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Modeling Crop and Water Allocation under Uncertainty in Irrigated Agriculture.

A Case Study on the Khorezm Region, Uzbekistan

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Abstract

Irrigated agriculture for cotton and wheat production forms the backbone of the rural economy in the Khorezm region. Ecological deterioration and inefficient resource use have resulted in and now present a significant threat to the livelihoods of those most dependent on this sector. Inefficient water use has led to rising ground water tables and widespread water and soil salinization has resulted. The high water demand in the region for crop production renders farmers vulnerable to the recurrently predicted decrease in water supply. Farmers in the Khorezm region are vulnerable to uncertain water supplies due to current policies which restrict their decision making in terms of what type of crops to grow, when and where. Similarly, there are ever increasing risks in terms of yields and price fluctuations due to natural conditions and fluctuations in the market.

This study contributes to understanding key obstacles and potential solutions to promoting sustainable development in the region. Moving beyond previous disciplinary approaches in this area, this work includes different crop allocation and water use options in a systems context, where linkages between the environment and socio-economic impacts are considered simultaneously in the analysis of economic and ecological benefits from different agricultural activities. To this end, a static, stochastic model for Khorezm was developed to explore potential risk reducing strategies for farmers, while accounting for the ecological consequences potential policies. Worldwide, mathematical modelling has proven to be an effective instrument for increasing the overall understanding of the complexity of water demand and supply processes, while analysing resource-saving alternatives that are both economically and ecologically sustainable. In order to maximize the utility and applicability of such an approach, each model must incorporate local agro-ecological, social and economic conditions.

A stochastic programming model was developed to combine the Expected Value-Variance (EV) approach with chance-constrained programming. Analysis was carried out using data from one Water Users' Associations (WUA), Shamahulum, located in the Khiva district of the Khorezm region. The developed model considered the optimization of water and land allocation of 300 fields, belonging to 99 farmers in one Water User Association (WUA). The availability of Geographical Information System (GIS) based data allowed the integration of spatial aspects into the model. The model was calibrated using various Constant Relative Risk Aversion levels (CRRA). The CRRA is adjusted as the core parameter in the base run of the model and is set to match the observed activity level in the case study WUA. Following the calibration, various simulations were conducted to account for the impact of different policy scenarios. The combined outcomes of the simulations provided a basis for assessing potential effects of different policy measures given the dynamics of the on-going reform strategies in Uzbekistan.

The model findings suggest that allocating the area to less water demanding crops and usage of alternative irrigation methods will help to secure farmer income. However, farmers remain unable to fully utilize these risk coping strategies due to occupation of more than 70% of the area with state order, low income crops, including cotton and winter wheat.

Key findings from the study indicate the possibility of improving water use efficiency (WUE) and thus the environmental situation in the region through the introduction of water pricing. Results also showed that economic and ecological development could be achieved simultaneously only under the presence of more flexible decision making at the farm level.

Zusammenfassung

Bewässerungslandwirtschaft für Baumwoll- und Weizenproduktion ist das Rückgrat der ländlichen Wirtschaft in der Khorezm Region Usbekistans. Ökologische Zerstörung und ineffiziente Ressourcennutzung haben zu einer signifikanten Bedrohung der Existenzgrundlage derjenigen Menschen geführt, die am meisten von diesem Sektor abhängen. Ineffiziente Wassernutzung hat steigende Grundwasserspiegel verursacht, mit der Folge verbreiteter Wasser- und Bodenversalzung. Die hohe Wassernachfrage für den Pflanzenbau in der Region Landwirte verwundbar für den wiederholt vorhergesagten Rückgang der Wasserversorgung. Landwirte in der Khorezm Region sind gefährdet durch unsichere Wasserversorgung gefährdet, da aktuelle Politiken ihre Entscheidungsfindung darüber, welche Pflanzenarten wann und wo anzubauen sind, einschränken. Ebenso bestehen steigende Risiken in Bezug auf Erträge und Preisfluktuationen aufgrund von natürlichen Bedingungen und Schwankungen am Markt.

Diese Studie trägt zum Verständnis der Haupthindernisse und potentiellen Lösungen für die Förderung von nachhaltiger Entwicklung in der Region bei. Als Weiterentwicklung von früheren disziplinären Ansätzen in diesem Bereich, bringt diese Arbeit verschiedene Allokationen von Anbaupflanzen und Optionen der Wassernutzung in einen Systemkontext, wobei Verbindungen zwischen der Umwelt und den sozioökonomischen Auswirkungen in der Analyse der wirtschaftlichen und ökologischen Vorteile verschiedener landwirtschaftlicher Aktivitäten gleichzeitig berücksichtigt werden. Zu diesem Zweck wurde ein statisches stochastisches Model für Khorezm entwickelt, um, unter Berücksichtigung der ökologischen Konsequenzen möglicher Politiken, die potentiellen risikovermindernden Strategien für Landwirte zu untersuchen. Weltweit hat sich die mathematische Modellierung als ein effektives Instrument erwiesen, um das Gesamtverständnis der komplexen Prozesse von Wassernachfrage und -angebot zu verbessern und gleichzeitig ressourcenschonende Alternativen, die sowohl ökonomisch als auch ökologisch nachhaltig sind, zu analysieren. Um den Nutzen und die Anwendbarkeit eines solchen Ansatzes zu maximieren, muss jedes Modell lokale agro-ökologische, soziale und ökonomische Bedingungen einbeziehen.

Es wurde ein stochastisches Programmierungsmodell entwickelt, um den Erwartungswert Varianz Ansatz (Expected Value Variance, EV) mit Chance-Constrained Programmierung zu kombinie-ren. Die Analyse wurde mit Rückgriff auf Daten einer Wassernutzervereinigung, Shamahulum, aus dem Khiva Distrikt der Khorezm Region durchgeführt. Das entwickelte Modell betrachtete die Optimierung von Wasser- und Landallokation von 300 Feldern, die im Besitz von 99 Landwirten einer Wassernutzervereinigung sind. Die Verfügbarkeit von Daten auf Basis des Geographical Information System (GIS) erlaubte die Integration von räumlichen Aspekten in das Modell. Das Modell wurde mit Hilfe verschiedener Konstanter Relativer Risikoaversionsstufen (Constant Relative Risk Aversion, CRRA) kalibriert. Die CRRA wurden im Grunddurchlauf des Modells als Hauptparameter eingerichtet und so eingestellt, dass sie dem beobachteten Aktivitätsniveau der Wassernutzervereinigung der Fallstudie entsprachen. Nach der Kalibrierung wurden verschiedene Simulationen durchgeführt, um den Einfluss verschiedener Politikszenarien aufzuzeigen. In Anbetracht der Dynamiken der fortlaufenden Reformstrategien in Usbekistan lieferten die kombinierten Ergebnisse der Simulationen eine Grundlage für die Bewertung der potentiellen Effekte verschiedener Politikmaßnahmen.

Die Modellergebnisse lassen darauf schließen, dass die Bebauung des Gebietes mit weniger wasserverbrauchenden Pflanzen und die Nutzung von alternativen Bewässerungsmethoden dazu beitragen werden, das Einkommen der Landwirte zu sichern. Allerdings ist es für die Landwirte weiterhin nicht möglich, diese risikovermindernden Strategien vollständig zu nutzen, da unter staatlicher Kontrolle auf mehr als 70% des Gebietes ertragsschwache Pflanzen, wie Baumwolle und Winterweizen, angebaut werden.

Schlüsselergebnisse der Studie deuten auf die Möglichkeit, die Effizienz der Wassernutzung – und damit die Umweltsituation in der Region – durch die Einführung von Wasserbepreisung zu verbessern. Die Resultate haben auch gezeigt, dass wirtschaftliche und ökologische Entwicklung nur dann gleichzeitig erreicht werden kann, wenn auf Farmebene die Möglichkeit einer flexibleren Entscheidungsfindung besteht.

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Acronyms and Abbreviations

AgroProm	Regional Department of MAWR
Birja	Local commodity exchange
Bonitet	soil fertility indicator
BUIS	Basin Management of Irrigation System
BVO	Basin Water Management Organization
CA	Central Asian
CDF	Cumulative Probability Distribution
CE	Certainty Equivalent
Dehkans	Peasant farmer in Uzbek
EV	Expected Value-Variance
FAO	Food and Agriculture Organization
FDA	Farmer and Dehkans Association
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GIS	Geographic Information system
GoU	Government of Uzbekistan
GM	Gross Margin
Hydromodule	Agro-ecological zone for determining crop water requirements
ICWC	Interstate Water Commission
IFPRI	International Food Policy Research Institute
Khakimiyat	Region or District Mayor Office
Kolkhoz	Former state farm
LP	Linear Programming
LPM	Lower Partial Moments
MAWR	Ministry of Agriculture and Water Resources
MOTAD	Mean of Total Absolute Deviations
MTP	Machine Tractor Park
NGO	Non-Government Organizations
NLP	Non-Linear Programming
OblHimiya	Regional Fertilizer Supply Department
OblStat	Regional Department of the Ministry for Macroeconomics and Statistics in Khorezm
OECD	Organization for Economic Co-operation and Development
O&M	Operation and Maintenance
PMP	Positive Mathematical Programming
QPR	Quadratic Programming
RWUA	Regional Department of Water Users Associations
Shirkat	New form of state farms established after the independence
SIMETAR	Simulation and Economics to Analyze Risk
Sovkhoz	Former state farm mainly specialized on vegetable and fruit growing
SoyuzNIHI	Soil Research Institute in Uzbekistan
SSIU	Soil Science Institute of Uzbekistan
SU	Soviet Union
Tomorqa	Small household plot

UIS	Irrigation System Management Organization
UNEP	United Nations Environment Programmer
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNS	Management Organization of Pumping Stations
UPRADIK	Irrigation Canals Division, branch of BVO
WUA	Water Users Association
WUE	Water Use Efficiency
ZEF	Centre for Development Research

Units

ha	hectare
kg	kilogram
km	kilometer
USD	United States Dollar
UZS	Uzbek Soum

Exchange rate

1 USD = 1250 UZB (Average exchange rate in 2005)

1 Introduction

1.1 The role of irrigation worldwide

Irrigated agriculture plays an important role in meeting ever growing food demands around the world. More than 40% of the world's agricultural production originates from only 17% of the world's arable land (IFPRI, 2004), and the total world area under irrigated agriculture has increased fivefold since the beginning of the 20^{th} century (Rosegrant *et al.*, 2002). An increased diversion of crops for biofuel production as well as droughts in many of the primary grain supplying countries, has significantly decreased food availability in recent years; agricultural commodity prices have increased worldwide during the last two years and the head of the United Nations World Food Programme recently described the soaring food prices as a 'silent tsunami' due to the vast number of people affected by resulting food shortages (OECD-FAO, 2006; WFP, 2008). Therefore, under rising demand and limited room for expansion of production, irrigated agriculture, which produces yields on average 2.3 times higher than rain fed agriculture (Garces-Restrepo *et al.,* 2007), is becoming more important in securing food supply and stabilizing agricultural production prices around the world.

1.1.1 Problems with irrigated agriculture

Over 70% of fresh water around the world is used for irrigation and water demand for irrigation already exceeds the current supply (IFPRI, 2004). There is a considerable need to increase irrigation efficiency globally as losses during transportation in channels and during field application are major sources of water loss in irrigated agriculture. According to FAO (2002), the overall water use efficiency must be increased, i.e. 'more crop per drop', from 38% to 42%, between 1998 and 2030 in more than 90 developing countries in order to have sufficient water resources to cover irrigation water demand.

The impacts of water scarcity are particularly acute in countries where the economy is heavily dependent on irrigated agriculture, such as in Uzbekistan. Up to forty percent of GDP in the Central Asian (CA) countries is generated by the agricultural sector which depends almost exclusively on water availability from the Amu Darya and Syr Darya rivers - the former tributaries to the Aral Sea. Low efficiency is often considered the cause of ecological problems, which is exemplified by the human induced disaster known as the Aral Sea Syndrome (WBGU, 1998). Between 1960 and 1999 Soviet engineers expanded the irrigated area from 4.5 million ha to 7.9 million ha in the Aral Sea basin to increase in particular the cotton production in the region (UNEP, 2000). The irrigated area in the upstream and downstream regions of the Amu Darya and Syr Darya rivers were expanded at the expense of the water inflow to the Aral Sea from both rivers. Due to the extension diversion of water for irrigated agriculture, combined with high inefficiency along the transportation system, the Aral Sea, once the world's fourth largest lake, lost over eighty per cent of its volume since 1960 and has resulted in many ecological and health problems in the region (Glantz, 1999).

1.1.2 Social-economic and ecological significance of irrigated agriculture in Uzbekistan

Uzbekistan is one of five countries located in the Aral Sea basin. Uzbekistan is considered as an agrarian country where agriculture contributes more than 30% to the gross domestic product, and agriculture is fully dependent on irrigation (Spoor and Khaitov, 2003). More than 30 percent of the able-bodied population is directly involved in agricultural production and more than 60 percent of the population lives in rural areas (ADB, 2004).

The Republic became a sovereign state in 1991 and has since been moving slowly from the former Soviet-style command state to a market oriented economy. The reforms included the transformation of the state and collective farms into various types of private farm holdings accelerated after 2003 (Spoor, 2007). Such reforms were guided by the tenet that "private farming" would use natural resources more efficiently and thus would contribute to improving the deteriorated ecological situation in the region. Yet, since the transformation has not been concluded as announced, and in fact still is based on an authoritarian and centralized political system established in the former Soviet system, improvements in natural resource use have not been as was expected (Spoor, 2007).

Farmers are still not free in their decision making with respect to what, when and where to crop. The state procurement order still predominates and farmers are obliged to allocate a high share of their land area to cotton and winter wheat. Uzbekistan is the world's fifth largest cotton producer and has obtained self-sufficiency in grain production in the post-Soviet period. However, cotton monoculture still dominates the cropping systems, as substantiated by the more than 50% share of annual cotton acreage on average in Uzbekistan (Müller, 2006).

Khorezm, located in the lower Amu Darya Basin, is one of twelve oblasts in Uzbekistan and the smallest administrative region. The economy of the Khorezm region is very dependent on irrigated agriculture, where contribution of the agriculture sector to regional GPD was equal to 67 percent in 2003 (Djanibekov, 2008). Moreover, the Khorezm region contributes approximately 3.7 percent to the country's overall GDP and is primarily from cotton export (Rudenko, 2008).

The Khorezm region is known for its rice and meat production in Uzbekistan (Veldwisch, 2008; Bobojonov *et al.*, 2008), as the region plays an important role in supplying the whole country with these products.

1.1.3 The increasing uncertainty within the irrigated areas

Rain is the main source for covering water demand of crops in rainfed agriculture (FAO, 2003a). Availability of rain water is considered as the main uncertainty factor, as it is fully dependent on the natural conditions of the region. The risk caused by unpredictable nature is often considered as production risk, which is induced by factors not related to human activities (Hardaker *et al.*, 2004).

Water requirements for crops in irrigated agriculture are fulfilled by rain as well as surface, irrigation water. In this case, the availability of water depends on natural as well as human factors. Similar to rainfed agriculture, natural factors (e.g. precipitation, air temperature) might affect the availability of irrigation water in specific regions. More specific to irrigated agriculture is the availability of irrigation water in the downstream regions as it is influenced by activities of farmers in the upstream regions and people involved in the water management; the interdependence creates difficulties to predict expected amount of irrigation water in many developing countries and increases complexity in decision making in crop and water allocation.

Uncertainty related with changing availability of irrigation due to changing natural factors is increasing in many countries of the world (FAO, 2003a). According to FAO (2003a), the availability of water should not be considered as a serious problem at the global level; however, remote water shortages are becoming more common in some countries and regions. One out of five developing countries is projected to face water shortage by 2030 (FAO 2003a). Moreover, producers must cope with yield uncertainties caused by weather changes, diseases and pest damages and price uncertainties caused by changes in markets as well (Millan and Berber, 1994).

Coping with uncertainty caused by irrigation water supply gained attention as one of the main subjects needing to be addressed following two drought years in 2000 and 2001 in Uzbekistan (Müller, 2006). The drought was particularly acute in tail-end regions, such as Khorezm. Müller (2006) demonstrated that the probability of receiving a sufficient amount of irrigated water decreased in the region during the last decades in the region. Conrad (2006) added a spatial dimension to this by showing that the probability of obtaining the expected amount of water was highest in Water Users Associations (WUAs) located closer to the river, while those WUAs further away from the river had the lowest probability. This resulted in increased uncertainty and risk in farming, particularly in remote areas; such risk results in a decline in income and health conditions for a population highly dependent on agriculture (Bucknall *et al.*, 2003).

Water demand in Khorezm has increased in recent years due to two primary causes: firstly, the operation and maintenance activities of the irrigation and drainage systems have deteriorated due to the lack of financial resources (Bucknall *et al.*, 2003); secondly, since the introduction of private farming, water demand has increased with the spread of rice production - a high income generating crop which consumes almost 6-7 times more (30-40 thousand m^3) water than cotton (Veldwisch, 2008). Water consumption for agriculture in Uzbekistan is extremely high when compared with average water use in other countries (e.g. 4-5 thousand m^3 in Israel) (Saifulin *et al.*, 2003).

Income from the state order crops - cotton and wheat - is very low, and negative in most cases (Djanibekov, 2008). Production expenses are higher than the revenues even though farmers receive subsidized inputs from the state. Farmers are cropping these crops despite the losses as they would otherwise lose land-use rights (Veldwisch, 2008). A high share of cotton and winter wheat in the crop mixes is sometimes shown as a risk-aversion strategy of the poorly trained farmers who have little experience in alternative production (Müller, 2006). However, the high share of arable land sown to state order crops prevents diversification of crops that could lead to increased income security and helping farmers to cope with price and weather induced yield uncertainties.

1.2 Motivation of the Study

Previous studies have focused on land and water use policies in Uzbekistan and their impact on current resource use strategies; many recommendations have been put forth for improving the ecological situation in the Aral Sea Region (see e.g. UNESCO, 2001; Micklin and Williams, 1994). Studies on the water and salt balance are among those most intensively conducted in the region (e.g. Abdullaev, 1995; Faizullaev, 1980; Isabaev, 1986; Jabbarov *et al.*, 1977; Rysbekov, 1986; Yusupov *et al.*, 1979). Field experiments were carried out in the scope of these studies to understand the water management at the farm level and suggestions on improvement of water use efficiency and achieving higher yields were developed.

Recently, new agronomic and ecological approaches have been considered, including alternative irrigations techniques (Kamilov *et al.*, 2003; Ibragimov *et al.*, 2007; Abdullaev *et al.*, 2007). These studies experimented using different irrigation techniques (drip irrigation, laser leveling) in order to come to the solution for increasing the yields and decreasing the environmental impacts of water use in the region, while looking at results from field experiments.

Crop diversification has a significant potential to improve the ecological and economic situation, owing primarily to improved land and water use which would reduce soil deterioration and increase yields (Prohens *et al*., 2003). This may in particular be of interest for Khorezm, since the agro-ecological conditions of the region allow producing a variety of cereals, vegetables, fodder and cash crops. Hence, preliminary results have shown that in Khorezm, ecological and financial benefits could be expected from increased crop diversification (Bobojonov *et al.*, 2008; Kohlschmitt *et al.*, 2008). Nonetheless, the overall understanding of the economic impacts of increased crop diversity needs to be developed further.

The results of the previous studies on increasing water use efficiency at the farm level need to be analyzed for the entire irrigation system before the advantages of different water saving technologies can be determined. Crop allocation and water use activities of farmers are very much influenced by each other and not isolated. Therefore, the potential economic and ecological impact from these technologies (crop diversification, water saving technologies) is more acute when the irrigation system level is considered.

Crop diversification is one potential risk coping strategy for a farmer (Prohens *et al.*, 2003). The potential options of crop diversification and adoption of alternative technologies on reducing the income risk is also a subject not studied in the Khorezm region. Certain social aspects such as state interventions and policies need to be considered when the potential impact of crop diversification and adoption of new technologies are considered. Most of the studies above were conducted on the field or farm level and the impact of state interventions and policies were not taken into account.

Therefore, there is an urgent challenge to analyze both the ecological situation and the economic performance of crop diversification and adoption of alternative irrigation technologies under the situation of limited freedom and low income of the farmers in the region. It is more urgent to look at the economic and ecological impact of different crop allocation and water use options at the irrigation system level. Water Users Associations (WUA) are considered as the key actors in land and water allocation in Uzbekistan (Veldwisch, 2008; Zavgorodnaya, 2006). Therefore, this study concentrates on analyzing the economic and ecological changes at the WUA level under different scenarios (e.g. introduction of water pricing, decreasing the state order areas) expected to be implemented in the near future.

1.3 Objectives, Research Questions and Hypotheses

1.3.1 Objectives of the study

The overarching objective of this study is to develop a framework for assessing economic and ecological changes from different crop and water allocation options under different policy scenarios in the Khorezm region. The influence of alternative irrigation methods into income and income risk of agricultural producers is analyzed. The impact of different crop allocation scenarios, water use options and adoption of alternative irrigation techniques into water use efficiency, is assessed at the WUA level under existing as well as anticipated state policy scenarios.

Strategies are developed for obtaining higher and more secure profits with the available resources, while concurrently reducing the many negative ecological effects of agricultural production.

Specific objectives of the study are:

- To develop a modeling tool for assessing the economic and environmental feasibility of different crop allocation patterns and water use options;
- To analyze the impact of alternative technologies on profit and risk of agricultural producers;
- To analyze the effects of future policy reforms on income and risk of farming systems;
- To asses ecological suitability of future policy reforms in the Khorezm region;

1.3.2 Research questions

The different scenarios analyzed in this study are designed to improve our understanding of the potential economic and ecological impacts of different policy measures. The simulations should improve our understanding of how farmers can increase their income and water use efficiency under the current as well as various future socio-economic and ecological situations, as well as identifying suitable risk reducing strategies.

1.3.3 Hypothesis of the study

The development of the irrigation sector may lead not only to ecological improvement, but make some risk coping options available during water-scarce years. Decreased state interventions (relaxed forms of the state order) might lead to increased flexibility for the farmers in their operations, allowing them to react more efficiently to environmental changes and market signals. The overall hypotheses of the study can be summarized as:

- Relaxing the state order increases risk coping strategy available to farmers;
- Introducing water saving technologies and diversifying crops grown will stabilize farmer income;
- Adopting new irrigation technologies will have positive effects on ecological sustainability of land and water use.

1.4 Conceptual Framework and Structure of the Study

Water use, land allocation planning, and decision making, all demand interdisciplinary research. Interdisciplinary studies are becoming more important in water and land use research.

The Center for Development Research at the University of Bonn has set up a long-term, interdisciplinary research project aimed at the "Economic and ecological improvement of land and water use in Khorezm" (ZEF, 2003; Vlek *et al.*, 2003). The present study was conducted within the framework of the ZEF Khorezm project and draws from several disciplines and addresses the interdisciplinary nature of water resource management as much as possible within the given time frame and resources. Economic tools were used to understand water and land use policies while considering ecological and social aspects, which combined, allowed for the examination of the influence of different ecological, social and economic changes on the welfare of agricultural producers.

Following this Introduction, Chapter 2 provides an overview of the socio-economic and agro-ecological situation in the region; this chapter lays the groundwork for the development of the study objective, research questions, and serves as a guideline in the model establishment process.

Stochastic mathematical programming was used to analyze the interlinkages between the state policy, farm income, risk and environmental aspects of different land use options. The theoretical background and methodology used in stochastic programming are reviewed in Chapter 3.

The empirical model used in this research, and the main data sources used in the model are presented in Chapter 4. Integration and application of geographical information system, water conveyance, and crop yield simulations in mathematical programming are also presented in this chapter. Chapter 5 presents the model results from the base run and from different policy scenarios, and provides a discussion of the results from the scenario analysis. The discussion of the results is carried out in Chapter 6, and Chapter 7 concludes and provides recommendations for future research.

2 Regional Background and Model Environment

This chapter gives an overview of important features of agricultural production in the Khorezm region, including socio-economic as well as ecological aspects of the land and water allocation as they currently exist in the Khorezm region. The ecological and political situation in the transition region is described in this chapter as well as the farming activities, the water-land allocation hierarchy, and the relations of different actors within the agricultural production. The input endowments and production technology used by agricultural producers in the region are also presented. The main agricultural policies, such as state procurement and subsidies in irrigation, are also presented.

2.1 General information on geography and ecology

2.1.1 Geographical description of the study area

The Khorezm region is located in the northwestern part of Uzbekistan, in the lower Amu Darya basin (Figure 2.1).

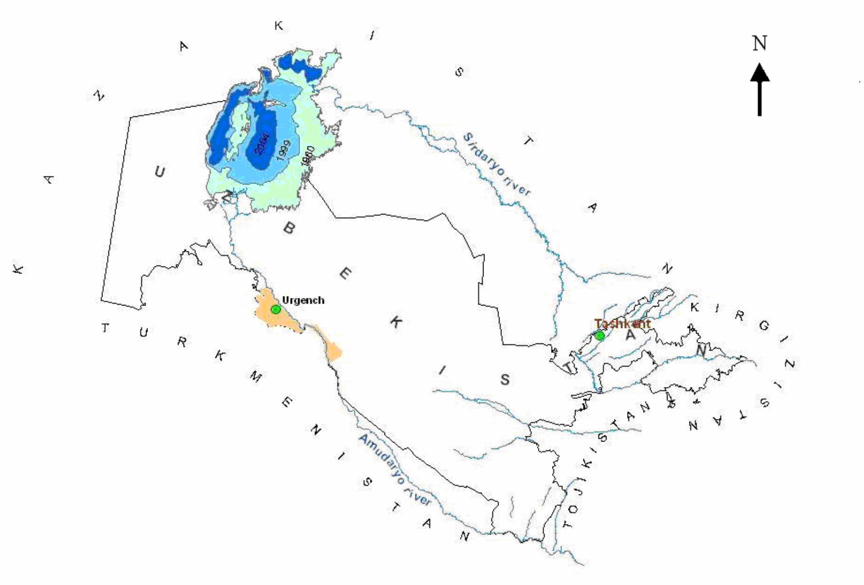

Figure 2.1: A stylized map of Uzbekistan.

Source: ZEF Khorezm project GIS lab, 2006

The geographic position of the region is between 41°08′ and 41°59′ N latitude and 60°03′ and 61°24′ E longitude.

Khorezm is home to 1.4 million people, 77.6 % of which are classified as rural (OblStat, 2005)[1]. The region has an extremely arid continental climate and is located between the Karakum and Kizilkum deserts. The mean annual temperature averaged 13°C over the past two decades, but daily extremes of -28°C and +45°C are recorded as minimum/maximum temperatures (Djalalov *et al.*, 2005). The coldest month is January and the hottest month is July (Forkutsa, 2006).

The soils in the region are of clayey, loamy and sandy-loamy textures (Nurmanov, 1966). According to SoyuzNIHI (1992), 21% of the soils in irrigated areas have heavy-loamy and 77.8% moderate-loamy textures. Soils are old-irrigated[2], and have a very complicated lithological profile (Faizullaev, 1980).

Available nitrogen in the soil ranges between 0.07 - 0.09%, and 1.01-1.34% humus on average is available in the soils, and is evidence of the very low natural fertility of Khorezm soils (MAWR, 1999). To compensate for such low fertility, chemical fertilizer usage is widespread in the region (Section 2.3.2).

2.1.2 Land use classification

In Khorezm, about 197 thousand hectares out of a total area of 605 thousand hectares are classified as sand, or desert area, and are thus not directly used for agricultural purposes (MAWR, 1999). From the remaining 408 about 270 thousand hectares are potentially suitable for crop growing, whereas the additional areas are water bodies, settlements or allocated to infrastructure.

There is potential for a wide variety of crops to be grown in the region, however, due to the state order, crops such as cotton (*Gossypium hirsutum* L.) and wheat (*Triticum aestivum* L.) dominate production (Kohlschmitt *et al.*, 2008). Farmers have shown a

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[1] *OblStat* is the local branch of Uzbekistan’s Statistical Office in Khorezm region
[2] anthropogenically modified, and technogenically disturbed soils

preference for planting rice (*Oryza sativa* L.) when possible (Veldwisch, 2008), other crops do not occupy more than 25% of the total cropped area in Khorezm (Figure 2.2). A detailed description of the state order system is presented in Section 2.2.2.

