81589

A WORLD BANK STUDY

Reducing the Vulnerability of Uzbekistan's Agricultural Systems to Climate Change

IMPACT ASSESSMENT AND ADAPTATION OPTIONS

William R. Sutton, Jitendra P. Srivastava,
James E. Neumann, Peter Droogers,
and Brent B. Boehlert

THE WORLD BANK

Reducing the Vulnerability of Uzbekistan's Agricultural Systems to Climate Change

A WORLD BANK STUDY

Reducing the Vulnerability of Uzbekistan's Agricultural Systems to Climate Change

Impact Assessment and Adaptation Options

William R. Sutton, Jitendra P. Srivastava, James E. Neumann,
Peter Droogers, and Brent B. Boehlert

THE WORLD BANK
Washington, D.C.

1 2 3 4   16 15 14 13

ISBN (paper): 978-1-4648-0000-9
ISBN (electronic): 978-1-4648-0001-6
DOI: 10.1596/978-1-4648-0000-9

Cover photo: © Matluba Mukhamedova / World Bank

Library of Congress Cataloging-in-Publication Data

Reducing the vulnerability of Uzbekistan's agricultural systems to climate change : impact assessment and adaptation options / William R. Sutton ... [et al.].
p. cm. — (World Bank studies)
Includes bibliographical references.
ISBN 978-1-4648-0000-9 (alk. paper) — ISBN 978-1-4648-0001-6
1. Crops and climate—Uzbekistan. 2. Climatic changes—Risk management—Uzbekistan. 3. Agriculture—Environmental aspects—Uzbekistan. 4. Agriculture and state—Uzbekistan. I. Sutton, William R., 1967- II. World Bank. III. Series: World Bank studies.
S600.64.U93R43 2013
632'.109587—dc23

2013022139

Contents

Preface		*xi*
Acknowledgments		*xiii*
About the Authors		*xv*
Abbreviations		*xvii*
Executive Summary		**1**
	Introduction	1
	Challenges and Opportunities for Uzbekistan's Agricultural Sector	3
	Vulnerability of Uzbekistan's Agriculture to Climate Change	4
	Stakeholder Consultations	11
	Menu of Adaptation Options	12
	Options for National Policy and Institutional Capacity Building	13
	Options for Specific AEZs	15
Chapter 1	**Current Conditions for Uzbek Agriculture and Climate**	**17**
	The Agricultural Sector in Uzbekistan	17
	Exposure of Uzbekistan's Agricultural Systems to Climate Change	21
	Uzbekistan's Current Adaptive Capacity	27
	A Framework for Evaluating Alternatives for Investments in Adaptation	32
	Structure of the Report	33
	Notes	34
Chapter 2	**Design and Methodology**	**35**
	Overview of Approach	35
	Climate Scenarios and Impact Assessment	37
	Development of Adaptation Menu	39
	Assessing Risks to Livestock	45

http://dx.doi.org/10.1596/978-1-4648-0000-9

	Uncertainty and Sensitivity Analysis	46
	Notes	46
Chapter 3	**Impacts of Climate Change on Agriculture in Uzbekistan**	**47**
	Climate Impacts on Crops and Horticulture	48
	Climate Impacts on Livestock	49
	Climate Impacts on Water Resources	51
	Effect of Irrigation Water Shortages on Crop Yields	58
	Notes	60
Chapter 4	**Identification of Adaptation Options for Managing Risk to Uzbekistan's Agricultural Systems**	**63**
	Options for Consideration	63
	Recommendations from Farmers	65
	Options Offered by the Team	72
	Greenhouse Gas Mitigation Potential of Adaptation Options	74
Chapter 5	**Cost-Benefit Analysis**	**79**
	Scope and Key Parameters	79
	Results of Quantitative Analyses: Cost-Benefit and Present Value Assessments	81
	Other Economic Analyses	88
	Sensitivity Analyses	92
	Analysis of Livestock Sector Adaptation	94
	Summary of Quantitative Results in AEZs	95
	Notes	98
Chapter 6	**Options to Improve Climate Resilience of Uzbekistan's Agriculture Sector**	**99**
	Options at the National Level	99
	Options at the AEZ Level	101
	Categorization of Short-, Medium-, and Long-Term Options	107
	Note	109
Glossary		*111*
Bibliography		*119*

Boxes

1.1	Developing a Range of Scenarios of Forecasted Climate for Uzbekistan	22
2.1	Impact Assessment Modeling Tools	41
4.1	Index-Based Insurance	74

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figures

ES.1 Estimated Effect of Climate Change on Mean Monthly Runoff, 2040s 9
ES.2 Adaptation Measures at the National Level 14
ES.3 Adaptation Measures for the Desert and Steppe AEZ 15
ES.4 Adaptation Measures for the Piedmont and Highlands AEZs 16
1.1 Average Area Harvested by Crop in Uzbekistan, 2006–08 19
1.2 Estimated Value of GDP for Selected Agricultural Products, 2008 21
1.3 Effect of Climate Change on Average Monthly Temperature for the Piedmont AEZ, 2040s 26
1.4 Effect of Climate Change on Average Monthly Precipitation for the Piedmont AEZ, 2040s 26
1.5 Wheat Yield in Some Selected Relevant Countries, Average 2007–09 31
1.6 Tomato Fresh Yield in Some Selected Relevant Countries, Average 2007–09 31
2.1 Flow of Major Study Action Steps 37
2.2 Analysis Steps in Action Step 3: Quantitative Modeling of Adaptation Options 40
3.1 Mean Monthly Irrigation Water Demand over All Uzbekistan Basins, 2040s 53
3.2 Annual Runoff for All Uzbekistan Basins, 2011–50 55
3.3 Mean Monthly Runoff for All Uzbekistan Basins, 2040s 55
3.4 Mean Unmet Monthly Irrigation Water Demand over All Uzbekistan Basins, 2040s 57
5.1 Estimated Crop Revenues per Hectare for the 2040–50 Decade before Adaptation Actions Are Taken 81
5.2 Benefit-Cost Analysis Results for Improved Drainage in the Eastern Portion of the Desert and Steppe AEZ—New Drainage Infrastructure 82
5.3 Benefit-Cost Analysis Results for Improved Drainage in the Eastern Portion of the Desert and Steppe AEZ—Rehabilitated Drainage Infrastructure 83
5.4 Benefit-Cost Analysis Results for New Irrigation Infrastructure in the Southwest Portion of the Piedmont AEZ 84
5.5 Benefit-Cost Analysis Results for Rehabilitated Irrigation Infrastructure in the Southwest Portion of the Piedmont AEZ 85
5.6 Benefit-Cost Analysis Results for Improved Water Use Efficiency in the Western Portion of the Desert and Steppe AEZ 86
5.7 Benefit-Cost Analysis Results for Optimizing Crop Varieties in the Eastern Portion of the Piedmont AEZ 88

http://dx.doi.org/10.1596/978-1-4648-0000-9

5.8 Benefit-Cost Analysis Results for Optimized Fertilizer Use in the Eastern Portion of the Piedmont AEZ 89
5.9 Impact of Improving Basin-Wide Irrigation Efficiency 91
5.10 Preliminary Analysis of the Benefits and Costs of Water Storage 93
5.11 Detailed Sensitivity Analyses: New Irrigation Infrastructure for Potatoes in the Highlands AEZ 95
5.12 Detailed Sensitivity Analyses: New Drainage Capacity for Irrigated Cotton in the Eastern Portion of the Piedmont AEZ 96
6.1 Adaptation Measures at the National Level Based on Team and National Conference Assessment 102
6.2 Adaptation Measures for the Desert and Steppe AEZ Based on Team and National Conference Assessment 105
6.3 Adaptation Measures for the Piedmont and Highlands AEZs Based on Team and National Conference Assessment 107

Maps

ES.1 Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios 6
ES.2 Effect of Climate Change on Precipitation through 2040s for the Three Climate Impact Scenarios 7
1.1 Agro-Ecological Zones in Uzbekistan 17
1.2 Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios 24
1.3 Effect of Climate Change on Precipitation through 2040s for the Three Climate Impact Scenarios 25
2.1 Agro-Ecological Zones in Uzbekistan 35
3.1 River Basins in Uzbekistan 51
3.2 Irrigated Areas in Uzbekistan 52

Tables

ES.1 Key Climate Hazards, Impacts, and Priority Adaptation Measures at the National and AEZ Levels 5
ES.2 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures 8
ES.3 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under High-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures 9
ES.4 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario 10

http://dx.doi.org/10.1596/978-1-4648-0000-9

ES.5 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields for Irrigated Crops, Including Effects of Reduced Water Availability 11
1.1 Value of Agricultural Products in Uzbekistan, 2008 19
1.2 Livestock Count and Area by Agro-Ecological Zone 20
2.1 Approach for Two Quantifiable Farm-Level Adaptation Options 43
3.1 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures 48
3.2 Effect of Climate Change on Crop Yields through 2040s across the Three Climate Scenarios 48
3.3 Irrigation Water Requirement Changes Relative to Current Situation to 2040s under the Three Climate Scenarios, for Each Crop and AEZ (Assuming No CO_2 Fertilization) 50
3.4 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario 57
3.5 FAO Crop Response Factors 59
3.6 Effect of Climate Change on Irrigated Crop Yields 2040–50 under the Three Impact Scenarios, Including Effects of Reduced Water Availability 60
4.1 Adaptation Options for Consideration 64
4.2 Farmers' Rankings of the Relevance of Eight Risks of Climate Change to Agriculture (1 to 5 Scale, with 5 Being Most Relevant) 67
4.3 Farmers' Ranking of Relevance of Climate Change Adaptation Options for Uzbekistan as a Whole and the Tashkent Region in Particular, December 2010 (1 to 5 Scale, with 5 Being Most Relevant) 67
4.4 Ranked AEZ- and National-Level Stakeholder Recommendations 70
4.5 Greenhouse Gas Mitigation Potential of Adaptation Options 75
5.1 Five Adaptation Measures with High Net Benefits: Piedmont AEZ 97
5.2 Five Adaptation Measures with High Net Benefits: Desert and Steppe AEZ 97
6.1 Adaptation Measures at the National Level Based on Team Assessment 101
6.2 Adaptation Measures for the Desert and Steppe AEZ 104
6.3 Adaptation Measures for the Piedmont and Highlands AEZs 106

http://dx.doi.org/10.1596/978-1-4648-0000-9

Preface

Changes in climate and their impacts on agricultural systems and rural economies are already evident throughout Europe and Central Asia (ECA). Adaptation measures now in use in Uzbekistan, largely piecemeal efforts, will be insufficient to prevent impacts on agricultural production over the coming decades. There is growing interest at country and development partner levels to have a better understanding of the exposure, sensitivities, and impacts of climate change at the farm level, and to develop and prioritize adaptation measures to mitigate the adverse consequences.

Beginning in 2009 the World Bank embarked on the Regional Program on Reducing Vulnerability to Climate Change in ECA Agricultural Systems for selected ECA client countries to enhance the ability of these countries to mainstream climate change adaptation into agricultural policies, programs, and investments. The multi-stage program has included activities to raise awareness of the threat of climate change, analyze potential impacts and adaptation responses, and build capacity among client country stakeholders and ECA Bank staff with respect to climate change and the agricultural sector. This report is the culmination of efforts by the World Bank, by institutions and researchers in Uzbekistan, and by a team of international experts headed by the consulting firm Industrial Economics, Inc. (IEc) to jointly undertake an analytical study, *Reducing the Vulnerability of Uzbekistan's Agricultural Systems to Climate Change.*

The approach of this volume is predicated on strong country ownership and participation, and is defined by its emphasis on "win-win" or "no regrets" solutions to the multiple challenges posed by climate change for the farmers of Eastern Europe and Central Asia. The solutions are measures that increase resilience to future climate change, boost current productivity despite the greater climate variability already occurring, and limit greenhouse gas emissions—also known as "climate-smart agriculture."

Specifically, this report provides a menu of practical climate change adaptation options for the agriculture and water resources sectors, along with specific recommendations, which are tailored to three distinct agro-ecological zones (AEZs) within Uzbekistan, as well as over-arching actions at the national level. This menu reflects the results of three inter-related activities, conducted jointly by the team and local partners: (1) quantitative economic modeling of baseline conditions and the effects of climate change and an array of adaptation options;

(2) qualitative analysis conducted by the team of agronomists, crop modelers, and water resource experts; and (3) input from a series of participatory workshops for national decision makers and farmers in each of the AEZs. This report provides a summary of the methods, data, results, and adaptation options for each of these activities.

This study is part of the World Bank's Europe and Central Asia (ECA) Regional Analytical and Advisory Activities (AAA) Program on Reducing Vulnerability to Climate Change in ECA Agricultural Systems. Uzbekistan is one of four countries to participate in the program, with the other country participants being Albania, Moldova, and the former Yugoslav Republic of Macedonia. A book, *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*, covering all four countries was published in April 2013 (the book can be found at http://dx.doi.org/10.1596/978-0-8213-9768-8). The book also contains a technical appendix with details on the methodologies applied.

Acknowledgments

This book was written by a team led by William R. Sutton when he was in the Sustainable Development Department in the Europe and Central Asia Region of the World Bank, together with Jitendra P. Srivastava, and in collaboration with a team from Industrial Economics, Inc. (IEc) comprising James E. Neumann, Peter Droogers, and Brent B. Boehlert. We are grateful to Dina Umali-Deininger, Sector Manager, Agriculture and Rural Development, Sustainable Development Department, Europe and Central Asia Region, for the valuable support and guidance, and to Ron Hoffer (ECSSD) for his constructive suggestions. We would like to thank the Country Director, Central Asia Country Unit, and the Country Manager for Uzbekistan for their support in furthering the agenda on climate change and agriculture.

Members of the IEc team also include Kenneth M. Strzępek, Ana Iglesias, Samuel Fankhauser, Andrew Schwarz, Richard Adams, Johannes Hunink, Richard Swanson, Dr. Rasalmat Khusanov, and Dr. Akmal Akramkhanov. The World Bank team also comprised Ana Bucher, Åsa Giertz, Gretel Gambarelli, Dilshod Khidirov, Sunanda Kishore, Brendan Lynch, John Mackedon, Oydin Dyusebaeva, and Leigh Hammill.

From the government of Uzbekistan, we are grateful for policy guidance and support provided by the Minister of Agriculture and Water Resources and by the Minister of Economy, State Committee on Nature Protection, to the study steering committee, co-chaired by Mohammed Kosimov, Assistant to the Deputy Minister of Agriculture and Water Resources, and Mr. Rustam Ibragimov, Head of the International Department, without whom this study would not have been possible. Other members of the steering committee included representatives from the Ministry of Agriculture and Water Resources, Ministry of Economy, State Committee on Nature Protection, Uzhydromet, the Scientific Center of Ministry of Agriculture and Water Resources, the Dekhan and Farmers' Association, and Design and Research Uzgipromeliovodkhoz Institute of the Ministry of Agriculture and Water Resources (UzGIP). The study greatly benefitted from the important contributions made through valuable inputs, comments, advice, and support provided by academia, civil society and NGOs, farmers, the donor community, and development partners in Uzbekistan throughout this program.

We gratefully acknowledge the Bank-Netherlands Partnership Program (BNPP) and the Trust Fund for Environmentally and Socially Sustainable Development (TFESSD) for providing funding for the program.

http://dx.doi.org/10.1596/978-1-4648-0000-9

About the Authors

William R. Sutton, Lead Economist and Cluster Coordinator for Agriculture, Rural Development, and Environment in the World Bank's Independent Evaluation Group, was formerly Senior Agricultural Economist in the World Bank's Europe and Central Asia Region. He has worked for more than 20 years to promote the integration of agriculture, environment, and climate change around the globe, including efforts in Sub-Saharan Africa, East Asia, and the Middle East and North Africa. He led the team that won the World Bank Green Award for work on climate change and agriculture in 2011. He holds a PhD in agricultural and resource economics from the University of California, Davis.

