	0.002	0.024	0.019	0.010	0.029	0.047	0.034	0.031
	Yangiarik	-0.003	0.021	0.019	0.002	0.032	0.045	0.035	0.031
	Khiva	-0.009	0.017	0.018	0.007	0.029	0.047	0.036	0.031
	Kushkupir	-0.003	0.019	0.019	0.008	0.030	0.047	0.036	0.031
	Shavat	-0.016	0.016	0.016	-0.002	0.027	0.041	0.031	0.028
	avg	*-0.014*	*0.017*	*0.017*	*-0.002*	*0.029*	*0.043*	*0.033*	*0.029*
effdstr065	Khazarasp	-0.006	0.023	0.022	0.003	0.037	0.055	0.042	0.037
	Khanka	-0.004	0.023	0.022	0.009	0.034	0.055	0.041	0.036
	Urgench	-0.007	0.019	0.021	0.007	0.032	0.052	0.037	0.033
	Yangibazar	-0.008	0.016	0.021	0.005	0.032	0.049	0.037	0.034
	Gurlan	-0.004	0.013	0.020	0.000	0.035	0.051	0.039	0.034

Table E.20 continued

		cotton	wheat	rice	ograin	alfalfa	vegetable	fruit	potato
	Bagat	0.006	0.027	0.023	0.013	0.037	0.061	0.043	0.039
	Yangiarik	0.004	0.022	0.024	0.011	0.036	0.062	0.043	0.039
	Khiva	0.002	0.020	0.023	0.010	0.037	0.060	0.045	0.039
	Kushkupir	0.004	0.023	0.024	0.011	0.037	0.060	0.045	0.039
	Shavat	-0.006	0.021	0.021	0.008	0.033	0.053	0.039	0.034
	avg	*-0.002*	*0.021*	*0.022*	*0.008*	*0.035*	*0.056*	*0.041*	*0.036*
effirr04	Khazarasp	-0.028	0.019	0.016	-0.010	0.032	0.043	0.034	0.030
	Khanka	-0.030	0.017	0.016	-0.008	0.028	0.041	0.032	0.028
	Urgench	-0.033	0.015	0.015	-0.008	0.026	0.039	0.028	0.026
	Yangibazar	-0.024	0.012	0.015	-0.008	0.026	0.036	0.028	0.026
	Gurlan	-0.014	0.012	0.013	-0.011	0.029	0.039	0.031	0.026
	Bagat	0.001	0.024	0.018	0.010	0.029	0.046	0.033	0.030
	Yangiarik	-0.003	0.020	0.018	0.000	0.031	0.044	0.035	0.030
	Khiva	-0.010	0.017	0.018	-0.003	0.029	0.046	0.035	0.030
	Kushkupir	-0.004	0.019	0.018	0.007	0.029	0.046	0.035	0.030
	Shavat	-0.018	0.015	0.016	-0.002	0.026	0.039	0.030	0.027
	avg	*-0.016*	*0.017*	*0.016*	*-0.003*	*0.029*	*0.042*	*0.032*	*0.028*
effirr06	Khazarasp	-0.001	0.025	0.025	0.012	0.039	0.062	0.045	0.040
	Khanka	0.001	0.025	0.024	0.011	0.037	0.061	0.045	0.039
	Urgench	-0.002	0.021	0.023	0.010	0.035	0.058	0.041	0.037
	Yangibazar	-0.004	0.017	0.023	0.010	0.035	0.054	0.040	0.037
	Gurlan	-0.001	0.015	0.022	0.005	0.037	0.056	0.042	0.038
	Bagat	0.008	0.029	0.025	0.014	0.040	0.068	0.047	0.043
	Yangiarik	0.009	0.025	0.027	0.016	0.045	0.077	0.053	0.048