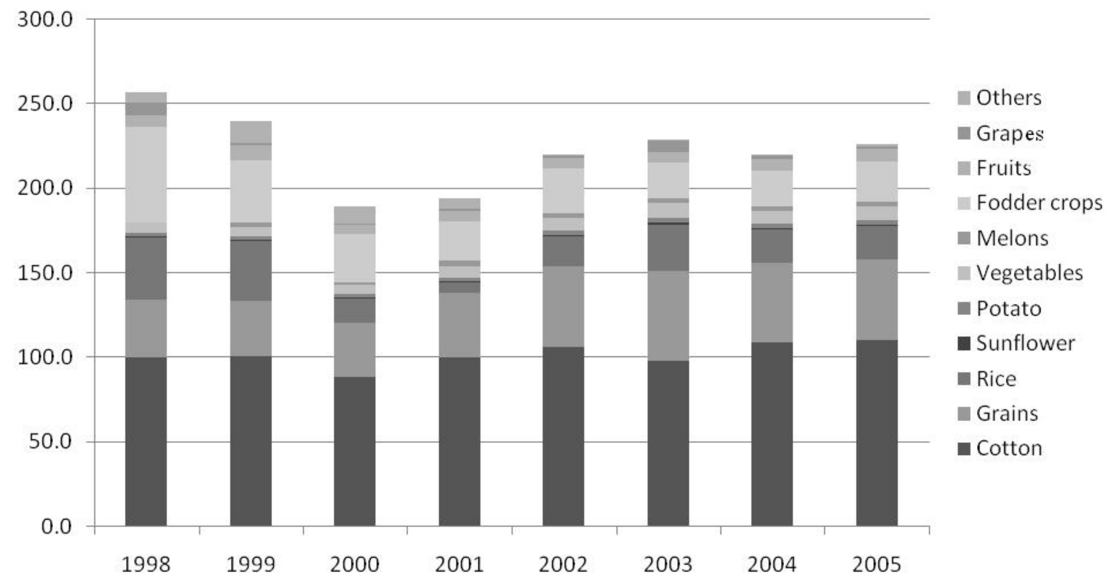

Figure 2.2: Cropping patterns in Khorezm region, thousand hectares

Source: FDA 2004; Oblstat 2005; Oblstat 2006; own estimations

2.1.3 Irrigation and water use

The annual precipitation in Khorezm is 100 mm year^{-1} and exceeds the evapo-transpiration of 1,400-1,600 mm year^{-1} (Glazirin *et al.,* 1999). Rainfall occurs predominantly during the fall-winter period, thus outside the vegetation period, which renders cultivation feasible through irrigation only.

The Amu Darya River is the main water source in the region. The water intake from the river amounts to around 5 km^3 per year, although there was a sharp decrease in water supply in 2000 and 2001 (UPRADIK, 2006). The water flow in the Amu Darya River increases from March onwards, reaches a maximum in June-July and sometimes August, and decreases until February.

The river water is distributed to the agricultural fields through an irrigation network consisting of *magistral, inter-farm* and *on-farm* canals[3]. Canals conveying water through different regions are defined as *magistral* canals. *Inter-farms* canals transport water from *magistral* canals to the boundary of former collective farms and present WUAs. There, *on-farm* canals convey water from the inter-farm canals to the field level networks.

Water is supplied by on-farm canals using gravity, and in some cases on-farm canal water is pumped into small ditches to facilitate water application to the fields located at more elevated points. Flood and furrow irrigation is the main and most widespread irrigation technique used, which explains the high gross water use of about 20 thousand m^3 ha^{-1} of water during the past two years (Figure 2.3) (UPRADIK, 2006).

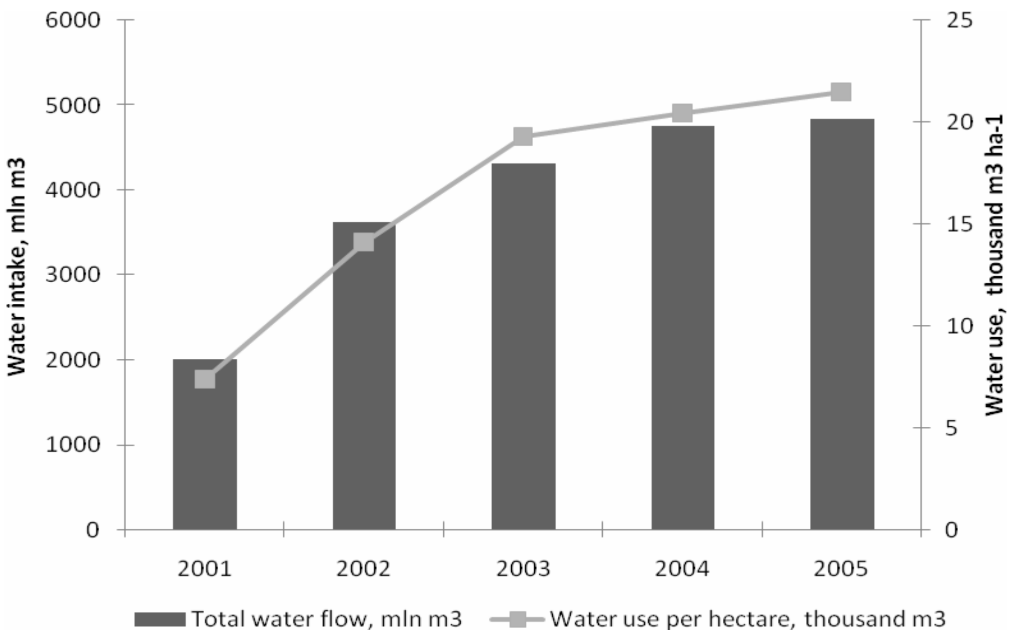

Figure 2.3: Water intake and water use per hectare in the region during the vegetation and leaching period

Source: UPRADIK, 2006

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[3] Classification of the canals according to Uzbek (Soviet) literature

The average efficiency of the irrigation system is estimated at 55%, meaning that 45% of the water taken from the river has infiltrated or evapotranspirated during the transportation and cannot be used directly for irrigation (Martius *et al.*, 2006).

The probability of receiving sufficient water for the crops is very low in areas furthest from the river (Conrad, 2006). Around 5 km^3 per year (20 thousand m^3 ha^{-1} in average) is not enough to ensure a reliable water supply to remote areas due to the low conveyance efficiencies. Annual and seasonal fluctuation in water supply both have also increased in recent years (Müller, 2006). This uncertainty in water supply is one of the key factors to be considered when water and crop allocation options are analyzed. An increase in water demand in the upstream regions, such as Tadjikistan and Afghanistan, is expected in the near future and may lead to a decrease in water availability in the downstream Khorezm region (Duhovniy and Sorokin, 2007; Martius *et al*., 2008).

2.1.4 Ecological problems, Aral Sea crisis

The continuous water losses caused by the current irrigation infrastructure have resulted in shallow groundwater tables and severe waterlogging of soils in the region (ZEF, 2003). The groundwater (GW) table may rise up to an average 0.7 meters below surface during the irrigation period, with a salinity content ranging between 1.68 g L^{-1} and 1.85 g L^{-1} (Ibrakhimov, 2005). The shallow GW tables, together with the intensive evaporation during the hot season, result in considerable capillary rise of water from the groundwater. This on the one hand contributes to secondary soil salinity (Ibrakhimov, 2005), and on the other provides a certain security in water supply, and therefore crop yields, during water scarce years (Forkutsa, 2006).

Farmers with poor knowledge, misguided policies and constraints in technology adoption are often considered as factors influencing land degradation in the region (Martius *et al.*, 2008). About 30 thousand hectares out of the 270 thousand hectares that could be potentially irrigated in the region are known as areas with low ameliorative conditions (AgroProm, 2003), meaning that crop production is impossible without improving the soil conditions first. Therefore, often the actually planted area is less than the potential available agricultural area due to high salinity and waterlogging. The Aral Sea catastrophe is not only creating environmental problems, but continues to threaten the welfare of the agricultural producers through declining yields and thus incomes (Bucknall *et al.*, 2003).

Due to the advancing soil salinity, leaching, which flushes the salts from the soil is a common practice throughout the region. Depending on the level of soil salinity, it is recommended to apply between 1500-6000 m^3 ha^{-1} of water during one or more leaching events (AgroProm, 2005a). Although leaching is generally effective in removing excess salt, it is also a key contributor to the rising groundwater table in the region and, therefore, ultimately increasing soil salinity in the long run as the current drainage system is inadequate for washing out excess salts (Ibrakhimov, 2005).

2.2 Land allocation, planning and execution

2.2.1 Farm types in the region

The former state collective (*kolkhozes* and *sovkhozes*) farms, the main production units during the Soviet period, have been dismantled under different reform steps but still form the basis of the production structure. These state farms used to be between 1000 to 2000 hectares in size, and crop production was organized by 10 to 15 brigades responsible for 100 to150 hectares each and mandated to produce according to the centrally set production targets. The collective farm workers received a salary from the state farms.

In 1993, the former *kolkhoz* and *sovkhoz* were reformed into *shirkats*, i.e. the Uzbek name for collective and joint-stock agricultural enterprises, respectively. Under the reformed system, land was still owned by the state and entire production process and organization differed hardly from the inherited ones (FAO, 2000). However, one key difference was the allocation of approximately 0.23 ha of land (*tamorqa* in Uzbek) to rural households within the boundaries of the *shirkat*. *Shirkat* workers complemented their consumer basket with the vegetables and grains produced on household plots; domestic livestock production also grew in importance following independence, and feed crops were also cultivated on household plots (Djanibekov, 2008). In the past 15 years, the total number of livestock kept by the Khorezmian households nearly doubled and currently accounts for almost 92% of the total regional livestock resources—occupying 15% of the total area (OblStat, 2005).

Large scale land privatisation imposed after 1998 provoked the emergence of a third type of agricultural producer, known as *fermer*s (private farms); although *shirkat*s retained the largest cropping areas and hence supplied the main share of the two state target crops – cotton and winter wheat—until 2004 (Bobojonov *et al.*, 2008; Ruzmetov *et al.*, 2003). The Government of Uzbekistan (GoU) has now completed the dissolution of *shirkats* into private farms. Several years after their establishment, *shirkat*s, as an agricultural production structure, became obsolete and private farm types the core of agricultural production. *Shirkat*s were transformed into private farms on the basis of a Presidential Decree issued on March 3rd, 2000; in 2006, 81 % of the area belonged to private farms, where only 2% were remaining in disposal of the state farms (Figure 2.4).

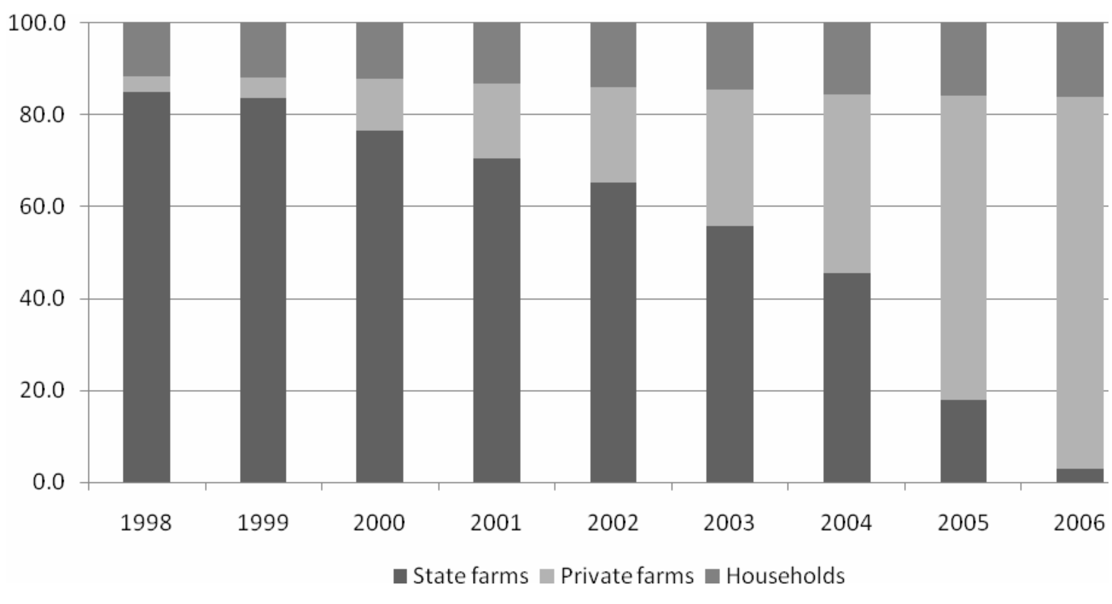

Figure 2.4: Dynamics of share of agricultural area in different farm types.

Source: OblStat, 2006; own calculations

The meaning of the word ‘private’ indicates a farm type operating on an area larger than ten hectares, yet under a land lease contract from the government, covering a minimum of 30 and a maximum of 50 years[4]. Under the new organization, private farmers did not gain the right to sell, exchange, and/or mortgage the land (Veldwisch, 2008).

A certain number of households have specialized in producing vegetables and melons, but the land occupied amounts to only 16% of the total area and actually the share of crops other than cotton and wheat is very small (OblStat, 2006). Although unconfirmed, some studies have postulated that the resource use efficiency and productivity of the household plots can be expected to be much higher when compared to private farms (Wall, 2006; Veldwisch, 2008).

2.2.2 State order policy

AgroProm (the Regional Department of Ministry of Agriculture and Water Resources) set the production plans for collective farms and organized the delivery of inputs and realization of outputs during the SU period. In addition, all processing plants as well as the input delivery organizations were controlled by AgroProm. This organization has received other responsibilities following the nationwide reforms that included the dissolution of *shirkats*, but in general the influence and impact of this organization has been reduced. The reforms included the privatization of processing and storage structures and are, as a consequence, no longer managed by AgroProm.

Regional targets for wheat and cotton are set centrally by the Ministry of Agriculture and Water Resources (MAWR). AgroProm allocates the state order area to the district AgroProms, which are the local branches of AgroProm, which then allocate it to the private farmers via Machinery Tractor Parks (MTPs) or Water User Associations (WUAs).

Following the dismantling of the *shirkat*s, MTPs or WUAs became the executive bodies of AgroProm responsible for allocating the area to be sown to cotton and winter wheat to

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[4] According to the latest Law on Private Farms from August 26,2004

private farmers (Veldwisch, 2008) (Figure 2.5). All crop producing farms are mandated to cultivate cotton and winter wheat, which usually accounts for about 70-80 percent of their total crop area. Of this 70-80%, the share sown to cotton averaged 46% and never exceeded the area determined under the state order.

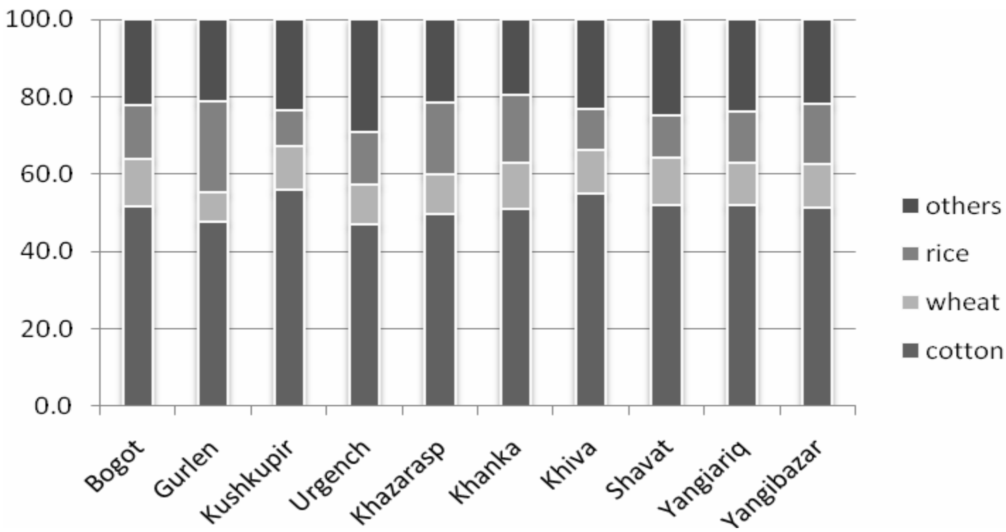

Figure 2.5: Intra regional distribution of crops, in percent from total area

Souce : OblStat, 2005

At present there is no state order for rice production as it was abolished in 2002 (Müller, 2006); there has been some discussion of the reintroduction of this quota, however, any time frame is not yet clear. The relatively high share of rice cultivation, which averaged about ten percent during last eight years, was in part due to favorable growing conditions in the Khorezm region (Bobojonov and Lamers, 2008).

According to state regulations, cotton producers are free to sell to whomever they want, however, only state-owned and state-run ginneries exist; they pay fixed prices. However, for wheat production, on half of all wheat produced is sold to the state at a fixed price. Of the remaining fifty percent, approximately one half (or 25% of all wheat produced) is sold at negotiated prices between the state and farmer and the final share (or remaining 25%) can be freely traded on the domestic markets (Bobojonov and Lamers, 2008).

2.2.3 *Bonitet*, defining state target amounts

Cotton and winter wheat are produced under the so-called ‘state-order’ or ‘state-procurement’ system. Within this system, each farm must deliver pre determined production goals as set by the government. There is, therefore, strong governmental control over crop distribution in the fields and, in return, the government ensures the supply and delivery of water and other inputs, sets the prices, and organizes the processing and export (in the case of cotton) (Rudenko, 2008). The amount of each commodity that farmers must deliver is determined by a soil fertility indicator, the so-called *bonitet* level of the soil. This indicator is used to identify the potential yield for a given soil type, which is determined using a 100-point scale (FAO, 2003b). The *bonitet* indicator is actually an index which includes multiple parameters in a single figure; the *bonitet* includes the soil texture, soil organic matter, soil salinity and the availability of drainage systems (Ramazanov and Yusupbekov, 2003).

Soil texture is considered the major characteristic of soil fertility; medium loam texture soils are the most suitable for cotton production and thus receive 100 points on the *bonitet* scale. Sandy or clay soils are less well suited to cotton production and, therefore, are ranked lower on the scale. Once this first quality parameter is identified, the index is adjusted to account for soil salinity. If the soil of a specific field is non-saline then the previously defined *bonitet* value in the first step remains unchanged. In case the soil shows a certain salinity level, the *bonitet* value will be reduced with an increasing level of soil salinity. The same procedure is applied for the availability of soil organic matter, nitrogen, phosphorous and the quality of the drainage in the area (Ramazanov and Yusupbekov, 2003). During this ranking procedure, the climatic variables, such as temperature and humidity, are considered as homogeneous in a single region.

Based on the *bonitet* score, potential yields were estimated for each value (Ramazanov and Yusupbekov, 2003). This method was then used by AgroProm to define the production amounts from any field and hence the amount of cotton and winter wheat that needs to be delivered. This method is used for the yield estimation of other crops as well. Thus, the highest fertile soil is given a score 100 (SSIU, 1989), and the maximum yield can be obtained from this soil under conditions where all inputs are utilized according to recommended watering and fertilizer practices.

2.3 Input use and input-output markets

2.3.1 Agricultural markets and agricultural commodity prices

Agricultural products of the region can be marketed through two main channels. Firstly, farmers can sell the products to the state, where the state purchase organization that procures cotton and winter wheat from farmers. Although the legislation allows selling cotton to any purchase company, in reality all cotton is sold to state-owned ginneries at a fixed price announced before the planting season (Rudenko, 2008). There are no alternative markets for farmers to sell cotton. The second way of realization is selling in agricultural markets, which plays an important role for farmers and households in the Khorezm region. Each district hosts at least one or two main markets which often are located in the centre of the districts or cities. Even though a wide range of non-food products are sold in these markets, agricultural products constitute, except cotton which is sold only to the state, the majority of all goods sold (Bobojonov and Lamers, 2008). Resellers operate mainly in the city markets of Urgench and Khiva. There is the third type of agricultural market where resellers can trade at the numerous small markets located in large streets or villages (Bobojonov, 2004). A recent market analysis that included commodity flow chains revealed the well-developed product exchange relations between districts of the Khorezm region with other regions of Uzbekistan (Bobojonov, 2004).

Price differences between markets often equal transportation costs (Bobojonov and Lamers, 2008). Transportation expenses from farm gate to the markets depend on the product, but are usually equal to about 5% of the total revenue; 10-15 % are demanded for vegetables and melons (Bobojonov, 2004). The transportation expenses of all farmers in the region are similar due to relatively standard distances to the district markets.

Due to the lack of a food processing sector in the Khorezm region, all agricultural products, with the exception of cotton and winter wheat, are sold in agricultural markets for preliminary consumption (Bobojonov, 2004). Prices in the markets change according to production in other regions, and annual and seasonal price variations for products such as potatoes, melons and vegetables are significant (Bobojonov, 2004).

Price information system or any other marketing services supporting agricultural producers do not exist. Farmers predict the price of agricultural products only based on their own observation during previous years (Bobojonov, 2004). Therefore, uncertainty associated with price fluctuations is a crucial factor that needs to be considered in the process of choosing crop mixes.

2.3.2 Fertilizer markets and fertilizer use recommendations

The timing and quantity of all input applications for the state order crops is centrally organized (Wall, 2006; Veldwisch, 2008). The state organization OblHimiya is involved in delivering mineral fertilizers to the farmers, but only for the crops produced under the state order. The amount of fertilizers which needs to be delivered and applied for each hectare of cotton and winter wheat is determined by AgroProm. In return, farmers receive fertilizers with subsidized prices for the crops cultivated under the state order. Farmers can purchase fertilizers for other crops from the Commodity Exchange. In 2005, the price of state provided fertilizer was 362[5] UZS kg^{-1} for pure nitrogen (N), and 495 UZS kg^{-1} for phosphorous (P_2O_5) (OblHimiya, 2005). In contrast, the market price for pure nitrogen was equal to 520 UZS kg^{-1} and 775 UZS kg^{-1} for phosphorous. The market price of fertilizer is more expensive than the state price, but fertilizer prices were still 36% lower than in neighboring countries (Djanibekov, 2008).

Nutrient requirements have been converted into fertilizer application recommendations by scientific institutes and were used as “norm” values by *kolkhozes* during the fSU period (Müller, 2006).

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[5] 1 USD = 1250 USB (Average exchange rate in 2005)

Table 2.1: Fertilizer use recommendation in the region

Crops	N	P_2O_5	K_2O
Cotton	240	165	110
Winter wheat	200	120	50
Rice	220	145	180
Maize for grain	220	140	90
Maize for fodder	220	140	90
Potato	150	100	75
Melon, water melon	75	110	50
Vegetables	200	110	75

Source: Agroprom, 2005b

After the land privatization reform was completed in 2006, AgroProm provided extension aid materials to farmers, such as small booklets containing recommendations on fertilizer, fuel and water application (RWUA, 2006). When it comes to state order crops, these "norm" values are imposed with regards to fertilizer application and irrigation water supply.

2.3.3 Pest and insect control, herbicide use

Biological control of insects in cotton and winter wheat production is wide spread. Herbicides are rarely used in cotton and winter wheat production and instead mechanical and manual weeding dominates. According to AgroProm (2006), the total expenses for insecticides, herbicides and biolaboratory service amounted to 26,786 soum ha^{-1} for cotton and 1,772 soum ha^{-1} for winter wheat which has the average share of 1.4% in total expenses (Rudenko, 2008). Herbicide and pesticide use is very limited for other crops also.

2.3.4 Machinery use and services

The machinery and other equipments of the former *shirkat*s were during the privatization process given to MTPs. MTPs are mandated to serve farmers located in the territory of the former *shirkat*s at prices fixed by AgroProm and district *Khakimyat*s[6] (Table 2.2). Payments for MTP services need to be conducted by bank transfer and only from the farm account.

Table 2.2: Expenses for machinery services in 2005

Activity	Full cost	Fuel cost	Share of fuel cost
Ploughing	34865	9643	0.28
Leveling	19773	2967	0.15
Furrowing	4303	1170	0.27
Chiseling	8666	2349	0.27
Planting	4834	1208	0.25
Cultivation	8525	1800	0.21
Cultivation and fertilizer application	5844	1424	0.24
Furrowing and fertilizer application	5844	1424	0.24
Pesticide or herbicide application	1705	395	0.23
Transportation	3246	600	0.18
Stem cutting	6320	1514	0.24

Source: Ugrench MTP, 2006

The agricultural machinery available at the MTPs provide a wide range of services, apart from grain combines that belong to KLASS and CASE centers, and which operate at the regional level. The machinery available at the MTPs was inherited from the former *shirkat*s and new equipment was purchased on a limited scale after independence. Due to the lack of spare parts, available machinery for farmers continues to decrease each year. Usually farms with more than 20 hectares in size own several machines, such as a tractors and seeders.

[6] *Khakimyat* is the Uzbek word for District Mayor office

The infrastructure of fuel (diesel) supply is similar to the fertilizer delivery system. Fuel is sold with a 15% discount to agricultural producers (Birja, 2005). Small-scale farmers usually hire machinery from MTPs or from neighboring farmers who own machinery. Land preparation is the most expensive service provided by MTPs (Table 2.2.). Also the fuel and machinery costs for each crop are determined by Agroprom.

Table 2.3: Fuel use and machinery expenses for different crops

Crops	Diesel kg ha^{-1}	Fuel cost soum ha^{-1}	Machinery service cost soum ha^{-1}
Cotton	379	88307	295636
Winter wheat	157	36581	122467
Rice	322	75026	251174
Maize for grain	304	70832	237133
Maize for fodder	249	58017	194231
Potato	319	74327	248834
Melon, water melon	270	62910	210612
Vegetables	192	44736	149768

Source: AgroProm 2005b, Birja 2005, own calculations

2.3.5 Labor use for agricultural activities

Labor demand is satisfied by permanent and seasonal labor and the demand fluctuates depending on as the season, i.e. planting, harvesting or weeding. Cotton and vegetables are harvested manually, and thus there is a significant rise in labor during this period.

The weighted average of labor use with the area of each crop in the region equaled 817 hours ha^{-1}. Table 2.5 shows that actual average labor use is higher than the recommended norms in some districts, but close in others (e.g. Khiva).

Table 2.4: Recommended labor use

Crops	Labor, hours ha^{-1}	Labor cost soum ha^{-1}
Cotton	1117	75956
Winter wheat	158	10744
Rice	720	48960
Maize	288	19584
Fodder crops	288	19584
Potato	1239	84252
Melon, water melon	979.5	66606
Vegetables	2130	144840

Source: AgroProm, 2005, FDA 2006, own calculations

Table 2.5: Actual labor use in different districts in 2005

Ditricts	Area, ha	Hours year ha^{-1}
Bogot	15351	1125.5
Gurlen	22183	992.9
Kushkupir	28006	832.6
Urgench	20705	1242.6
Khazarasp	25908	1263.0
Khonka	13603	950.9
Khiva	14589	949.6
Shavat	21531	1161.6
Yangiark	9060	1220.7
Yangibazar	24715	1074.4

Source: FDA 2006, own presentation

The difference between the actual labor use and the norms used is due to the substitution of some machinery work by manual labor, such as is common during the cotton harvest (Müller, 2006).

2.3.6 *Hydromodule* zones, water demand estimation

Crop water demand is estimated by geographic location and is determined by the *hydromodule* zone of the area; this method was established during the Soviet period and is still used by water management organizations for planning water supply schedules. Climate, soil texture over the soil profile and groundwater level is taken into account for identifying crop water requirements in flood and furrow irrigation techniques. Since climate is considered homogenous throughout the Khorezm region, soil texture and groundwater levels are the main parameters determining crop water requirements in the existing nine different *hydromodule* zones.

Depending on soil texture, the *hydromodule* zone ranges between I and III in areas with groundwater levels deeper than three meters, *hydromodule* zones IV - VI belong to the areas where groundwater ranges between two and three meters. *Hydromodule* zones VII - IX belong to shallow groundwater tables, where groundwater is in the range of one to two meters. Because of the shallow groundwater tables, the last three hydromodule zones predominate in the Khorezm region (SAYUzNihi, 1992; Agroprom, 2005b). More information on these zones is provided in Table 2.6.

Table 2.6: *Hydromodule* zones in *hydromorph* soil

Hydromodule zone	Soil characteristics
VII	Thick sandy and sandy loamy layers
VIII	Light and medium loamy, heavy loamy with light texture in deeper layers
IX	Heavy loamy, clay compacted soil, heterogeneous soil layers

Source: SAYUzNihi, 1992

The recommended water application norms for the hydromodule zone VII is lower compared to the others owing to the loamy soil texture, and higher for sandy loamy and clay soils (Table 2.7). These norms are supposed to be updated regularly, but the last update occurred 15 years ago (AgroProm, 2005b). Nevertheless, the water use norms are widely employed by WUA's and other water management organizations to plan water delivery to secondary water users.

Table 2.7: Water application norms in different *hydromodule* zones, m^3 ha^{-1}

Hydromodule zones	Cotton	Maze	Vegetables	Melons	Winter wheat	Others	Rice
VII	6400	6200	10500	4500	5600	5900	30000
VIII	4900	4600	8400	3500	4700	5200	35000
IX	5300	4900	9600	3800	5000	5700	40000

Source: AgroProm, 2005a

Müller (2006) analyzed the actual water input use in Khorezm and found that the water input use was close to the norm values.

2.4 Water supply organizations

2.4.1 Water distribution structure

In the President's Decree issued on 24th of March 2003 and a resolution of the Cabinet of Ministers of the 21st of July 2003, fundamental changes to the irrigation distribution system were adopted, including the former administrative-territorial management of irrigation water was replaced by a system based on hydrological boundaries for irrigation system management.