Jitendra P. Srivastava, former Lead Agriculturist at the World Bank, is globally recognized for his contributions in the fields of agricultural research, education, agri-environmental issues, and the seeds sector. Prior to working at the World Bank, he served in leadership and technical roles at the International Center for Agricultural Research in the Dry Areas (ICARDA), the Ford Foundation, and the Rockefeller Foundation, and was professor of genetics and plant breeding at Pantnagar University, India, where he received the first Borlaug Award for his contribution to the Indian Green Revolution. He holds a PhD from the University of Saskatchewan, Canada, in plant genetics.

James E. Neumann is Principal and Environmental Economist at Industrial Economics, Incorporated (IEc), a Cambridge, Massachusetts-based consulting firm that specializes in the economic analysis of environmental policies. Mr. Neumann is the coeditor with Robert Mendelsohn of *The Impact of Climate Change on the United States Economy*, an integrated analysis of economic welfare impacts in multiple economic sectors, including agriculture, water resources, and forestry. He specializes in the economics of adaptation to climate change and was recently named a lead author for the Intergovernmental Panel on Climate Change (IPCC) Working Group II chapter on the "Economics of Adaptation."

Peter Droogers is Scientific Director for FutureWater, an international research and consulting organization that combines scientific research with practical solutions for water management, headquartered in the Netherlands. He is a globally recognized expert in agricultural water productivity and water management, has published more than 30 peer-reviewed papers and book chapters on these topics, and consults on three continents.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Brent B. Boehlert is Senior Associate at Industrial Economics, Incorporated, an international consultancy based in Cambridge, Massachusetts. He is trained as an agricultural economist and water resources engineer, and is an expert on climate change impact and adaptation assessment, with a particular focus in the water and agriculture sectors. His recent published research includes estimation of the economic costs of adapting to climate change, the impact of climate change on global agricultural water availability with implications for food security, effects of climate change on drought risk, and forecasts of hydroindicators for climate change impacts on thousands of global water basins.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Abbreviations

AAA	Analytical and Advisory Activities Program
AEZ	agro-ecological zone
ATTC	Agriculture Technology Transfer Centers
B-C ratio	benefit-cost ratio
CMI	Climate Moisture Index
ECA	Europe and Central Asia
FAO	Food and Agriculture Organization of the United Nations
GCM	global circulation model
GDP	gross domestic product
GIS	Global Information Systems
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
LAP	Land Administration and Protection
MAWR	Ministry of Agriculture and Water Resources
NPV	net present value
O&M	operations and maintenance
R&D	research and development
SEI	Stockholm Environment Institute
SPAM	Spatial Production Allocation Model
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WEAP	Water Evaluation and Planning System

http://dx.doi.org/10.1596/978-1-4648-0000-9

Executive Summary

Introduction

Agricultural production is inextricably tied to climate, making agriculture one of the most climate-sensitive of all economic sectors. In countries such as Uzbekistan, the risks of climate change for the agricultural sector are a particularly immediate and important problem because the majority of the rural population depends either directly or indirectly on agriculture for their livelihoods. The rural poor will be disproportionately affected because of their greater dependence on agriculture, their relatively lower ability to adapt, and the high share of income they spend on food. Climate impacts could therefore undermine progress that has been made in poverty reduction and adversely impact food security and economic growth in vulnerable rural areas.

Recent trends in water availability and the presence of drought in Uzbekistan have underscored these risks, as has the presence of agricultural pests that may not have previously been found in Uzbekistan. Although drought and pest introductions cannot always be directly tied to climate change, an increase in extreme temperature and rainfall events is consistent with the best-known science of the impacts of climate change, and pests are also known to migrate as temperatures change.

The need to adapt to climate change in all sectors is on the agenda of national governments and development partners. International efforts to limit greenhouse gases and to mitigate climate change now and in the future will not be sufficient to prevent the harmful effects of temperature increases, changes in precipitation, and the increased frequency and severity of extreme weather events.

At the same time, climate change can also create opportunities, particularly in the agricultural sector. Increased temperatures can lengthen growing seasons, higher carbon dioxide (CO_2) concentrations can enhance plant growth, and in some areas rainfall and the availability of water resources can increase as a result of climate change.

The risks of climate change cannot be effectively dealt with, and the opportunities cannot be effectively exploited, without a clear plan for aligning agricultural policies with climate change, for developing key agricultural institution capabilities, and for making needed infrastructure and on-farm investments. Developing such a plan ideally involves a combination of high-quality quantitative analysis and consultation of key stakeholders, particularly farmers, as well as in-country agricultural experts.

In order to be effective, plans for adapting the sector to climate change must strengthen both human capital and physical capital in their capacity. Many of these investments would also yield instant returns in terms of increased agricultural productivity. However, the capacity to adapt to climatic changes, both in mitigating risks and in taking advantage of the opportunities that climate change can create, is in part dependent on financial resources. Adaptive capacity is therefore particularly low among small-holder farmers with limited access to financial resources. As a result, development partners will continue to have an important role in enhancing the adaptive capacity of the Uzbekistan agriculture sector.

In response to these challenges, the World Bank and the government of Uzbekistan embarked on a joint study to identify and prioritize options for climate change adaptation of the agricultural sector.

The approach for this study was centered on four objectives:

- Raising awareness of the threat of climate change
- Analyzing potential impacts on the agricultural sector and assessing adaptive capacity
- Identifying practical adaptation responses and the potential for greenhouse gas emission reductions
- Building capacity among national and local stakeholders to assess the impacts of climate change and to develop adaptation measures in the agricultural sector, defined to encompass crop (including cereals, vegetables, fruits, and forage) and livestock production.

The first phase of this work involved raising awareness of the threats and opportunities presented by climate change, beginning with a national Awareness Raising and Consultation Workshop. The second phase of the study involved quantitative and qualitative analysis of climate impacts and adaptation and mitigation options, a capacity-building workshop, and consultations with Uzbek farmers and experts. The analysis was conducted to provide results that are specific to three agro-ecological zones (AEZs) and five major river basins of Uzbekistan, to key crops important to the Uzbekistan agricultural economy, and across a range of future climate change scenarios.

The third phase of the study was to develop a plan for the Uzbekistan agricultural sector to be more resilient to current and anticipated changes in climate, while also contributing to greenhouse gas emission reductions. The methods used here include: benefit-cost analysis, where data are available; qualitative analysis by a team that visited the country; and, consultations with Uzbek farmers to evaluate the impacts of climate change and the needs for better adapting to it. A previous draft of this report was discussed in detail at the National Dissemination and Consensus Building Conference organized in Tashkent, Uzbekistan, at which participants reached an overall consensus on a set of recommended adaptation options for adoption.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Challenges and Opportunities for Uzbekistan's Agricultural Sector

The study revealed a number of challenges and opportunities for Uzbekistan's agricultural sector under projected climate changes:

- *Temperature will increase and precipitation will become more variable in Uzbekistan as a result of climate change.* These findings are consistent with recent changes in climate in Uzbekistan, particularly the significant decline in precipitation noted by farmers since 2008, and will persist and grow more severe over the next few decades.
- *The direct temperature and precipitation effect of future climate change on irrigated crops will be a reduction in yields for most crops but an increase in yields for grasslands and alfalfa*. Under the medium-impact climate change scenario, the direct effect will be a reduction in yields of irrigated crops, including cotton, wheat, apples, tomatoes, and potatoes by about 1–13 percent by 2050 across all AEZs. At the same time, climate change can improve yields of grasslands in all AEZs by 12–43 percent by 2050, and also improve yields for alfalfa in most AEZs provided that sufficient irrigation water is available.
- *Water shortages could severely limit irrigation water availability*. When effects of water shortages are taken into account, climate change has a much greater negative effect on almost all crops, in almost all river basins, with reductions of 10–25 percent in yields through 2050.
- *Farmers in Uzbekistan are not adequately adapted to current climate, particularly regarding efficient use of irrigation water.* This effect is sometimes called the "adaptation deficit," which in Uzbekistan can be substantial for many high-value crops, such as tomatoes. As a result, many of the climate adaptation measures identified in this report can have immediate benefits in improving yields, as well as bolstering resiliency to future, more severe climate change.
- *Although precipitation is on average likely to increase in Uzbekistan, climate change will worsen current competition over water resources because irrigation water demands will increase with higher temperatures.* AEZ- and river basin-specific water modeling suggests that, even without climate change, increases in non-agricultural demands for water will cause shortages in the next decades; this confirms the findings of Uzbekistan's Second National Communication to the UNFCCC. With climate change, certain areas, particularly basins in the western part of the country, will face severe water shortages.
- *Direct effects of climate change could be negative for the livestock sector, particularly beef cattle, chickens, and even sheep.* While methods to reliably quantify the effects from climate change on the livestock sector are not currently available for application to Uzbekistan, it can be expected that the temperature stress effects on livestock will be gradual. Farmers also confirm that they have not seen an immediate effect of climate on their livestock production. The indirect effect of climate change on livestock is likely to be positive, as climate change is projected to improve grassland and alfalfa productivity.

http://dx.doi.org/10.1596/978-1-4648-0000-9

- *National-level adaptation and capacity building is a high priority, and many measures are "win-win" in nature.* While mitigating negative climate change impacts is a long-term process, there are several measures that could be undertaken immediately to strengthen the sector's adaptive capacity. These include expanding extension service capacity, encouraging consolidation of private dekhan farmland into larger holdings to facilitate more substantial investments in on-farm technology (particularly more efficient irrigation), and encouraging private sector efforts to adapt to climate change, especially by allowing more flexibility in crop choice. Institutional capacity improvements should focus on identifying seeds for drought- resistant varieties and temperature-tolerant livestock breeds on the current international market for adoption in Uzbekistan, as well as training farmers in more efficient use of water. Uzbek farmers identified these measures during consultation meetings, and economic analysis also indicates that they have high benefit-cost ratios. This means that they are "win-win" in nature, and that they have positive economic returns also under current climate conditions while supporting the sector in adapting to climate change.
- *At the AEZ and farm levels, high-priority adaptation measures include optimizing water application efficiency, particularly for vegetable crops, and providing more climate-tolerant and pest-resistant seed varieties and the know-how to cultivate them effectively for high yield.* Other measures with high benefit-cost ratios include improving drainage capacity, rehabilitating secondary irrigation capacity, and optimizing fertilizer application. Improving drainage capacity is the most effective method to address issues associated with increasing salinization of soils. All of these measures also have high benefit-cost ratios and are favored by Uzbek farmers.

Table ES.1 provides a summary of the key findings, including the climate change impacts (incorporating assessments of sensitivity, adaptive capacity, and vulnerability), climate hazards that cause those impacts, and the priority adaptation options to address the impacts at both the national and AEZ levels.

Vulnerability of Uzbekistan's Agriculture to Climate Change

Analysis of recent climate data and information gathered from farmer workshops both support an increasing trend in temperature in Uzbekistan. Farmers have also observed an increasing trend in extreme heat events. The analysis indicates this trend will accelerate in Uzbekistan in the near future, as shown in map ES.1. Although uncertainty remains regarding the degree of warming that will occur, the climate is already changing and the overall warming trend is clear and is evident in all AEZs. Over the next four decades, the average increase in temperature will be about 2–3°C. This can be compared with the increase of about 1.5°C observed over the last 50 years.

Precipitation changes are more uncertain than temperature changes, as indicated in map ES.2. The medium-impact forecast indicates an increase in precipitation nationally of between 40 and 50 millimeters in the Desert and Steppe and

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table ES.1 Key Climate Hazards, Impacts, and Priority Adaptation Measures at the National and AEZ Levels

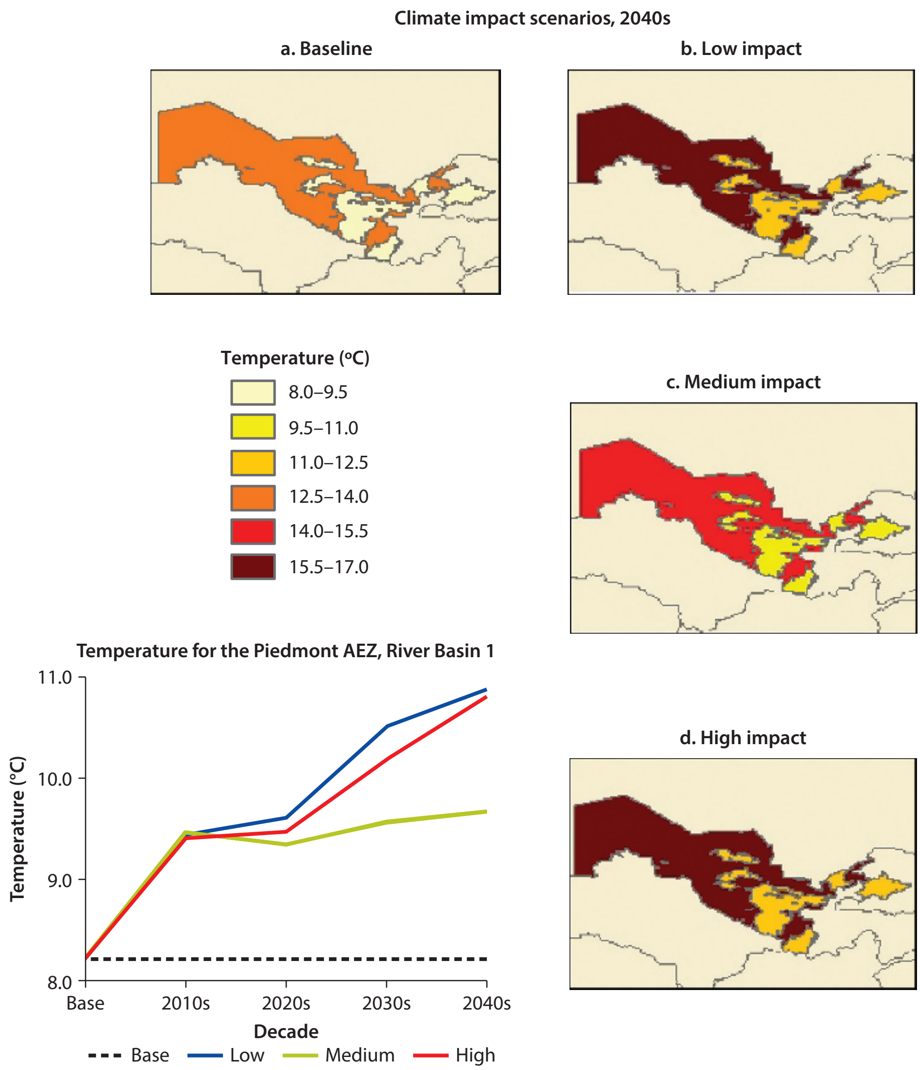
		Adaptation measure to address impact								
		National level			*AEZ level*					
Climate change impact	*Cause of impact (climate hazard)*	*Improve farmer access to technologies and information*	*Improve crop insurance programs*	*Encourage private sector involvement in adaptation*	*Improve crop varieties*	*Improve irrigation efficiency*	*Improve irrigation infrastructure*	*Improve drainage*	*Optimize agronomic practices: fertilizer application and soil moisture conservation*	*Improve livestock management, nutrition, and health*
Rainfed and irrigated crop yield reductions	Higher temperatures	✓		✓	✓			✓	✓	
	Increased pests and diseases	✓		✓	✓			✓		
Rainfed crop yield reductions	Lower and/or more variable precipitation	✓		✓	✓	✓	✓	✓	✓	
Irrigated crop yields reduction	Decreased river runoff and increased crop water demands	✓			✓	✓	✓	✓	✓	
Crop quality reductions	Change in growing season	✓		✓	✓		✓	✓	✓	
	Increased pests and diseases	✓		✓	✓			✓		
Livestock productivity declines	Higher temperatures (direct effect)	✓		✓						✓
	Reductions in forage crop yields (indirect effect)	✓		✓	✓		✓	✓	✓	✓
Crop damage occurs more frequently	More frequent and severe hail events	✓	✓							
	More frequent and severe drought events	✓	✓		✓		✓			
	More frequent and severe flood events	✓	✓					✓		
	More frequent and severe high summer temperature periods	✓	✓		✓		✓			

Piedmont zones, and a decrease of 10 millimeters in the Highlands zone. The range of outcomes across the low- and high-impact alternative scenarios, however, is considerable; in the Piedmont AEZ, by 2050, annual rainfall could be 50 millimeters less or 150 millimeters more than current precipitation.