	Khiva	0.007	0.023	0.027	0.013	0.044	0.075	0.053	0.048
	Kushkupir	0.008	0.026	0.028	0.015	0.044	0.075	0.053	0.048
	Shavat	0.002	0.025	0.026	0.012	0.039	0.065	0.047	0.042
	avg	*0.003*	*0.023*	*0.025*	*0.012*	*0.040*	*0.065*	*0.047*	*0.042*
effdstr06irr05	Khazarasp	-0.006	0.024	0.023	0.008	0.038	0.057	0.043	0.038
	Khanka	-0.003	0.023	0.023	0.010	0.035	0.057	0.042	0.037
	Urgench	-0.006	0.020	0.021	0.009	0.032	0.054	0.038	0.034
	Yangibazar	-0.007	0.017	0.022	0.008	0.033	0.050	0.038	0.034
	Gurlan	-0.004	0.013	0.020	0.000	0.036	0.052	0.040	0.035
	Bagat	0.007	0.028	0.024	0.013	0.037	0.063	0.044	0.040
	Yangiarik	0.008	0.024	0.026	0.014	0.041	0.071	0.049	0.045
	Khiva	0.006	0.022	0.026	0.012	0.041	0.070	0.050	0.045
	Kushkupir	0.007	0.025	0.027	0.014	0.041	0.070	0.050	0.044
	Shavat	0.000	0.024	0.024	0.011	0.037	0.060	0.045	0.039
	avg	*0.000*	*0.022*	*0.024*	*0.010*	*0.037*	*0.060*	*0.044*	*0.039*
effirr05	Khazarasp	-0.009	0.022	0.021	0.003	0.036	0.051	0.040	0.035
	Khanka	-0.008	0.021	0.020	0.008	0.033	0.051	0.038	0.034
	Urgench	-0.011	0.018	0.019	-0.002	0.030	0.048	0.034	0.031
	Yangibazar	-0.011	0.015	0.019	-0.001	0.030	0.045	0.034	0.031
	Gurlan	-0.006	0.013	0.018	-0.002	0.033	0.047	0.037	0.032
	Bagat	0.005	0.026	0.022	0.012	0.034	0.057	0.040	0.036
	Yangiarik	0.005	0.023	0.024	0.013	0.038	0.064	0.044	0.040
	Khiva	0.003	0.021	0.024	0.011	0.038	0.063	0.046	0.040
	Kushkupir	0.005	0.023	0.025	0.012	0.038	0.063	0.046	0.040
	Shavat	-0.004	0.022	0.022	0.009	0.034	0.055	0.041	0.035
	avg	*-0.003*	*0.020*	*0.022*	*0.006*	*0.034*	*0.054*	*0.040*	*0.036*
effdstr06	Khazarasp	-0.010	0.022	0.021	0.003	0.036	0.051	0.040	0.035
	Khanka	-0.008	0.021	0.020	0.008	0.033	0.051	0.038	0.034
	Urgench	-0.011	0.018	0.019	-0.002	0.030	0.048	0.034	0.031
	Yangibazar	-0.011	0.015	0.019	-0.001	0.030	0.045	0.034	0.031
	Gurlan	-0.006	0.013	0.018	-0.003	0.033	0.047	0.037	0.032
	Bagat	0.005	0.026	0.022	0.012	0.034	0.057	0.040	0.036
	Yangiarik	0.002	0.021	0.022	0.010	0.034	0.057	0.040	0.036
	Khiva	-0.001	0.019	0.022	0.010	0.035	0.056	0.042	0.036
	Kushkupir	0.002	0.021	0.022	0.011	0.034	0.056	0.042	0.036
	Shavat	-0.009	0.019	0.019	0.001	0.031	0.049	0.036	0.032
	avg	*-0.005*	*0.020*	*0.021*	*0.005*	*0.033*	*0.052*	*0.038*	*0.034*