The Ministry of Agriculture and Water management is responsible for the planning of Water allocation in Uzbekistan and collaborates intensively with the Interstate Commission for Coordination (ICWC). Transboundary water management between Central Asian (CA) and Afghanistan is performed by BVO (Basin Water Management Organization) 'Amu Darya', which is the executive body of the ICWC. The Khorezm region and part of Karakalpakistan is served by the lower- Amu Darya Basin Management, which consists of five Irrigation System Management bodies (Figure 2.6, Appendix 1). The main task of BUIS (Basin Management Department of Irrigation

System) is allocating water to Irrigation Systems and Magisterial Canals (UISs); the UISs then delegate tasks to sub-UISs (Irrigation System Management Organization), which ultimately distribute water to WUAs based on properties of the different canal types (e.g. capacity, conveyance losses).

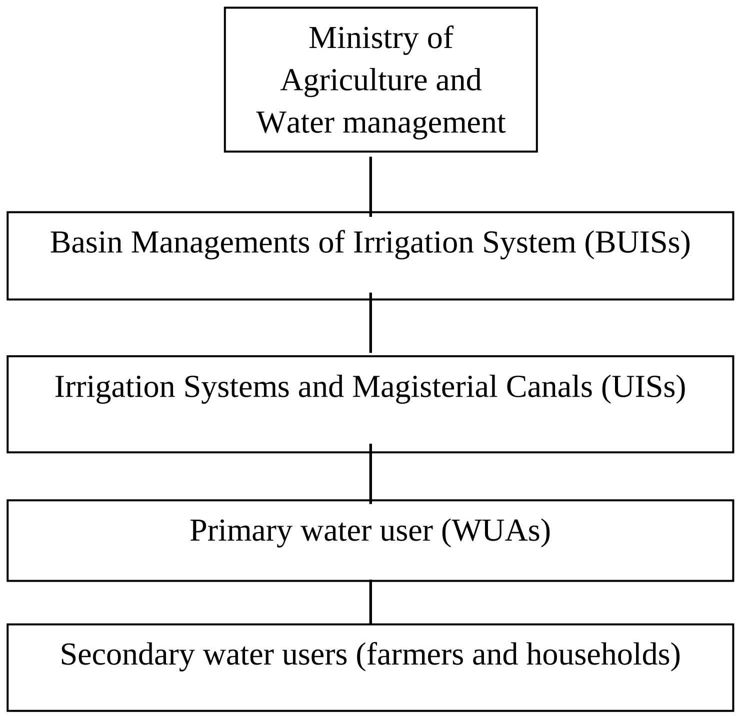

Figure 2.6: Organization of the present water management bodies

Source: Khamraev et al., 2006

The water flow in transboundary (*magistral*) canals is controlled by BUIS and the UPRADIK (Irrigation Canals Division, branch of BVO in the Khorezm region), whereas the water distribution to the Inter Rayon canals is executed by UISs. The Inter-farm canals are managed by canal heads seconded by staff and which function as an extended branch of UIS in the different districts. Water distribution by on-farm canals is managed by the WUAs.

Water from the irrigation channels is usually pumped to the lower degree channels and the organization of the necessary pumping stations (*Upravleniye Nasosnih Stansiy*, UNS) is one of these main structures in the region. During the fSU period and early independence, all pumping stations belonged to the UNS responsible for the maintenance of pumps and energy supply (UNS, 2006). After the dissolution of the *kolkhozes*, most of the pumps were transferred to WUAs or sold to farmers. Nowadays, UNS manages only pumping stations which operate at the level of magistral or inter-rayon canals (UNS, 2006).

2.4.2 Water users associations (WUA)

WUAs are newly assembled organizations established primarily in the territory of former *shirkats* (RWUA, 2006). As of 2006, 113 WUAs were created in the Khorezm region, with an average territory of 2,205 ha each comprising on average 134 farms (RWUA, 2006). The main task of the WUA is to supply water to users at the required time and amount, cleaning the canals and drainages within the WUA boundaries, and maintaining other infrastructure to remain operational. The obligations of both parties, the farmers as the end-water users and the WUAs as the water supplier, are concluded is a nationwide standardized contract.

The organizational set-up of a WUA is that of a non-governmental (NGO) structure that should operate to the benefit of its members, i.e. the farmers/water users. Recent studies have found that WUAs operate as a state organization in the Khorezm region, and probably elsewhere in Uzbekistan (Zavgorodnaya, 2006; Veldwisch, 2008). The state orders and regulations on land and water allocation are mainly delivered to the farmers by WUA staff. Veldwisch (2008) showed that state authorities utilize the WUA jurisdiction to control farmers' activities and secure certain yields from state order crops.

2.5 Expenses of water management organizations, water price

Farmers do not pay directly for their water consumption in the region, but water pricing is expected to be introduced.[7] The irrigation sector is still subsidized by the state including the expenses of all water management organizations; only the budget of the WUA is based on fees collected from water users (RWUA, 2006). The fee contributed by

[7] According to the Law of Republic of Uzbekistan "On water and water use", 06.05.1993

farmers/members to the WUA depends on the crops grown by each farmer. At the onset of each growing season, the WUA estimates its future expenses for the forthcoming year, and estimates the water demand of each farmer based on their farm plan.

The fee per cubic meter of water is derived as the total expenditures of WUA divided by the total water demanded (RWUA, 2006). Therefore, although farmers *de facto* pay for water, it is only for recovering expenses incurred by the WUA. The expenses of all other organizations involved in the water distribution are covered by the government of Uzbekistan.

Table 2.8: Share of expenses of different water management organizations per cubic meter of water

Organizations	Main activity	Expenses for 1 m^3 water, UZS	Share in total expenses, %
Tuyamuyun water reservoir	Water collection	0.27	11.8
BWO/Upradik	Management of water flow in magistral canals	0.08	3.5
UIS	Water distribution for Inter district canals	0.51	22.3
UNS	Pumping activities	0.84	36.7
WUAs	Distribution to farmers	0.26	11.4
OGME	Drainage disposal	0.33	14.4
Total*		2.29	100

Source: RWUA, 2006; UPRADIK, 2006; UNS, 2006

The expenses of the water management organizations include:

- Wages, social payments, travel expenses of the workers involved in water management,
- Municipal payments, maintenance expenses, renting and operation expenses of the infrastructure

- Purchase of assets and equipments
- Cleaning canals and drainages

The analysis of the cost structure of the different water management organizations showed that the wages of the workers, the rent of buildings and the operational costs took the highest share in the total budget.

Pumping activities account for the largest share of overall expenditure due to the high demand of electricity for the existing infrastructure; in areas where water supply depends solely on pumping, costs account for more than 36.7% of total expenditure presented in Table 2.8. While the WUAs receive money from the farmers and other water management organizations from the state, available resources are often insufficient to carry out the required O&M in many areas (AgroProm, 2003). For example, in 2003, water management organizations on average could afford to clean only 60% of the canals due to insufficient funds (AgroProm, 2003).

2.6 Conclusions

This chapter summarised the key ecological and political conditions in the Khorezm region; the information demonstrates the importance of private farms in the supply of the main agricultural products in the region (i.e., cotton, wheat, rice). Private farms form the backbone of agricultural production in the region and, therefore, this study is mainly concerned with crop and water allocation as well as risk management on private farms. Moreover, WUAs are of strategic importance in land and water use in Uzbekistan, therefore one of the WUAs in the region, the Shamahulum WUA, is chosen as a case study WUA for the model simulations.

Irrigation in agricultural production is essential to regional production, and, therefore, the availability of water determines farmers' productivity; for this reason, irrigation water availability in the WUA and crop yield response to irrigation water are considered as one of the main parameters in the model. Conveyance efficiency of irrigation canals in the WUA and water application efficiencies are elaborated in the model due to their influence on the ecological situation in the region. Price uncertainty is very high due to underdeveloped markets and processing in the region. Moreover, uncertainty associated with yield variation due to environmental degradation in the region must also be considered in the analysis of crop and water allocation decision-making in the region.

The current state procurement system for cotton and wheat was taken into account in establishing the model. However, market liberalization, i.e. the elimination of the state quota for cotton and wheat, is expected to be implemented in the near future as practiced in the neighboring Central Asian countries (Spoor, 2007) and, therefore, land and water allocation under a liberalized market scenario was also addressed in the analysis. Furthermore, water pricing is expected to be implemented as one policy change in the region, therefore, change of profits and resource allocation under water pricing is also analyzed.

3 The theoretical background: Decision making under uncertainty

This chapter reviews the importance of uncertainty and risk in agricultural production. A brief introduction to different sources of risk in farming is presented. The main approaches of ordering choices under uncertainty are discussed. An introduction to the mathematical programming used in this study is given.

3.1 Uncertainty and risk in agriculture

Several definitions are used in different studies for the terms uncertainty and risk, and the distinction between them dates back to Knight (1921). According to Knight's explanation, risk refers a situation in which mathematical probabilities can be assigned to a random event. In contrast, uncertainty exists in a situation where randomness cannot be measured and probabilities cannot be assigned. The distinction between risk and uncertainty, however, is not always possible in usual farm planning due to the limited time period for the estimation of income distributions or subjective assessment of probabilities assigned by farmers (Hazell and Norton, 1986). In the framework of the following study, therefore, uncertainty and risk are considered as synonymous.

Risk in agriculture is multidimensional and may include separately or simultaneously production, market, institutional, political, sovereign, relationship as well as human risk (Hardaker *et al.*, 2004; McConnell and Dillon, 2002). The main sources of production risk include unpredictable weather conditions, or the impact on production of natural factors such as pests and diseases or other unexpected events. Market risks usually result from unpredictable input and output prices which are caused by variations in production and supply. Institutional, political, sovereign, and relationship risk result from unexpected policy and macroeconomic changes, or changes in contact agreements. Hardaker (2000) distinguishes the human risk separately from other risk types, and defines human risk as a risk associated with farmers or farm workers, accidents in agricultural activities, such as using machinery, and improper input application.

Different potential sources and types of risk are numerous and vary depending on geographic location, as well as on the socioeconomic environment. Due to an infinite number of possible risks, studies often focus on an isolated risk and exclude other potentially relevant risk sources. McConnell and Dillon (1997), two pioneers in the field of agricultural risk management, argued that the most important forms of risk come from the natural environment and markets due to the high dependency of agricultural production on agro-ecological conditions. Unpredictable weather conditions, pests and diseases all create instability in terms of yields, therefore rendering agriculture a risky business. Price, yield and resource uncertainty within agricultural systems are thus considered as the main stochastic variables in most of the studies dealing with risk in agriculture (Anderson, 1979). Variations in temperature, humidity, moisture or water availability and other growth factors may cause annual yield fluctuations, thereby creating income instability. Similarly, income is vulnerable to local and world market prices. Decision making on farm activities therefore becomes more difficult under uncertainty. The next section introduces decision making theory under uncertainty.

3.2 Assessing risky alternatives

Decisions in the farming business involve the selection of one option over an alternative option (Anderson and Dillon, 1992). Selection of one or another option depends on the decision maker's beliefs about the chance of occurrence of uncertain events and the decision maker's preferences for the different alternatives (Bawa, 1975; Anderson and Dillon, 1992).

A decision maker's beliefs are usually considered as subjective probabilities, thereby implying a probability distribution of outcomes associated with different alternative activities.

Assessing risky alternatives can be illustrated in case of two stochastic profits X_i and X_j, whose cumulative distribution functions are $F_i(x)$ and $F_j(x)$ respectively. For ordering these uncertain prospects a preference function $\Phi(F(x)) \in R$ is needed that has the property:

$$\Phi(F_i(x)) \geq \Phi(F_j(x)) \qquad 3.1$$

where X_i is preferred to X_j, with at least one strict inequality.

In many cases, the preference function of the decision maker is not known or at least not completely specified (Bawa, 1975). In such cases, one may postulate certain conditions with respect to the shape of the preference function (e.g. monotonically increasing), and select those alternatives belonging to the most efficient set. This leads to the concept of stochastic dominance described in greater detail in the following section.

3.3 Stochastic dominance

Stochastic dominance is one of the main methods of ordering risky alternatives (choices, prospects) when the preference function is unknown. Only limited information is required about the preference of the decision maker, and is mainly restricted to risk preferences (Hardaker *et al.*, 2004). In this method, alternative risky activities are compared in terms of full distribution of outcomes and the comparison is done at each point along the distributions. Several stochastic dominance criteria can be derived depending on the assumptions about risk preference of the decision maker; these include first, second and third-degree stochastic dominance.

First-degree stochastic dominance (FSD) assumes that the decision maker has positive marginal utility, where the preference function is an increasing function of returns (monotonically increasing) (Bawa, 1975). In this case, the decision maker behaves rationally and seeks to maximize his own utility by selecting the activity with the highest payoffs. Under this condition, the decision maker always prefers more wealth to less wealth.

Considering two alternative activities X_i and $X_{j,}$ with cumulative distribution functions $F_i(x)$ and $F_j(x)$ respectively, In the FSD, X_i dominates $X_{j,}$ if:

$$F_i(x) \geq F_j(x) \qquad 3.2$$

for all values of x, and with at least with one strong inequality. The cumulative distribution function (CDF) of X_i must always lie below the right hand side of the CDF of $F_j(x)$ when a graphical comparison is carried out. The comparison can be illustrated in the example of two crops: potatoes (P) and rice (R) with the CDFs (of gross margins) of $F_P(x)$ and $F_R(x)$ as depicted in Figure 3.1.

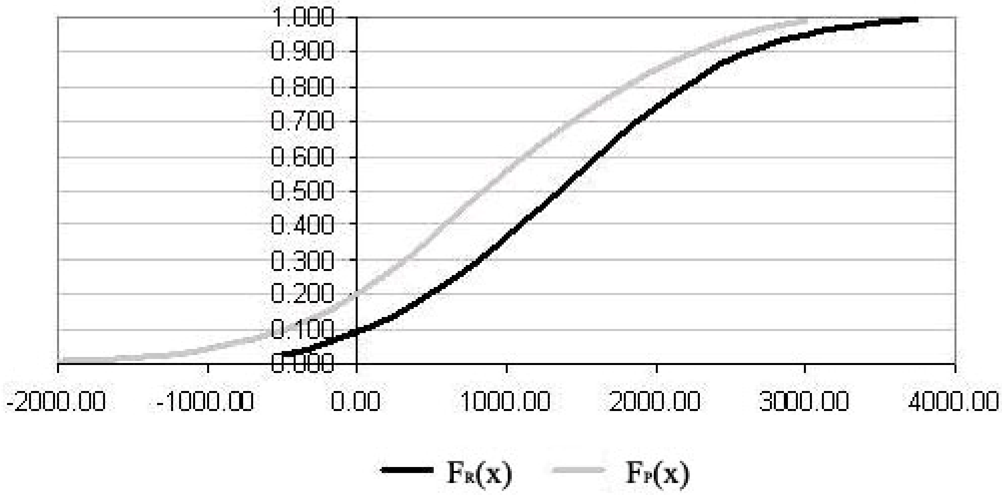

Figure 3.1: Illustration of first-degree stochastic dominance analysis

It can be seen that the CDF of rice always lies below the right had side of the CDF of potatoes ($F_P(x) > F_R(x)$); based on this curve, it can be interpreted that rice will be preferred to potatoes under FSD.

The selection of a dominating crop was simplified in the example above, however, the power of the first-degree scenario is limited if two CDFs intersect. In this case, neither of them is dominating. In this situation, an additional assumption of the preference function of the decision maker is necessary to compare the alternatives.

An additional restriction of the preference function included under conditions of second-degree stochastic dominance (SSD) is that the decision maker must be risk averse. Under this scenario, the slope of the preference function must be positive but decreasing. Risky choices are therefore ordered by comparing the areas under the CDFs of different alternatives in SSD. X_i dominates X_j under the conditions of the SSD if:

$$\int_{-\infty}^{x} F_i(x) \leq \int_{-\infty}^{x} F_j(x) \qquad 3.3$$

for all values of *x*, with at least one strict inequality.

SSD is illustrated in the example of two alternative crops: melons and tomatoes in Figure 3.2. The CDFs of the gross margins (GMs) of these example crops are presented in

Figure 3.2. In Figure 3.2, it can be seen that two CDFs intersect and it is difficult to find the dominating activity under the FDS criteria. The areas under two CDFs therefore would need to be estimated under SSD criteria. The difference between the two areas under the CDFs is equal to the area between two CDFs, which is divided into two areas (area A and B).

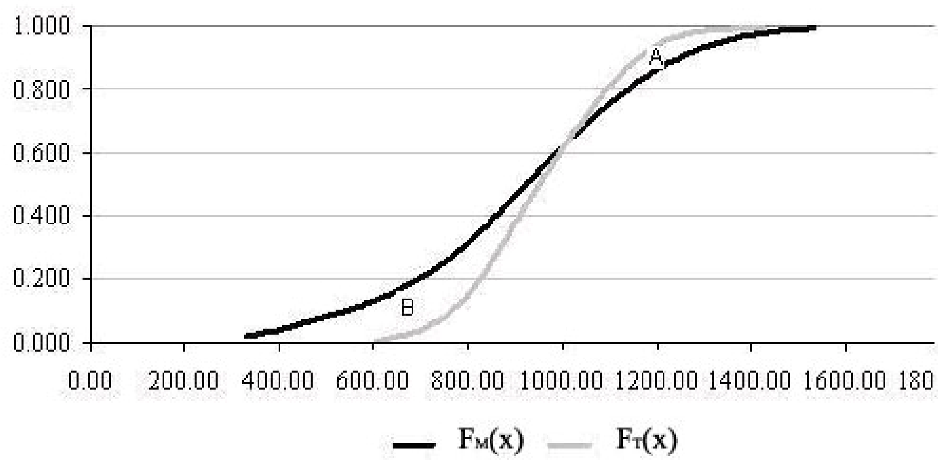

Figure 3.2: Illustration of second-degree stochastic dominance

In Figure 3.2, $F_T(x)$ lies to the right of $F_M(x)$ in the area B, and $F_M(x)$ lies to the right of $F_T(x)$ in the area A. Visual examination shows that the area B is bigger than the area A, which means that the area under the CDF of tomatoes is smaller than the area under melons. From this result, X_T is preferred to X_M according to second-degree stochastic dominance. The areas under the CDFs are compared visually in this example and the difference was clear; however, in other cases it might be difficult to judge by sight alone and then computer software can be used to compare the areas under CDFs (Hardaker *et al.*, 2004).

In some cases, the application of second-degree stochastic dominance may not help to find dominating alternatives (e.g., when the number of choices considered is too large) (Hardaker *et al.*, 2004); third-degree stochastic dominance (TSD) can be used in this situation. The same assumption about utility as considered in the second-degree stochastic dominance is assumed in third-degree stochastic dominance, but with an additional assumption that the decision maker has decreasing risk aversion with increasing income. In this case, X_i is preferred over X_j if:

$$\int_{-\infty}^{x}\int_{-\infty}^{x} F_j(x) - F_i(x) \geq 0 \qquad 3.4$$

for all values of *x*, with at least one strict inequality. While third-degree stochastic dominance may provide some further insight, several authors have shown that the additional information provided (discriminating power) under third-degree stochastic dominance compared to second-degree stochastic dominance is very limited (e.g. Anderson *et al.*, 1977).

The main advantage of using stochastic dominance is that the preference function of the decision maker is not required and a comparison of risky alternatives is based on the probability distribution of outcomes (Hardaker *et al.*, 2004). However, an assessment of probability distributions of alternative risky prospects is often difficult due to data availability for a relatively small time period (Hazell and Norton, 1986). Moreover, pairwise comparisons of probability distributions become difficult when the number of comparisons being made is increasing, and when the number of alternatives increases. Furthermore, stochastic dominance analysis is used only under conditions where risky choices are alternatives and they cannot be selected simultaneously (i.e. when only one option can be selected). When the selection of several activities is to be made from a set of alternative choices, the stochastic dependencies between prospects need to be considered. Under these circumstances, the stochastic dominance is no longer optimal and instead an expected utility approach could be applied (Hardaker *et al.*, 2004).

3.4 Expected utility approach

The most used decision rule in economics is the principle of expected utility (EU) (the Bernoulli principle) (Hazell and Norton, 1986). According to the expected utility theory, developed by von Neuman and Morgenstern (1944), the decision maker prefers the activity with the highest expected utility among the risky alternatives. The preference function in this case is formalized as:

$$\Phi(F_i(x)) = E(U(F_i(x)) = \int_{-\infty}^{\infty} U(x) f_i(x) dx \qquad 3.5$$

The expected utility can be converted into monetary values, known as the certainty equivalent (CE) and derived by taking the inverse of the utility function (Hardaker, 2000):

$$CE = U^{-1}(E(U(x)) \qquad 3.6$$

The CE shows the certain amount of money which is rated equivalent to the uncertain outcome of the risky event with the given utility function of the decision maker (Robison and Barry, 1987). Ranking choices by the CE gives the same result as ordering the choices using EU (Hardaker, 2000). The advantage of using the CE, however, is that the same measuring unit with the activities can be used (e.g. USD or EURO), which is easier to interpret than the expected utility values (Hardaker *et al.*, 2004).

The CE depicts the difference between the expected value of the risky choice E(x) and the risk premium (π):

$$CE = E(x) - \pi \qquad 3.7$$

The CE can be used as a measure of risk efficiency and the option with a higher CE is preferred to one with a lower CE (Hardaker, 2000). In the equation above, it can be seen that the CE depends on the expected value and the risk premium. The risk premium can be assessed when the risk preference of the decision maker is known (Hardaker, 2000).

The shape of the utility function reflects the risk attitude of the decision maker. However, it is difficult to quantify the degree of risk aversion from the shape of the utility function due to the arbitrary scaling of the utility function (Hardaker *et al.*, 2004). Arrow (1965) and Pratt (1964) developed a measure of absolute risk aversion, which is not effected by linear transformation of the utility function:

$$R_a(x) = -\frac{U''(x)}{U'(x)} \qquad 3.8$$

where $R_a(E(x))$ indicates the absolute risk aversion measured at the expected value. The utility function must be specified explicitly to determine the degree of absolute risk aversion ($R_a(x)$).

The negative exponential function is one of the most used functional forms defined as (Meyer, 2007):

$$U(x) = 1 - e^{-\lambda x}, \ \lambda > 0 \qquad 3.9$$

where,

$$R_a(x) = \frac{-U''(x)}{U'(x)} = \lambda$$

In this form, $R_a(x)$ is the constant and equal to λ, and is known as Constant Absolute Risk Aversion or CARA.

The meaning of the CARA is that risk preference of the decision maker does not change with increasing or decreasing wealth (Hardaker *et al.*, 2004). A decision maker is more likely to have Decreasing Absolute Risk Aversion (DARA) with increasing wealth (Berg, 2002). The power function has the property of DARA and it is also one of the most used functional form for the utility function (Hardaker *et al.*, 2004; Meyer, 2007) and defined as:

$$U(x) = \frac{1}{1-\theta} x^{1-\theta} \qquad 3.10$$

where $R_a(x)$ is defined as:

$$R_a(x) = \frac{-U''(x)}{U'(x)} = \frac{\theta}{x} \qquad 3.11$$

which can be also written as:

$$\frac{-U''(x)x}{U'(x)} = \theta \qquad 3.12$$

According to Hardaker (2004), the left hand side of the equation ($-U''(x)x / U'(x)$) represents a measure of relative risk aversion for wealth. The power function (3.10) represents Constant Relative Risk Aversion (CRRA), which is determined by the coefficient θ.

Pratt (1964) has developed a method of deriving an approximate risk premium value (Robinson and Barry, 1987); this can be formalized as:

$$\pi = \frac{1}{2} R_a(E(x))V(x) \qquad 3.13$$

where V(x) notes the net variance. The certainty equivalent (Equation 3.7) may be rewritten as:

$$CE = E(x) - \frac{1}{2} R_a(E(x))V(x) \qquad 3.14$$

Finally, equation 3.11 can be substituted into 3.8 and the CE equivalent can be rewritten as (Berg, 2002):

$$CE = E(x) - \frac{\theta}{2E(x)} V(x) \qquad 3.15$$

where, x should be expressed in terms of wealth (W) and relative risk aversion θ is independent of the magnitude of wealth. According to Hardaker (2000), wealth is usually defined as:

$$W = W_0 + y - c_p \qquad 3.16$$

where, W_0 is initial wealth, y is transitory income and c_p is a permanent consumption assumed constant as developed by Friederman (1957).

Theoretically, it is well accepted that the absolute risk aversion coefficient will decrease with increasing wealth, as an individual can take more risks when he or she has more wealth (Hardaker *et al.*, 2004). Therefore, the power function is preferred due to its property of decreasing risk aversion (DARA).

There are many other functional forms, such as hyperbolic absolute risk aversion (HARA) form (Merton, 1971), expo-power (EP) form (Saha, 1993), the power risk aversion (PRA) form (Xie, 2000), flexible three parameter (FTP) form (Conniffe, 2006), which are discussed in detail by Meyer (2007). Some of these functional forms have more flexibility in their representation of risk aversion, but these functional forms are rarely used due their complexity. The more simple forms, such as CARA and CRRA, are therefore more widely used (Hardaker *et al.*, 2004), and can be easily incorporated into mathematical programming models.

3.5 Mathematical programming approach

As discussed in the sections above, stochastic dominance and the expected utility approach can be used for ordering risky choices in the farm planning process. In cases where too many alternatives exist, mathematical programming may be required as it is able to support a whole-farm planning process. Moreover, planning one part of the farm business might have an influence on another part and mathematical programming allows one to solve the problem in a systems context, where the impacts of one decision can be seen on another (Hardaker *et al.*, 2004). Furthermore, mathematical programming allows one to estimate maximum benefits under conditions of constrained resources - a situation which is common for agricultural producers (Hardaker *et al.*, 2004). Mathematical programming allows one to find an optimal solution, therefore, while taking into account constraints at the farm level as well as external constraints.

One widely used type of problem addressed via mathematical programming is the optimization problem, where the decision maker faces several alternative choices and selects the activity (or several activities) which brings optimal satisfaction (McCarl and Spreen, 1997). Almost all optimization models consist of some objective function that is subject to a set of constraints. The most widely used mathematical programming method for problems in agriculture is linear programming (Hardaker *et al.*, 2004); this will be described in the next section.

3.5.1 Linear programming

The most common form of linear programming in agriculture is a simple profit maximization model, otherwise known as a resource use minimization model. Mathematic formulation of a single time period model is presented in equations 3.17-3.19; the objective function of the model is to maximize total profit and can be written as:

maximize $$Z = \mathbf{c}'\mathbf{x} - f \qquad 3.17$$

subject to $\mathbf{Ax} \leq \mathbf{b}$ 3.18

and $\mathbf{x} \geq 0$ 3.19

where:

Z denotes the objective function

F is the fixed costs

x is a n ×1 vector of activity levels, e.g. hectares of crops

c is a n ×1 vector of activity net returns, e.g. gross margins

A is a m ×n matrix of technical coefficients, e.g. the amount of resource hired to produce one unit of activity

b is a m ×1 vector of available resources

The objective of the model presented is to find a set of production activities that yield maximal total profit (3.17), but the resources used for the activities must not exceed available fixed resources (3.18), and any negative activity (allocated hectares cannot be less than zero) must not be involved (3.19).

The LP approach has several advantages and disadvantages. One distinct advantage of LP is comparatively low data-demands and flexibility in the performance of scenario building, as discussed in McCarl and Speen (1997). One additional advantage is computational efficiency; therefore, LP is used in many large-scale problems (e.g. Chuvieco, 1993; Guerra and Lewis, 2002; Öhman, 2001; Jansen *et al* 2005).

The assumption of linearity of the objective-function, and therefore the constraints in LP, may be invalid in many situations (McCarl and Speen, 1997). Piecewise linearization of a nonlinear equation has shown to be a solution to this shortcoming (Hazell and Norton, 1986). The certainty assumption of the LP model may not be representative of reality when dealing with the situation under imperfect knowledge. Most of the mathematical programming models used in the past did not consider the importance of risk in agricultural decision making, however, accounting for risk aspects is becoming one of the most widely developed methods (Hardaker *et al.,* 2004). Numerous models exist to handle such situations under conditions of uncertainty; the expected value-variance approach is one of the most used approaches (Robison and Barry, 1987).

3.5.2 Expected Value-Variance approach

The model mentioned above can be extended in order to be able to handle uncertainty in farm planning. Optimization of the certainty equivalent discussed in section 3.4 is most used approach due its deductive strength and easily applicability in optimization models (Robison and Barry, 1987; Berg, 2003).

Optimization of the certainty equivalent according to the Equation 5.15 can be considered as the objective function and optimization problem may be written as:

maximize $$\mathrm{CE} = \mathbf{E}(\mathbf{c})'\mathbf{x} - f - \frac{\theta}{2\mathbf{E}(\mathbf{c})'}\mathbf{x}'\mathbf{V}\mathbf{x} \qquad 3.20$$

subject to $$\mathbf{A}\mathbf{x} \le \mathbf{b} \qquad 3.21$$

and $$\mathbf{x} \ge 0 \qquad 3.22$$

where:

E(x) is a n ×1 vector of expected activity net returns
V is a n ×n of activity net return variance-covariance matrix
θ is a coefficient of constant relative risk aversion

In this model, activity returns are treated as stochastic variables. For example, price of the agricultural products might be an uncertain aspect to the farmer and yield of agricultural products might vary year to year depending on uncontrollable factors such as weather, diseases and pests. Farmers want to maximize their net returns but want to have risk in a minimum level at the same time (Millan and Berbel, 1994). Therefore, choosing an optimal activity level depends on the variability of different activities, a covariance relationship between them, and expected income. The model maximizes the certainty equivalent subject to resource availability and non-negative activity levels.