The annual averages, however, are less important for agricultural production than the seasonal distribution of temperature and precipitation. The forecast temperature increases are higher, and precipitation declines are greater in July

http://dx.doi.org/10.1596/978-1-4648-0000-9

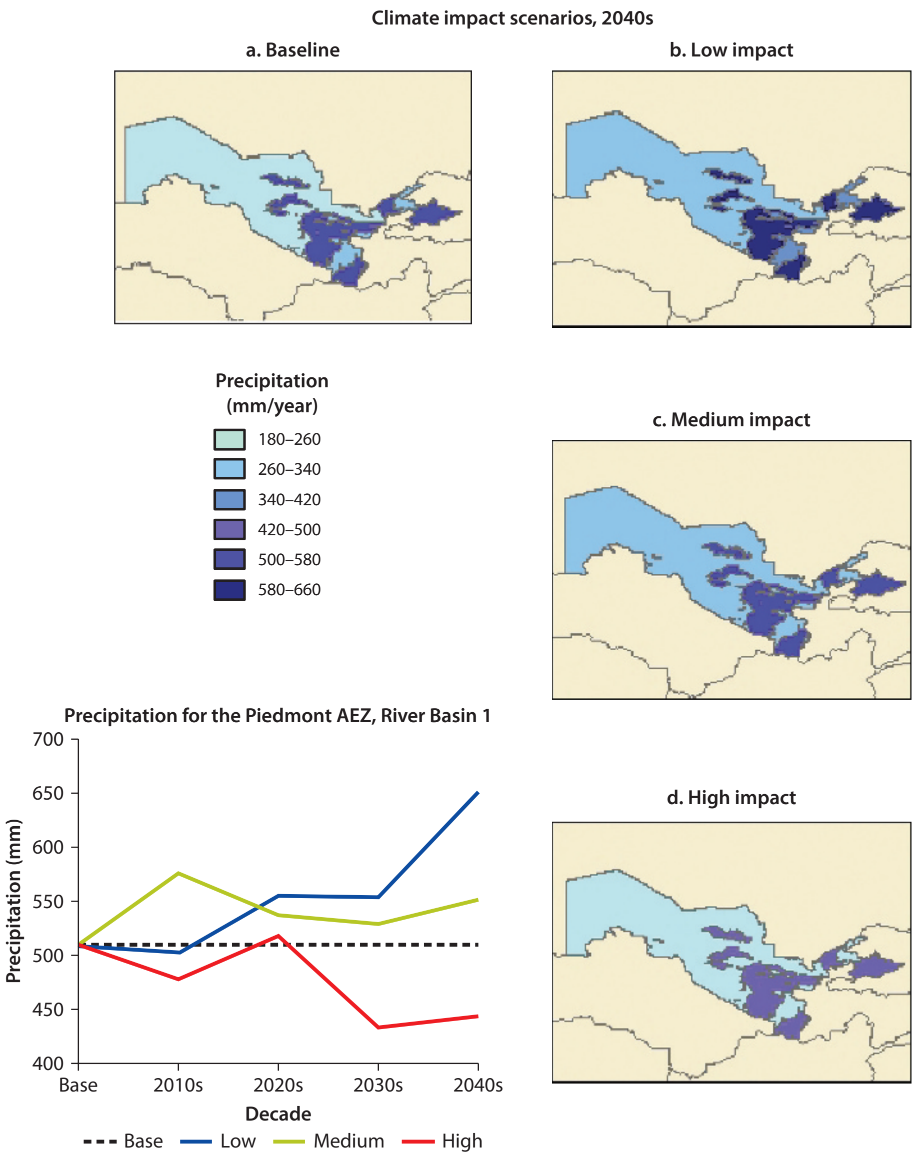
Map ES.1 Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios



and August relative to current conditions; the June-through-August temperature increase can be as much as 4–5°C in the Piedmont AEZ, for example. In addition, forecast precipitation declines could occur in the key June-through-August period in the Desert and Steppe AEZ, when precipitation is already lowest, even though the annual results suggest an overall increase in precipitation.

These seasonal changes in climate have clear implications for crop production if no adaptation measures are adopted beyond those that farmers already employ, such as changing planting dates in response to temperature changes. The results

Map ES.2 Effect of Climate Change on Precipitation through 2040s for the Three Climate Impact Scenarios



Sources: © Industrial Economics. Used with permission; reuse allowed via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0.

for climate change impacts on crops, assuming no adaptation is implemented, are summarized in table ES.2. The results show that yields of the key commodity crops that currently dominate Uzbekistan's agricultural sector (cotton and wheat) will decline for the medium impact scenario of future climate change in most AEZs, mainly as a result of heat and water stress. Wheat yields might increase in the eastern portion of the Piedmont AEZ.

Table ES.2 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures
% change

Irrigated/rainfed	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont East*	*Piedmont Southwest*
Irrigated	Alfalfa	3	2	3	22	1
	Apples	−8	−5	−9	−1	−8
	Cotton	−6	−5	0	−2	−6
	Potatoes	−6	−4	−7	2	−7
	Tomatoes	−5	−6	0	−1	−7
	Winter wheat	2	−2	−1	13	−4
	Spring wheat	−10	−5	−13	5	−12
Rainfed	Grassland	12	15	12	43	−1

Note: Results are average changes in crop yield, assuming no adaptation and no irrigation water constraints and no effect of carbon dioxide fertilization, under medium-impact scenario. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases.

Even assuming no shortage of irrigation water availability, yields of apples, potatoes, and tomatoes are forecast to decline about 1–9 percent under the medium climate change scenario. Grassland and alfalfa yields, on the other hand, are expected to show increased yields throughout Uzbekistan, with grassland yields increasing up to 43 percent, and alfalfa yields increasing 1–22 percent.

Some adaptation issues might arise around the relative viability of winter wheat—which could decline in some areas where a winter freeze is less frequent—and spring wheat, which has a wider growing area but requires more irrigation and provides a different quality of yield. Aggregate yield data for Uzbekistan are only available as an average for the two types, but in general, yields for spring wheat are about 10 percent lower, so a switch from winter to spring wheat would result in overall yield losses as well as an altered crop rotation.

Yields could be reduced much more severely, however, under the high-impact climate change scenario, which forecasts higher temperatures and lower precipitation and soil moisture in virtually all regions of Uzbekistan. Table ES.3 provides a summary of yield results for the high-impact scenario if no adaptation measures are taken, and illustrates that wheat and apples in particular could suffer large yield losses in all three AEZs.

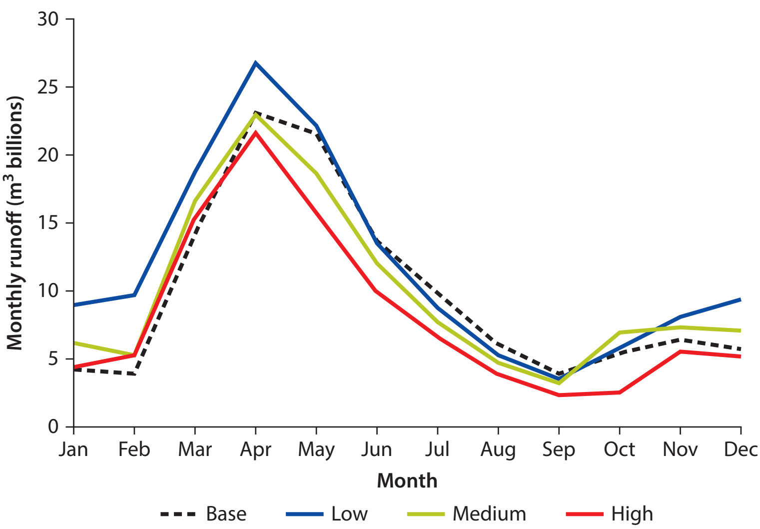
The water resource management implications of the high-impact scenario are similarly severe, because climate change both increases irrigation water demand and decreases overall water supply. This is especially critical given the relatively high share of irrigated agriculture in Uzbekistan and the very high share (93 percent) of freshwater withdrawal that is used for irrigation. Irrigation water demand during the summer months increases 25 percent in 2050 relative to historical conditions, and during the same months, overall water availability declines by an average of 30–40 percent by the decade of the 2040s, as illustrated in figure ES.1. The net effect of rising demands and falling supply is a significant

Table ES.3 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under High-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures
% change

Irrigated/rainfed	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont East*	*Piedmont Southwest*
Irrigated	Alfalfa	3	2	3	27	1
	Apples	−22	−14	−19	−24	−19
	Cotton	−10	−8	0	−9	−9
Rainfed	Grassland	10	−9	3	28	−5
	Potatoes	−10	−11	−13	−12	−11
	Tomatoes	−16	−12	0	−10	−15
	Winter wheat	−8	−5	−2	19	−19
	Spring wheat	−31	−16	−30	−12	−29

Note: Results are average changes in crop yield, assuming no adaptation and no irrigation water constraints and no effect of carbon dioxide fertilization, under high-impact scenario. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases.

Figure ES.1 Estimated Effect of Climate Change on Mean Monthly Runoff, 2040s



reduction in water available for irrigation, with severe water shortages occurring in the summer months in the decade of the 2040s under the high-impact scenario.

Together with an expected increase in water demand from the municipal and industrial sectors through economic expansion, the net effect of rising irrigation demands and falling water supply is a significant reduction in water available for irrigation. Once again, it is likely that these factors could result in water shortages within the next decade, but by the 2040s water shortages will be severe under all climate scenarios, especially under the high-impact scenario.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table ES.4 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario

	Climate scenario (shortfall in irrigation water, m^3 and percent of total irrigation demand)					
	Low impact 2040s		*Medium impact 2040s*		*High impact 2040s*	
Basin	*m^3 thousands*	*% shortfall*	*m^3 thousands*	*% shortfall*	*m^3 thousands*	*% shortfall*
Syr Darya East	615,927	11.6	940,601	17.5	3,627,991	51.6
Syr Darya West	122,023	1.9	325,942	4.7	2,817,031	34.4
Amu Darya	2,174,069	8.7	4,807,848	17.8	8,405,243	28.9
Aral Sea East	0	0	0	0	0	0
Aral Sea West	0	0	0	0	0	0
Subtotal	2,912,019	8.0	6,074,391	15.4	14,850,265	33.5

Water shortfalls for the irrigation sector are outlined in table ES.4—the estimates presented are the amounts and percentage shortfalls relative to total water amounts demanded in the basin for irrigation purposes. The most severe irrigation water shortages by the 2040s are forecast to occur in the Syr Darya East basin, an area where irrigation is prevalent and most agricultural production remains highly reliant on irrigation to maintain current yields. Shortages are also forecast for the Syr Darya West and Amu Darya basins, while no shortages are expected for the Aral Sea East and Aral Sea West basins.

Three climate change stressors therefore combine to yield an overall negative impact on crop yields throughout Uzbekistan:

1. The direct effect of temperature and precipitation changes on crops
2. The increased irrigation demand required to maintain even reduced yields
3. The decline in water supply associated with higher evaporation and lower rainfall.

All of these effects are worst during the summer growing season. The net effect of these three factors on irrigated agriculture is illustrated in table ES.5. As shown in the table, nearly all crops, in all AEZs and basins and across all scenarios, are negatively affected by climate change.

These are especially severe for crops like apples, tomatoes, potatoes, spring wheat, and cotton, with yield decreases of more than 20 percent under many scenarios. This could render production of the crops unviable without effective adaptation measures. The effects on alfalfa and grasslands are less severe, and potentially even positive in the case of grasslands.

The direct effects of climate change on livestock could also be severe, but the methods available for quantitatively assessing effects on livestock are relatively untested. There is a robust literature establishing that temperature increases

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table ES.5 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields for Irrigated Crops, Including Effects of Reduced Water Availability
% change

Scenario	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont East*	*Piedmont Southwest*
Low impact	Alfalfa	−2	−13	−12	24	−13
	Apples	−13	−23	−19	0	−20
	Cotton	−11	−19	−15	−3	−16
	Potatoes	−11	−22	−20	0	−19
	Tomatoes	−8	−21	−18	−2	−14
	Winter wheat	−1	−13	−14	19	−17
	Spring wheat	−9	−18	−18	5	−18
Medium impact	Alfalfa	−2	−16	−15	1	−17
	Apples	−12	−22	−25	−18	−25
	Cotton	−10	−20	−15	−17	−21
	Potatoes	−10	−21	−24	−16	−23
	Tomatoes	−9	−23	−18	−18	−24
	Winter wheat	−2	−20	−18	−7	−21
	Spring wheat	−14	−22	−28	−13	−28
High impact	Alfalfa	−33	−28	−27	−39	−28
	Apples	−49	−39	−43	−63	−42
	Cotton	−36	−31	−25	−49	−32
	Potatoes	−41	−37	−38	−57	−37
	Tomatoes	−45	−38	−29	−56	−40
	Winter wheat	−40	−32	−31	−42	−43
	Spring wheat	−55	−41	−50	−57	−49

Note: Results are average changes in crop yield, assuming no effect of carbon dioxide fertilization. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases.

decrease livestock productivity, but modeling tools are not available that are suitable for quantifying the effect in the Uzbekistan context. The indirect effect of climate change on livestock feed supplies, including grasslands and alfalfa, would be positive, and provides a potential counter-balance to the negative direct heat stress effects.

Stakeholder Consultations

Extensive stakeholder consultations with local government officials, farmers, and local experts conveyed several messages. These included:

- *Increase farmer know-how and skills through capacity building*: Capacity building was universally mentioned, especially as related to improving extension services to small farmers. Specific topics for capacity building included improving farmers' skills in countering the increased incidence of pests,

http://dx.doi.org/10.1596/978-1-4648-0000-9

especially for wheat and apples, improved training for the selection of pest-resistant and/or heat-stress-tolerant seed and crop varieties from both international and national sources, and providing information on improving on-farm water use efficiency.

- *Invest in on-farm irrigation infrastructure*: Although few specific suggestions were provided, drip irrigation was specifically mentioned as a high-priority adaptation response.
- *Improve the availability and affordability of crop insurance*: Farmers were specifically interested in insuring against drought and pest damages.
- *Improve water use efficiency*: The efficient use of water was foremost in the minds of farmers. Drip irrigation and sprinkler irrigation were most often mentioned. Water capture and storage techniques, such as small holding reservoirs were also suggested.
- *Increase access to seed variety and new information*: Farmers mentioned the need for better research and development regarding modern seed varieties, and increased availability of newly-developed seeds. When asked about farmer interaction with extension services, they said they had none.
- *Improve irrigation and drainage infrastructure*: Generally, these options focused on rehabilitating existing irrigation and drainage canals and installing more water conserving technologies such as drip irrigation. Traveling within the region, the consultant team noticed significant visible damage to irrigation delivery systems and blocked drainage canals.
- *Encourage private sector adaptation*: This option was strongly supported, and included both development of robust input supply chains, and allowing farmers increased possibilities to fully own land and select what crops and varieties to plant.