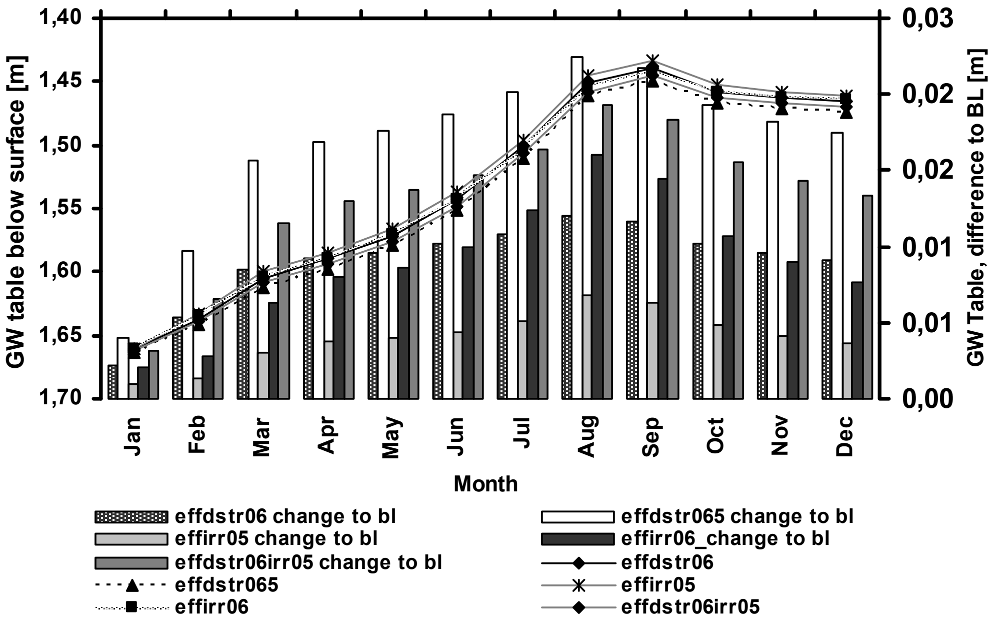

Figure E.4 Groundwater table depth and change compared to Baseline1 for different efficiency experiments under status quo scenario, absolute values (in m)

Table E.21 Acreage per crop and district, comparison Baseline3 to Baseline2, absolute values (in ha)

	cotton	wheat	rice	ograin	alfalfa	vegt	fruit	potatoe	*sum*
Khazarasp	4913	-4164	-2472	-25	-1072	-766	-406	-78	*-4069*
Khanka	5352	-5735	-1624	22	-1357	-765	-324	-296	*-4727*
Urgench	3678	-5340	-1410	48	-698	-1145	-505	-415	*-5788*
Yangibazar	3781	-4190	-1201	11	-1716	-423	-734	-229	*-4701*
Gurlan	2173	-3267	-925	130	-1053	-840	-614	-401	*-4797*
Bagat	2111	-4955	-1226	86	-466	-458	-288	-107	*-5303*
Yangiarik	2289	-3209	-1998	37	244	-599	-273	-330	*-3839*
Khiva	2592	-4254	-413	61	171	-1796	-350	-458	*-4448*
Kushkupir	2584	-4762	-565	196	-2104	-677	112	-414	*-5630*
Shavat	4640	-6465	-1180	27	-1837	-669	-441	-320	*-6245*
tot	34112	-46341	-13015	593	-9887	-8138	-3823	-3047	***-49547***

Table E.22 Variable production costs per district for Baseline3 scenario and experiments with modified water supply of +50 and -50, total values (in 10^6 USD)

Variable cost in 10^6 USD	lib_scen_bl	wsdt+50	wsdt-50
Khazarasp	4.47	6.98	5.67
Khanka	4.39	5.22	6.31
Urgench	3.69	5.24	4.67
Yangibazar	3.09	4.41	4.54
Gurlan	4.66	7.91	5.60
Bagat	3.39	5.75	3.37
Yangiarik	2.65	3.91	2.77
Khiva	2.90	4.08	3.48
Kushkupir	4.10	6.31	3.34
Shavat	3.87	4.55	5.68
sum	*37.21*	*54.35*	*45.42*

Table E.23 Change of variable production costs per district and per crop for Baseline3 scenario and experiments with modified water supply of +50 and -50, total values (in 10^6 USD)

	cotton	**wheat**	**rice**	**ograin**	**alfalfa**	**vegt**	**fruit**	**potatoe**
				Change Baseline3 and wsdt+50				
Khazarasp	-2.6	175.1	116.0	172.8	68.6	182.6	189.2	5.5
Khanka	-5.7	29.1	33.5	371.3	157.0	25.3	319.2	11.6
Urgench	1.7	2.3	86.1	251.1	74.1	202.7	222.9	4.4
Yangibazar	0.5	95.4	114.0	326.4	274.9	295.2	363.4	9.6
Gurlan	-1.6	26.0	144.1	281.6	61.2	218.7	322.0	4.6
Bagat	14.3	187.8	192.4	11.1	5.8	214.7	211.9	1.1
Yangiarik	3.6	29.2	172.7	298.9	45.7	259.4	27.5	3.8
Khiva	-0.5	53.7	214.5	281.1	40.6	235.2	248.5	4.6
Kushkupir	39.2	64.0	189.6	-1.3	21.1	19.1	3.2	0.9
Shavat	1.4	1.8	71.8	400.3	187.9	9.9	15.6	10.6
				change Baseline3 and wsdt-50				
Khazarasp	60.9	-12.0	-22.7	-14.0	-17.1	-3.6	10.5	-6.3
Khanka	70.1	40.6	-16.9	-20.7	34.4	-16.1	0.8	-9.7
Urgench	51.4	43.6	-26.6	-30.2	35.3	-10.9	-2.0	-14.8
Yangibazar	59.3	34.7	-17.5	5.7	149.2	2.7	4.0	-9.2
Gurlan	55.4	31.0	-26.4	-24.1	-10.6	8.7	0.5	-8.7
Bagat	19.6	0.8	-35.1	-70.2	-58.0	3.8	-31.1	-12.6
Yangiarik	16.5	11.2	-16.2	5.6	-36.2	-1.1	42.6	-8.2
Khiva	36.7	7.4	-32.7	-15.3	-20.8	-3.3	-6.7	-14.7
Kushkupir	8.2	-31.3	-37.1	-80.5	-52.1	-71.2	-77.8	-10.7
Shavat	58.3	60.1	-17.0	-37.6	106.5	-4.4	-4.8	-10.5