Resource use and availability in this model is considered as deterministic. For example, production of a certain amount of winter wheat requires a certain amount of fertilizer and labor; the availability of fertilizer and labor is known to the farmer at the beginning of the planning period. The model could be extended further if resource availability is unknown to the decision-maker; this will be discussed in the following section.

3.5.3 Chance constrained programming

Uncertainty in the farm business might come from different sources, as discussed in Section 3.1. Resource availability is one source of uncertainty to the decision-maker. In this case, risk in agriculture might occur in the constraint side of the model (McCarl and Spreen, 1997).

Chance constrained programming is most commonly used when risk in farm planning exists due to resource availability (McCarl and Spreen, 1997). Chance constrained formulation was developed by Charnes and Cooper (1959) and considers the feasibility of resource requirements in probabilistic terms (Hazell and Norton, 1986); and can be formalized as:

$$\Pr\left[\mathbf{Ax} \leq \mathbf{b}\right] \geq \alpha \qquad 3.23$$

where:

"Pr" denotes "probability"

α is a n ×1 vector of prescribed level of probabilities (for each constraint)

This equation shows that the total resource use must not exceed its availability with the requirement of a α level of confidence. However, not all constraints are necessarily stochastic; deterministic constraints can be distinguished from stochastic ones. For example, main resources used by the farmer can be fertilizer, labor, credit and water. Some resource stocks might be known to the farmer, while others not known. In this case, stochastic constraints (Equation 3.25) can be separated from deterministic ones (Equation 3.24):

$$\mathbf{Dx} \le \mathbf{d} \tag{3.24}$$

and

$$\Pr[\mathbf{Gx} \le \mathbf{g}] \ge \alpha \tag{3.25}$$

where:

D is a m ×n matrix of technical coefficients of known resources

d is a m ×1 vector of available resources known before the planning season

G is a l ×n matrix of technical coefficients of uncertain resources

g is a l ×1 vector of resources whose available is uncertain

When resource availability is normally distributed with a mean **E(g)** and standard deviation **σ**, then a linearized form of equation 3.25 can be presented (McCarl and Spreen, 1997):

$$\mathbf{Gx} \le \mathbf{E(g)} - \mathbf{k}\sigma \tag{3.26}$$

where, **k** is a l ×1 vector of standardized normal values for preferred confidence **α**

Irrigation water availability is often an uncertain parameter in most developing countries, where farmers often do not know the exact amount of irrigation water they could receive. In this situation, chance constraint formulation becomes very suitable. Moreover, not only resource availability is an uncertain parameter but price and yield variations are also issues to be considered in usual farming business. In this case, chance constraint formulation could be combined with an EV approach (McCarl and Spreen, 1997). Maximization of the certainty equivalent can be carried out subject to deterministic and probabilistic constraints. Uncertainty related to activity net returns can be taken into account in the objective function, while uncertainty related to resource availability (e.g. irrigation water) can be handled in the constraints.

4 Methodology, Empirical Model

This chapter gives a full description of the mathematical programming model developed within this study. The methods of handling multidimensional risk in irrigated agriculture are presented. Incorporation of GIS data on agro-ecological properties of the farms into mathematical programming is discussed. A description of the data sources used in the model is given.

4.1 The case study Water User Association (WUA)

The case study Water User Association (WUA) Shamahulum is situated in the Khiva district of the Khorezm region (Figure 4.1). In 2006, the total cropping area of this WUA was 1885 hectares, 419 hectares of which were occupied by *dehkan* farms, 144 hectares were under perennial crops, and 1,322 hectares were available for annual crops (Shamhulum WUA, 2006). This WUA was selected based on data availability and because the Shamahulum WUA is one of the WUAs in the region where water pricing might be introduced in the near future.

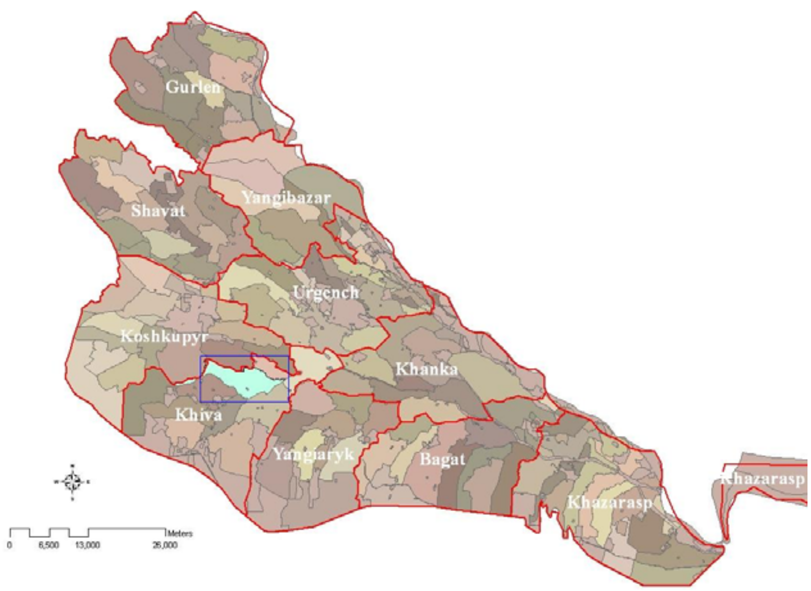

Figure 4.1: Location of Shamahulum WUA

Source: ZEF Khorezm project CDB, 2006

The main crops in this WUA are cotton, wheat, rice, maize for grain, fodder crops and vegetables.

WUAs in the region are classified into ten distance classes depending on the distance from the river (Conrad, 2006). The Shamahulum WUA is located in the ninth distance class and average water availability is lower than other WUAs in the region (Conrad, 2006). Distance (along the irrigation system) from the river to the main WUA water intake point was equal to 91 kilometers on average (Conrad, 2006).

In 2006, there were 217 farmers in the WUA with total 1466.5 ha of land. The largest farm in the WUA has 38.1 ha and the smallest one 0.9 ha of agricultural land.

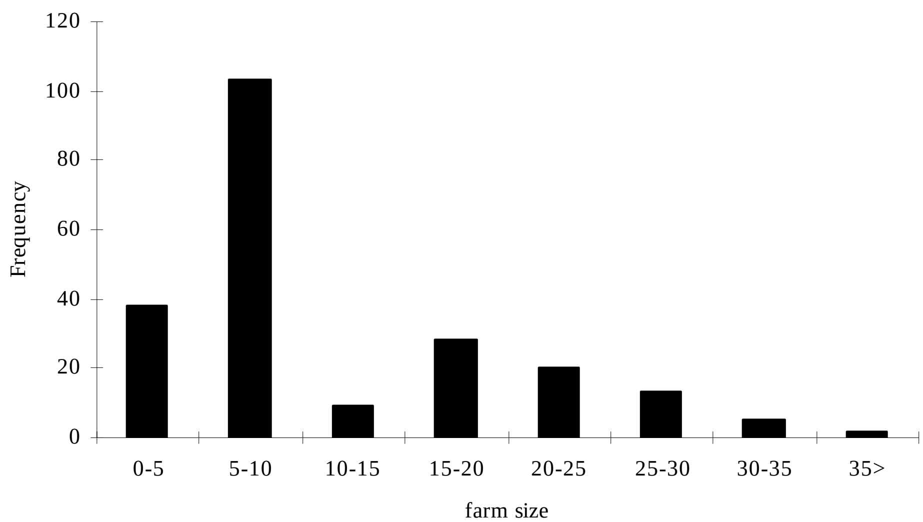

Figure 4.2: Distribution of the farm areas in Shamahulum WUA

As seen in Figure 4.2, the majority of farmers have between 5-10 hectares of land in the WUA. According to the information of the WUA administration, all farmers in the WUA, except horticultural farms and *dehkan*s, are obliged to produce the state order crops.

GIS information on location of the farmers, *bonitet* and *hydromodule* zones were available for 1,226.9 hectares out of total 1,322 hectares available for annual crops. GIS data on household plots (total 419 hectares) and perennial crop growing farmers (total

144.2 hectares) were not available; therefore, household and perennial crop farmers were excluded from the model.

4.2 Integration of agro-ecological data in optimization model

Previous studies in the region have shown yields, water use and profit for agricultural producers depend very much on soil properties of the farm (Forkutsa, 2006; Veldwisch, 2008). Location of the farm in the irrigation system is also an important factor for obtaining the necessary amount of water (Conrad, 2006).

Obtaining desired information about agro-ecological properties of the farms in the WUA was difficult from secondary sources and often farmers do not have this information. Therefore, soil fertility (*bonitet*), soil *hydromodule* zone, and distances from the water intake source were obtained using GIS maps. Mathematical programming and GIS tools were therefore combined in the development of a spatial crop allocation model with integrated spatial data in order to estimate an optimal solution. This combined approach allows for spatial and economic considerations (Chuvieco, 1993; Guerra and Lewis, 2002; Öhman, 2001; Jansen *et al.,* 2005), as well as the consideration of risk aspects of different activities. This combined method is suitable for land and water resource allocation in irrigated agriculture, where location of the agricultural area within the irrigation network is very important. The integration of spatial information within the analysis also improves the visualization of the model results for greater clarity in discussion.

4.3 Data sources

The necessary data for the development of the model were obtained from several data sources. The crop yields in the region during 1996 and 2005, and input prices for 2005 were obtained from Regional Statistical Departments (OblStat). Output prices were available for 2001-2006 on a monthly basis from OblStat (2006). Price of fodder crops and by-product prices of cotton and maize for grain were derived from Samandarov (2007). Actual crop allocation in the case study WUA, water management structure, water delivery expenses, water use amounts were available from Water and Land Management Organizations and Administration of the Shamahulum WUA.

Yield – soil quality relationship, input requirements of crop were available from local organizations (Land Cadastre Committee, 2005), as well as from scientific publications in the region (Ramazanov and Yusupbekov, 2003).

Irrigation network, the soil productivity (*bonitet*) map, soil texture and *hydromodule* zone map, and GIS data on location of farm fields, were all available from the Khorezm project of ZEF/UNESCO Central Data Base (CDB).

Semi-official interviews conducted by the author with managers, economists and engineers key organizations such as UPRADIK, AgroProm, UNS, FDA, UISes and WUAs in the region and farmers were very important in order understand the agricultural system in depth.

Data on economic and ecological performance of alternative irrigation methods were derived from the literature available on Uzbekistan, or in countries with similar agro-ecological properties (Kamilov *et al.*, 2003; Ibragimov *et al.*, 2007; Humphreys *et al.*, 2005).

Information on inflation rates was obtained from the World Bank data sets (World Bank, 2006) on Uzbekistan. Information on total available labor per hectare in the Khiva district was available from secondary statistical sources (FDA, 2006). Data on fertilizer use, water demand, fuel use were collected from different data sources (e.g. AgroProm, 2005; FDA, 2006), and were used for the estimation of variable costs for different activities.

4.4 Empirical model for the study problem

Following the analysis of the specification of agricultural production in the region (Chapter 2), yield and commodity price uncertainty as well as risk associated with the availability of irrigation water were found to be the main stochastic parameters to be considered in the model development process.

Risk associated with price fluctuations and yield variability is taken into account in the objective function of the model, and is considered as economic risk in the relevant studies (e.g. Millan and Berbel, 1994). Risk associated with unreliable water supply is taken into account in the constraints part of the model and considered as a technical risk (Section 4.3.8.3). The following sections present more detailed information on the model specifications.

4.4.1 Model activities

The model estimates the optimal spatial cropping pattern (crop mixes) and water distribution by allocating crops according to the agro-ecological comparative advantages and risk associated with each type of crop growing activity. The estimations also take into account several farm and WUA level constrains.

Cotton, winter wheat, rice, maize (maize for grain), fodder crops, potatoes, vegetables and melons are the main crops in the model. Flood and furrow irrigation techniques are used as standard irrigation methods in the model, as other techniques (e.g. drip irrigation) are not yet practiced in the region (ZEF, 2003). Each crop could be cultivated with different water use levels, using either flood or furrow irrigation methods. In the model simulations, additional techniques will be introduced, such as laser-leveling and drip irrigation. All crops could be planted with these two alternative irrigation methods; only rice could not be cultivated under drip irrigation. Production of cotton and winter wheat was also not considered with alternative technologies due to the high costs associated with technology and low income from these crops. All other crops were considered to be grown under alternative technologies.

The main decision variables in the model are the cropping areas (H_{ji}) in each of the 300 fields in the WUA, and amount of water use for each activity (x_{ji}). The farmers might have one or more (e.g. five) fields depending on the farm, therefore, these 300 fields belong to 99 farmers (Figure 4.3).

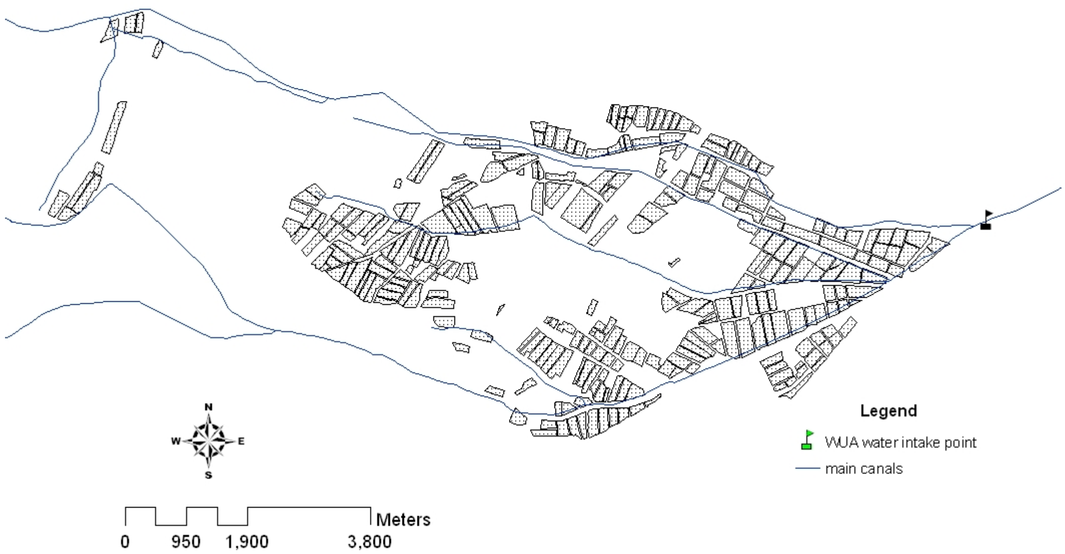

Figure 4.3: Location of the fields in the WUA

Indices j and f indicate 300 fields and 99 farmers respectively, where index i notes crops in the model. The model will therefore find optimal cropping patterns and optimal water use intensity for each of the 300 fields.

There were eight crops in the base case, and crops with alternative irrigation methods are considered as different activities. For example, the production of potatoes production with conventional irrigation, laser-leveling, and drip irrigation methods are considered as three different cropping activities due to the difference in production technology. Number of total crops in the simulation with alternative irrigation methods was equal to 19. These 19 crops potentially could be produced on any one of the 300 fields, with different levels of water use if farm resources are available.

The criteria for defining optimal crop-mixes for different locations include expected income, which depends on agro-ecological conditions, and the variance or risk associated with the type of activity, as well as agro-ecological and socio-economic constraints. Ago-ecological (e.g. water, field size) constraints are mainly considered on the field level (for each of the 300 fields), and socio-economic (e.g. state order, labor) constraints are considered on the farm level (for each of these 99 farms). Moreover, the certainty equivalent (CE) is estimated for each farm; more detailed information on this is presented in the next section.

4.4.2 Objective function of the model

Expected gross margin is one of the main factors for selecting optimal crop(s) (index *i*) for the given field (index *j*) in the farm, which is estimated as (Berg, 2003):

$$E(GM_{ij}) = E(p_i)E\lfloor f_{ji}(x_{ji})\rfloor + b_{ij} - c_{ij} + \text{cov}\lfloor f_{ji}(x_{ji}), p_i \rfloor \qquad 4.1$$

Where,

$E(GM_{ij})$	is the expected gross margin
$E(p_i)$	is the expected price of commodity
$E\lfloor f_{ji}(x_{ji})\rfloor$	is the expected yield
$f_{ji}(x_{ji})$	is the yield water respond function, explained in the next chapter
x_{ji}	is the water application level,
c_{ij}	is the variable cost of production
b_{ij}	is the income from selling byproducts

Expected gross margin is mainly determined by the expected yield, which mainly depends on agro-ecological factors (e.g. soil fertility), output prices, and variable costs. Variable costs depend on input use intensity (e.g. water, fertilizer), and spatial location of the field in the irrigation system.

The production costs and income from byproducts are assumed to be deterministic in the model and variance of the gross margins ($V(GM_{ji})$) is formalized as (Berg, 2003):

$$V(GM_{ji}) = E(p_i)^2 V\left[f_{ji}(x_{ji})\right] + V(p_i)E\left[f_{ji}(x_{ji})\right]^2 + 2E(p_i)E\left[f_{ji}(x_{ji})\right]\text{cov}\left[f_{ji}(x_{ji}), p_i\right] \quad 4.2$$

where,

$V(p_i)$	is the variance of the commodity price
$V\left[f_{ji}(x_{ji})\right]$	is the variance of the yield
$\text{cov}\left[f_{ji}(x_{ji}), p_i\right]$	is the price yield covariance

Price and yield covariance is one of the most important parameters in the model objective function and estimated as:

$$\text{cov}\left[f_{ji}(x_{ji}), p_i\right] = \rho_i Stdev(f_{ji}(x_{ji}))Stdev(p_i) \quad 4.3$$

Where,

ρ_i	correlation of crop price and the yield
$Stdev(f_{ji}(x_{ji}))$	standard deviation of crop yield
$Stdev(p_i)$	standard deviation of crop price

Standard deviations of yields were available from the production function (see the next section) for each water application level. Yield and price correlation of cotton is assumed to be very close to zero (-0.01) due to the state control over cotton price (Rudenko, 2008). The price paid by the state is not changed depending on cotton yield in the region or production amount. The price of cotton is announced at the beginning of each vegetation period and stays unchanged until the following year (Rudenko, 2008). The correlation coefficient was estimated for all other crops from the regional level yield and prices during 2001 and 2005. Due to limited number of observed years, average price-yield price correlation is used for all crops, which was equal to -0.44.

The objective function of the model is set to maximize the sum of certainty equivalents (CE) from different farms:

$$\max\ TotCE = \mathbf{u}'\mathbf{y} \qquad 4.4$$

where $\mathbf{u}$ is a m×1 vector of ones and $\mathbf{y}$ is a m×1 vector or certainty equivalents of farms (index *f*) estimated as:

$$\mathbf{y} = \mathbf{E}(\mathbf{z}) - \frac{\lambda}{2}\mathbf{V}(\mathbf{z}) \qquad 4.5$$

where $\mathbf{E}(\mathbf{z})$ is a m×1 vector of expected incomes, $\mathbf{V}(\mathbf{z})$ is a m×1 vector of farm income variances and λ is a Constant Absolute Risk Aversion estimated as:

$$\lambda = \theta / \mathbf{E}(\mathbf{z}) \qquad 4.6$$

where, θ is a Constant Relative Risk Aversion.

Only transit income is assumed to be affected by the decision variable (Robison and Barry, 1997; Berg, 2003) and expected income and variance of farm income is estimated as:

$$\mathbf{E}(\mathbf{z}) = \mathbf{E}(\mathbf{g})\mathbf{h} - \mathbf{f} \qquad 4.7$$

$$\mathbf{V}(\mathbf{z}) = \mathbf{h}'\mathbf{Q}\mathbf{h} \qquad 4.8$$

where $\mathbf{h}$ is a n ×1 vector of crop areas in different fields (indices *j* and *i*), $\mathbf{E}(\mathbf{g})$ is a n ×1 vector of expected gross margins (Eq. 4.1), $\mathbf{Q}$ is a n ×n variance-covariance matrix estimated as:

$$\mathbf{Q} = \mathbf{SRS} \qquad 4.9$$

where $\mathbf{S}$ is a n ×n diagonal matrix of standard deviations (estimated from Eq. 4.2) and $\mathbf{R}$ is a n ×n matrix of gross margin correlations. Gross margins within the farm are considered in the objective function in order to capture risk reducing effect of diversification. Gross margin correlations are estimated from standard deviations of crop expected yields, expected prices, standard deviation of yields, standard deviation of prices, price-price correlations, yield-yield correlations and price-yield correlations using

Excel @Risk stochastic simulation engine. There was no correlation assumed between cotton price and prices of other crops due to selling cotton mainly to the world market. The price of cotton in the region is fixed by the state. Positive price-price correlation between other crops was obtained, and was equal to 0.24 in average. Positive yield-yield correlations were found for all crops, and were equal to 0.34 on average.

4.4.3 Monte Carlo Simulations, yield water response

A yield production function can be estimated using data from field experiments, key informant interviews, expert knowledge, and empirical estimations (Börner, 2006). A sufficient number of observations for each input level, however, may not be available from the methods above (Llewelyn and Featherstone, 1996). Furthermore where farm level water measures are not developed (e.g. Uzbekistan), no precise information is available on the exact amount of water applied to achieve certain yields. In the case of too few observations or missing observations, stochastic simulation techniques can be a good method for establishing stochastic crop yield input response functions (Berg, 1998). For example, the Monte Carlo method is one such technique used for solving certain problems based on repeated random simulations (Berg and Kuhlmann, 1993).

The influence of irrigation water supply dominates yield response in irrigated agriculture (Robert and Werner, 2007), and Müller (2006) showed that irrigation water availability is the most limiting factor to agricultural production in the region. Therefore, this study concentrates mainly on yield variance associated with water use levels and availability in the WUA. Water application is considered as the only controllable input, while other inputs, such as fertilizers, are imputed according to the demand and recommendations by the state. Fertilizer application is still under the state control for the state order crops in the region but not constrained for other crops (Veldwisch, 2008). According to the Liebig’s principle, crop yield increases linearly with an increase of limiting nutrients until maximum yield is reached or another nutrient becomes limiting (Paris and Knapp, 1989; Grimm *et al.*, 1987). According to this principle, it is assumed in this model that crop yields increase linearly with water application (Figure 4.4). Recent results showed that a zero level of irrigation water can still result in a certain cotton yield and this is due to capillary rise from groundwater in the study region (Forkutsa, 2006). Therefore, despite the absence of irrigation water, water can be supplied to crops via ground water. Thus, the total amount of plant available water is the sum of water applied by the farmer and the capillary rise from groundwater.

The maximum achievable yield (y_{max}) is an uncertain parameter because of dependency on uncontrollable inputs, such as temperature, pests and other factors (McConnell and Dillon, 1997). These factors are unknown to the decision maker at the beginning of the planning year (Berg, 2003). Likewise, the amount of water from the groundwater (*s*) is also unknown to farmers. Therefore, maximum achievable yield and capillary rise from groundwater are introduced as stochastic parameters into the model.

The share of the water contribution from groundwater is assumed to be normally distributed with the mean ($\bar{s}$) and standard deviation (σ_s) (Forkutsa, 2006). The maximum achievable yield is also normally distributed with a certain mean ($\bar{y}_{\max}$) and standard deviation ($\sigma_{y_{\max}}$).

Thus, the stochastic components of the model can be represented as (Berg, 2003):

$$y = a^{-1}(x+s) \text{ for } y \le y_{\max} \text{ and } y = y_{\max}\text{, otherwise}$$

with

$$y_{\max} = N\{\bar{y}_{\max}, \sigma_{y_{\max}}\} \text{ and } s = N(\bar{s}, \sigma_s)$$

Where x is the water application level and a is the water uptake coefficient, which shows the increase in yield from each additional unit of water (see Section 4.3.5).

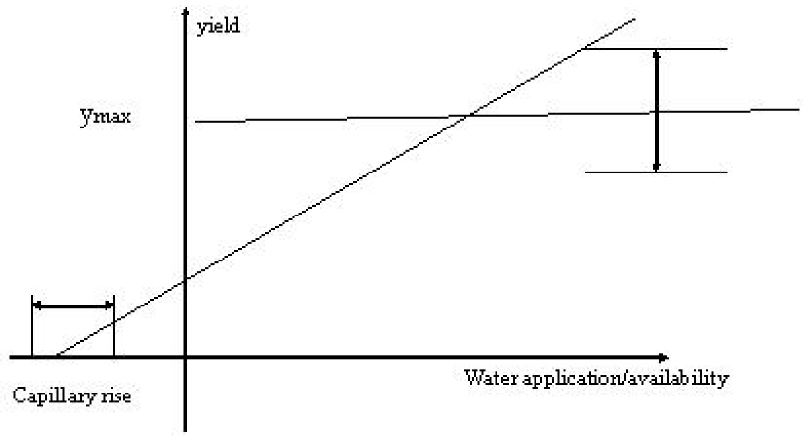

Figure 4.4: Linear production function with random variations

Source: Adapted from Berg (2003)

Based on this information, stochastic simulations were carried out with 1000 random simulations for each crop and water application level as simulated in relevant studies (Börner, 2006; Berg, 2003). The results of the stochastic simulations are shown in Figure 4.5 and 4.6, using an example of potato and melon production.

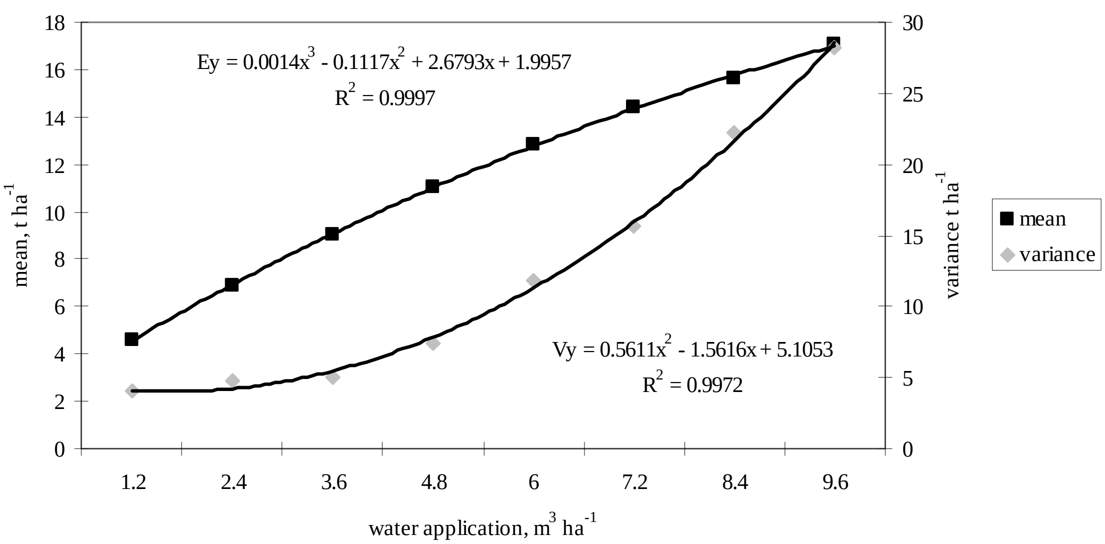

Figure 4.5: Mean and variance of potato yield as a function of water application

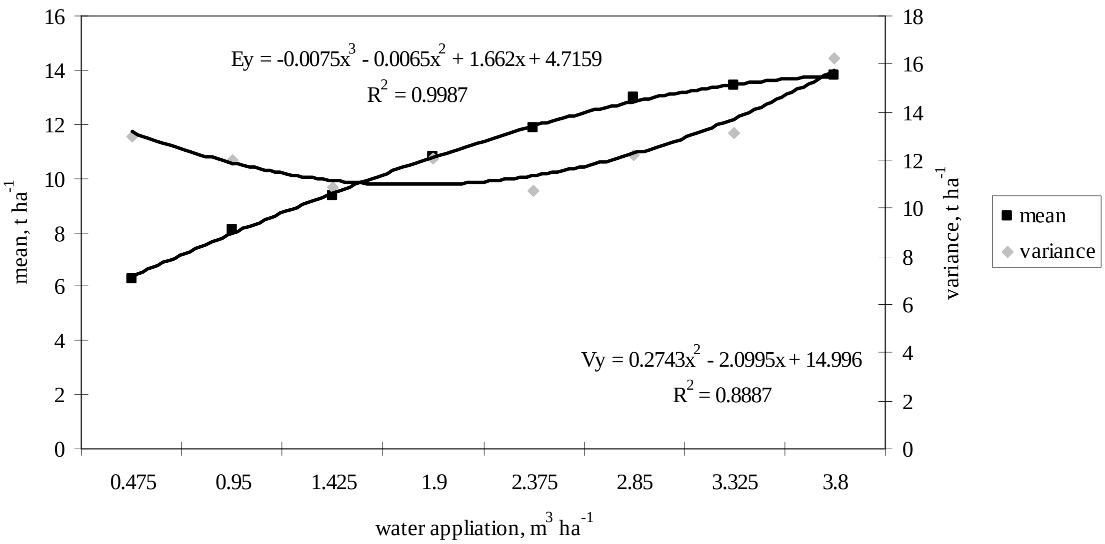

Figure 4.6: Mean and variance of melon yield as a function of water application

Several functional forms were examined for the expected yield function and the cubic function was found to be the best fitting functional form and can be formalized as:

$$Ey = \mu_1 x^3 + \mu_2 x^2 + \mu_3 x + \mu_4 \qquad 4.10$$

Where,

Ey	expected yield
x	water application level
μ_1	cubic coefficient
μ_2	quadratic coefficient
μ_3	linear coefficient
μ_4	constant.