Menu of Adaptation Options

The proposed menus of adaptation options to improve the resilience of Uzbekistan's agricultural sector to climate change are derived from the results from the quantitative modeling, qualitative analysis, and from the farmers' consultations. These options rank high on four criteria for prioritizing options from among a large menu of 29 farm-level adaptation options, 14 infrastructure options, 13 programmatic options, and four indirect adaptation options. The four criteria are:

- *Net economic benefits* (quantified benefits minus costs).
- *Expert assessment of ranking* for those options that cannot be evaluated in economic terms.
- *"Win-win" potential*. These include measures with a high potential for increasing the welfare of Uzbek farmers, with or without climate change.
- *Favorable evaluation by the local farming community*. These results are based on the results of the first and second stakeholder consultations.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Adaptation options were evaluated based on their potential to increase resilience to climate change, using the above-stated evaluative criteria. Some options, if adopted, may also yield benefits in the form or reduced greenhouse gas mitigation potential. In particular, measures such as soil conservation that can enhance the retention of carbon in the soil, and optimization of agronomic practices, which can reduce energy and fertilizer use, yield greenhouse gas mitigation as well as climate change adaptation benefits. While it was not possible to quantitatively evaluate these benefits in a comprehensive manner, a qualitative analysis of the potential for recommended measures to yield greenhouse gas mitigation benefits is also included in this report.

These results were discussed in detail at the National Dissemination and Consensus-building Conference in Tashkent in March 2011. At that time, the conference participants developed their own ranked set of measures to be elevated for discussion. Figures ES.2, ES.3, and ES.4 also include those measures that were considered high priority for implementation by conference participants.

Options for National Policy and Institutional Capacity Building

Three measures for adoption at the national level were identified. The basis for the ranking of these options is the qualitative analysis of potential net benefits by the team, coupled with recommendations from farmer stakeholder and expert groups.

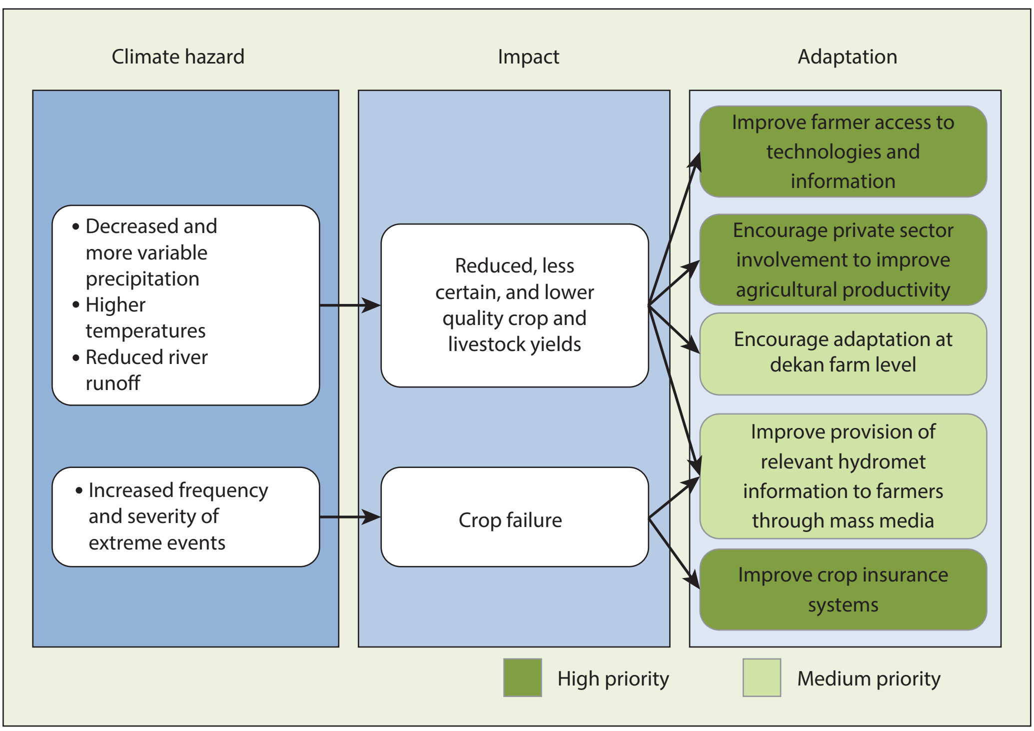
1. *Increase the access of farmers to technology and information through farmer education, both generally and for adapting to climate change.* The team recommends that the capacity of the existing extension agency be improved in two areas: (1) to support better agronomic practices at the farm level, including implementation of more widespread demonstration plots and access to better information on the availability and best management practices of high-yield crop varieties, with a particular focus on pest-resistant varieties for wheat and apples; and (2) to support the same measures but with a focus on maintaining yields during extreme water stress periods that are likely be more frequent with climate change. The first part of this option is a short-term measure to close the adaptation deficit, and the second part is a long-term measure to ensure yield gains are not undermined by future climate change. Investing in extension has a high benefit-cost ratio in the quantitative analysis.
2. *Investigate options for crop insurance, particularly for drought.* The Uzbekistan Country Note observes that crop insurance, while presently available in Uzbekistan, is not viable for the vast majority of agricultural producers. This conclusion was supported in the farmer workshops, but farmers still remain eager to explore insurance options. The Country Note also suggests that a possible way to expand coverage could be via the piloting of a privately run index-based weather insurance program. This approach has many potential advantages over traditional multiple-peril crop insurance, including simplifi-

http://dx.doi.org/10.1596/978-1-4648-0000-9

cation of the product, standardized claim payments to farmers in a district based on the index, avoidance of individual farmer field assessment, lower administrative costs, timelier claim payments after loss, and easier accommodation of small farmers within the program. The program may be particularly suitable for Uzbekistan, where the institutional hydrometeorological capacity is relatively sophisticated and could support an index-based approach. The drawback of an index-based approach may be the inability to readily insure coverage of damage from pests. In addition, insurance systems need to be carefully designed to maintain incentives for farmers to invest in damage mitigation, such as through better water use efficiency.

3. *Encourage private sector involvement to most efficiently adapt to climate change*. There may be a tendency to assume that adaptation to climate change is a public sector function, but as the economic analysis in this study demonstrates, there is strong private sector incentive—with economic benefits greatly exceeding costs—for measures that will improve the resilience of Uzbekistan agriculture to climate change. The national government should focus on putting in place policies that enable the private sector to effectively assist in adaptation, for example, by allowing farmers greater flexibility to choose cropping patterns to adapt to local conditions, conducting testing of seed and livestock varieties for their suitability for

Figure ES.2 Adaptation Measures at the National Level



http://dx.doi.org/10.1596/978-1-4648-0000-9

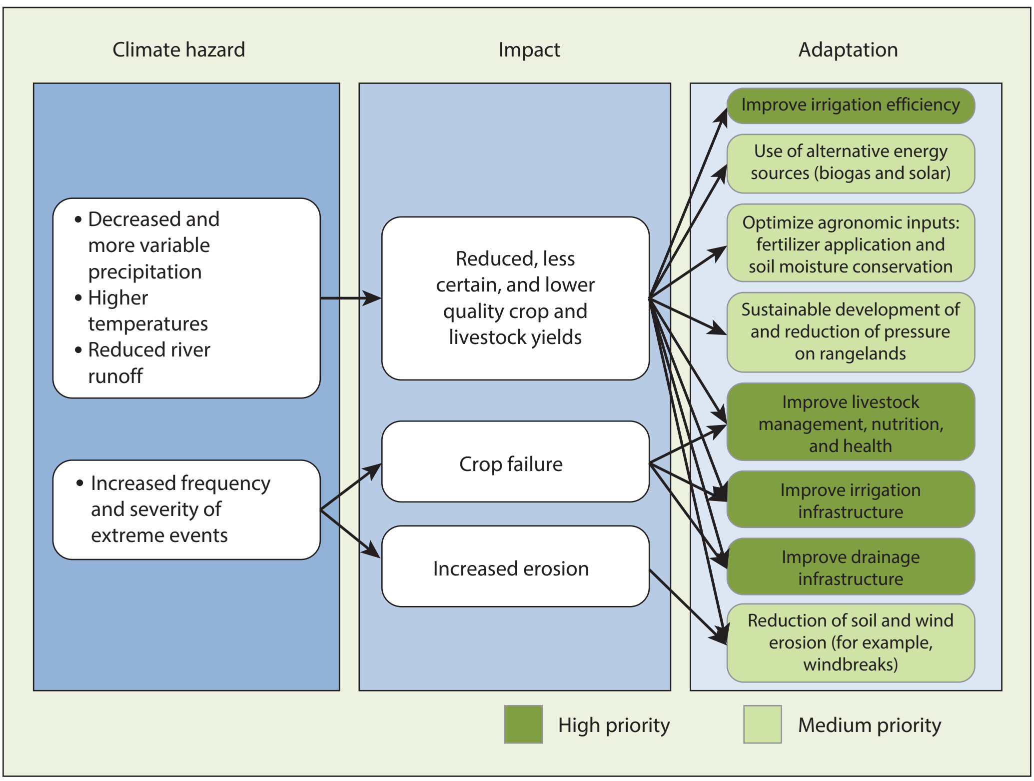
Uzbek climate, terrain, and soil conditions, and making recommendations through extension of the best varieties, but allowing the private sector to provide those varieties. They should also focus on providing financial incentives—where possible—to conserve water and otherwise practice agricultural land stewardship, through reform of water quota systems and similar policy measures.

Combining the above priorities with the options emerging from the National Conference generates an overall set of adaptation measures at the national level. Figure ES.2 links the climate change hazards to impacts, and then these impacts to the national-level adaptation options. Measures shaded in darker green represent options that were recommended by both the consultant team's assessment and the National Conference group.

Options for Specific AEZs

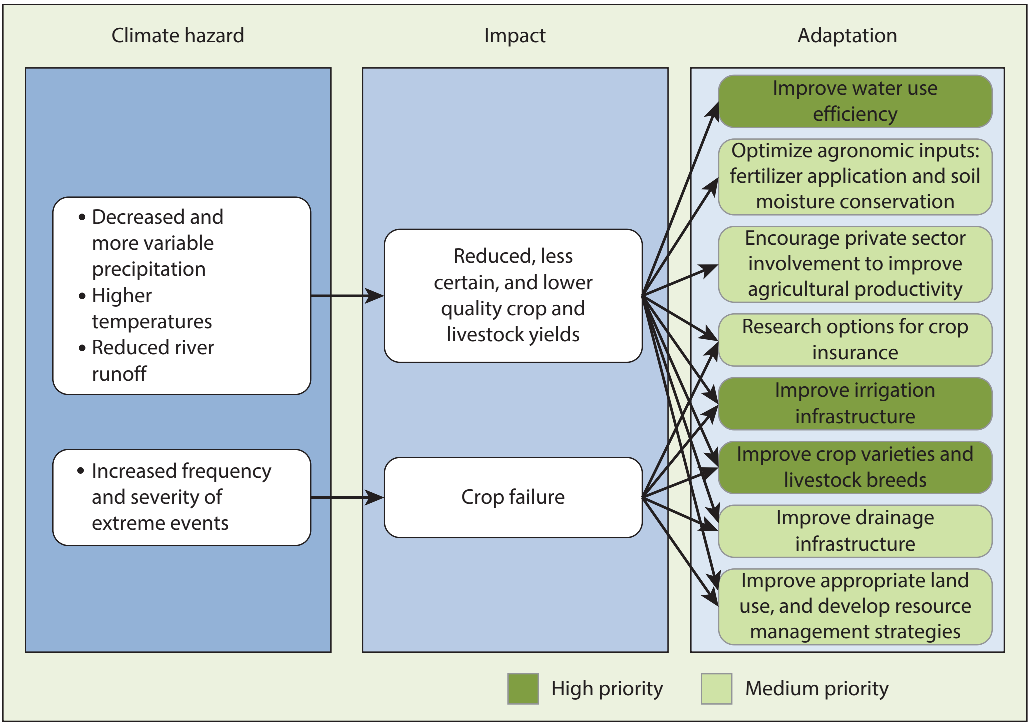
As summarized in figures ES.3 and ES.4, a number of options emerge from the quantitative, farmer, and National Conference evaluations of measures as most advantageous for adapting to climate change in each AEZ.

Figure ES.3 Adaptation Measures for the Desert and Steppe AEZ



http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure ES.4 Adaptation Measures for the Piedmont and Highlands AEZs



http://dx.doi.org/10.1596/978-1-4648-0000-9

CHAPTER 1

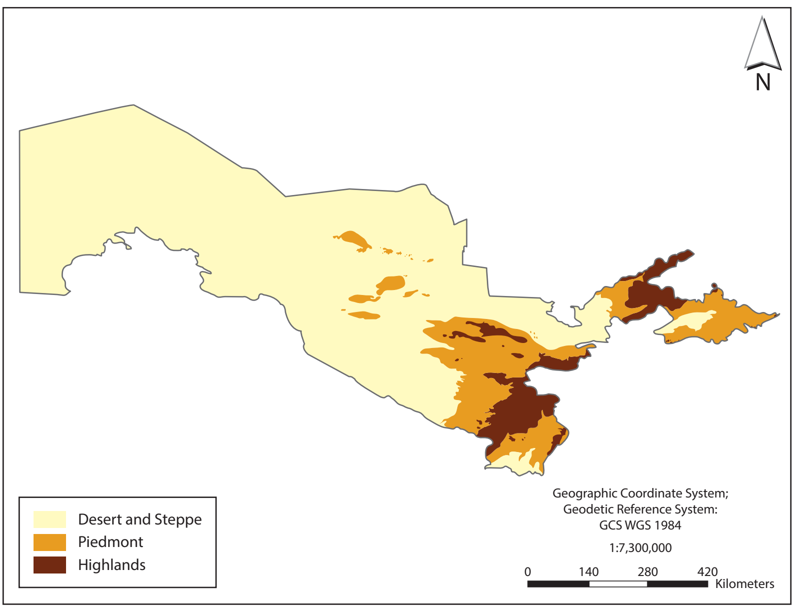
Current Conditions for Uzbek Agriculture and Climate

The Agricultural Sector in Uzbekistan

Uzbekistan is a land-locked country located in central Asia. It has a surface area of 448,900 km^2 and shares borders with Kazakhstan to the west and north, Kyrgyzstan and Tajikistan to the east, and Afghanistan and Turkmenistan to the south (Sutton et al. 2008). Administratively, Uzbekistan is divided into 12 provinces, one autonomous republic and one independent city.

For the purposes of this study, Uzbekistan is divided into three agro-ecological zones, or AEZs, as shown in map 1.1. The area within each of these AEZs differs

Map 1.1 Agro-Ecological Zones in Uzbekistan



Sources: © Industrial Economics. Used with permission; reuse allowed via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). AEZs: Consultative Group on International Agricultural Research—Consortium for Spatial Information.

in terms of terrain, climate, soil type, and water availability. As a result, baseline agricultural conditions, climate change impacts, and adaptive options will be different in each AEZ.