11.6 Appendix F – sets, variables and parameters used in the model

Table F.24 Indices of the model

Indices	Description	Items
gw, ggw	*groundwater sources*	gw1-gw10, according to district units
dr, ddr	*drainage sources*	dr1-dr10, according to district units
dt, ddt	*districts*	d1-d10: d1=Khazarasp, d2=Khanka, d3=Urgench, d4=Yangibazar, d5=Gurlan, d6=Bagat, d7=Yangiarik, d8=Khiva, d9=Kushkupir, d10=Shavat
m, mm0	*months*	m1*m12: Jan-Dec
c	*crops*	cotton, wheat, rice, other grains, alfalfa, vegetables, fruits, potato
soil	*soil type*	light, medium, heavy soil

Table F.25 Sets of the model

Sets	Indices	Description
irri_m	*m*	m4-m12
gw_dt	*gw, dt*	gw1.d1-gw10-d10
dt_dr	*dt, dr*	d1-10.dr1-10
dt_soil_c	*dt,soil,c*	demand sites-soil type-crop pattern relationship d1-d10.light/medium/heavy.cotton/wheat/rice/ograin/alfalfa/vegt/fruit/potato
c_m	*c, m*	crop growth periods cotton.(m4-m10), rice.(m4-m9), wheat.(m10-m12, m1-m6), ograin.(m5-m9), alfalfa.(m3-m10), fruit.(m3-m10), vegt.(m4-m10), potato.(m4-m9)
c_mm0	*c, m, mm0*	cumulative crop periods

Table F.26 Variables of the model

Variables	Indices	Description
obj		objective variable, regional welfare in USD
aprft	*ddt*	agricultural gross margins in USD
ws_dt	*ddt, m*	water supply by month in 10^6 m^3
wrt	*ddt, m*	return flow in 10^6 m^3
hg	*ggw, m*	groundwater table in m
pump	*ggw, ddt, soil, c, m*	pumping in 10^6 m^3
wfld	*ddt, soil, c, m*	total water applied in fields in 10^6 m^3
ge	*ddt, soil, c, m*	groundwater extract in mm
dp	*ddt, soil, c, m*	percolation from crop root zones in mm
pe	*ddt, soil, c, m*	effective precipitation in mm
wcp	*ddt,soil, c, m*	surface water applied in fields in 10^6 m^3
wacp	*ddt, soil,c, m*	surface water effectively used by crops in 10^6 m^3
eta	*ddt, soil,c, m*	actual ET in mm/month
drn	*ddt, m*	drainage from a demand site in 10^6 m^3
ryld	*ddt, soil,c, m*	relative stage yield to the max yield no unit
mryld	*ddt,soil, c*	minimum relative yield over all period no unit
sryld	*ddt, soil,c*	relative seasonal yield to max yield no unit
acp	*ddt, soil, c*	irrigated crop area in ha

Table F.26 continued

Variables	Indices	Description
Z	*ddt, soil,c,m*	soil moisture content in root zone, no unit, in %
kw	*ddt,soil,c, m*	soil moisture stress coeff. for transpir, transp reduction factor no unit
kap	*ddt, soil,c, m*	coeff. f soil water stress for soil evaporat, evaporat coeffic no unit
alp1	*ddt*	slack variable, no unit
alp2	*ddt*	slack variable, no unit
ks	*ddt, soil,c, m*	salinity coefficient no unit
yield	*ddt,soil,c*	crop yield in t/ha
costs	*ddt,soil,c*	production costs in 10^6 USD
price	*ddt,soil,c*	sales prices in 10^6 USD
are_ges	*ddt*	total cropped area in ha
cpp_calc	*ddt, c*	calculated optimal crop selling price in 10^6 USD
wacp_ha	*ddt,soil,c*	water at field per ha
dem	*ddt,c*	demand in t