The quadratic functional form was found to be the best fitting in case of variance, which can be formalized as:

$$Vy = \omega_1 x^2 + \omega_2 x + \omega_3 \qquad 4.11$$

Where,

Vy yield variance

ω_1 quadratic coefficient

ω_2 linear coefficient

ω_3 constant.

Production functions of mean yields have decreasing marginal productivity for all crops (e.g. using more inputs beyond a certain threshold will not increase the yield). However, characteristics (e.g. the shape) of the variance function of crops are different depending on the standard deviation of yield ($\sigma_{y_{\max}}$), and standard deviation of groundwater contribution (σ_s) (Börner, 2006). It can be seen in the Figure 4.5 and 4.6 that the variance is always increasing with additional water use in the case of potato production. In contrast, the variance decreases up to a certain point and then starts to increase in the case of melon production.

4.4.4 Estimation of expected yields

Crop yield is one of the main stochastic variables in the model. Yield can only be partly controlled by farmers with the management of input use, such as fertilizer, labor and machinery. Several exogenous, stochastic factors, such as temperature, solar radiation, rainfall and other growth factors which are beyond of the control of the farmer and are the main sources of uncertainty in agricultural production (Pannell *et al.*, 2000). Farmers may not experience a loss of expected income with lower yields when fewer inputs are applied as the cost of the production are also lower (Dorward, 1999), however, a reduction in yields due to weather variation may cause serious losses as this can occur even with high levels of inputs.

Probability distributions of yields are estimated from the district level, cross-sectional data for 10 years (1996-2005), and for ten districts in the region (OblStat, 2005; OblStat, 2006). Thus, the number of observations for each crop was equal to 100. The mean and standard deviation of the yields derived from the district level includes uncertainty related to the management (human) risk (embedded risk) and all other uncertainty factors, but mainly depicts the uncertainty associated with weather variations, which is considered as non-embedded risk in the literature (e.g. Dorward, 1999). McConnell and Dillon (1997) discussed that the risk associated with weather variations is dominating in such data sets because the influence of weather conditions is common to all growers. It can be interesting to model non-embedded risk as the estimation of the probabilities of a particular outcome for a given yield allows for measuring uncertainty due to weather variations in the region when the access to inputs are not limited (Janssen and Van Ittersum, 2007).

The distribution of yields is assumed to be normal for the study region, as in most of the studies in this field (e.g. Berg, 2003; Börner, 2006). However, Chi-Square Tests[8] were carried out to prove or reject the null hypothesis that the yields are normally distributed (Moore and McCabe, 2006). Such an analysis can be done with the statistical software SIMETAR of Excel add-ins tool (Richardson, 2004). The SIMITAR provides information on P-values for each test and information about accepting or rejecting the null hypothesis with a given confidence interval. The Chi-Squared test results are presented in Table 4.1. Only the hypothesis that the yield of maize is normally distributed is rejected. The hypothesis of normal distribution of other crops cannot be rejected.

The test results show that the P-value is very small for maize, meaning that the fodder maize yields are not normally distributed. Distribution of cotton yields was normally distributed, with a 99% confidence level. The test results with a 95% confidence level showed that all other crops are normally distributed.

Coefficient variation for all crops was in the same range with studies in Europe, (e.g. Berg, 2002) except for maize for fodder and potatoes, which were higher when compared to other countries (e.g. Europe); this can be partially explained by poor resource use (e.g. low soil quality), and low skill levels of agricultural producers.

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[8] An alternative test for Kolmogorov-Smirnov, Shapiro-Wilks, Anderson-Darling, and Cramer-von Mises tests

Table 4.1: Chi-Squared Test results

	X^2 value	p value
Cotton	18.3[9]	0.033*
Winter wheat	11.9	0.219
Rice	7.4	0.597
Maize	26.2	0.002
Fodder crops	8.8	0.457
Potato	12.3	0.196
Vegetable	14.2	0.117
Melons	7.7	0.565

As discussed in Section 4.3.1, there are 300 fields with different agro-ecological properties. The potential (mean) yield ($\bar{y}_{\max}$) in these fields are different depending on the soil fertility criteria of these fields (Ramazanov and Yusupbekov, 2003). Therefore, estimation of the potential yield in each of these fields (presented in Figure 4.3) was done according to the methodology described in Section 2.2.3:

$$\bar{y}_{\max ji} = cf_i bn_j \qquad 4.12$$

The yield of certain crop (i) depends on the *bonitet* level (bn_j) of the field and yield coefficient (cf_i) of each crop; this is usually obtained using the maximum yield in the region. Maximum obtainable yields in the Khorezm region on the best quality soil and using resources (e.g. fertilizer, water) according to the norm values are presented in Table 4.2. Maximum yields in the region for some crops (e.g. winter wheat, potato) are lower than average yield levels in Europe (e.g. Berg, 2002).

[9] Confidence interval was 99%

Table 4.2: Maximum yield and coefficient of variation of yields

Crops	Max yield	Coefficient of variation	Yield coefficient cf_i
Cotton	4.5	0.21	0.045
Winter wheat	6	0.29	0.06
Rice	7	0.26	0.07
Maize	7.5	0.25	0.075
Fodder crops	30	0.59	0.3
Potatoes	19	0.41	0.19
Melons	25	0.30	0.25
Vegetables	30	0.21	0.3

Sources: Land cadastre comity, 2007; Land cadastre comity, 2005; OblStat, 2005; own estimations

GIS data on soil *bonitet* presented in Figure 4.7 were obtained from the regional soil *bonitet* map with a resolution of 25.000 meters.

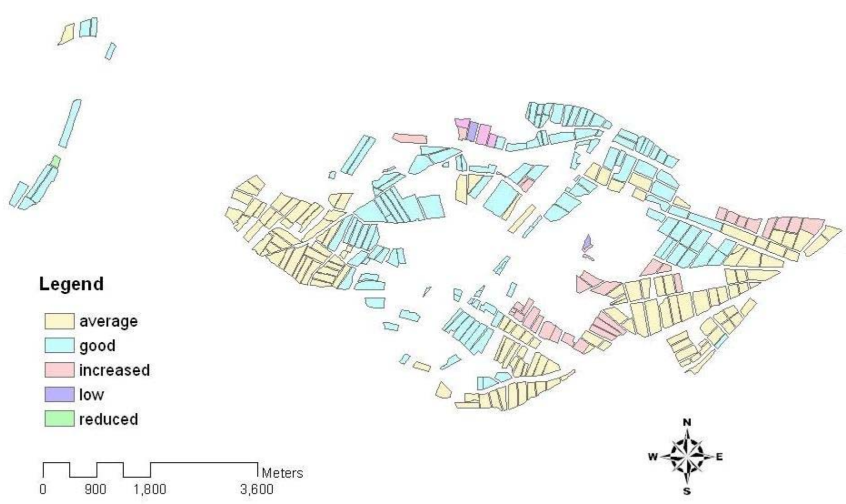

Figure 4.7: Spatial distribution of soil *bonitet* in the WUA

Most of the farm fields in the modelled WUA have a soil fertility level (‘average’, ‘good’, ‘increased’) higher than regional average and only a few of them have very low soil fertility (‘low’ and ‘reduced’), i.e. below 55 points.

Table 4.3: Soil fertility characteristics in different *bonitet* levels (points)

Group	Points	Fertility characteristics
1	91-100	Very high
2	81-90	High
3	71-80	Increased
4	61-70	Good
5	51-60	Average
6	41-50	Reduced
7	31-40	Low
8	21-30	Very low
9	<20	Extremely low

Based on the information presented in Table 4.2 and Figure 4.7, $\bar{y}_{max}$ was estimated for each of the 300 fields.

4.4.5 Estimation of water uptake coefficients

The water uptake coefficient (a_{ji}) is a parameter of the level of linear yield increase for each additional unit of water applied. This coefficient is a crucial parameter in the estimation of the production function when using Monte Carlo Simulations. The uptake coefficient was estimated based on the following equation:

$$a_{ji} = x_{ji} / \bar{y}_{max\,ji} \qquad 4.13$$

Where,

$\bar{y}_{max\,ji}$ is the mean yield in the j^{th} field for the i^{th} crop

x_{ji} is the amount of irrigation water required to achieve the potential yield

The irrigation water requirement for crops was estimated according to *hydromodule* zones (SoyuzNIHI, 1992; Rahimbayev, 1991). Irrigation water requirements according to this method include field application losses and crop water demand as described in Section 2.3.6.

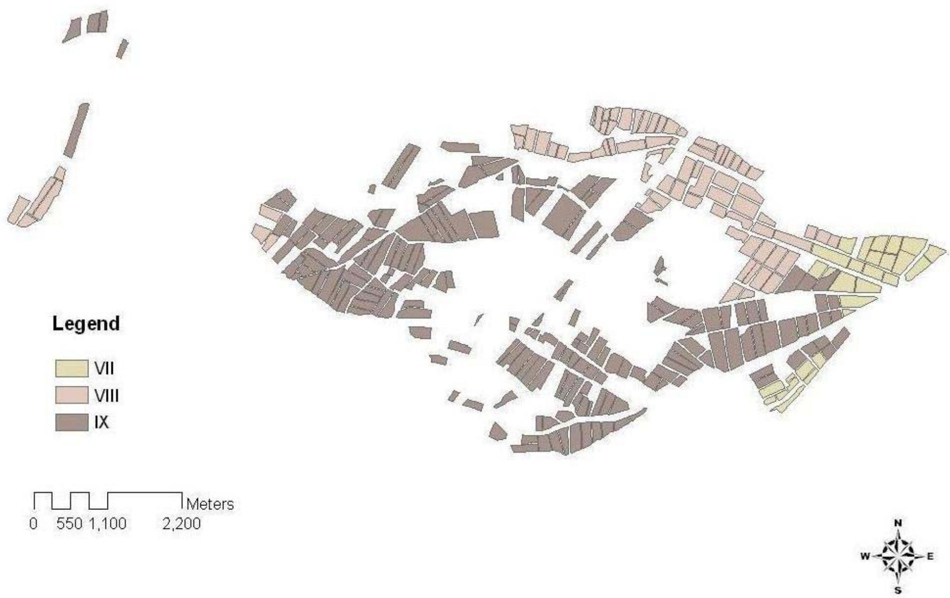

Figure 4.8: Hydromodule zones in the WUA

Hydromodule zones in the WUA (Figure 4.8) were estimated from soil texture maps in different layers and based on the methodology described in SoyuzNIHI (1992) and Rahimbayev (1991).

4.4.6 Commodity prices and variable costs

Agricultural commodity prices were available on a monthly basis during 2001-2006. Year 2005 was taken as a base year for gross margin estimations because the information on input prices was available only for 2005. Prices in other years are corrected with the observed inflation rates in Uzbekistan. Only prices during the summer and autumn seasons were considered for potatoes, vegetables and melons because the largest share of these crops is observed during these two seasons, and these products are not stored for more than several days (Bobojonov and Lamers, 2008). In the model, the farm gate prices are obtained by excluding transportation expenses. The transportation costs based on the market price in the region was available from Bobojonov (2004) and Atayev (2006). The transportation expenses and farm gate prices were considered to be the same for all modelled farms because of relatively equal distances to the nearest local market point. Expected price $E(p_i)$ and price variance $V(p_i)$ of commodities were estimated from monthly prices, corrected for inflation, and are presented in Table 4.4.

Table 4.4: Standard deviation and expected prices of commodities, UZS kg^{-1}

	Expected price $E(p_i)$	Coefficient of variation of prices
Cotton	280	0.32
Winter wheat	176.6	0.18
Rice	564.9	0.32
Maize	218.2	0.40
Fodder crops	107.4	0.11
Potatoes	181.4	0.47
Melons	171.0	1.02
Vegetables	102.2	0.35

Source: ObStat, 2006; Bobojonov, 2004; Atayev, 2006; Samandarov, 2007; own estimations

The coefficient of variation for several crops, including melons, potatoes and vegetables, is higher than other agricultural product prices; this can be primarily explained by underdeveloped infrastructure (e.g. storage, processing) in the region. A lower coefficient of variation for fodder prices might be explained by production of fodder crops aimed mainly at self-sufficiency and only limited parts are sold to the markets (Djanibekov, 2008).

Estimation of the variable costs can be presented as:

$$c_{ij} = Fr_i + Lb_i + M_i + x_{ji}WP \qquad 4.14$$

Where,

Fr_i expenses for fertilizers

Lb_i labor expenses

M_i machinery costs, including machinery service and fuel use

WP price for cubic meter of water

Farmers grow the state order crops with subsidized inputs; irrigation water is also subsidized and farmers paid a fee to the WUA, which was equal to 0.5 UZS m^3. Variable costs might change depending on the volume of water applied to each crop. Usage of fertilizers containing potassium is not included for cotton and winter wheat because of low usage in the region (Appendix 2).

The fixed costs of farms was obtained from Rudenko (2008), which was equal 195 thousand UZS ha^{-1} on average; the costs include taxes, pension fund payments, road fund taxes, and salary of workers which are related to the whole farm and not to the specific product.

4.4.7 The constraints in the model

4.4.7.1 Land constraints

The area of each field was estimated from GIS polygons and imported into GAMS. The maximum area of each field is constrained according to:

$$\sum_i \mathrm{H}_{ji} \leq \mathrm{Ar}_j \text{ for all j} \qquad 4.15$$

Total allocated area (hectares) for different crops in the field *j* should not exceed total available area Ar_j estimated from the GIS data.

4.4.7.2 *Labor constraints*

Farmers usually hire additional labor for rice transplanting and cotton harvesting seasons when their family labor is insufficient (Veldwisch, 2008). Labor use in the model is calculated as own and hired labor availability, together. The labor constraint of each farm can be formalized as:

$$\sum_{j}\sum_{i} \mathrm{L_i H_{ji}} \leq \mathrm{Lav_f} \quad \text{for all f} \quad \text{and} \quad j \in f \qquad 4.16$$

Where,

L_i the labor hours requirement of crop *i* , hours ha^{-1}

H_{ji} the hectare of i^{th} crop in field *j*, hectares

Lav_f the total available labor hours if farm *f*, hours $year^{-1}$

4.4.7.3 *Risk in water availability, chance constrained programming*

Uncertainty in the farm business might come from different sources. Chance constrained programming can be applied when risk at the farm level exists due to uncertainty in resource availability (Charnes and Cooper, 1959).

In the Khorezm region, the availability of irrigation water is a significant constraint for crop growing activities (Müller, 2006). Chance constrained programming based on Charnes and Cooper (1959) was applied in order to account for the risk associated with water availability in the modeled WUA; this risk could be considered as technical. Water availability is often assumed to be normally distributed in relevant studies (e.g. Millan and Berbel, 1994) and a test for normality has shown that water availability in the district is normally distributed. In this case, the linear chance constraint equation can be presented as:

$$\sum_{i} \mathrm{IR_{ji} H_{ji}} \leq \overline{w} - Z_{\alpha}\sigma_{w} \qquad 4.17$$

Where,

$\overline{w}$ expected water availability

IR_{ji} field level crop water requirement during the vegetation period

σ_w standard deviation of water availability

Z_α standardized normal distribution percentile for the value of α

In the model, the amount of water use includes irrigation water demand (x_{ji}) and conveyance losses (CL_{ji}) and is estimated as:

$$IR_{ji} = x_{ji} + CL_{ji} \qquad 4.18$$

Irrigation water required in the field level takes into account the losses during the transportation of water from the water intake point of the WUA. The WUA staff needs to take into account the efficiency of the system where the field of the farmer is located. For example, if a farmer needs 10 thousand m^3 of water for his field, a WUA technician might release 11 or 12 m^3 thousand of water from the central water distribution point in order to achieve the required amount in the field.

Conveyance losses are estimated as:

$$CL_{ji} = x_{ji} lss_j \qquad 4.19$$

where lss_j is inefficiency (transportation losses) of the irrigation system (Appendix 4).

The mean value of water availability per hectare and standard deviation were estimated from secondary statistics for the years 1993-2005 for the Khiva district where Shamahulum WUA is located. This information was used to estimate expected water availability $\overline{w}$ and the standard deviation of water availability (σ_w) for the whole WUA.

The value of α is assumed to be 0.1 (90 percent confidence interval) as in other studies (e.g. Millan and Berbel, 1994), which gives 1.29 for Z_α when looking at a standard normal probability table. The value of α was modified in several scenario analyses where probability of water availability is expected to change.

4.4.7.4 The state order constraints

In the modelled WUA, 56 % of total area was allocated to cotton and 19% for winter wheat due to the state order for these crops (Shamahulum WUA, 2006). The hectare of the state order for each farm is assumed to be equally distributed for all modeled farmers (Section 2.2.2). This information was elaborated as a minimum level constraint in the model as follows:

$$\sum_j H_{\mathrm{jcot}} \geq Ar_f St_{\mathrm{cot}} \text{ for all f and } j \in f \qquad 4.20$$

$$\sum_j H_{jww} \geq Ar_f St_{ww} \text{ for all f and } j \in f \qquad 4.21$$

Where,

H_{jcot} is the area allocated to cotton (*cot*),

H_{jww} is the area under winter wheat (*ww*),

Ar_f is the total available land in the farm and

St_{cot}, St_{ww} is the share of the area of cotton and winter when respectively.

Based on the obtained information, St_{cot} was set to 0.56 and St_{ww} to 0.19 in the base scenario. According to this constraint, each farm is obliged to allocate a certain area to state order crops. The value of St_{cot} and St_{ww} were reduced under scenarios where the impact of a decreased state order area was analyzed.

4.4.8 Ecological performance indicators in the model

Overall project efficiency is used when performance of the irrigation system in the special region is considered (Bos *et al.*, 1993, Barrett Purcell & Associates, 1999). Overall project efficiency is found by dividing crop water requirements in the considered system by total water inflow into the system (Bos *et al.*, 1993). According to this concept, overall water use efficiency (WUE) of the modelled WUA can be estimated as:

$$WUE = \frac{\text{Ic}}{\text{Itot}} \cdot 100 \qquad 4.22$$

Where,

WUE	is the overall water use efficiency of the WUA,
Ic	is the crop water use in the WUA, and
Itot	is the total water inflow into the WUA.

The higher the WUE, the lower the environmental damage of the activities in the WUA. Depleted water might be available for other crops due to capillary rise, but the salinity of the water will be very high and thus can cause further soil salinization (Ibrakhimov, 2005). Therefore, an infiltrated amount of water is considered as water application losses.

Field application efficiency is used to estimate total water used by crops in the WUA. Field application efficiency is estimated by dividing the crop water requirement by water delivery in the field (Bos *et al.*, 1993). Crop water demand is assumed to be equal to crop evapotranspiration (FAO, 1998), and estimated field application efficiencies for different crops are presented in Table 4.5. Field application efficiency is different depending on the *hydromodule* zone of the field.

Applied water might be lower than water consumed by a plant in the region. This discrepancy is primarily explained by capillary rise from the shallow groundwater tables (Forkutsa, 2006). Contribution from the groundwater is also important to meet crop water demand in the region (Forkutsa, 2006), which is taken into account in the production function. However, the reliance on ground water may cause more risk in the long run due to its contribution to increasing soil salinity as described in Section 2.1.4. Therefore, the contribution of ground water into the WUE is not considered; only WUE of the surface water use is considered as the ecological parameter in the model as it is mainly considered by water management organizations in Uzbekistan (Murray-Rust *et al.*, 2003).

Table 4.5: Water use efficiency in different *hydromodule* zones, conventional technology

Crops	ETc mm	Water delivery to the field[10], mm			Field application efficiency %		
		VII	VIII	IX	VII	VIII	IX
Cotton	799	640	490	530	100	100	100
Winter wheat	383	560	470	500	68	81	77
Rice	1050	3000	3500	4000	35	30	26
Maize for grain	704	620	460	490	100	100	100
Fodder crops	700	620	460	490	100	100	100
Potato	625	1050	840	960	59	74	65
Melons	619	450	350	380	100	100	100
Vegetables	619	1050	840	960	59	74	64

Source: RWUA, 2006; Conrad 2006; Tischbein 2007; own estimations

4.5 Calibration and validation of the model results

4.5.1 The optimization software

Optimisation is performed in the modelling language of a General Algebraic Modelling System (GAMS), using a CONOPT3 solver, which can handle large scale and non-linear mathematical programming problems. Finding a feasible solution is difficult when the objective function of the model is highly non-linear; in this instance, initial values must be assigned to the decision variables, and this is an important step in order to obtain realistic results in GAMS (Kalvelagen, 2001). Therefore, the model was run using a linear objective function in the initial optimization process. The solution obtained from the linear programming (LP) model was then used as an initial value in the main model.

[10] Were available from *hydromodule* zoning as described in Chapter 3

4.5.2 Model calibration

In order to obtain robust results from policy and technological changes introduced in the scenario simulations, several model parameters are usually calibrated to produce values which are close to the observed situation (Schmid and Sinabell, 2005).

Several methods exist to calibrate the model parameters so that the actual situation is reproduced to the extent possible. Additional constraints such as crop rotation, technology, price and policy constraints are then introduced to force the model to reproduce as closely as possible the observed situation (McCarl, 1982). Imposing upper and lower bounds on model activities is another way to achieve the most realistic results, imposing such constraints, however, might significantly decrease the model flexibility for further scenario analysis (Howitt, 1995).

Another widely used method of model calibration is Positive Mathematical Programming (PMP) (Heckelei, 2005). According to this approach, the observed situation is considered as the optimal situation and dual values of the imposed model constraints are then incorporated into linear or nonlinear objective functions by imposing additional nonlinear terms (e.g. quadratic) (Howitt, 1995).

The risk preference of the decision maker is usually not available for the modeller and it can be parameterised and used as a calibration parameter in the model (Howitt *et al*., 2002; Heckelei, 2002). In this study, the parameter of the Constant Relative Risk Aversion coefficient (θ) is adjusted to calibrate the model results to the observed situation.

Due to the absence of information on crop allocation at the field and farm level, the cropping patterns at the WUA level were used for the calibration and validation of the model results. Different levels of the Constant Relative Risk Aversion coefficient (θ) were tested in order to find the best fitting result to the activity levels observed in the WUA. The model was run within the feasible bounds of the Constant Relative Risk Aversion coefficient θ in order to find the risk aversion level that best replicates the observed cropping activities in the WUA[11]. Model results for several values of θ are presented in Table 4.6.

Table 4.6: Comparison of model results with the actual cropping patterns, in percent from the total area in the WUA

Crops	Actual cropping patterns	Model result θ=2.8	θ=11	θ=24
Cotton	56.7	56	56	56
Winter wheat	18.7	19	19	19
Rice	2.2	1.4	2.1	2.4
Maize for grain	3.8	0	3.7	11.5
Vegetables	6.4	11.8	7.5	5.1
Melons	0.1	0.4	0.3	0.1
Others	12.1	11.4	11.4	5.8

The discrepancy between the observed situation and model results was higher when the value of θ was equal to 2.8 and 24. The closest result to the observed situation was obtained when the value of θ was equal to 11. An approximate value of Constant Absolute Risk Aversion (λ) is estimated for each of these farms in the WUA based on Equation 4.6, which was in range of 0.07-0.009 depending on the expected income.

4.5.3 Validation of the model results

In order to validate the model results, the base run results are compared with the observed values for the WUA. The comparison is done using a percentage of total cropping areas. Validity of the model results were analysed using a regression technique which can be formalized as:

[11] The model looped in GAMS within the feasible bound of constant risk aversion to find the closest result to the observed situation

$$Are_m = be_0 + be_1 Are_a$$

Where Are_m is the modelled land allocation, Are_a is the actual land allocation and be's are parameters to be estimated. This method allows one to see how the model results match or differ from the observed situation. When regression parameters are identified, be_0 should be zero and be_1 should be equal to one when the model perfectly reproduces the actual situation. The regression was carried out for different values of θ and the best fitting results were obtained when θ is equal to 11. Only regression parameters obtained from models results with θ equal to 11 are presented below.

Table 4.7: The regression parameters

	Coefficients	Standard Error	t Stat
be_0	0.22	0.28	0.76
be_1	0.98	0.01	79.78

The regression parameters presented in the Table 4.9 show that the value of be_1 is not exactly equal to one and be_0 is also not equal to zero. However, the value of be_0 is not significantly different from zero with 95% confidence level and the value of be_1 is very close to one; therefore, the model results are assumed to correspond to the observed situation.

4.6 The model limitations

The model developed in the framework of this study is a tool for analyzing different risk reduction strategies, thereby improving farm income and the ecological situation. There are, however, several limitations of this approach.

In the model, the objective of all producers is considered jointly; in reality, however, the objectives of individual producers might differ (Janssen and Van Ittersum, 2007).

Due to the limitations associated with data availability, the model considers only a single crop allocation period where inter-cropping or secondary cropping options are not incorporated. Continuous yield response functions to fertilizer, labor and machinery use could improve the model, however, this was not possible under existing data availability.

One further limitation of this model is concerning irrigation WUE. The model includes irrigation WUE as the main ecological indicator, although there are several other indicators (e.g. rising groundwater tables, soil and irrigation water salinity) for the ecological situation in the region. Due to the static nature of the model, however, it is not possible to include long term ecological effects of different policy measures. Being static, the model cannot simulate the influence of different land and water use options into the ecological situation over several time horizons. Nonetheless, there is evidence that the ecological problems in Khorezm are mainly caused by low WUE (ZEF, 2003), which supports the usage of WUE as the main ecological indicator in the model.

5 Model Results

This chapter presents the model results in the baseline as well as the results from different scenario simulations. In addition to the baseline scenario, there were six scenarios tested. Apart from the baseline scenario, each scenario reflects an expected policy and/or technological change to be implemented in the near future. The results of each scenario contribute to the decision making process as they shed light on the potential positive and negative economic and ecological implications of proposed policy changes. The main parameters changed among the different simulations are presented in Table 5.1, and a full description of each scenario is presented in the subsequent sections. Each scenario was ultimately designed to understand two primary effects: firstly, changes to farmer income and, therefore, risk of agricultural producers; secondly, changes to water use efficiency at the Water User Association (WUA) level and, therefore, the ecological implications of proposed policy and technological changes.

Table 5.1: Short description of different scenarios

N=	Scenario name	Scenario description
1	Baseline scenario	The baseline examines the expected income, income variance, crop and water allocation under *usual farming conditions*. The base run reflects the actual situation in the WUA
State order system in place		
2	Water scarcity	This scenario is relevant to the case where farmers want to secure their profit when *insecurity related to water supply* is higher and the expected amount of water in the WUA is lower than in the baseline scenario
3	Water pricing, the state order	In this scenario, *changes in WUE and income of farmers* are explored under a higher level of water pricing. The simulations were carried out under existing state order situation.
4	New technology, the state order	Potential gains from *introducing water saving technologies* are analyzed under the current state order policy. New technologies such as laser leveling and drip irrigation are introduced as new activities into the model which are not yet practiced in the region, but have significant potential for the future
State order system relaxed		

5	Market liberalization	Relaxing the state order by <u>*decreasing the area sown to cotton and winter wheat*</u> were the main simulation parameter in this scenario. However, the other model parameters such as input-output prices are also adjusted for the situation, where state subsidies on inputs were removed
6	Water pricing, market liberalization	Water pricing under liberalized market conditions is introduced in this scenario; by exploring different prices for water it is possible to find an optimum price for <u>*creating water saving incentives*</u> when farmers have control over land allocation decisions. Economic feasibility of water pricing is analyzed.
7	New technology, market liberalization	The potential gains from water saving technologies under relaxed state order system were analyzed in this scenario. This scenario helps to analyze the change of incentives for adoption of alternative technologies if the influence of the area under the state order crops decreases.

The analysis in Scenarios 2, 3 and 4 are carried out under the conditions of existing state order; therefore, a situation of increased water scarcity (Scenario 2), the introduction of a price for water (Scenario 3) and the introduction of alternative irrigation methods (Scenario 4) are all considered under the <u>*existing state procurement system*</u>.