The terrain of Uzbekistan is primarily characterized by desert plains, with about 20 percent of the territory comprising mountains and foothills in the eastern and north-eastern parts of the country (Centre of Hydrometeorological Service 2008). In map 1.1, these primary desert plains are shown in yellow, comprising the Desert and Steppe AEZ at 60–150 meters above sea level. The country's most fertile areas are shown in orange, comprising the Piedmont AEZ at 400–1,000 meters above sea level, and hilly mountainous areas are shown in brown, comprising the Highlands AEZ at over 1,000 meters above sea level.[1] Salinization and soil erosion are two major issues in Uzbek agriculture, potentially reducing the agricultural viability of the Piedmont zone and making the Desert and Steppe zone even less suitable for agriculture. Both of these problems affect at least half of Uzbek agricultural land and lead to reduced yields and abandonment of cropland.

Recent Trends in Uzbek Agriculture

Agriculture is important to rural areas of Uzbekistan, making up between 20 percent and 35 percent of GDP since 1995, though its share of the total economy has decreased over the past few years. Despite this, the percent of rural population has increased[2] and now accounts for about two-thirds of Uzbekistan's population (World Food Programme 2008). Although the agriculture sector has been growing, the pace of growth has been outstripped by other sectors such that the agricultural contribution to gross domestic product (GDP) has declined from 32 percent in 1997 to 21 percent in 2009.[3] However, Uzbekistan is still an agrarian society with the agriculture sector providing 34 percent of the country's employment (Sutton et al. 2008; World Bank 2009d). While economic growth has averaged 5 percent per year, this has not significantly increased living standards. This suggests that Uzbekistan has the third highest poverty rate in Central Asia. Further, the poverty rate was also generally higher in rural than in urban areas (World Food Programme 2008), which leaves a significant amount of the population highly vulnerable to any climatic or economic event that affects the agricultural sector.

In 2009, agriculture made up 21 percent of Uzbekistan's US$33 billion USD GDP.[4] The annual and perennial crop sectors make up 53.4 percent of the value of agricultural production, while the livestock sector accounts for the remaining 46.5 percent (table 1.1).[5]

Although field crops such as wheat and cotton are grown extensively and occupied 80 percent of irrigated land in 2007,[6] (see figure 1.1) they provide a relatively small share of revenues. Cotton accounts for 40 percent of cultivated lands, and accounts for about 40 percent of export earnings (World Food Programme 2008); however, cotton's share in total farm revenue is just 8 percent (World Bank 2009b). Other field crops garner a higher price. For example, tomatoes have a market price of approximately US$1,160 per ton compared to cotton

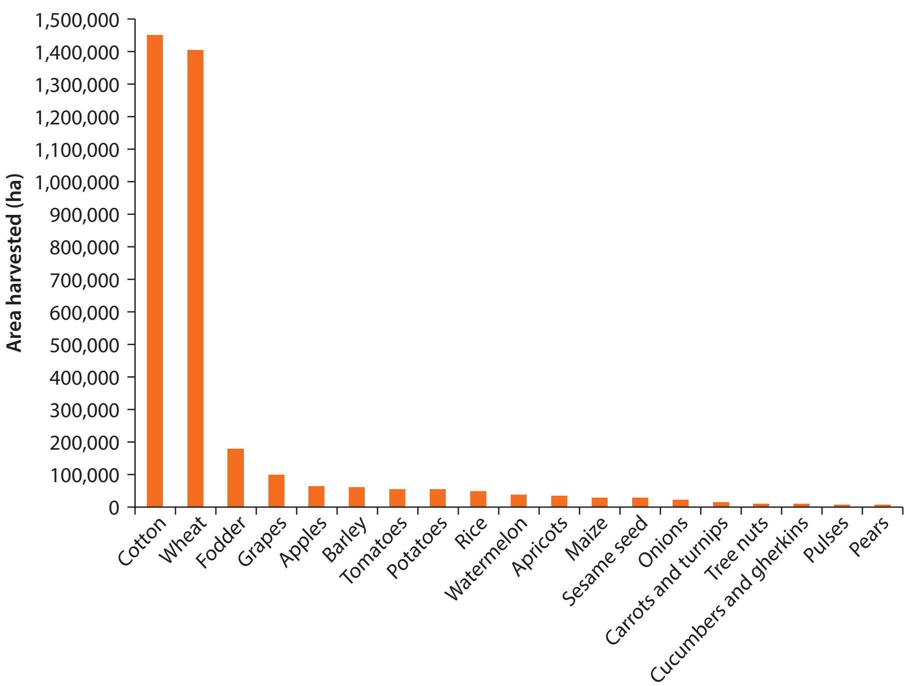
http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 1.1 Value of Agricultural Products in Uzbekistan, 2008

Description	*Value (US$ millions, 2008[a])*	*% of sectors listed*
Cereals	717	7.7
Fibers	2,405	25.7
Fruit and tree crops	1,744	18.6
Livestock	3,695	39.5
Vegetables	794	8.5
Total	9,356	100

Sources: State Statistics Committee of Uzbekistan 2010; World Bank 2009a, Data and Statistics for Uzbekistan. Accessed February 15, 2011, http://www.worldbank.org.uz/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/UZBEKISTANEXTN/0,,menuPK:294213~pagePK:141132~piPK:141109~theSitePK:294188,00.html.
a. Used an exchange rate for 2008 of sum 1319/US dollar.

Figure 1.1 Average Area Harvested by Crop in Uzbekistan, 2006–08



Sources: Adapted from www.faostat.fao.org and World Bank 2009. Project Appraisal Document to the Republic of Uzbekistan—Ferghana Valley Water Resources Management: Phase 1 Project. Washington, DC.

at US$340 per ton and wheat at US$140 per ton.[7] From 2000 to 2007, cotton and fodder areas declined and wheat areas increased. Additionally, the planted area of potatoes, vegetables, and melons increased from 6 percent to 7.1 percent.[8] Uzbekistan's agricultural sector is highly regulated, and farmers are obligated to production quotas for wheat and cotton, which is sold centrally at regulated prices. Inputs for this production are provided by the state.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 1.2 Livestock Count and Area by Agro-Ecological Zone

	Desert and Steppe	*Piedmont*	*Highlands*
Cattle	2,710,000	4,210,000	1,110,000
Goats	486,000	1,270,000	401,000
Pigs	55,200	35,200	1,580
Poultry	9,860,000	17,300,000	1,910,000
Sheep	2,420,000	6,590,000	2,390,000
Area (km^2)	315,000	101,000	31,300

Sources: FAOSTAT Gridded Livestock Data of the World 2005 and FAOSTAT 2009.

Agriculture in Uzbekistan is highly dependent on irrigation. Seventy-nine percent of land under wheat production is irrigated, and similarly high figures apply for cotton. Further, 93 percent of freshwater withdrawals go to agriculture. Due to the spatial variability of soils and climate, and access to water, infrastructure, and other inputs, many areas of Uzbekistan outside of the Piedmont zone are unsuitable for high-value vegetable production and hence the reliance on more resilient, less input-intensive crops such as fodder for livestock in the Desert and Steppe zone. Most agricultural areas are within the Amu Darya and Syr Darya river basins, and these rivers provide approximately 70 percent of irrigation water (World Food Programme 2008).

Trends within the field crop sector over the last decade indicate that total irrigated area used in agriculture declined 2.1 percent and total arable land declined 15.7 percent from 2000 to 2007,[9] while high-value vegetable crop areas remained roughly constant, with a slight increase in 2009 (FAOSTAT 2009).

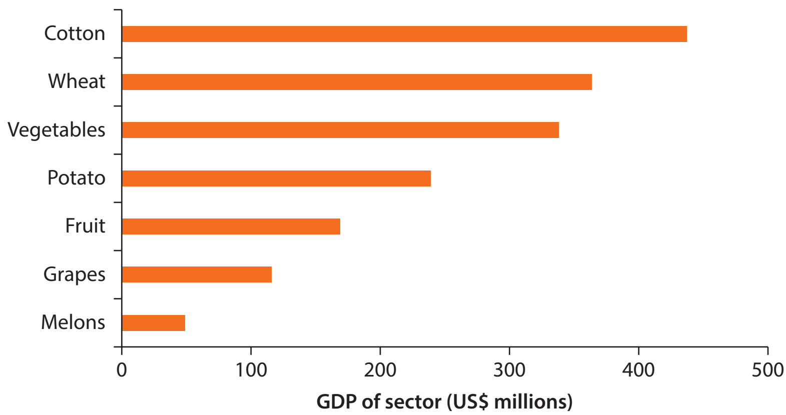
Livestock is also important to the Uzbek agricultural economy. After Uzbekistan gained independence in 1991, large-scale post-Soviet state and collective farms became production cooperatives, composed of association or production shares, in addition to traditional household plots, named "*dekhan*" farms. *Dekhan* farms proved much more profitable than the cooperatives and the production cooperatives were therefore converted into private farms. Today, ninety-five percent of livestock is bred on *dekhan* farms, which occupy 84.3 percent of total land and 14 percent of irrigated areas (Lerman 2009; World Bank 2009b). The numbers of livestock, including cattle, chickens, goats and sheep, have continued to increase over the past decade, possibly as a result of the growing rural population. Table 1.2 shows the breakdown of livestock counts by AEZ, along with the area of each AEZ. The Piedmont AEZ appears to support the greatest concentration of livestock per unit area, although the Highlands AEZ seems well suited to supporting goats and sheep.

Crop Focus for This Study

Based on extensive consultation with the Uzbek steering committee and in particular the MAWR, this study focuses on seven crops: four field crops (cotton, wheat, tomatoes, and potatoes), one fruit (apples), and two crops used for livestock production (alfalfa and grassland pasture). Figure 1.2 provides estimates of

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure 1.2 Estimated Value of GDP for Selected Agricultural Products, 2008



Source: State Statistics Committee of the Republic of Uzbekistan.

the share of GDP of agricultural production of these seven types of crops (apples and tomatoes could not be distinguished from the more general fruit and vegetable categories using currently available data).[10]

For all cases except grassland pasture, climate impacts were assessed on irrigated crops. Available information suggests that in all cases, these crops are most commonly farmed with irrigation. For example, a recent study found that 79 percent of the area planted with wheat is irrigated (Dixon et al. 2009). While the focus on irrigated crop production reflects both the most prevalent conditions and the largest share of production value for these crops, significant areas in Uzbekistan are under rainfed production. These areas may be more negatively affected by climate change than the irrigated crops.

Exposure of Uzbekistan's Agricultural Systems to Climate Change

Potential impacts of climate change on world food supply have been estimated in several studies (Parry et al. 2004). Results show that some regions and crops may improve production, while others will suffer yield losses. In Uzbekistan, the implications of climate change for Uzbek agriculture could be substantial. Increased temperature accelerates crop phenology, which typically means that there is less time for crops to develop the harvestable portions of the plant. High temperature and drought stress during critical growth periods can also reduce yields. Additionally, salinization and soil erosion reduce soil suitability for crops and can have negative impacts on yields. For some crops (for example, winter wheat), increased temperatures can enhance yields, although the absence of required cold periods in the winter would reduce yields.

There are many potential effects of increased temperatures on agriculture, including decreased livestock production, decreased water availability due to a decline in soil moisture, increased evapotranspiration, and reduced yield of water storage reservoirs through increased evaporation. The effect on crops and

http://dx.doi.org/10.1596/978-1-4648-0000-9

water resources from changes in precipitation is generally more uniform than the effects from changes in temperature, at least for rainfed crops, for which greater precipitation leads to higher yields and less precipitation reduces yields. Crop production and most livestock production (except karakul sheep grazing in the desert) are limited to irrigated areas (Lerman 2009). In Uzbekistan, because most crops are irrigated, local precipitation does contribute to soil moisture but the effect of changes in local precipitation is less acute than in predominantly rainfed areas. Instead, agricultural production depends critically on the overall and agricultural sector-level availability of water resources in the main river systems of the country, as well as the condition of storage and water delivery infrastructure for irrigation.

Forecast Climate Changes for Uzbekistan

The first step in understanding the exposure of Uzbekistan's agricultural systems to climate change is to understand the potential for changes in climate from the current baseline. This study captures a broad range of climate model forecasts by identifying low-, medium-, and high-impact scenarios through the year 2050. The scenarios are designed to represent a broad range of the potential for climate to affect agriculture, as defined by a change in an indicator called the Climate Moisture Index (CMI) (see box 1.1 for an explanation).

Box 1.1 Developing a Range of Scenarios of Forecasted Climate for Uzbekistan

Climate change analyses require some forecast of how temperature, precipitation, and other climate variables of interest might change over time. Because there is great uncertainty in climate forecasts, it is best in a study such as this one to attempt characterize a range of alternatives. The central concept used to select future climate scenarios is based on measures most likely to be relevant for the degree of impacts of climate to the agricultural sector. Because both temperature and precipitation affect agricultural productivity, scenarios are chosen based on a CMI, which, in turn, is based on the combined effect of temperature and precipitation. Since it is linked to soil moisture, it is considered well correlated with potential agricultural production.

Each scenario in the study corresponds to a specific global circulation model (GCM) result from among those used by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment of the science of climate change. A wet CMI scenario means that the location experienced the smallest impact (or change in) CMI; that is, the low-impact scenario in this study. A dry scenario corresponds to high potential impact. The specific global general circulation model basis for the medium scenario is the closest consistency with the model mean CMI for a total of 56 available GCMs.

The advantage of this approach is that it provides a representation of a broad full range of available scenarios for future climate change in a manageable way, and that all climate

box continues next page

Box 1.1 Developing a Range of Scenarios of Forecasted Climate for Uzbekistan *(continued)*

scenarios are based on distinct GCM results, which are themselves internally consistent in terms of the key GCM outputs used as inputs to the crop, livestock, and water resource impact modeling.