Table F.27 Parameters of the model

Parameter	Indices	Description
surwat_all	*ddt*	surface water applied to district, in 10^6 m^3
pumpwat_all	*ddt*	water pumped in 10^6 m^3
twat_all	*ddt*	total water applied to district, surface and pumped water in 10^6 m^3
surwat_crop	*ddt, c*	surface water applied to crops, in irrigation months in 10^6 m^3
pumpwat_crop	*ddt, c*	water pumped in 10^6 m^3
totwat_crop	*ddt, c*	total water applied to crops, surface and pumped Water in 10^6 m^3
watcost_all	*ddt*	water costs for crops per district in 10^6 USD
watcost_crop	*ddt,c*	water costs for crops in 10^6 USD
revenue_all	*ddt*	revenues from crop harvested per district in 10^6 USD
revenue_crop	*ddt,c*	revenues from crop harvested per crop in 10^6 USD
grossmargin_all	*ddt*	gross margins per district in 10^6 USD
grossmargin_crop	*ddt,c*	gross margins per crop in 10^6 USD
e-WUE_all	*ddt*	economic water use efficiency for districts in USD/m^3
e-WUE_crop	*ddt,c*	economic water use efficiency for crops in USD/m^3
ky(s)	*c*	seasonal crop response coefficients, no unit
dpth_min	*gw*	groundwater tank min. depth to the base level in m
dpth_max	*gw*	aquifer max depth to the base level in m
hg0	*gw*	initial aquifer depth to the base level in m
pump_cp	*gw*	groundwater pumping capacity in 10^6 m^3
aqa	*ggw*	groundwater tank surface area in ha
sy	*gw*	aquifer specific yield coefficient, no unit
trans	*gw*	hydraulic conductivity in aquifers in cm/day
rdpth	*c*	root depth in cm
r_sr	*dt, soil, c*	ratio irrigation surface runoff/losses in total losses
gct	*dt*	groundwater pumping cost in USD/m^3
sct	*dt*	surface water price in USD/m^3
csmp_dt	*dt*	drainage from non-irrigation water use in %
eff_dstr	*dt*	distribution efficiency
eff_drn	*dt*	drainage efficiency, here drainage over total irrigated water supply
eff_irr	*dt,soil,c*	irrigation efficiency, application efficiency
se	*dt, soil, c, m*	average soil salinity
ks	*dt, soil,c, m*	salinity coefficient, no unit
areatotal	*dt*	total irrigated crop area in ha
er0	*dt, c, m*	effective rainfall in mm/month
rain	*dt,m*	avg. monthly rainfall in mm
et0	*dt, m*	reference evapotranspiration in mm/month
area_cp	*dt,c*	cropping area per district and soil, in ha

Table F.27 continued

Parameter	Indices	Description
tarea	*dt,soil*	total irrigated area in ha per soil
pot_yield	*dt,soil,c*	potential yield in Khorezm t/ha
niwd	*dt,m*	M&I water uses in 10^6 m^3
kc	*c, m*	crop coefficient, no unit
kct	*c, m*	crop coefficient for transpiration, no unit
ky	*c, m*	crop yield response coefficient, no unit
hg00	*gw,m*	groundwater in 2003 in cm
cc	*dt, soil*	soils pore connectivity index, no unit
mm	*dt, soil*	soil connectivity and turtuosity parameter, no unit
smp	*dt, soil*	saturated soil matrix potential in cm suction
khs	*dt, soil*	effective saturated hydraulic conductivity in cm/month
zs	*dt, soil*	soil moisture at field capacity, pF2 in cm^3*cm^{-3}
zw	*dt, soil*	soil moisture at wilting point, pF4.2 in cm^3*cm^{-3}
z0	*dt, soil*	initial soil moisture
cpp	*dt, c*	crop price USD/t
otc	*dt, c*	crop planting cost USD/ha
b	*c, m*	salinity effecting coefficients-slope, no unit
ctd	*c, m*	threshold of electrical conductivity in saturating extract of soil in ds/m
ws_dt0	*dt, m*	water supply to demand site by month in 10^6 m^3
init_acp	*dt,soil,c*	initial cropping area in ha
min_area	*dt,c*	minimum crop area, in ha
e	*dt,c*	crop price elasticity of demand, no unit
e_a	*dt,c*	factor a, a=production-b·price, no unit

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