Scenarios 5, 6 and 7 are proposed scenarios <u>*under the relaxed state procurement system*</u>. Scenario 5 represents the situation of a liberalized market economy; in Scenario 6, a price for water is introduced, while in Scenario 7, alternative irrigation techniques, including drip irrigation, are introduced.

5.1 The baseline scenario

The baseline scenario reflects the current situation in the WUA, i.e. business as usual (BAU). Farmers were producing cotton and winter wheat in the bulk of their area according the state order. Cotton is then sold to the state at fixed prices announced each year at the beginning of the vegetation period (Rudenko, 2008). Rice, fodder crops and vegetables are produced in the remaining area and sold in the agricultural markets. Farmers were receiving a lower price for cotton than the world market prices, however, inputs for production are heavily subsidised by the state (Rudenko, 2008). For example, fertilizer and diesel are sold at significantly lower prices than found on the world market. There is similarly no market price for water and farmers pay a nominal fee to the WUA for irrigation water. On average, the fee to the WUA was equal to 0.5 UZS m^3 in 2005. Also reflected in the baseline scenario is the fact that farmers are currently cultivating crops with either flood and furrow irrigation (ZEF, 2003), and no alternative irrigation technology, such as drip irrigation, was in use.

To begin, the model output reports on five key variables from the baseline data and the results are aggregated to include a total of 300 fields from 99 farms. The five variables include the certainty equivalent (CE), risk premium, expected income, crop selection, water use and water use efficiency (WUE). The results are presented at the aggregated, WUA level. The aggregation of the results is done to avoid the extensive number of tables that would accompany a model run for each field.

Certainty Equivalent (CE)

The value of the objective function, also known as the certainty equivalent (CE), can be interpreted as the amount of wealth which is rated equivalent to the uncertain outcome of the risky prospect. The CE is estimated as expected wealth, minus a risk premium (as introduced in Chapters 3 and 4) which is estimated per farm. Aggregated (WUA total) CE obtained in the baseline was equal to 254.5 million UZS, expected income was equal to 283 million UZS and risk premium was equal to 28.4 million USZ.

Crop selection and spatial distribution

The largest cropped area among the 99 farms included in this model is sown to cotton. While cotton is not the most economically beneficial crop, farmers are obliged under the existing state procurement system to plant a certain share of their land each year to cotton. For the baseline scenario, the area sown to cotton is therefore included as a minimum level constraint in the model.

Analyzing the spatial distribution of crops and income is also very important in order to understand the importance of farm location within the WUA. The spatial distribution of crops showed that all crops are almost equally distributed to all locations in the WUA. Only a clear spatial dependence is observed in the case of rice growing. The map presented in Figure 5.1 shows the distance from the field to the water intake point, and the impact this has on the area sown to rice. Farmers located nearer to the main water inlet point (WUA water intake point) planted more rice than farmers located further away from the water source.

Figure 5.1: Spatial distribution of rice in the WUA, base scenario

Expected Income

As seen in Table 5.2, expected GM from growing cotton was very low for the aggregated sample, with significant variance between farms. The expected GM from growing winter wheat was similarly low at approximately 237.1 thousand UZS per hectare (ha) and this crop showed the least standard deviation among the different crops. While rice, potato and vegetable production had the highest expected income per hectare, water demand for these crops is also very high and thus depends on water availability in any given year.

Therefore, the largest share of area was allocated to fodder crops and maize for grain, despite that these crops show a lower expected income compared to rice, potato and vegetables.

Table 5.2: The main model results in the base run, aggregated at the WUA level

	Cotton	Winter wheat	Rice	Maize	Fodder crops	Potato	Melons	Vegetables.
Total planted area, ha	687.1	233.1	26.1	45.2	140.0	85.9	3.9	5.6
Expected GM, thousand UZS ha^{-1}	125.6	237.1	1595.5	1065.6	1178.0	1455.8	1072.9	1292.3
Standard deviation 10^6 UZS	8.9	4.6	22.8	11.3	25.5	38.7	57.0	19.7

Figure 5.2 shows the spatial distribution of expected income for the whole WUA and no clear relationship between the distance from the water source and expected income is observed. Expected income was estimated for farmers based on distance from the water source. Distances were classified into three categories: close to the water sources (d<5 km), average distance class (5 km <d<10 km), and far distance class (d>10 km). In this Scenario, it was hypothesized that farms closer to the water source would have higher expected incomes than those located further from the water source, as they suffer from less water variability (or shortages). However, as shown in Figure 5.3, this hypothesis could not be verified and no clear trend was observed. In contrast, income in the second distance class was higher than in the first class and this is primarily explained by the variation in soil type and fertility. As seen in Figure 5.4, there is a clear trend in earnings depending on the soil fertility of the farm. Farmers with a *bonitet* level ranging from 50-60 points are considered to have ‘low’ soil quality; 60-70 and 70-80 are considered ‘average’ and ‘good’ soils, respectively. An average income of farms with low, average and good soil fertility was equal to 118 thousand UZS ha^{-1}, 284 thousand UZS ha^{-1}, 442

thousand UZS ha^{-1} , respectively. Farms with low fertile soil could obtain only 27% of the income obtained by farms with good fertile land.

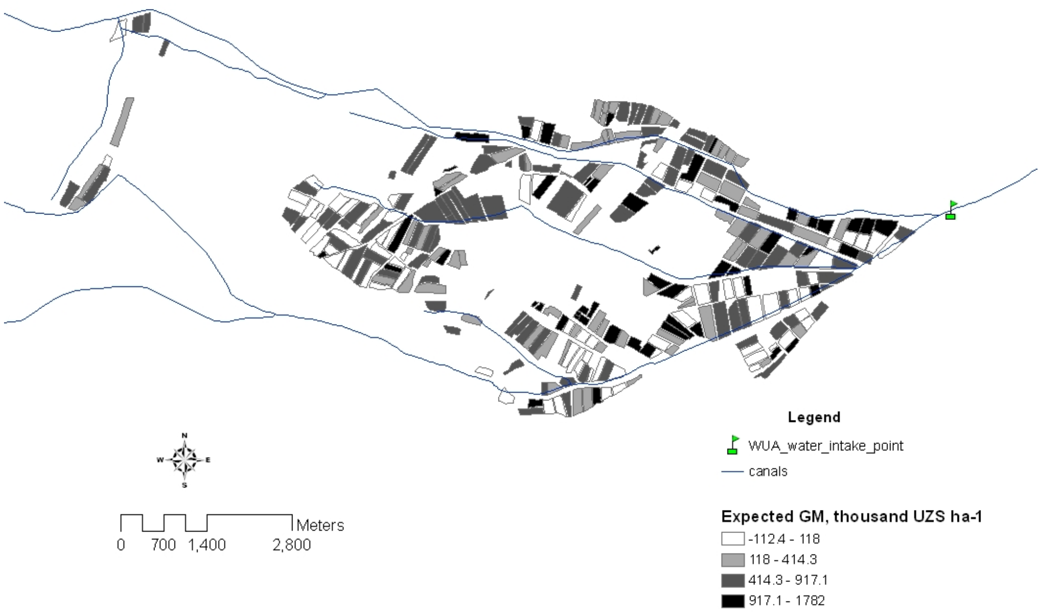

Figure 5.2: Spatial distribution of expected GM, baseline scenario

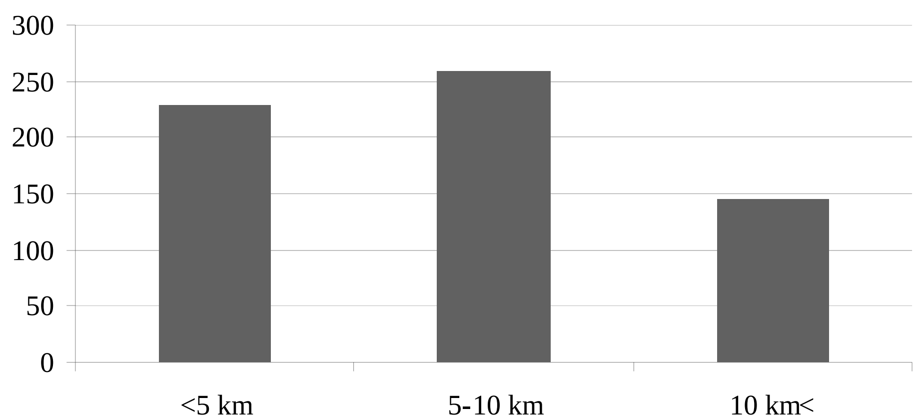

Figure 5.3: Expected income of farmers in different distance classes, thousand UZS ha^{-1}, baseline scenario

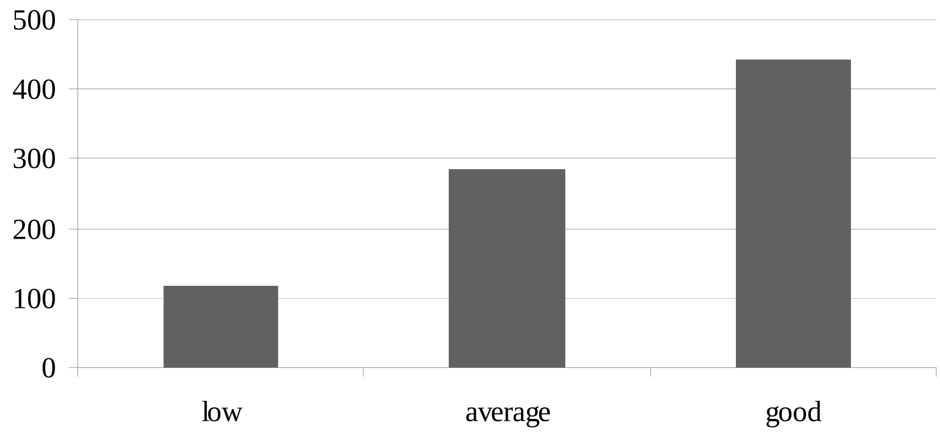

Figure 5.4: The expected income of farmers with different soil fertility levels, thousand UZS ha^{-1}, baseline scenario

Farm size also had an impact on expected income. Farms were grouped into three sizes: small-scaled (< 5 ha), medium-scaled (between 5 and 15 ha) and large-scaled (>15 ha). As seen in Figure 5.5, while there were some differences in expected income, the variation between the categories was not large.

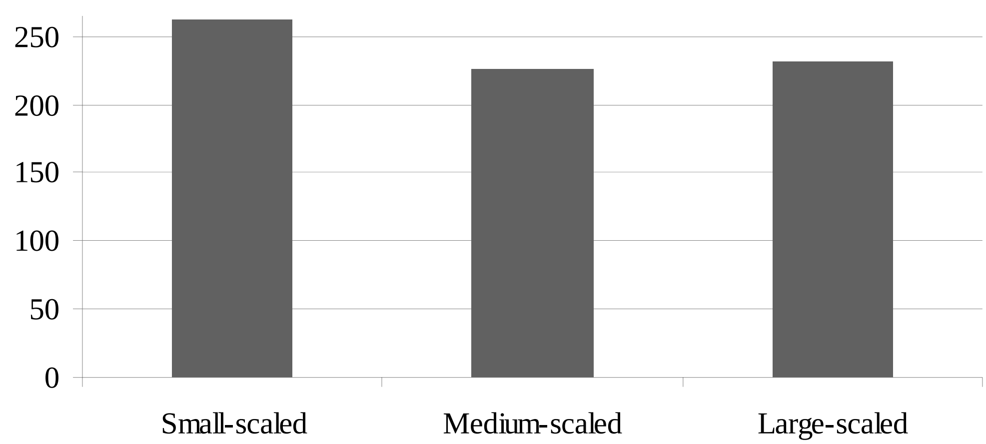

Figure 5.5: Expected income by different farm sizes, thousand UZS ha^{-1}

Water allocation

Total water use and losses among crops is highest for rice and lowest for melons and fodder crops. Figure 5.6 shows that more than 25 thousand m^3 of water is infiltrated to the groundwater from planting rice in one hectare. It is clear, therefore, the negative contribution to the ecological situation is very high from growing rice. If the ecological costs associated with such high water losses were properly valued, the high gross margins estimated from rice production would be significantly reduced. The shadow price for water was equal to 8.8 UZS m^3; several times higher than fee paid by the farmers (0.5 UZS m^3).

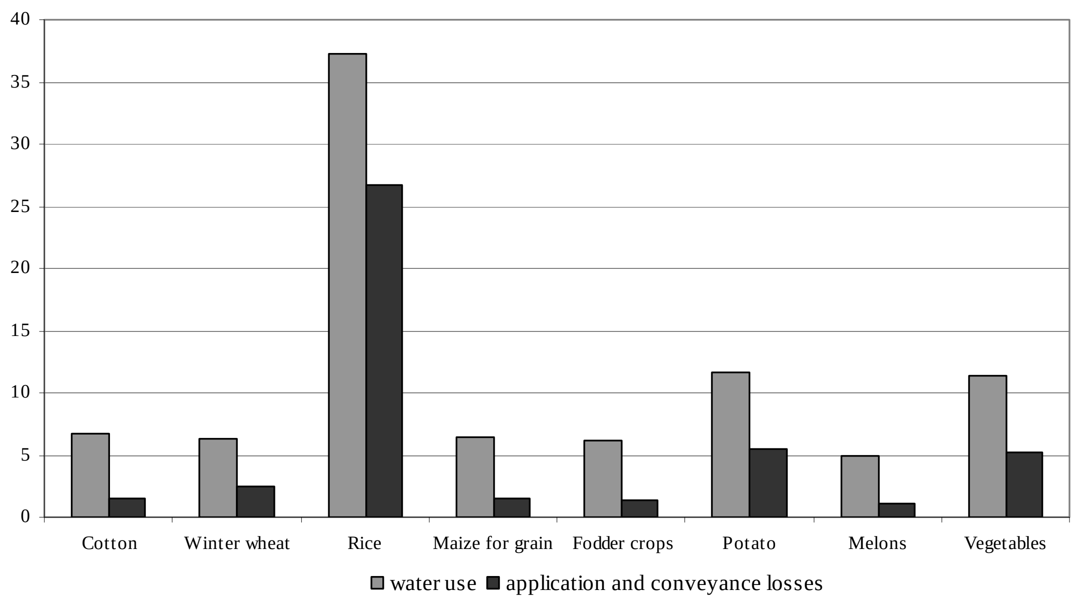

Figure 5.6: Water application and beneficial water use of different crops, thousand m^3 ha^{-1}

Water use efficiency

Water use efficiency (WUE) in the WUA is estimated by dividing total beneficial water used by crops into total water inflow into the WUA (Bos *et al.* 1993) (see Chapter 4 for further discussion). Overall WUE at the WUA level was estimated at 65.2% in the baseline; this indicates approximately 35% of the total received water was lost during conveyance and application in the fields. The WUE presented here is estimated for the first part of the planting season and is expected to be lower when the second planting season is included. The difference between the first and second planting period is due mainly to the expected area sown to rice in the second season; it is common practice in the region for farmers to sow rice after the winter wheat harvest (Veldwisch, 2008).

5.2 Scenario 2: Water scarcity

Water availability for irrigation is a key limiting factor in determining income for agricultural producers (Bucknall *et al.*, 2003). Decreasing glacier volume in the mountains of Tajikistan and Kyrgyzstan, increasing water demand in the countries located in the upstream areas of the Amu Darya for electricity generation (e.g. Tajikistan), combined with a rising demand for water intensive crops, are contributing to water shortages in the region (Müller, 2006; Duhovniy and Sorokin, 2007; Veldwisch, 2008).

Scenario 2 was designed to investigate the role of crop and water allocation in determining profit for farmers when the water supply becomes more insecure. This scenario allows for greater understanding of how expected income will be affected when water supply to the WUA is lower than in the baseline scenario. When water uncertainty increases, farmers are expected to become more risk averse and will allocate crops with the knowledge of potential water shortages. Farmers are expected, therefore, to secure their income by selecting less water-intensive crops, rather than relying on crops which may have a higher market price, but require a more certain water supply (e.g. rice).

In Scenario 2, the prescribed level of probability, α, increased from 90 percent (in the baseline Scenario) to 95 %; this can be interpreted as farmers wanting a 95% probability that their water demands will be met. Moreover, expected income is assumed to be lower and risk aversion of the decision makes is higher. All other parameters were the same as in the baseline scenario, and the increased probability level was the only difference in this scenario.

The overall certainty equivalent (CE) decreased in Scenario 2 to 223.6 million soums, from 254.5 million UZS in the baseline scenario. Aggregated expected income also declined from 283 million UZS to 251.4 million UZS which risk premium staying almost is the same level with the base scenario as shown in Table 5.3. Meanwhile, overall water use efficiency in the WUA increased to 74.5 % from 66.8 % in the baseline. As shown in Table 5.3, water intensive crops, such as rice and vegetables, were dramatically reduced or disappeared all together from the cropping scheme with the expectation of greater water shortages; on the other hand, the area sown to maize for grain and melons increased due to their comparatively lower water demand.

The shadow price for water in the baseline was equal to 8.8 UZS m^3. In Scenario 2, the shadow price was increased to 31.6 UZS m^3, as the availability of water was expected to be lower.

Table 5.3: Crop allocation, expected income and CE, Baseline vs. Scenario 2

Scenario No.		(1) Baseline	(2) Water Scarcity
Crop allocation (ha)	Cotton	687.1	687.1
	Winter Wheat	233.1	233.1
	Rice	26.1	-
	Maize	45.2	86.6
	Fodder	140	181.4
	Potato	85.9	16
	Melons	3.9	22.6
	Vegetables	5.6	-
Expected income (million UZS)		283	251.4
CE (million UZS)		254.5	223.6
Overall WUE		65.2	74.4
Risk premium (million UZS)		28	27.8

5.3 Scenario 3: Water pricing under existing state order system

The introduction of a price for water has proven to be an effective economic instrument for improving water use efficiency worldwide (Azevedo and Baltar, 2005). A price for water is not only important to create water saving incentives, but similarly provides means for improved financial support for organizations involved in water management. The influence of a price for water on WUE was, therefore, considered in Scenario 3. A price for water is expected to be implemented by the GoU in the near future, although the exact amount has not yet been announced (FAO, 1997b). There is evidence that the introduction of water pricing could prove an effective method for increasing WUE in Uzbekistan (FAO, 1997b).

The main purpose of this scenario was to analyze crop and water allocation, income, and change in WUE, after introducing a price for water under the existing state-order system. Because the price for water to be charged by the GoU is not yet known, different prices for water were tested. All model parameters were the same as in the baseline scenario, except for the water price. As introduced in Chapter 2, farmers pay only 0.5 UZS m^3, which covers expenses of the WUA; expenses of all other existing water management organizations are covered by the state. Farmers would need to be charged a minimum of 2.3 UZS m^3 to cover operation and management (O&M) expenses for the existing water management organization.

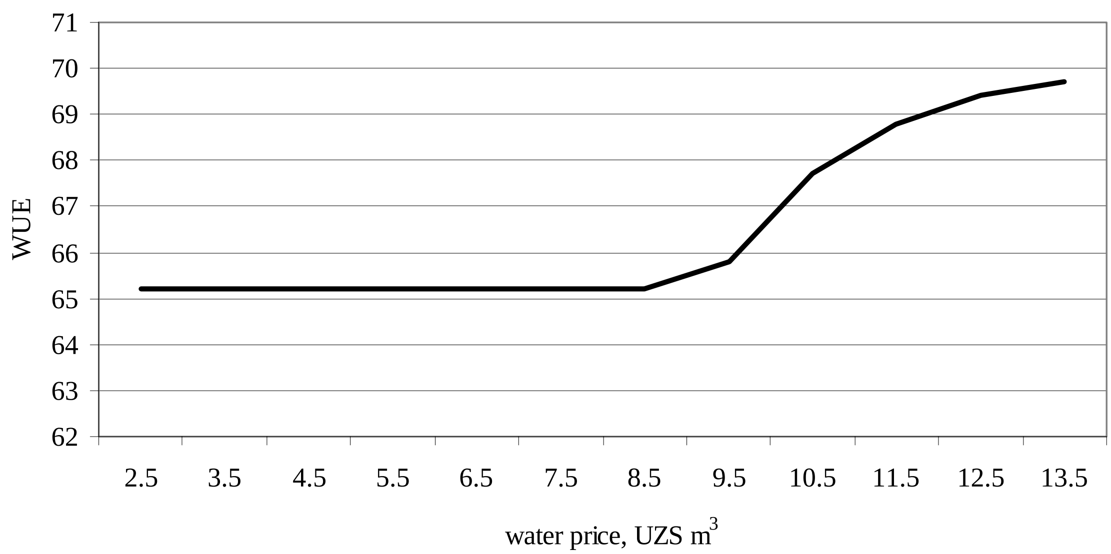

Figure 5.7: Scenario 3: The relationship between changes in the price for water (per m^3) and the effect on WUE

Therefore, only values higher than 2.3 UZS m^3 were considered in the simulations for Scenario 3[12]. As shown in Figure 5.7, the price for water was increased from 2.3 UZS m^3 until improvements in WUE appeared. The overall WUE at the WUA level started to increase when the price reached approximately 9.5 UZS m^3. With a price around 11.5 UZS m^3, WUE increased significantly and was five times higher than the cost recovery price of water management organizations; this value is used in other simulations as it has a significant impact on WUE.

At a price of 11.5 UZS m^3, WUE increased to 68.5%, from 65.2% (in the baseline scenario). This increase was achieved as the total area sown to rice was decreased (Table 5.4), and water application decreased for other crops. However, the CE also decreased to 139.1 million UZS, from 254.5 million UZS in the baseline. Overall expected income decreased to 174.3 million UZS, from 283 million UZS; as shown in Figure 5.8, farmers with the lowest soil quality showed the greatest losses.

Table 5.4: Expected impacts from 11.5 UZS m^3 water price, baseline Scenario vs. Scenario 3

Scenario No.		(1) Baseline	(3) Water pricing
Crop allocation, ha	Cotton	687.1	687.1
	Winter Wheat	233.1	233.1
	Rice	26.1	12.7
	Maize	45.2	106.8
	Fodder	140	115.8
	Potato	85.9	55.3
	Melons	3.9	3.1
	Vegetables	5.6	12.9
Expected income (million UZS)		283	174.3
CE (million UZS)		254.5	139.1
Overall WUE		65.2	68.5
Risk premium (million UZS)		28	35

[12] For completeness, a price lower than 2.3 UZS m3 was tested, however, the results showed no significant change to the baseline model.

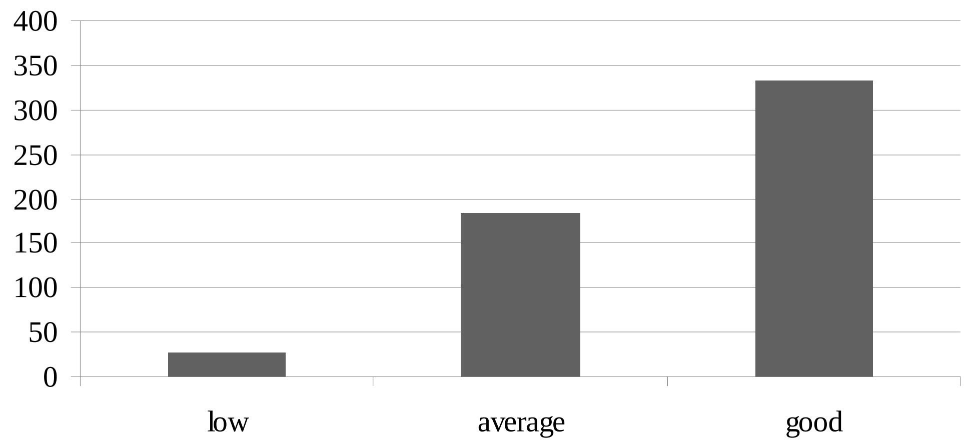

Figure 5.8: The effect of 11.5 UZS m^3 water price on farmers expected income, based on soil quality (Scenario 3)

In Scenario 3, one can see that increased water prices have an effect on WUE and improved WUE would have positive externalities for the environment. The introduction of higher prices for water, however, could result in dramatic losses in income for agricultural producers. Income among farmers is already very low due to the rigid state order system. Therefore, in Scenarios 5-7, the state order system will be decreased and various parameters are analyzed to understand the impact of removing the state order system on farmer income and water use.

5.4 Scenario 4: Introduction of new technologies under existing state order system

The primary goal of this scenario was to analyze the change of income, water use efficiency and crop allocation when water saving technologies would be available for agricultural producers in the region. Water saving technologies can lead to improved yields and water use efficiency. While there are many such technologies, considered here are only those technologies suitable for local conditions, including laser leveling and drip irrigation (Kamilov *et al.* 2003; Egamberdiev *et al.*, 2008)[13].

[13] Further information on laser leveling and drip irrigation is provided in the Annexes

Increasing WUE in the Khorezm region is crucial for improving the overall soil conditions, as well as ensuring water availability for maintaining or improving crop yields. Drip irrigation methods have been proven to reduce water demand by as much as 35%, while resulting in yields as much as 21% higher compared to traditional furrow and flooding methods used across Uzbekistan (Kamilov *et al.*, 2003). Due to the naturally high saline soils in the region, the accumulation of salt in the rootzone may be one negative side effect of using drip irrigation (Burt and Isbell, 2005); however, leaching of salts from the soil is widely practiced in the region. For the purpose of Scenario 4, it was assumed that drip irrigation could be used for all crops except rice, which is grown only under flooded conditions in Uzbekistan (Veldwisch, 2008). Moreover, production of the state order crops are also not considered for drip irrigation and laser leveling due to their low gross margin and high expenses related to investment expenses for these technologies. Preliminary estimations have shown that these technologies are not interesting for the state order crops. Involvement of these crops in the optimization process might increase memory demand and thus led to exceeding upper memory limit in the GAMS, where upper limit is equal to 1.7 Gigabits in Windows 32 bit operation system (www.gams.com).

The cost of introducing a drip irrigation system (Netafim), per one hectare, was estimated to cost 2 million UZS in the Khorezm region, with an average lifetime of eight years (Bekchanov, 2004). For the purpose of the model estimations, the cost was assumed to be equally distributed over eight years with an additional five percent maintenance cost each year, after the first year.

The use of laser leveling has proven to increase water use efficiency and yields in most of the countries in the world (Humphreys *et al.*, 2005). Laser leveling could be extremely suitable for the region as 70% of the total cropped area is roughly (unevenly) leveled (UNDP, 2007). Proper leveling would allow for a more equal distribution of water in flood and furrow irrigation and, therefore, decrease the amount of water needed for irrigation. Laser leveled fields have proven to reduce water demand by as much as 20%, while resulting in yields as much as 15% higher compared to traditionally leveled fields (Humphreys *et al.,* 2005). The expense of leveling one hectare of land was estimated to be 150 thousand UZS; this technology is, therefore, significantly less expensive than introducing a drip irrigation system. Laser leveling may need to be repeated every 3-5 years depending on the crops being grown and irrigation method used (Egamberdiev *et al.*, 2008). For the purpose of the model estimations, the expense for laser leveling was equally distributed over a three year period.

Laser leveling one hectare of land requires approximately six hours using the standard type of tractor found in the region (Egamberdiev *et al.*, 2008). The process of laser leveling is ideally carried out in a window of two to three months in the late autumn and early spring, as the soil is otherwise frozen in the winter months or cropped in the summer months. For the purpose of the model estimations, it was assumed that one laser leveler is available in the WUA, and is able to operate for a maximum of 360 hectares during a given year.

Laser leveling and drip irrigation are currently not practiced by farmers in the region and research on these technologies is very limited; the different constraints that could ultimately reduce the farmers' willingness to adopt these different types of technology is, therefore, not available. However, the adoption of each technology within the context of this model is driven by economic incentives alone and other uptake factors, such as social conditions, are not considered within the scope of the model (Drechsel *et al.*, 2005).

The main objective of Scenario 4 is, therefore, to consider economic and environmental attractiveness of the alternative technologies, as measured by expected income and water use efficiency. To this end, water saving technologies are introduced under the current state order system; all other parameters of the model are kept as in the baseline scenario.

Laser leveled fields (referred to as laser leveling from here onwards) require 20 % less water than under roughly leveled fields. Similarly, when drip irrigation was introduced, water use was 35% lower than under conventional furrow irrigation. Because less water was required under these alternative irrigation methods, area sown to rice and potato increased; these crops have the highest water demand, but similarly the highest expected income. The CE increased to 357.9 million UZS, from 254.5 million UZS in the baseline scenario. Availability of additional technology increased the overall expected income to 389.3 million UZS, from 283 million UZS in the baseline (Table 5.6). The overall comparative advantage of different technologies depends on expected income, the variance of income, as well as resource availability (e.g. water, labor). Expected income and variance of income depends on agro-ecological properties of the field (such as *bonitet*, *hydromodule* zone and location in the irrigation system). For simplicity, the level of adoption of each technology can be considered as a proxy for its comparative advantage, and is indicated by the area using this technology.