This study's scenario	*Global general circulation model basis for the scenario*	*Relevant IPCC SRES scenario*
High impact	Geophysical Fluid Dynamics Laboratory, Climate Model 2.1 (US)	A1B
Medium impact	Centre National De Recherches Météorologiques, Coupled Model 3 (FRANCE)	B1
Low impact	UK Met Office, Hadley Center Global Environmental Model 1 (UK)	A2

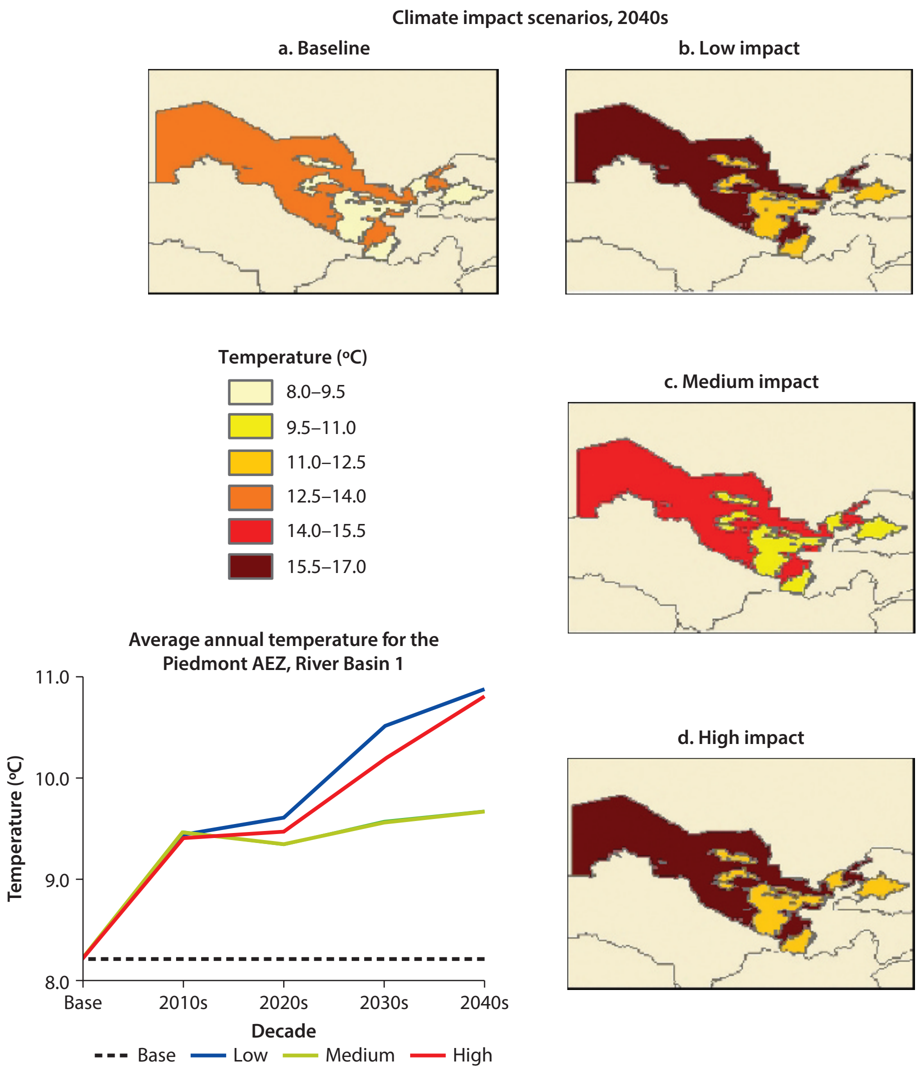
Maps 1.2 and 1.3 summarize the resulting forecast of changes in climate at the AEZ level from the current baseline period through 2050, by decade. Map 1.2 presents changes in temperature by AEZ from the baseline to the 2040s. Temperature under all scenarios increases gradually from the current base through 2050, with similar temperature increases under the medium- and high-impact scenarios and a lower increase under the low-impact scenario. This increasing trend in temperatures is consistent with the observed historical trends, where mean minimum and maximum temperatures have increased since 1938 (ClimateWizard), and with information gathered from farmer workshops conducted in Uzbekistan. In addition to increases in average temperature under the scenarios, a more variable climate is projected with a higher probability of more extreme events such as droughts and heat waves.[11]

Data analysis supports the conclusion that the historical trend in temperature will accelerate in Uzbekistan in the near future. Although there remains uncertainty in the degree of warming that will occur in Uzbekistan, the overall warming trend is clear and is evident in all three AEZs, with average warming over the next 50 years for the medium scenario of about 2–3°C, which is much greater than the increase of less than 1.5°C observed over the last 50 years. In all scenarios, the warming trend relative to current conditions is about the same magnitude across the three AEZs, but the range of current temperatures across AEZs is quite large, with average temperatures in the Desert and Steppe zone about 4°C higher than in the Piedmont zone.

Map 1.3 presents changes in precipitation by AEZ from the baseline to the 2040s. For precipitation, by 2050 the low, medium, and high scenarios indicate uncertainty in the direction of effect as well as its magnitude, with the low scenario forecasting an increase in precipitation, the high scenario forecasting decreases, and the medium scenario having mixed results. The use of GCMs also means that the decadal trend in precipitation is not smooth over time. This is consistent with

http://dx.doi.org/10.1596/978-1-4648-0000-9

Map 1.2 Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios

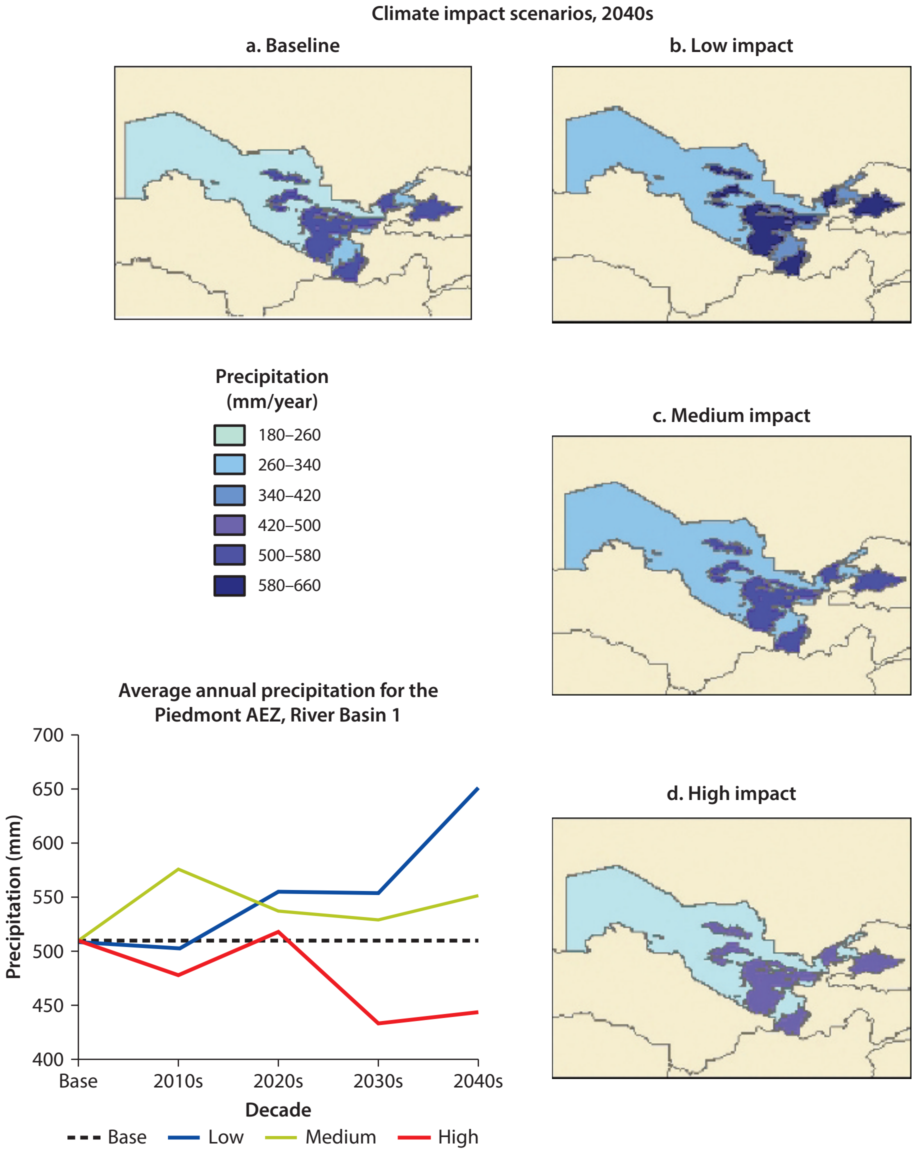


Sources: © Industrial Economics. Used with permission; reuse allowed via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0.

current climate science, which suggests that short-term and long-term trends in precipitation can vary substantially, with some scenarios showing increases in precipitation in the short term and decreases in the long term, and vice versa.

Precipitation changes are much more uncertain than temperature changes, as indicated when comparing map 1.2 with map 1.3. The medium-impact forecast indicates an increase in precipitation of about 48 millimeters per year in the Desert and Steppe zone and about 42 millimeters per year in the Piedmont zone, but a decrease in precipitation of about 10 millimeters in the Highlands zone.

Map 1.3 Effect of Climate Change on Precipitation through 2040s for the Three Climate Impact Scenarios



Sources: © Industrial Economics. Used with permission; reuse allowed via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0.

The yearly averages, however, are less important for agricultural production than the seasonal variation of temperature and precipitation. The forecast temperature increases are higher, and precipitation declines greater in July and August relative to current conditions. For example, the June-through-August temperature increase can be as much as 4–5°C in the Piedmont AEZ. In addition, forecast precipitation declines could occur in the key June-through-August period in the Desert and Steppe AEZ, when precipitation is already at its lowest, even though the annual results suggest an overall increase in precipitation. Figures 1.3 and 1.4 present the monthly baseline and forecast temperatures and precipitation for the Piedmont AEZ.

The most pressing problems in agriculture in Uzbekistan include inefficient water use, soil salinization, wind erosion, and water erosion. Uzbekistan also has a need for proper drainage. Salinity costs Uzbekistan US$1 billion per year (Sutton et al. 2008). Uzbekistan's soils are high in salts, and irrigation leaches and deposits salts into groundwater or further along the catchment. Reusing water downstream for irrigation and rising groundwater cause problems with

Figure 1.3 Effect of Climate Change on Average Monthly Temperature for the Piedmont AEZ, 2040s

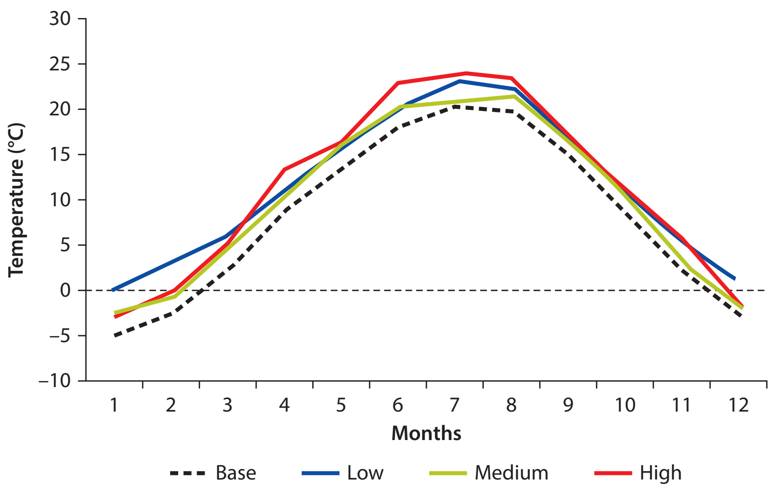
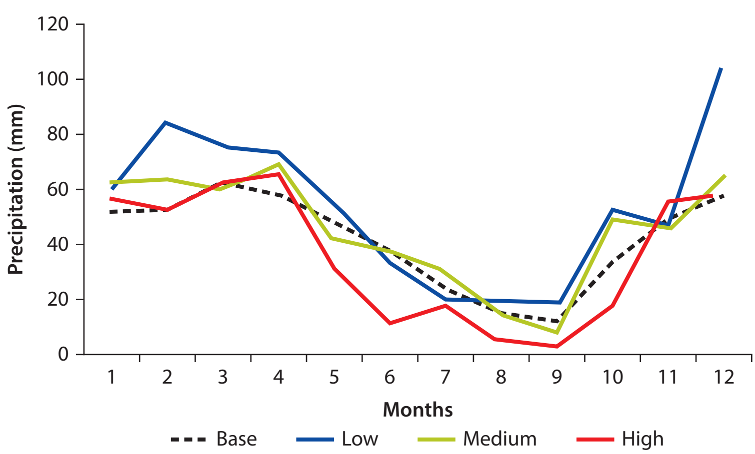


Figure 1.4 Effect of Climate Change on Average Monthly Precipitation for the Piedmont AEZ, 2040s



http://dx.doi.org/10.1596/978-1-4648-0000-9

salinity. Specifically, 51 percent of irrigated land is salinized, of which 4 percent is strongly saline, 17 percent is moderately saline and 30 percent is slightly saline.[12] Of the 4.26 million ha of irrigated land, 20,000 ha are abandoned yearly due to soil salinity and uneconomically high pumping lifts (World Bank 2007b).

Soil erosion is also a pressing concern. FAO states that erosion from winds affects 50 percent of irrigated land and a significant area of rainfed and pasturelands, and water erosion affects 6 percent of irrigated and 20 percent of rainfed lands (FAO 2006). Anthropogenic effects that accelerate erosion and contribute to land degradation include poor cultivation practices, overgrazing, and salinization (Sutton et al. 2008).

Within the contexts of this study, detailed modeling of the effects of climate change on the key crops in Uzbekistan was undertaken.[13] As described in greater detail in chapter 3, the forecast changes in climate summarized in maps 1.2 and 1.3 will increase the vulnerability of these crops in Uzbekistan as follows:

- Cotton, wheat, apple, potato, and tomato yields are forecast to experience a decline in yields of about 1–2 percent per decade across all AEZs in the medium scenario.
- Grassland and alfalfa yields are expected to show significantly increased yields; grassland yields are expected to increase 9–17 percent in all AEZs under the medium scenario.
- Livestock is known to be vulnerable to increasing temperatures, but the effect of climate change on livestock feed stocks, including grasslands and alfalfa, is positive.

Uzbekistan's Current Adaptive Capacity

Assessing adaptive capacity in Uzbekistan's agricultural sector is challenging, because adaptive capacity reflects a wide range of socioeconomic, policy, and institutional factors at the farm, regional, and national levels. Considerations in determining the variation in adaptive capacity across the country also include current climatic exposure (described above), social structures, institutional capacity, knowledge and education, and access to infrastructure. Specifically, areas under marginal rain-fed production will have less adaptive capacity than areas that are more productive and irrigated agricultural land. In addition, financial resources are one of the key factors in determining adaptive capacity, as most planned adaptations require investments. By that measure, Uzbekistan ranks relatively low in overall adaptive capacity in the agriculture sector. Finally, agricultural systems that are poorly adapted to current climate are indicative of low adaptive capacity for future climate changes.

This section reviews three aspects of adaptive capacity: (1) current agricultural policies and institutional capacities at the national level; (2) evidence of adaptive capacity at the farm level based on consultations with Uzbek farmers; and (3) a brief review of evidence that Uzbek agricultural systems for the crops focused on here may be poorly adapted to current climate, reflecting a high current "adaptation deficit."

http://dx.doi.org/10.1596/978-1-4648-0000-9

National Policies and Institutional Capacity

From a national perspective, a high degree of adaptive capacity in the agricultural sector is characterized by: a high level of functionality in the provision of hydrometeorological and relevant geo-spatial data to farmers to support good farm-level decision-making; provision of other agronomic information through well-trained extension agents and well-functioning extension networks; in-country research oriented toward innovations in agronomic practices in response to forecast climate changes; and demonstrated resilience to current weather events. In addition, in high-adaptation capacity countries, systems exist to ensure that collective water infrastructure is well-maintained and meets the needs of the farming community, along with systems to resolve conflicts between farmers and other users over water provision. In Uzbekistan, some of these conditions exist, but others are currently inadequate, as outlined below:

- *The ability to collect, generate, and provide meteorological data to farmers appears to be high, but the provision of those data to farmers for decision-making appears mixed.* Uzhydromet appears to have good infrastructure and well-trained staff able to collect and provide agriculturally relevant meteorological data to farmers. During the farmer consultations, however, farmers noted that the agricultural extension service is not oriented toward ameliorating risks from climate, and could provide better integration with hydrometeorological data provision, particularly related to short-term precipitation forecasts and seasonal water availability for irrigation. The extension service could expand its capacity to advise on adapting agricultural systems to the climate risks outlined in this study.

- *Agricultural research capabilities in some areas are strong, and the presence of ICARDA and other CGIAR centers in Tashkent are also an advantage, but the penetration of high-yield varieties for the key wheat and cotton crops and crop diversification could be expanded*. Agricultural research capacity under the MAWR crop institutes was not evaluated within the scope of this study. In some areas, such as field crops, MAWR institutes appear to be well-integrated with the ICARDA office in Tashkent. In general, however, climate change is not taken as a major risk to agricultural production in Uzbek agricultural research, and is therefore not optimally addressed and coordinated with extension services. Improvement in this area includes research on leveraging advances in seed varieties and farming practices shown to be effective in other countries, particularly in cotton production, and coordination with the extension service to demonstrate these results locally, particularly for small-scale farmers.