Table 5.5: Crop allocation (in ha) under different irrigation methods in Scenario 4

Irrigation method	Traditional	Laser leveling	Drip irrigation
Cotton	687	-	-
Winter wheat	233.1	-	-
Rice	-	35.5	-
Maize for grain	-	8.9	-
Fodder crops	-	78.6	-
Potato	-	174	6.7
Melons	-	0.13	-
Vegetable	-	2.7	-

Table 5.6: Main model results, baseline Scenario vs. Scenario 4

Scenario No.		(1) Baseline	(4) Irrigation technologies
Crop allocation, ha	Cotton	687.1	687
	Winter Wheat	233.1	233.1
	Rice	26.1	35.5
	Maize	45.2	8.9
	Fodder	140	78.6
	Potato	85.9	180.7
	Melons	3.9	0.13
	Vegetables	5.6	2.7
Expected income (million UZS)		283	389.3
CE (million UZS)		254.5	357.9
Overall WUE		65.2	65
Risk premium (million UZS)		28	31.2

As shown in Table 5.5, the higher the area under each technology, the higher the comparative advantage of that technology.

Only a limited area was cultivated under drip irrigation and primarily to potatoes. Higher initial investments, combined with a limited area for high value crops, constrained farmers from adopting drip irrigation.

In the model, 300 ha of the WUA are considered to be laser leveled; as seen in Table 5.5, the additional economic benefits gained, exceeded the costs of implementing this technology. Also seen in Table 5.6, WUE at the WUA level did not change (nearly 65% as in the baseline scenario).

5.5 Scenario 5: Market liberalization.

It is widely assumed in the literature the abolishment or decrease of the state order will improve the ecological conditions as well as farm income by increasing crop diversification (Spoor and Khaitov, 2003; Bucknall *et al.*, 2003). The following three scenarios consider, therefore, anticipated changes in the state procurement system. For Scenario 5, farmers allocate less area to the state order crops (cotton and wheat) and have more freedom in their decision making to plant alternative crops. Relaxing the state order is, therefore, the main simulation parameter in this scenario. Previous studies have shown that there are several other parameters which must be simultaneously considered if the state order is decreased; for example, agricultural input prices will likely rise due to the removal of existing state subsidies (Rudenko and Lamers, 2007; Bobojonov *et al.*, 2008). Similarly, O&M costs of water management organizations will no longer be financed by the state and water supply would be paid for by farmers. Therefore, several exogenous parameters of the model were changed to reflect the fact that farmers have increased decision making, but will need to pay higher prices for previously subsidized services and inputs.

Djanibekov (2008) has shown that farmers have to pay higher (market) prices for fertilizers and fuel, and these inputs were estimated at the border price. The main parameters changed in this scenario include fertilizer prices (increased by 36% on average) and fuel prices (increased by 24%), as well as the price paid to farmers for cotton, and prices for other commodities. One study of the cotton value chain for the Khorezm region found that farmers receive on average 66% of the world market price (Rudenko, 2008) and, therefore, the price farmers receive for their cotton was increased by 34% in the model. Djanibekov (2008) has demonstrated that people consume more when their increase in income is due to the removal of the state order and commodity prices in the markets increase. Therefore, prices of other agricultural commodities were also increased by 4% as a result of increased consumption in the region (Djanibekov, 2008). Approximately 2.3 UZS were charged per m^3 of water, i.e. the average amount needed to cover expenses of the water management organizations in the region (see Chapter 2).

Agricultural production has been recently liberalized in other Soviet countries, such as Azerbaijan, Kazakhstan and Kyrgyzstan, and there is some evidence this has resulted in increased market insecurity (e.g. Spoor, 2007). However, quantitative data on the level of market distortions in these countries are not available. To control for such potential market insecurity under the elimination of the state quota, in the following simulation it is assumed that the standard deviation of crop prices increases when market insecurity increases beyond their observed values. For Scenario 5, when the state order was removed, the area sown to cotton decreased to 14% of the total area, from 56% (in the baseline); similarly, winter wheat decreased to 5% from 19% (in the baseline).

The CE sharply increased to 853.7 million UZS, from 245.5 million UZS in the baseline, as a result of liberalization in the agricultural sector. Farmers had more opportunity to cultivate high value crops due to the release of land from the mandatory cultivation of the less profitable cotton and wheat.

As seen in Table 5.7, the area under fodder crops, potato and vegetables increased at the expense of cotton and winter wheat. The increase of area under fodder crops and potato when considering the increased income variance for these crops (as explained in Section 5.1, Table 5.2) may be explained by the decreasing risk aversion (DARA) property of the objective function (see Chapter 3). Farmers become less risk averse as their income rises and could choose crops with higher income, even though gross margin variance of these crops is higher compared to other crops.

Table 5.7: The main model results in the Scenario 5 vs. baseline Scenario

	Scenario No.	(1) Baseline	(5) Market Liberalization
Crop allocation, ha	Cotton	687.1	217.6
	Winter Wheat	233.1	65.2
	Rice	26.1	14.2
	Maize	45.2	53.9
	Fodder	140	662.8
	Potato	85.9	187.1
	Melons	3.9	6.4
	Vegetables	5.6	17.6
Expected income (million UZS)		283	903.2
CE (million UZS)		254.5	853.6
Overall WUE		65.2	67.5
Risk premium (million UZS)		28	50.4

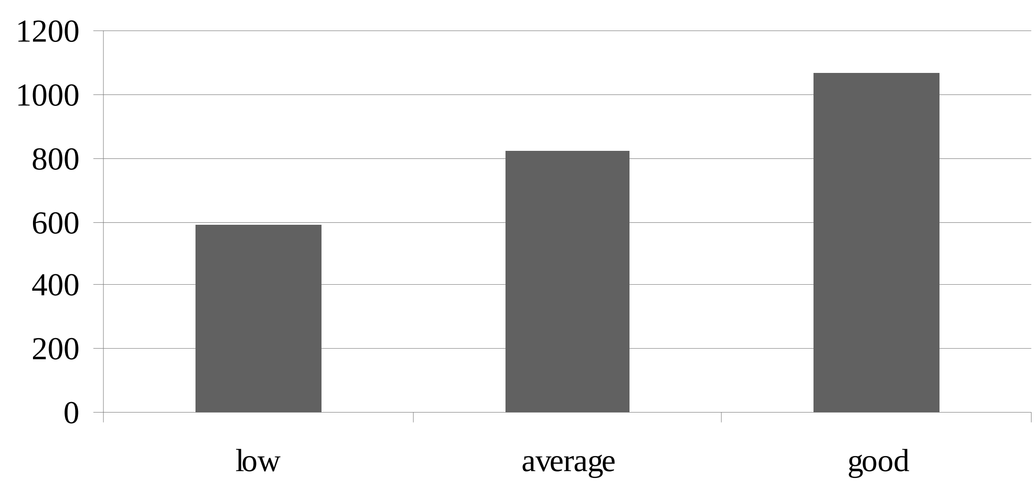

Figure 5.9: The expected income of farmers with different soil fertility levels, thousand UZS ha^{-1}, Scenario 5

The difference in expected income in farms with different soil fertility remained in Scenario 5 (Figure 5.9); however the difference in expected income between farm groups was lower in this scenario when compared to the baseline scenario. Farms with low soil fertility could obtain only 27% of the income obtained by farms with land classified as good in the baseline scenario and farms with low fertile soil could obtain 55% of the income obtained by farms with good fertile land in this scenario. This can be explained by the increase in decision making flexibility at the farm level and the fact that farmers could allocate their land according to the comparative advantages of their soil type after the reduction of the area sown to cotton or winter wheat.

Relaxing the area under state order crops and the consequential increase in crop diversification indicates an improvement of the ecological situation in the WUA is possible. The level of improvement was very low, as indicated by the 2.5% increase in WUE compared to the baseline.

Diversification of the cropping patterns and allocating the land according to the comparative advantages could motivate farmers to increase their WUE. However, 2.5% increase might not seem very high and higher level of water price might be required in order to increase the WUE further. Moreover, as introduced in Chapter 2, the price of water must be higher than 2.3 UZS m^3 (which was considered in Scenario 5) in order to increase the service level of water management organizations, which is very low at the moment.

A higher level of water price was analyzed in the next sections which could help to increase WUE on the one hand and could increase financial ability of water management organization on the other.

5.6 Scenario 6: Water pricing under liberalized market conditions

Scenario 6 introduces a price for water under liberalized market conditions. A value of 2.3 UZS m^3 price was introduced in Scenario 5, as it is a minimum level of price needed by the WMOs if the state doesn’t finance O&M. This scenario is designed to improve our understanding of how water pricing can create incentives for water conservation when farmers have greater decision making power over cropping area and timing.

This scenario builds on Scenario 5. All model parameters were the same with the Scenario 5 except a higher level of water pricing was analyzed in this scenario. The difference between Scenario 3 and Scenario 6 is that water pricing was simulated under free market economy in this Scenario, while for Scenario 3 simulations with water pricing were carried out under state-order conditions.

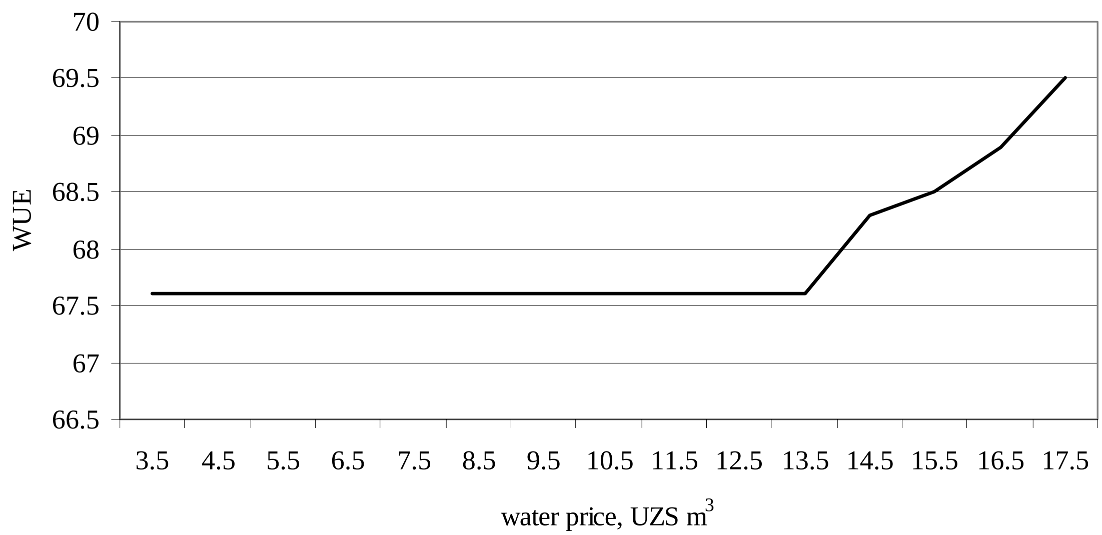

Figure 5.10: Scenario 6: Effect of increased water pricing on WUE within the WUA, under liberalized market conditions

As shown in Figure 5.10, an increase in WUE can be seen when the price for water is set to 13.5 UZS m^{-3} or higher. A considerable jump was observed when the price was equal to 17.5 UZS m^3; for this reason, 17.5 UZS m^3 is considered as the optimum water price in this simulation. Further increase up to certain level could be achieved with further increase of water price however, a price of 17.5 UZS m^3 for water is considered in the remaining of the discussions in this Scenario.

The CE was equal to 705.3 million UZS in this Scenario and expected income was equal to 757.6 million UZS. There was a decrease in the CE and expected income when compared to Scenario 5; however, this value was still higher than the baseline scenario (see Table 5.8). The overall WUE was equal to 69.5 % due to a decrease in rice cultivation and water application for other crops.

Table 5.8: The main model results with water price of 16.5 UZS m^3, Scenario 6 vs. baseline Scenario

Scenario No.		(1) Baseline	(6) Water pricing under market liberalization
Crop allocation, ha	Cotton	687.1	223.6
	Winter Wheat	233.1	39.6
	Rice	26.1	4.7
	Maize	45.2	103.8
	Fodder	140	691.2
	Potato	85.9	141.2
	Melons	3.9	8.3
	Vegetables	5.6	12.2
Expected income (million UZS)		283	757.6
CE (million UZS)		254.5	705.3
Overall WUE		65.2	69.5
Risk premium (million UZS)		28	52.3

As shown in Figure 5.11, only a limited area of land is allocated for rice in Scenario 6 and all rice cultivation is located near to the water source. Similarly, the area allocated to rice under this simulation is classified as *hydromodule* zone *VII* (Figure 4.8 in Chapter 4). This soil type has the lowest water demand. A further increase in area sown to rice in the remote areas with similarly high *hydromodule* zones will ultimately increase the water demand. An increase in water demand forces the expected income to decrease, due to the higher price for water. In Scenario 6, therefore, the model allocated rice production only to areas where the water demand is lowest; further expansion of rice production under existing conditions could otherwise lead to a decrease in expected income.

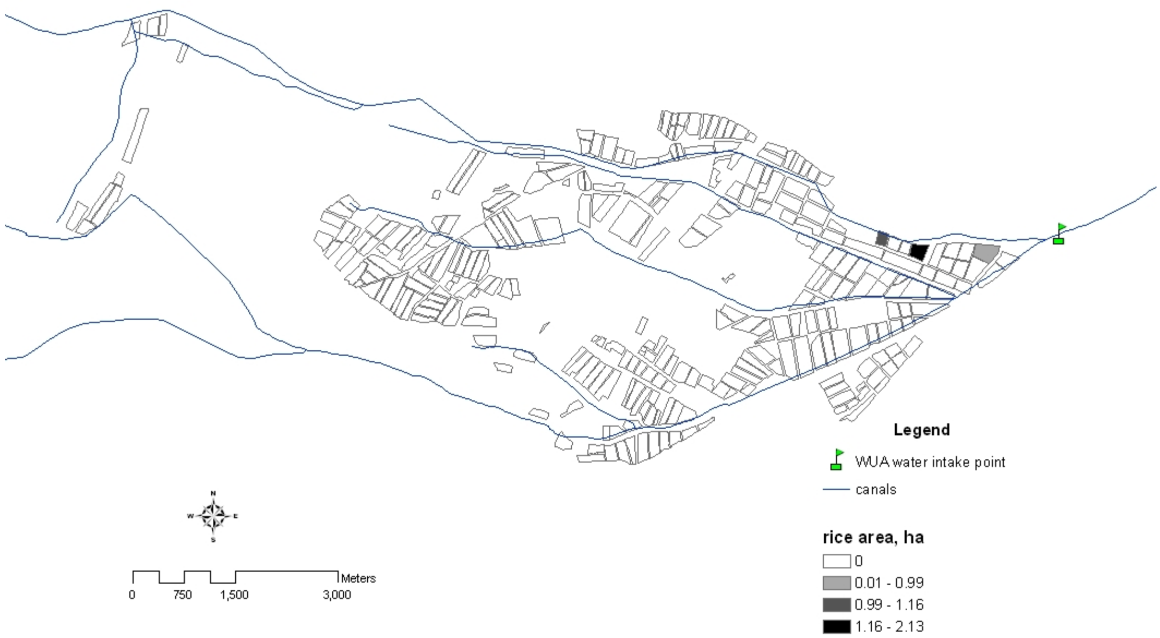

Figure 5.11: Spatial distribution of rice area in the WUA, Scenario 6

5.7 Scenario 7: Introduction of new technologies under liberalized market conditions

The potential gains from water saving technologies under the relaxed state order system were analyzed in this scenario. This scenario is designed to understand changes in incentives with respect to alternative technologies when the state-order is decreased. This scenario will similarly help to understand how the adoption of new technologies under market liberalization will affect income and water use efficiency in the WUA. This scenario is very similar to Scenario 5; the only difference being the availability of alternative technologies as considered in Scenarios 4.

The highest CE was obtained in this scenario which was equal to 1,067 million UZS with expected income of 1,153 million UZS (Table 5.10). Table 5.9 demonstrates that the area under drip irrigation increased when compared to Scenario 4. Farmers were more interested in drip irrigation when the state order is decreased, which was not the case in Scenario 4.

Table 5.9: Crop allocation under different irrigation methods in Scenario 7, ha

Irrigation method	Traditional	Laser leveling	Drip irrigation
Cotton	209.5		
Winter wheat	74.1		
Rice		57.2	
Maize for		3.4	
Fodder crops	2.3	216.7	167.5
Potato		78.6	406.6
Melons			
Vegetable		3.8	4.6

Table 5.10: The main model results in the Scenario 7 vs. baseline Scenario

	Scenario No.	(1) Baseline	(7) Irrigation technologies under market liberalization
Crop allocation, ha	Cotton	687.1	209.5
	Winter Wheat	233.1	74.1
	Rice	26.1	57.2
	Maize	45.2	3.4
	Fodder	140	386.5
	Potato	85.9	485.2
	Melons	3.9	
	Vegetables	5.6	8.4
Expected income (million UZS)		283	1,153
CE (million UZS)		254.5	1,067
Overall WUE		65.2	68.3
Risk premium (million UZS)		28	86

More land was available for high value crops and water resources became scarce to plant high value crops when the area under the state order was reduced. Farmers increased the usage of drip irrigation technologies for vegetable, potato and maize for grain as presented in Table 5.9. There were improvements was observed in water use efficiency in this scenario unlike the Scenario 4.

6 Discussion of the results

This chapter presents a discussion of the results reported in Chapter 5. A comparison of the model outcomes is presented and interpretation provided.

6.1 *Certainty equivalent, expected income and risk*

The objective function of the model maximizes the sum of farm certainty equivalents (CE). The CE can be interpreted as the amount of wealth which is equivalent to the uncertain outcome of the risky event, i.e. inverse utility function (Robison and Barry, 1987). Figure 6.1 shows the comparison of the aggregated CE values obtained in the different scenarios estimated in Chapter 5. By comparing the values of the CE in different scenarios, one can rank policies in terms of expected utility for farmers in the WUA.

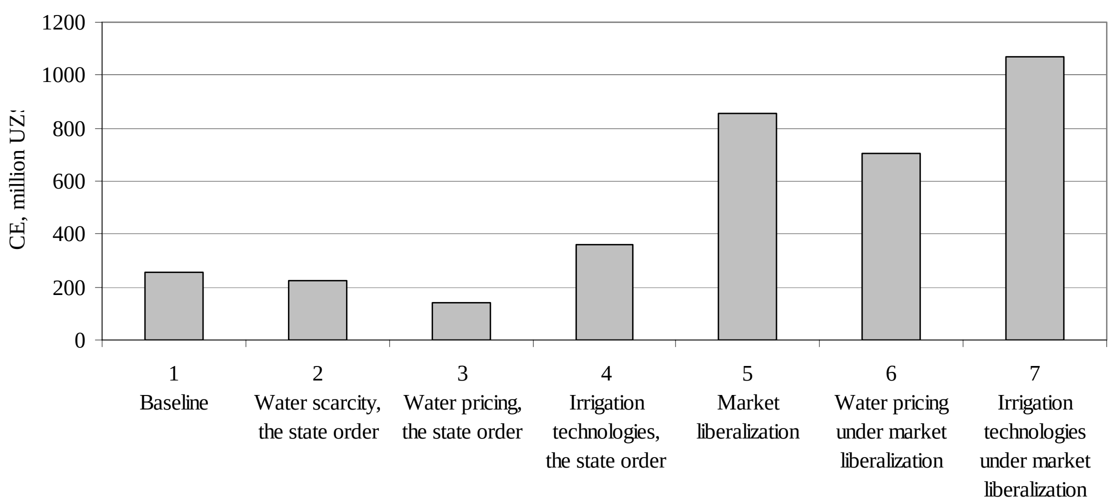

Figure 6.1: Variation in the Certainty Equivalent (CE) under different scenarios

Relevant studies have demonstrated the welfare (e.g. income, health) of agricultural producers is dependent on the availability of irrigation water in the region (e.g. Bucknall *et al.*, 2003; Müller, 2006). The model results supported such studies, as seen by the change in CE depending on the expectation of water supply. The CE decreased in Scenario 2 from 254.5 million UZS to 223.6 million UZS in the baseline scenario, when water supply in the WUA was expected to be lower than in the baseline scenario (Figure

6.1). Overall expected income was also lower when compared to the baseline scenario (Figure 6.2). A decrease of overall expected income from 283 million UZS to 251.4 million UZS may not indicate significant losses, however, farmers located in the tail end of the canal will suffer more when water shortage occurs (Scenario 2).

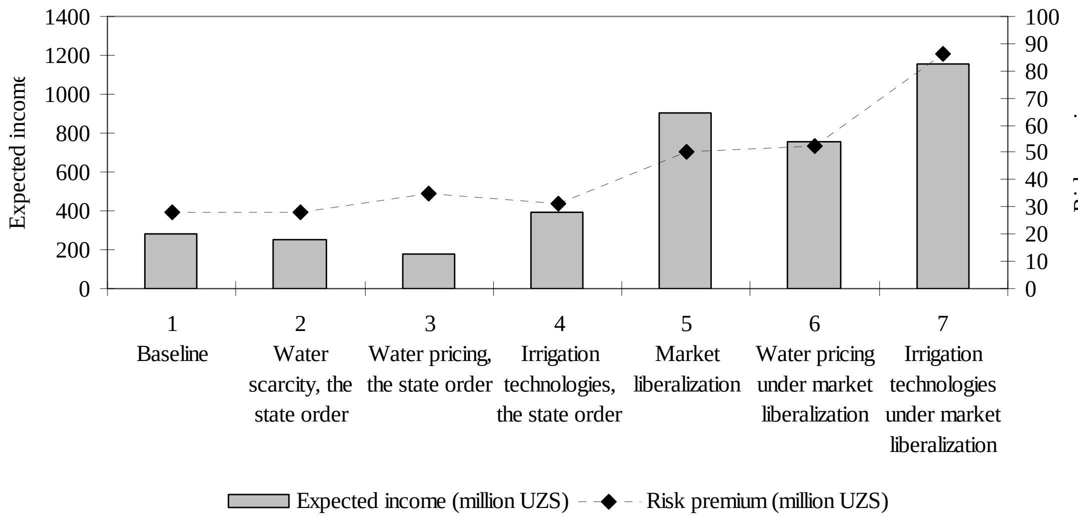

Figure 6.2: Overall expected income and risk premium in different scenarios[14]

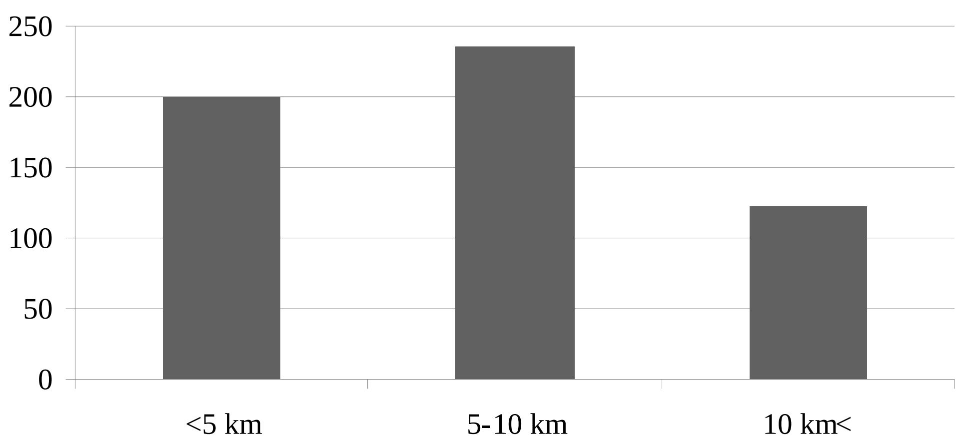

Figure 6.3: Expected income of farmers in different distance classes, thousand UZS ha^{-1} under conditions of water scarcity, Scenario 2

[14] Points in the figure are joined with line for better visualization only

Under existing state order conditions, farmers located in the tail end could expect to earn slightly more than 100 thousand UZS ha^{-1}under conditions of water scarcity. The model results indicate farmers located in tail end of the irrigation system are willing to take greater risks under irrigation water supply uncertainty than upstream farmers. Similar findings were reported by Bucknall (2003), where farmers located in the downstream areas were found to be more vulnerable to poverty, than farms located upstream. Moreover, risk premium became relatively higher (the share in the expected income) when compared to the base scenario indicating higher uncertainty in this scenario.

The largest decline in CE was observed in Scenario 3, when the price for water reached 11.5 UZS m^3, i.e. the price set to achieve ecological improvement in the region under the state order. The expected income of farmers decreased and risk premium became relatively higher when compared to the condition without water pricing. CE also decreased from 283 million UZS to 174.3 million UZS, in the baseline Scenario. The implementation of a water price might significantly decrease the income of agricultural producers, which is already very low under the state order system. The introduction of additional costs on the expected income side of the objective function makes income variance higher than expected income (i.e. when comparing to the baseline). Thus, agriculture in the region became more risky than before with the introduction of a price for water. Therefore, the introduction of water pricing to improve ecological conditions may not be an optimum solution under the existing state order system, unless accompanied by other protectionist measures to ensure farmer income was not threatened.

The CE and expected income increased in Scenario 4, when new technologies were available for the farmers under the state order system. The CE increased from 254.5 million UZS to 357.9 million UZS. The model results revealed that the availability of new technologies would increase the income of agricultural producers in the region; however, there are certain limitations for technology adoption under the current state order system (to be discussed in Section 6.5).

The abolishment or decrease of the state order is expected by many to improve the economic, social and environmental conditions in the region by allowing for an increase in crop diversification and, therefore, more sustainable production with higher income

(Spoor and Khaitov, 2003; Bucknall *et al.*, 2003). Therefore, the final three scenarios in the model were designed to test this hypothesis and understand the immediate effects of removing the state order on farmer welfare. The CE and expected income jumped very high in Scenario 5, when the state order for cotton and wheat was relaxed in the market liberalization scenario. The CE increased from 245.5 million UZS in the baseline, to 853.7 million UZS, thereby supporting the assumptions of Khaitov (2003) and Bucknall (2003). The risk premium under this scenario was also relatively lower when compared with the baseline scenario. Results described in Section 5.4 similarly indicated that farms with poor quality soils have greater income security when allocating crops according to their comparative advantages; a freedom which is limited under the state order system.

While farmer income would increase under a relaxed state order, adverse effects may occur when subsidies for inputs are similarly abolished. Nonetheless, greater diversification of the present cropping patterns would allow for farmers to make decisions based on local conditions and, with higher expected income. The ability of farmers to cope with risks is also likely to increase, as has been observed in the neighboring countries of Uzbekistan where the state order system has already been eased or abandoned (i.e. in Kazakhstan) (Spoor, 2007). Increased crop diversification will likely result in higher utility for farmers, assuming markets are liberalized, even under increased price uncertainties.

A decrease in the CE and expected income was observed in Scenario 6, when a water price of 17.5 UZS m^3 was introduced under market liberalization; this result can be compared to the situation of market liberalization without (low level) water pricing tested in Scenario 5. The CE was equal to 705.3 million UZS in this Scenario; the result appears to be more favorable as the expected income is equal to 757.6 million UZS, and is still several times higher than the baseline scenario (283 million UZS).

The highest CE and expected income were observed in Scenario 7 under conditions of market liberalization, combined with new irrigation technologies. In this scenario, the CE was equal to 1,067 million UZS, and the expected income was equal to 1,153 million UZS. The introduction of water saving technologies in Scenario 7 increased the chance of obtaining higher income; however, at the same give more options to cope with the risk associated with water supply in the region. From this scenario, one could conclude that agricultural production in the region would become less sensitive to spatial and temporal variations in the water supply if water saving technologies were introduced.

6.2 Overall water use efficiency (WUE) and field level water use

A high level of water use, 16-18 thousand m^3 ha^{-1}, and low water use efficiency in flood and furrow irrigation, are argued as the main sources of ecological degradation in the region (e.g. ZEF, 2003; Saifulin *et al.*, 1999). Improving water application efficiency at the field level is thus considered as one of the main mechanisms for improving environmental conditions in the region. To this end, several scenarios were tested within the framework of the study to analyze the effects of improving WUE. Overall WUE in the WUA, estimated by dividing crop beneficial water use by total irrigation water flow into the WUA, was equal to 65.2 % in the baseline scenario. The WUE was higher than presented by Conrad (2006) for the whole region, where WUE (the depleted fraction) was equal to 48% when the entire vegetation period was considered. Discrepancy between the numbers might therefore be explained by the difference in the time period for the estimation of the WUE—in this model only the first planning period is included.[15] Once farms have satisfied the state order (i.e. in the second half of the planting period), there is evidence of increased water demand for crops such as rice and vegetables in most areas (Veldwisch, 2008). Therefore, overall WUE would be lower than 65.2 percent in the second half of the vegetation period, and would thus fall in the same range with the findings of Conrad (2006). Data limitations did not allow for calibration and validation of the model for the second half of the vegetation period; therefore, discussion is limited only to the first part of the vegetation period. However, the influence of certain policies on CE, expected income and other model parameters in the second half of the vegetation period is assumed to be in the same direction as observed in the first part of the vegetation period.

The highest overall WUE of 74.4 % was obtained in Scenario 2, when farmers secured their income in order to cope with the risk caused from water supply uncertainty. The

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[15] due to model simulation only for the first planting season

results from this scenario are inline with the theory that efficiency increases as resource availability declines.