- *Economic reform of farm enterprises is ongoing.* Farm enterprises have evolved considerably in Uzbekistan in recent years, providing additional flexibility and generally improving the ability of agricultural enterprises to respond to climate and economic disturbances, but more remains to be done. From 1990 to 1998, the previous large-scale post-Soviet state and collective farms were transformed into production cooperatives (shirkats), established of association

http://dx.doi.org/10.1596/978-1-4648-0000-9

or production shares. They functioned in addition to the traditional household plots, renamed as dekhan farms. Since 2001, seeing that most of shirkats were less profitable, the government began the process of transforming shirkats into private farms, sometimes called peasant farms, which are organized as legal bodies. In the current state, as discussed in the Awareness Raising and Consultation Workshop, the complete agricultural sector is comprised mainly of dekhan and private farms, with the role of shirkats restricted to highly specialized operations. In 2007, dekhan farms accounted for over 60 percent of gross agricultural output, private farms an additional one-third of output, and shirkats the remainder (Lerman 2008). The dekhan farms tend to specialize in vegetables, fruits, and livestock, providing what appears to be the majority of food crops and the vast majority of livestock. The private farms have less flexibility in their choice of production and are mainly focused on cotton and wheat production, with inputs being received from supplying organizations. A small numbers of private farms are engaged in cultivation of vegetables, melons, orchards, grapes and livestock production. Accordingly, it will be important to provide greater flexibility for private farms to choose cropping patterns.

- *Farm size and ownership/land tenure are issues*. In 2008, reforms led to an increase in size of farms, resulting in an average crop area of about 56 hectares for all farms, with vegetable and melon farms just over 20 hectares. Farmland is leased for a period of 50 years, with ownership retained by the state and requirements for farmers to meet a state production quota on cotton and wheat. Reforms encouraged crop rotations and provided access to loans for private farms. However, the lack of long-term land ownership remains a disincentive for on-farm improvements and land stewardship.

- *Irrigation infrastructure is extensive, but overall and on-farm water efficiency could be improved*. The irrigation network in Uzbekistan is extensive, but in recent years investments in maintaining this infrastructure appear to have decreased. Overall system and on-farm water use efficiency is difficult to estimate, but is by most accounts much lower than optimal, with only about a quarter of the distribution channels equipped with anti-seepage lining, for example. Pumping infrastructure is relatively old and as a result less energy efficient than newer infrastructure. There are few incentives for application of water saving-technologies because farmers do not see the direct costs of water provision. Instead, water costs are covered by an overall land tax and are not tied to use of inputs, and water user associations are not yet well-established. Some recent reforms appear promising, however. The announced Program on Land Development and Soil Fertility Improvement (2008–12) is designed to provide farmers with land reclamation machinery and equipment that might reduce water currently needed for leaching of salinity (about 20 percent of water is used for leaching purposes, to reduce salinity levels in soils sufficiently to support crops). The introduction of new irrigation practices and water saving technologies may also be considered under the program.

http://dx.doi.org/10.1596/978-1-4648-0000-9

- *The integration of the agricultural sector into international markets is incomplete*. Uzbekistan is one the world's largest exporters of cotton, and has applied for accession to the World Trade Organization (WTO) with the intention of integrating its agricultural markets internationally. The country currently has observer status in the organization. Some high-value crops with export potential, however, such as vegetables and potatoes, are under export restrictions. Most of the production of these crops occurs at dekhan farms, where the state is the main buyer of agricultural produce.

- *There is a low level of crop diversity*. The dominance of cotton and wheat in the current agricultural system leave Uzbekistan's agricultural sector highly susceptible to price fluctuations in these commodities. This, combined with restrictions on exports of other crops, suggests that farmers have limited means to adapt to changing yield and price conditions. There is also low participation in currently available crop insurance programs.

Adaptive Capacity Assessment from Farmer Consultations

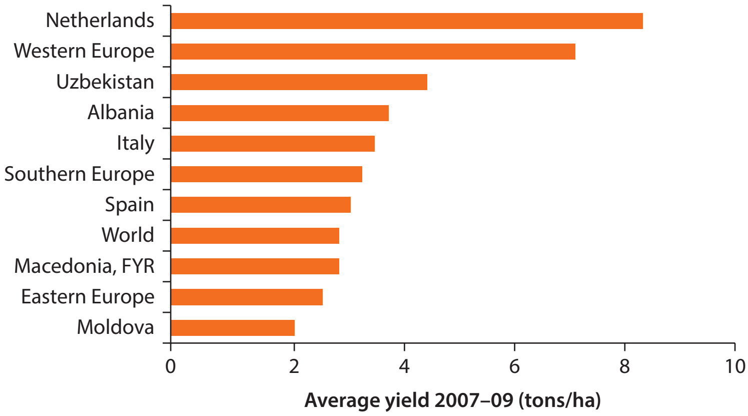
As described more fully in chapter 4, the team consulted with farmers in an initial consultation. In this first encounter, farmers identified several climate stressors of concern, including an increased number of pests and diseases, air pollution, limited snow cover and cold temperatures, erratic and low rainfall, and heat stress. The farmers also expressed concerns that the current extension service was not adequate to help them address these problems.

Crop Yields and Practices for Selected Crops

One observable indicator of adaptive capacity is the degree to which current agricultural crop yields and practices keep pace with those in other countries and international averages for key crops. The result of such an assessment gives a sense of what it sometimes termed "adaptation deficit," or the degree to which agricultural practices are not adapted to current climate. If crop yields are relatively low by international standards, it suggests current marginal production may have little resiliency in the face of new climate stresses, and a high potential to be devastated by climate changes.

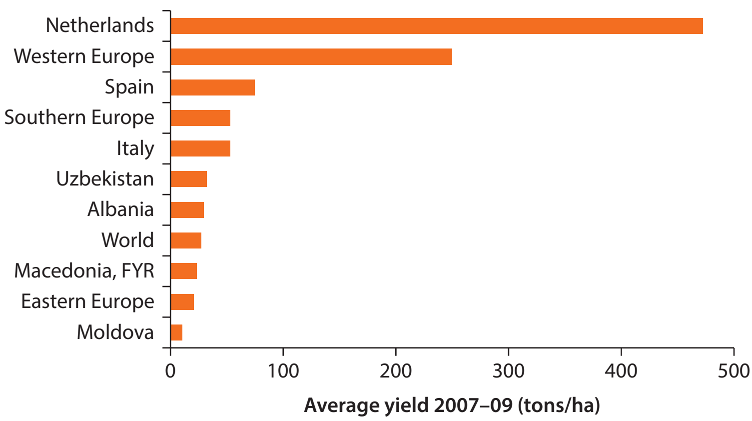
Relative yields for two important Uzbek crops were reviewed through analysis of FAO data: wheat and tomatoes. For wheat, FAO statistics suggest that overall wheat production in Uzbekistan is about 4.6 tons per hectare, reflecting a mix of rainfed and irrigated wheat. This is less, on average, than yields for parts of Europe, but relatively high internationally and greater than for the United States (figure 1.5). One reason for the large average wheat yield is that Uzbekistan has a relatively high portion of irrigated wheat. However, these yields are relatively low for irrigated agriculture (World Food Programme 2008). Under irrigation, a good commercial wheat grain yield by international standards is 6–9 tons per hectare. These values are reached in Uzbek regions where the crop that is cultivated before wheat is a crop other than cotton, and where wheat yields are up to 7.0 tons per hectare. However, in regions where cotton is cultivated before

Figure 1.5 Wheat Yield in Some Selected Relevant Countries, Average 2007–09



Source: FAOSTAT 2009, Crop Production. Accessed December 2010 from http://faostat.fao.org/site/567/default.aspx#ancor.

Figure 1.6 Tomato Fresh Yield in Some Selected Relevant Countries, Average 2007–09



Source: FAOSTAT 2009, Crop Production. Accessed December 2010 from http://faostat.fao.org/site/567/default.aspx#ancor.

wheat, yields are much lower due to high inefficiencies from late sowing dates (World Bank 2009b). Internationally, winter wheat generally has yields about 10 percent higher than spring wheat due to a longer growing period, but the composition of winter and spring wheat varieties in Uzbekistan is unknown.

Tomatoes in Uzbekistan have relatively low overall yields compared to European production (figure 1.6). A good commercial tomato yield under irrigation is about 250 tons per hectare fresh fruit, of which around 90–95 percent is moisture. In Uzbekistan, where most of the tomatoes are irrigated, yields generally fall far short of this level. On average, yields are about 33 tons per hectare. However, tomato yields are higher under greenhouse conditions.

Cotton is also a critically important crop to Uzbekistan. The average cotton yields from 2004 to 2007 in Uzbekistan were 2.5 tons per hectare, while the international average cotton yields were 3.2 tons per hectare (World Bank 2009b). The Ministry of Finance estimates a break-even point of 2.6 tons per hectare for cotton yields, and as many Uzbek regions have yields below average, a significant number of producers do not make profits from cotton production (World Bank 2009b).

The overall conclusion from the review is that current wheat and cotton production enjoys a significant comparative advantage because of the widespread accessibility of irrigation capacity in Uzbekistan, but that the full extent of the comparative advantage may not yet be exploited because of the limited use of internationally available high-yield and drought-resistant crop varieties. For tomatoes, however, there remains significant room for enhancing adaptive capacity to current climate in Uzbekistan. As indicated later in this study, many of the options for adapting Uzbek agriculture to climate change have very high benefit-cost ratios for measures that focus on improving tomato yield.

A Framework for Evaluating Alternatives for Investments in Adaptation

The need to adapt to climate change in all sectors is now clear. International efforts to limit greenhouse gases and, in the process, to mitigate climate change now and in the future will not be sufficient to prevent the harmful effects of temperature increases, changes in precipitation, and increased frequency and severity of extreme weather events.

At the same time, climate change can also create opportunities, particularly in the agricultural sector. Increased temperatures can lengthen growing seasons, higher carbon dioxide concentrations can enhance plant growth, and in some areas rainfall and the availability of water resources can increase as a result of climate change.

The risks of climate change cannot be effectively dealt with, and the opportunities cannot be effectively exploited, without a clear plan for aligning agricultural policies with climate change, for developing key agricultural institution capabilities, and for making needed infrastructure and on-farm investments. Developing such a plan ideally involves a combination of high-quality quantitative analysis and consultation of key stakeholders, particularly farmers, as well as in-country agricultural experts.

This study provides a framework for evaluating alternatives for investment in adaptation, for the Uzbek national government, potentially assisted by the donor community, and for the private agricultural sector. The framework has two critical components:

1. *Rigorous quantitative assessments that consider the current climate as well as several scenarios of future climate change, supplemented by the judgments of a team*. The quantitative analyses rely on local data to the extent possible to

assess the risks of climate change to specific crops and areas of the country, but also to assess whether the costs of investments justify the benefits in terms of enhancing crop yield now and in the future. In addition, the study considers the specific water resource availability conditions at the basin level, now and in the future.
2. *Structured discussions with local experts and farmers to evaluate the potential for specific adaptation strategies to yield economic benefits as well as the feasibility and acceptability of these options.* The input of Uzbek farmers to this process proved critical to ensure that the quantitative analyses were reasonable and that the project team did not overlook important adaptation actions.

Further, the study provides a ranking of the options based on both quantitative and qualitative results. The ranking can be used to establish priorities for policy-makers in enhancing the resilience of the Uzbek agricultural sector to climate change. Two types of results from this study should therefore be most critical for Uzbek policy-makers:

- *Increase farmer know-how and skills through capacity building*: Capacity building was universally mentioned, especially as related to improving extension services to small farmers. Specific topics for capacity building included improving farmers' skills in countering the increased incidence of pests, especially for wheat and apples, improved training for pest-resistant, and/or heat-stress-tolerant seed and crop variety selection from both international and national markets, and providing information on improving on-farm water use efficiency.
- *Invest in on-farm irrigation infrastructure*: There appears to be much potential for the application of water efficiency improvements, such as drip irrigation.

The most effective plans for adapting the sector to climate change will involve both human capital and physical capital enhancements and many of these investments can also enhance agricultural productivity right now, under current climate conditions. These options, such as improving water use efficiency and access to high-yield seed varieties, will yield benefits as soon as they are implemented and provide a means for farmers to autonomously adapt their practices as climate changes.

Structure of the Report

The remainder of this report consists of five chapters. Chapter 2 summarizes the design and methodology for the study and chapter 3 reviews the results of the impact assessment, chapter 4 describes the stakeholder processes employed to identify and evaluate adaptation options, and chapter 5 provides a benefit-cost analysis of selected options. Finally, chapter 6 presents the overall menu of adaptation options at the national level and for each AEZ.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Notes

1. Adapted from: http://www.fao.org/ag/AGP/AGPC/doc/counprof/Uzbekistan/uzbekistan.htm; Centre of Hydrometeorological Service, Cabinet of Ministers, 2007. Climate Change and its Impact on Hydrometeorological Processes, Agro-Climatic and Water Resources of the Republic of Uzbekistan, Tashkent; Iglesias, A. et al. 2007. Adaptation to Climate Change in the Agricultural Sector, AEA Energy & Environment, Didcot; & World Bank team analysis of climate change implications.
2. This article is an outgrowth of analytical work carried out during the period June 2007-May 2008 under the auspices of UNDP/Tashkent and Mashav—Division for International Cooperation in Israel's Ministry of Foreign Affairs. It relies on data from official publications of the State Statistical Committee of Uzbekistan.
3. World Bank. 2009a. Data and Statistics for Uzbekistan (accessed February 15, 2011), http://www.worldbank.org.uz/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/UZBEKISTANEXTN/0,,menuPK:294213~pagePK:141132~piPK:141109~theSitePK:294188,00.html.
4. The World Bank. 2009a. Data and Statistics for Uzbekistan. Accessed at: http://www.worldbank.org.uz/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/UZBEKISTANEXTN/0,,menuPK:294213~pagePK:141132~piPK:141109~theSitePK:294188,00.html on February 15, 2011.
5. The State Statistics Committee of the Republic of Uzbekistan.
6. The State Committee on Land and Cadastre of the Republic of Uzbekistan (former Goscomzem). World Bank. 2009. Impact of Recent Agricultural Reform Policy of Uzbekistan (Draft). Tashkent.
7. The State Statistics Committee of the Republic of Uzbekistan.
8. The State Committee on Land and Cadastre of the Republic of Uzbekistan (former Goscomzem). World Bank. 2009. Impact of Recent Agricultural Reform Policy of Uzbekistan (Draft). Tashkent.
9. The State Committee on Land and Cadastre of the Republic of Uzbekistan (former Goscomzem). World Bank. 2009. Impact of Recent Agricultural Reform Policy of Uzbekistan (Draft). Tashkent.
10. World Bank. 2009a. Data and Statistics for Uzbekistan (accessed February 15, 2011), http://www.worldbank.org.uz/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/UZBEKISTANEXTN/0,,menuPK:294213~pagePK:141132~piPK:141109~theSitePK:294188,00.html; The States Statistics Committee of the Republic of Uzbekistan.
11. Centre of Hydrometeorological Service, Cabinet of Ministers. 2008. Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change, Tashkent.
12. Centre of Hydrometeorological Service, Cabinet of Ministers. 2008. Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change, Tashkent.
13. A further factor in evaluating vulnerabilities is the fertilizing effect, for some crops, of increases in ambient CO_2 concentrations. Those results are reviewed in chapter 3.