The WUE was higher than the baseline in Scenario 3, when a water price of 11.5 UZS m^3 was introduced under the state order system. It can be assumed that introducing a water price will impact on the crop allocation and, in turn, on environmental conditions (FAO, 1997b), thereby increasing the financial ability of water management organizations (Azevedo and Baltar, 2005). With greater financial capital, water management organizations would have more opportunities to invest in irrigation O&M, as existing infrastructure is deteriorating and contributing to worsening ecological conditions in Uzbekistan (Bucknall *et. al.*, 2008).

Higher WUE was obtained by reducing water application for rice and shifting the area to less water intensive crops. However, the results demonstrated that WUE at the WUA level could be increased when the price for water is several times higher than the presently anticipated price of 2.3 UZS m^3 water. Sensitivity analysis showed that a water price of 11.5 UZS m^3, which is 5-7 times higher than the present operation and maintenance costs of the irrigation and drainage network, may lead to greater water saving behavior. Farmers may be adversely affected only when water prices are several times higher than the currently discussed prices. These results are very much in line with others in different countries of the world (e.g. Molle and Berkoff, 2001; Perry, 1996). However, the likelihood of income losses resulting from the introduction of a price for water makes this mechanism unattractive as a policy tool for improving ecological conditions under the existing state order system; such isolated mechanisms designed to improve the ecological situation in the region may instead lead to higher rates of poverty (Saifulin *et al.*, 1999).

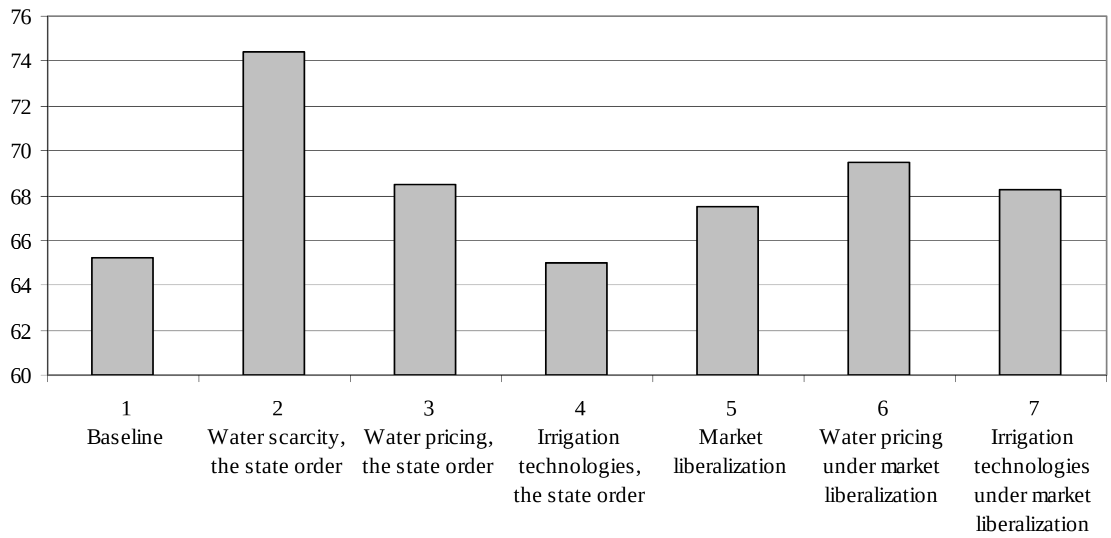

Figure 6.4: Overall WUE in the WUA in different scenarios

In Scenario 4, water saving technologies were introduced under the state order system and the overall WUE in the WUA was almost the same as in the baseline (Figure 6.5). One would expect an increase in the overall WUA when water saving technologies were used by farmers.

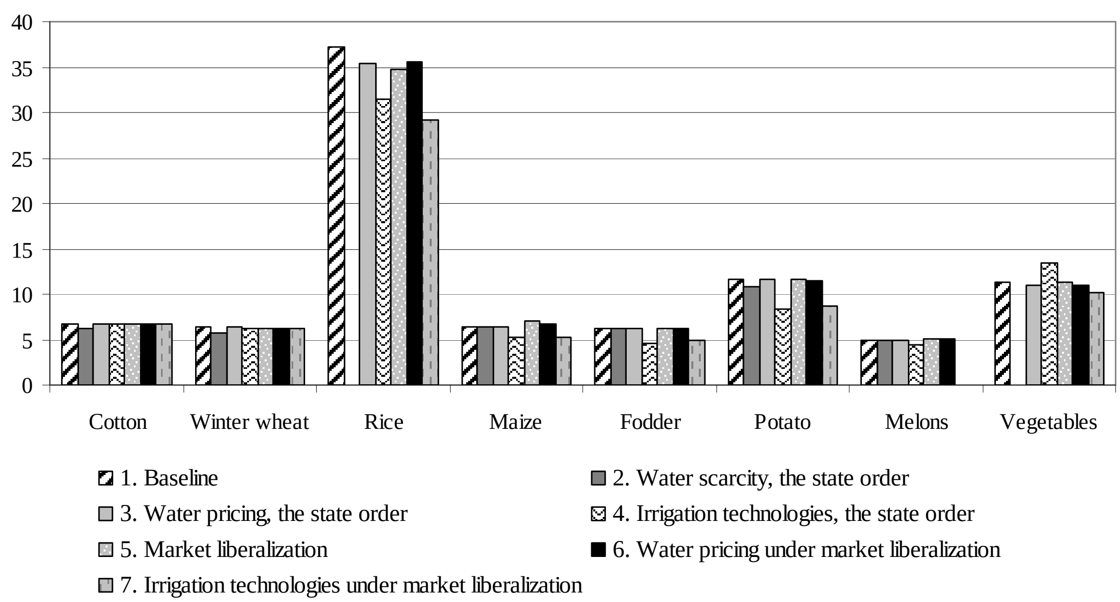

Figure 6.5: Field level water use in different scenarios, thousand m^3 ha^{-1}

However, model results did not support this assumption and overall WUE in the WUA was in the same range as in the baseline scenario. Adoption of water saving technologies only in the limited area did not create environmental improvement in the WUA.

Slight improvement in WUE was observed in Scenario 5, when the state order system was relaxed. WUE increased by around 2% compared to the baseline scenario. Although the long-term benefits from crop diversification could not be considered with the static nature of the model, the results show that some environmental improvement could be achieved shown by positive change of WUE. However, only 2% increase of the WUE might not guaranty sustainable development and further measures such as water pricing might be required in order to increase water saving incentives.

In Scenario 6, where a price for water was introduced under market liberalization (equal to 17.5 UZS m^3), overall WUE increased compared to the baseline from 65.2 to 69.5%. The observed increase in this scenario is due primarily to a shift in the cropping patterns; the area sown to water intensive crops decreased as low water demand crops increased. Similarly, there was a decline in water used for rice in the WUA as farmers moved away from this crop. Under the removal of the state order, combined with the introduction of a suitable water price, the total farm based income of the WUA would remain several times higher than the base scenario as described in the Section 6.1. Therefore, contrary to Scenario 3, the introduction of water pricing could be a feasible option under liberalized market conditions to both improve farmer income and ecological conditions in the region.

Overall WUE was 68.3% in Scenario 7, when water saving technologies were introduced under market liberalization conditions. Water use at the field level was decreased compared to the baseline Scenario (Figure 6.4), and thus could give some increase in overall WUE.

The lowest level of water use at the field level was obtained when water saving technologies were introduced. However, a decline in the water application levels did not lead to an increase in overall WUE under the existence of the state order system. The expected ecological improvement in these scenarios was not realized. However, some positive change was observed with the introduction of water saving technologies under a free market economy. These findings, therefore, reflect the complexity of water use efficiency and ecological conditions at different policy conditions. Contrary to what others have reported (e.g. Saifulin *et al.*, 1999), an increase in WUE at the farm level will not always lead to an increase in WUE at the system level.

6.3 Crop allocation

The share of different crops in the WUA in the baseline Scenario is very similar to the share of crops at the regional level (discussed in Chapter 2). Only the share of rice in the WUA is lower than the share of rice in the region. This is mainly explained by location of this WUA in the tale end of the system (Conrad, 2006), and the lower water availability compared to the regional average.

Crops with the lowest water demand, such as maize for grain fodder and melons, became the most suitable alternatives under increased water shortages, as simulated in Scenario 2. Crops demanding less water become more valuable if farmers want to have more secure income under an uncertain water supply. The main tradeoff exists between planting rice and other alternative crops such as maize for grain, melon and fodder crops under different water availability conditions.

Table 6.1: WUA level crop allocation under different scenarios, ha

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
	Baseline	**Water scarcity, the state order**	**Water pricing, the state order**	**Irrigation technologies, the state order**	**Market liberalization**	**Water pricing under market liberalization**	**Irrigation technologies under market liberalization**
Cotton	687.1	687.1	687.1	687	217.6	223.6	209.5
Winter Wheat	233.1	233.1	233.1	233.1	65.2	39.6	74.1
Rice	26.1	-	12.7	35.5	14.2	4.7	57.2
Maize	45.2	86.6	106.8	8.9	53.9	103.8	3.4
Fodder	140	181.4	115.8	78.6	662.8	691.2	386.5
Potato	85.9	16	55.3	180.7	187.1	141.2	485.2
Melons	3.9	22.6	3.1	0.13	6.4	8.3	
Vegetables	5.6	-	12.9	2.7	17.6	12.2	8.4

Table 6.1 shows the area under alternative crops (e.g. maize, fodder) increased at the expense of high water demanding crops, such as rice and vegetables, when water availability in the system declines.

The recurrently predicted water shortages (Müller, 2006; Duhovniy and Sorokin, 2007) will definitely increase risk to farm income in the Khorezm region. At present, farmers do not have many options for coping with risk related to the water supply due to limited capital and, therefore, access to alternative technologies. Model results revealed that crop selection is the main coping strategy for dealing with uncertainty related to irrigation water supply. A similar trend was observed in Müller (2006), where the area of rice in the region changed depending on the amount of available water from the Amu Darya River.

Similar results were observed in Scenario 3 with the introduction of water pricing under state order conditions. High water intensive crops became less attractive when farmers had to pay 11.5 UZS m^3 for water. The discussions are inline with the findings of Djanibekov (2008), where the area of fodder crops increased at the expense of area sown to rice when water pricing is introduced in the sector model.

In contrast, the area of high water demand crops, such as rice and potatoes, has increased when alternative irrigations technologies made available (Scenario 4). Increased water application efficiency reduced the water demand of all crops and, as a consequence, more water was available for high water demand crops. The results from this scenario provide further evidence that negative impacts of increased water use efficiency include the planting of water more intensive crops, and thus expected ecological improvement at the system level might not be achieved.

The area under fodder crops, maize and vegetables increased at the expense of cotton and winter wheat in Scenario 5, when the state order for cotton and winter wheat is relaxed. One would expect the area of rice to also increase but it declined due to the limited water supply. Farmers in the WUA preferred to allocate their crops with less water demand when they received more freedom in crop selection. The total area under water intensive crops decreased even more in Scenario 6, when 17.5 UZS m^3 was introduced under market liberalization conditions.

Farmers have a greater chance of increasing area sown to rice when water saving technologies were introduced under market liberalization conditions (Scenario 7). Similar to the Scenario 4, availability of water saving technologies reduced water demand of crops and increased the chance of planting more water intensive crops such as rice and vegetables.

Further analysis of spatial crop allocation has shown field location plays an important role in crop selection (see Figures 5.1 and 5.11). Moreover, being close to the main water distribution point is a distinct advantage for farmers under conditions of expected water shortages.

6.4 Technology adoption

Potential benefits from water saving technologies were analyzed in Scenarios 4 and 7. Scenario 4 analyzed the potential economic and ecological gains from alternative irrigation technologies under the current state order system, while Scenario 7 considers the technology adoption under liberalized market conditions.

The model results in Scenario 4 reveled that the relatively cheap water saving technologies, such as laser leveling, may become lucrative to farmers in the current situation. These can be seen from the cultivation of almost 300 hectares for laser leveling technology (Table 6.2). More expensive technologies, such as drip irrigation, are beyond the financial means of the average farmer under the existing state order conditions. However, the results in Scenario 7 showed that easing the state order could dramatically change this situation—in particular, farmers would be allowed to cultivate high value crops and hence would have a vested interest in water saving technologies.

These scenarios explain why the adoption of new irrigation methods is very slow in the region. Farmers have limited income due to allocating the highest share of their land to state order crops that are not profitable. Land for crops of higher value is, therefore, scarce. As a result, farmers' financial ability is limited and they are not able to invest in water saving technologies. Moreover, a credit system in the region in also underdeveloped. At present, farmers can take credit from banks in the region only under the condition that the money is spent to purchase inputs for state order crops (Rudenko, 2008). Taking credits for other crops is very difficult or interest rates are very high (Rudenko, 2008).

Table 6.2: Area under different technologies in Scenario 4 and Scenario 7

	Traditional		**Laser leveling**		**Drip irrigation**	
Crops	**Scenario 4 New technology, the state order**	**Scenario 7 New technology, market liberalization**	**Scenario 4 New technology, the state order**	**Scenario 7 New technology, market liberalization**	**Scenario 4 New technology, the state order**	**Scenario 7 New technology, market liberalization**
Cotton	687	209.5				
Winter wheat	233.1	74.1				
Rice			35.5	57.2		
Maize			8.9	3.4		
Fodder		2.3	78.6	216.7		167.5
Potato			174	78.6	6.7	406.6
Melons			0.13			
Vegetable			2.7	3.8		4.6
Total	920.1	285.9	299.83	359.7	6.7	578.7

Although the model allowed assessing economic and ecological benefits that could potentially be gained when water saving technologies are adopted, the necessary data and details of each water saving technology considered originated from research outcomes as found in neighboring regions and not particularly from the study region. Given that the agro-ecological conditions in these countries are very similar to those prevailing in the study region Khorezm, the use of the externally obtained information can be assumed to be reliable. However, the absence of reliable and accurate data from the study region means there is some level of uncertainty in the model results and, therefore, they must be interpreted with caution. Additional research in the study region is needed to allow for further validation of the model. Furthermore, it should be recognized that decisions by farmers to invest in water saving technologies will not be based on financial indicators alone; social barriers to adoption of such technologies have proven significant in other study regions (Drechsel *et al.*, 2005), and hence this aspect of adopting new technologies also requires further research in the region.

7 Summary and Conclusions

7.1 Introduction

Irrigated agriculture for cotton and wheat production forms the backbone of the rural economy in the Khorezm region. Ecological deterioration and inefficient resource use have resulted in and now present a significant threat to the livelihoods of those most dependent on this sector. Excessive and inefficient water use combined with significant losses during water transport and application have caused widespread degradation of the arable land. Inefficient water use has in turn led to rising ground water tables and widespread water and soil salinization has resulted. The high water demand in the region for crop production renders farmers vulnerable to the recurrently predicted decrease in water supply. The probability of obtaining sufficient irrigation water in the Khorezm region has decreased during the last decade; expected declines in water availability in the near future are the result of an increasing water demand in upstream regions, continuous extension of irrigated areas with high water demanding crops, and the unpredictable effects of climate change. Farmers in the Khorezm region are vulnerable to uncertain water supplies due similarly to current policies which restrict their decision making in terms of what type of crops to grow, when and where. Similarly, there are ever increasing risks in terms of yields and price fluctuations for agricultural producers due to natural conditions and fluctuations in the market.

Maintaining a profitable agricultural sector without sacrificing ecological health is a major challenge to farmers and water users associations in the region, as well as for regional and national water accounting and distribution structures. Worldwide, mathematical modelling has proven to be an effective instrument for increasing the overall understanding of the complexity of water demand and supply processes, while analysing resource-saving alternatives that are both economically and ecologically sustainable. In order to maximize the utility and applicability of such an approach, each model must incorporate local agro-ecological, social and economic conditions. To this end, a static, stochastic model for Khorezm has been developed to further our understanding of potential risk reducing strategies for farmers, while accounting for the ecological consequences potential policies.

7.2 Analytical framework

The Expected Mean-Variance (EV) approach, in combination with chance-constraint programming, was selected as the most suitable for handling the multiple sources of risk faced by the farming population in the study region. The core data used in the model were obtained from primary collection and secondary sources. This study is part of a larger Pilot Project in the region and a large data set was collected during the same period, thereby providing a comprehensive basis for the interdisciplinary approach to land and water allocation adopted in this study. To deal with the lack of information on and knowledge about field level water use and crop yields, water yield response models were developed using Monte Carlo simulations.

The developed model considered the optimization of water and land allocation of 300 fields, belonging to 99 farmers in one Water User Association (WUA). The availability of Geographical Information System (GIS) based data allowed the integration of spatial aspects into the model.

The model was calibrated using various Constant Relative Risk Aversion levels (CRRA). The CRRA is adjusted as the core parameter in the base run of the model and is set to match the observed activity level in the case study WUA. Following the calibration, various simulations were conducted to account for the impact of different policy scenarios, including the removal of governmental subsidies, decreasing the state order production for cotton and winter wheat, changes in probabilities of water supply, and the introduction of water conservation technologies. The combined outcomes of the simulations provided a basis for assessing potential effects of different policy measures given the dynamics of the on-going reform strategies in Uzbekistan. However, the model is not designed as a predictive tool; instead, the purpose is to aid in decision making by highlighting the effects of different policy tools on a range of factors. Therefore, the model output, such as overall WUE, certainty equivalent (CE), overall expected income and water prices, are not considered as forecasts, but should be used for understanding the direction of the influence of a proposed policy.

7.3 Results

Consideration of benefits from different policy and technology changes on farm as well as on system level is one of the main advantages of this model. The previous studies in the region considered the effect of different policy and technology changes on farm level and while using disciplinary approach. This study allowed analyzing the changes while taking into account inter relations between farms on land and water use while considering economic as well as ecological changes results from different policies.

Model results reveled that farmers gain highest utility under the scenarios with relaxed state order for cotton and winter wheat. Farmers had more flexibility in their farming decisions and adjusted their farming activities according to their comparative advantages in the local markets when the state order system was relaxed. More freedom in crop allocation increased the risk-coping strategy of farmers, which is argued to be very limited under the current political system. The highest CE and expected income were obtained with the introduction of water saving technologies under market liberalization conditions.

Highest WUE was observed when water availability in the WUE is expected to be lower, but decreased water availability brings more insecurity in the productions, especially to the farmers located in the tale end of the irrigation system. Results of the model simulation show that increasing WUE and obtaining environmental improvement in the region is very difficult under current state order system. Even with the introduction of water saving technologies under the state order system, farmers might not have the opportunity to adopt this technology due to scare land for high profitable crops. Relaxing the state order area might create some possibilities of increasing the WUE. Introducing water saving technologies under the condition of free market economy may create a more environmentally friendly production system which was not observed when water saving technology was introduced under the state order system. However, a 2-3% increase in WUE might not be considered enough in order to achieve sustainable development in the region and a water pricing instrument might be used in order to increase water saving incentives.

Increased WUE could be obtained with the introduction of water pricing. However, the introduction of water pricing under the existing state order system resulted in a sharp drop in expected income of the farmers and made them more vulnerable to poverty. The introduction of water pricing under anticipated market liberalization conditions showed to be the most favorable option as the drop in expected income was not as high as observed under the state order system.

Crop selection has shown to be one of the main risk coping strategies of farmers under the expectation of water scarcity. Crops with a relatively low water demand became very valuable when water scarcity was expected. Farmers increased their area under alternative crops such as maize, fodder and melons when water availability was expected to be lower than in the baseline scenario.

Scenarios with alternative irrigation methods demonstrated that indeed availability of water saving technologies will increase the income of agricultural producers, while increasing their risk coping strategies in water scarce years. However, there are financial limitations for technology adoption under the current state order system. Most of the area is occupied by low profitable state order crops and income of agricultural producers is very low. The adoption of expensive technologies, such as drip irrigation, is thus very limited. Under the existing state order conditions, cheaper technologies, such as laser leveling, are probable options for the region's farmers. Usage of other water saving technologies may become plausible once the state order system is relaxed.

7.4 Conclusions and policy implications

The use of a stochastic, mathematical model proved to be an effective instrument to analyze the potential impact of policy measures on sustainable development of the agricultural sector. All three pillars of sustainable development, including social welfare, ecological conditions and economic factors, were considered simultaneously in the model. The results from this study highlight certain policy measures that could both improve ecological conditions, while improving social and economic welfare in the region. Such "win-win" scenarios were found when the area sown to cotton and wheat were reduced. With the relaxation of the state order, crop diversification increased and income increased, allowing for farmers to invest in water saving technologies. Under conditions where farmers had greater decision making in terms of what crops to grow, higher incomes were obtained and, therefore, the introduction of a price for water became a plausible option for improving ecological conditions, without sacrificing socioeconomic welfare. Introduction of water pricing is not an option due to the financial constraints of agricultural producers under the existing state order system. The introduction of water saving technologies would not result in significant improvement since these technologies require a certain level of investment which is not currently an option for the farmers in the region; agricultural activities as they are currently practiced yield low income and this is insufficient to cover investment expenses in new, water-saving technologies.

Within the scope of this study, the practicalities of relaxing the state order and the barriers to such policy changes are not addressed. However, any level of reduction in the state order will increase the risk coping ability of the farmers when complete abolishment of the state order is not an option. Especially, such flexible state order policy could be much desired by farmers in years when the probability of receiving enough water is expected to be low than normal years.

Although the model was developed specifically for the Khorezm region, the results and conclusion drawn from the model simulations are applicable for other regions of Uzbekistan and other Central Asian Countries with similar agro-climatic, social and economic conditions.

7.5 Further research

The model designed within this study allows one to investigate the economic, social and ecological impacts from policy and technology options expected to be implemented in the near future in the Khorezm region. While the model served as an appropriate tool for exploring win-win options for economic and ecological improvement, some level of uncertainty in the model results remains due to existing data limitations.

Resource availability (e.g. water, labor) is a constraint in the model and is based on annual average availability of resources for the given farmers in the WUA. Higher frequency data would significantly improve the model specification. Moreover, the model does not include a cropping calendar in the land endowments of the farm and, therefore, considers only a single crop allocation period where inter-cropping or secondary cropping options are not incorporated.

An area requiring further attention is with respect to water saving technologies in the region. The results from this study point to an increased need for additional, comprehensive research on various water saving technologies in the Khorezm region; region-specific data on various water saving technologies would allow for improving the model parameters.

Due to the static nature of the model, it was not possible to include long term ecological effects of different policy measures and findings were limited to short term ecological benefits, shown by change in overall WUE in the WUA. Further data collection and calibration of the model for multiple years are necessary steps in order to understand the dynamic effects of different policy scenarios on ecological welfare in the region.

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8 Appendices

Appendix 1

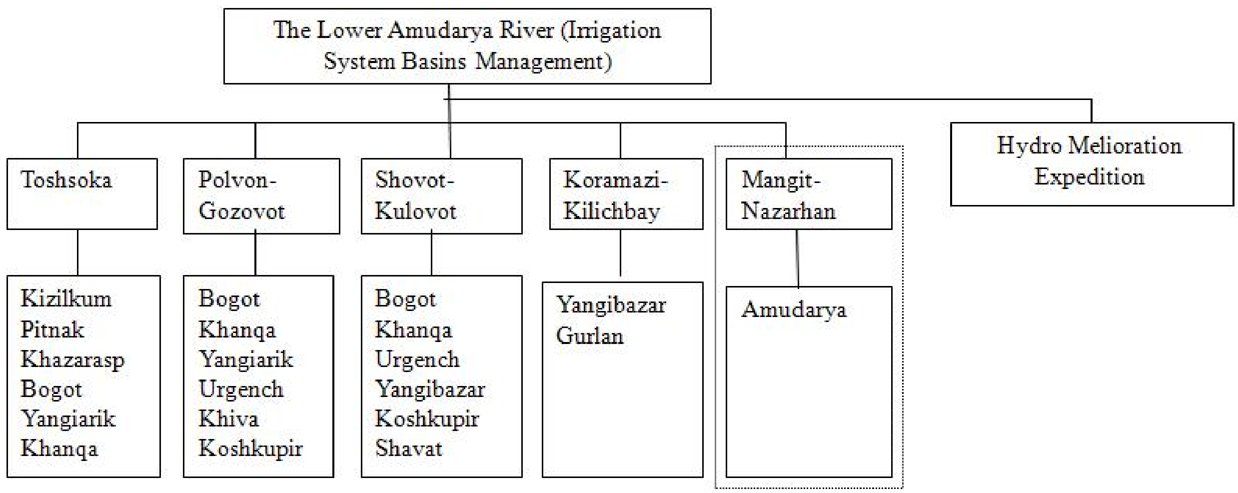

Figure 8.1: Lower Amudarya River Basin management

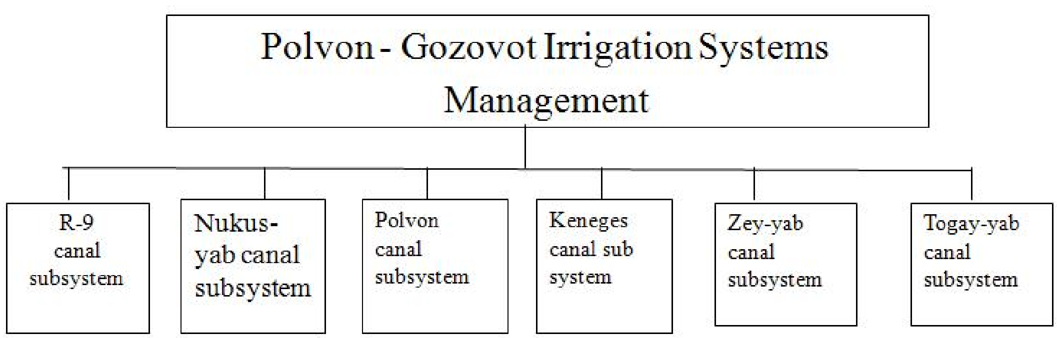

Figure 8.2: UIS irrigation management, Polvon-Gozovot

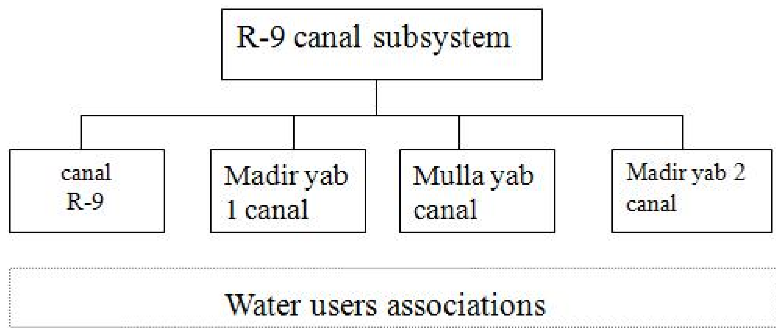

Figure 8.3: Canal management structure, R-9

Source: MAWR, 2006; Palvon – Gozovot Irrigation System Management, 2006

Appendix 2

Table 8.1: Average fertilizer delivered to cotton and winter wheat, kg ha^{-1}

	N	P_2O_5	K_2O
2002	377.3	73.8	3.5
2003	322.1	70.4	3.1
2004	196.5	31.0	7.5
2005	289.1	74.5	17.2

Source: OblHimiya 2005, FDA 2006, own estimations

Appendix 3

Water application losses, field level water use efficiency

Table 8.2: Water use efficiency in different *hydromodule* zones, laser levelling

	ETc mm	Water demand, mm			Water use efficiency %		
		VII	VIII	IX	VII	VIII	IX
Cotton	799	512	392	424	100	100	100
Winter wheat	383	448	376	400	85	100	95
Rice	1050	2400	2800	3200	44	38	33
Maize for grain	704	496	368	392	100	100	100
Maize for fodder	700	496	368	392	100	100	100
Potato	625	840	672	768	74	93	81
Melons	619	360	280	304	100	100	100
Vegetables	619	840	672	768	73	92	80

Source: Humphreys et al., 2005; WUA, 2005; Conrad 2006; Tischbein 2007; own estimations

Table 8.3: Water use requirement in different hydromodule zones, drip irrigation

Crops	*Hydromodule* zones		
	VII	VIII	IX
Cotton	416	318.5	344.5
Winter wheat	364	305.5	325
Rice	1950	2275	2600
Maize	403	299	318.5
Fodder crops	403	299	318.5
Potato	682.5	546	624
Melons	292.5	227.5	247
Vegetables	682.5	546	624

Appendix 4

Conveyance efficiency

Table 8.4: Conveyance losses of different canals in Shamhulum WUA

Canal Hierarchy	Soil type	Length of canal	Conveyance losses
Interfarm canal	Light	120 m	negative
Interfarm canal	Heavy	7 km	2%
Farm channel	Light	1 km	6%
Farm channel	Moderate	1 km	3%
Farm channel	Moderate	1 km	4%
Field channel	Moderate	300 m	10 - 18 %

Source: Awan, 2007

The average weighted average according to the canal length was equal to 3% km^{-1}