CHAPTER 2

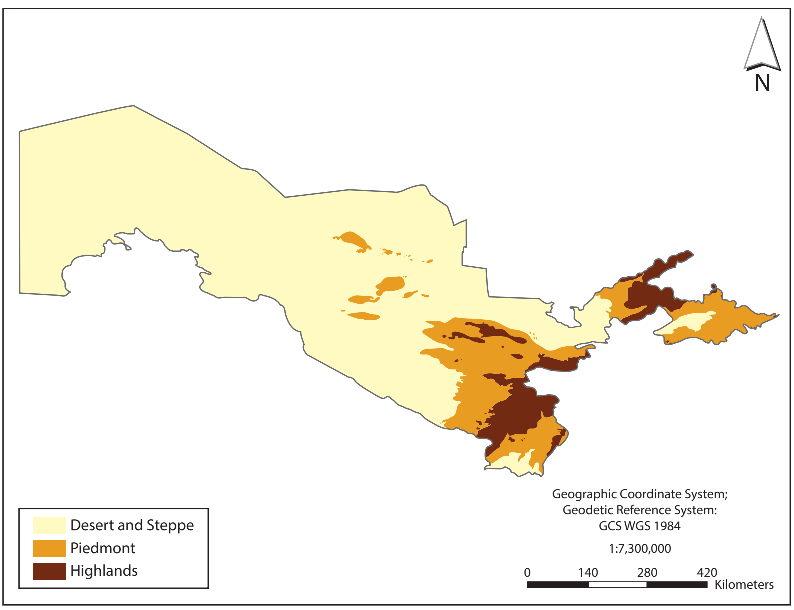
Design and Methodology

Overview of Approach

The overall scope of the assessment of adaptation options is as follows:

- *Geographic scope*: The analysis is conducted at the agro-ecological zone (AEZ) level, as indicated in map 2.1, using representative farms in each of the zones.
- *Crops*: Based on the availability of existing crop models, consultation with Uzbek counterparts, and the availability of appropriate data to support modeling, the following crops are evaluated quantitatively: cotton, wheat, tomatoes, potatoes, applies, alfalfa, and rainfed pasture (grasslands).

Map 2.1 Agro-Ecological Zones in Uzbekistan



Sources: © Industrial Economics. Used with permission; reuse allowed via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). AEZs: Consultative Group on International Agricultural Research—Consortium for Spatial Information.

http://dx.doi.org/10.1596/978-1-4648-0000-9

- *Future climate*: Three future climate scenarios were developed based on projections of temperature and precipitation at the country level in 2050. The three scenarios are designed to reflect a range of global circulation model (GCM) outcomes for agriculture that include a low-impact, medium-, and high-impact outcome. The climate scenarios were selected based on a country-level analysis and then applied consistently across all three AEZ regions.
- *Time period*: Results were generated using decadal averages from 2010 to 2050 (that is, 2010s, 2020s, 2030s, and 2040s).
- *Economic assumptions*: The results are based on two economic projections: continuation of current conditions, prices, and markets, and an alternative crop price projection through 2050 as developed and recently published by the International Food Policy Research Institute (IFPRI).
- *Baseline for evaluation*: The benefits and costs are estimated for each of the options relative to the "current conditions" baseline. As a result, in some cases the benefits and costs of adaptation options may reflect benefits of both adapting to climate change and improving the current agricultural system; these are identified as "win-win" in nature.

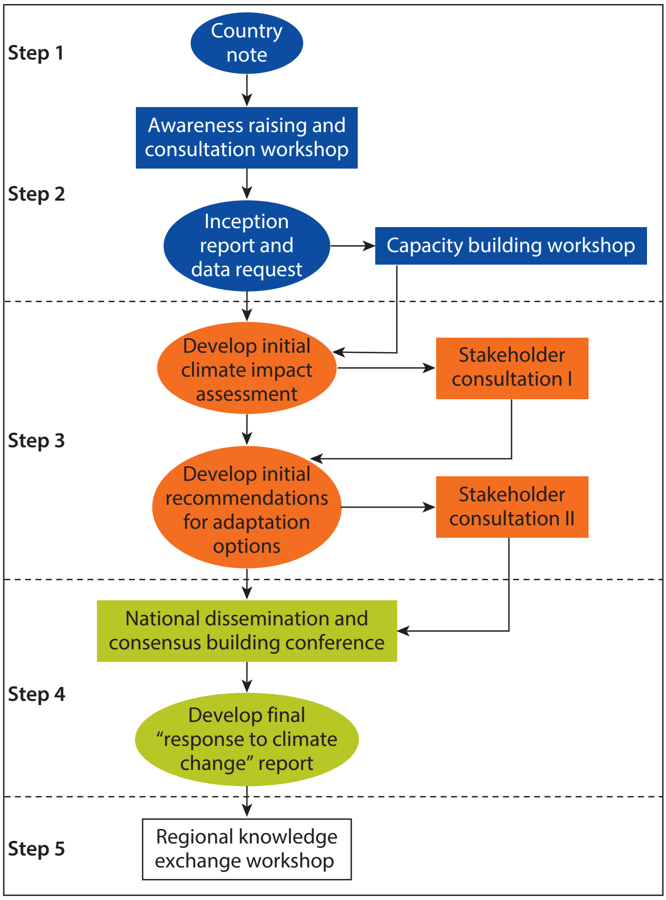
The overall study was conducted in three stages, as outlined in figure 2.1. The first stage, focused on awareness raising and developing an overall methodology and scope for the study, began in May 2010 with an Awareness Raising Workshop organized by the World Bank and the MAWR.

The second stage was the climate impact assessment for the agricultural sector, beginning with data collection and culminating in a capacity building session. At the conclusion of the impact assessment an initial stakeholder consultation was conducted, which involved a participatory process with farmers to continue awareness raising, establish a reasonable baseline for the analysis, and gather ideas for adaptive measures to assess in the third stage. A small team travelled to each of the agro-ecological zones to report on the results of the initial climate impact assessment modeling and collect stakeholder input on adaptation options that might be pursued in response to these projected impacts.

The third stage involved refinement of the impact assessment and additional analysis to develop the quantitative analysis, a qualitative assessment, and recommendations from Uzbek farmers for the adaptation menu. In March a second stakeholder workshop was conducted with farmers, to provide them an opportunity to review and comment on the draft menu of adaptation options. The study culminated in the Uzbekistan National Dissemination and Consensus Building Conference, held in March 2011, and this report has been revised to reflect those outcomes.

The remainder of this chapter describes three key steps in our quantitative analysis. The next section describes how future climate scenarios were developed and applied to conduct an agricultural sector climate impact assessment, modeling a baseline of effects of changed climate on the current agricultural system,

Figure 2.1 Flow of Major Study Action Steps



before adaptation. The section titled "Development of Adaptation Menu" provides details on our assessment of the effect of specific adaptation options on crop yields and farm revenues. The section titled "Assessing Risks to Livestock" provides an overview of assessment of risks to livestock.

This chapter focuses on the methods used in the quantitative analysis. The final set of options in chapter 6, however, includes elements of quantitative modeling, qualitative assessment, and participatory strategies among farmers. The other elements of the overall approach are described in chapter 4.

Climate Scenarios and Impact Assessment

The impact methodology was developed in four steps: (1) identify major agricultural growing regions in Uzbekistan; (2) gather baseline data; (3) develop climate projections; and (4) use baseline and climate projection data to conduct the impact assessment.

Step 1: Identify Agricultural Growing Regions of Uzbekistan

Results were generated for "representative farms" in each of the major agricultural production regions of Uzbekistan, at least one of which must be in each of the three agro-ecological zones (AEZs). Presenting the results at this spatial scale allows the use of baseline data from meteorological stations that are co-located with agricultural regions, and avoids needing to either interpolate data between stations or rely upon global sources of gridded data (which have already used interpolation). Note that this approach focuses the analysis on regions that are currently active in agricultural production and does not evaluate regions that may become newly suitable for agriculture as the climate changes.

Information on rainfed and irrigated crop coverage across Uzbekistan was collected based on remote sensing data from several international sources (for example, MIRCA dataset for 26 irrigated and rainfed crops at ~5 minute resolution, McGill dataset for 175 crops at ~5 minute resolution, Spatial Production Allocation Model [SPAM] dataset of detailed global crop maps from IFPRI). Unfortunately, local meteorological data were not provided in time to be incorporated into crop modeling.

Step 2: Gather Baseline Data

Baseline meteorological, soils, and water resources data were provided from in-country and global sources. While station-level meteorology is preferred, it was unfortunately not provided to the project team in Uzbekistan in time for crop modeling. As a result, global sources for the meteorological and soils data inputs were used. In-country data and global sources were obtained for the water resources requirements. These requirements include:

- *Meteorological*. Because AquaCrop is a daily model, the crop modeling methodology requires at least 10 years of daily historical data in the major agricultural regions of Uzbekistan.
- *Soil characteristics*. Crop modeling requires data on soil type, suitability, erosion potential, and hydrology characteristics.
- *Water resources*. Water resources modeling requires at least 10 years of average daily (preferred) or monthly historical river flow data for gauging stations along the mainstem rivers of each major drainage basin in Uzbekistan. These were provided by in-country sources. In addition, locations and active storage volumes of each major reservoir were obtained from global and in-country sources.

Global sources of data were used only when necessary, and when available at a grid-cell level. In those cases, global gridded meteorological data were translated to the agricultural production regions, and daily data for grid cells covering that region was spatially averaged.

Step 3: Develop Climate Projections

The climate projections combine information from the baseline datasets with projections of changes in climate obtained from GCM results prepared for the

http://dx.doi.org/10.1596/978-1-4648-0000-9

United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. As noted in box 1.1 in chapter 1, three climate scenarios were developed for Uzbekistan. The scenarios are defined by the Climate Moisture Index (CMI), which is an indicator of the aridity of a region.[1] Based on the average of CMI values across Uzbekistan, the driest, wettest, and "medium" scenarios were selected from among the 56 available GCM combinations deployed by IPCC for 2050. The following two subtasks were then conducted:

- *Generate decadal monthly changes in precipitation and temperature*. Monthly changes in climate were generated based on differences between future projections of temperature and precipitation and twentieth century baseline outputs for each GCM. Based on available literature, absolute changes in temperature and relative changes in precipitation are presented.
- *Translate these monthly decadal changes to daily changes*. Crop modeling under future climate change also requires daily data for the 2010–50 period, but the GCMs only produce 12 monthly outputs for each decade between 2010 and 2050 (that is, four sets of 12 monthly values). Therefore, decadal monthly changes were used, combined with the earliest decade of available in-country daily station data, to scale the future projections.[2]

Step 4: Conduct Impact Assessment

The impact assessment uses the process-based crop model AquaCrop to analyze changes in crop yields across Uzbekistan, and the CLIRUN model to analyze changes in water runoff. The Water Evaluation and Planning System (WEAP) model is then used, using the inputs from CLIRUN to analyze potential basin-level shortages in water available to agriculture. Any estimated water shortage from the WEAP model is fed back to the biophysical step to estimate the net effect of the shortage on irrigated crop yields. As outlined in the next chapter, future water shortages for agriculture are projected in most basins in Uzbekistan, but in other basins sufficient irrigation water is forecast to be available under climate change.

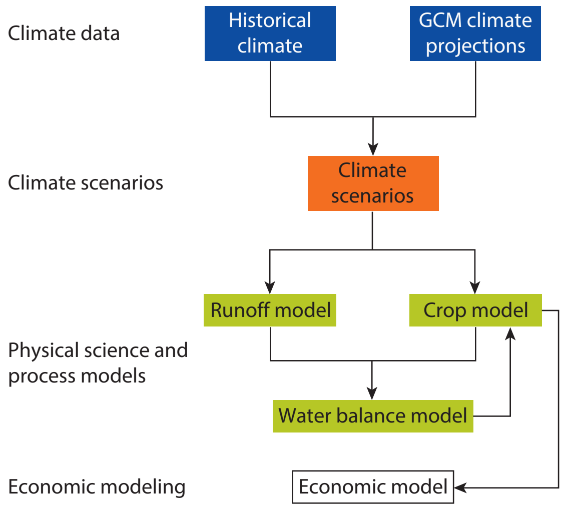
The interactions between these tools are presented in figure 2.2. Note that this figure also includes an economic model that is applicable to the adaptation assessment (described below). The AquaCrop, CLIRUN, and WEAP tools are briefly described in box 2.1.

Development of Adaptation Menu

Building on the four steps of the impact assessment, there are three additional steps necessary to develop the adaptation menu: (5) select and categorize a set of adaptation options to be considered for Uzbekistan; (6) conduct qualitative and quantitative assessments of those options; and (7) develop a ranked order menu of adaptation options.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure 2.2 Analysis Steps in Action Step 3: Quantitative Modeling of Adaptation Options



Note: GCM = global circulation model.

Step 5: Select and Categorize Adaptations Options

A set of adaptation alternatives were defined and categorized. This list was supplemented by stakeholder recommendations from consultation workshops. The adaptation options fall into four categories:

- *Programmatic*. Investments in programs and policies that are targeted specifically at agriculture (that is, research and development, extension services)
- *Farm management*. Non-infrastructure farm management improvements aimed at improving farm productivity (that is, changing planting dates or crop varieties)
- *Infrastructural*. Infrastructure investments that improve farm productivity and/or reduce variability. These may include farm-level investments such as rainwater harvesting, or sectoral investments such as irrigation infrastructure or reservoir storage.
- *Indirect*. Broad investments in programs, policies, and infrastructure that indirectly benefits agriculture (that is, road improvements).

A list of categorized adaptation options for Uzbekistan is provided in chapter 4.

Step 6: Conduct Adaptation Assessment

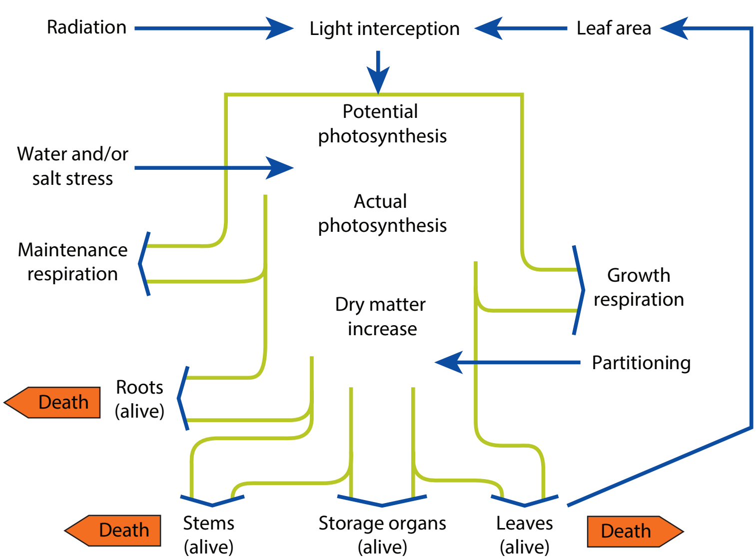
The adaptation options are evaluated based primarily on four criteria: (1) net economic benefits (quantified where possible, otherwise based on expert assessment), (2) robustness to different climate conditions, (3) potential to aid farmers with or without climate change, otherwise referred to as "win-win-win" potential, and (4) favorable evaluation by stakeholders. Because of data limitations, not all

http://dx.doi.org/10.1596/978-1-4648-0000-9

Box 2.1 Impact Assessment Modeling Tools

The three models used in this study are AquaCrop, CLIRUN, and WEAP. Below is a brief description of each of these models. All are in the public domain, have been applied worldwide frequently, and have a user-friendly interface:

- *AquaCrop*: The strengths of this process model are in its simplicity to evaluate the impact of climate change and evaluation of adaptation strategies on crops, and also in its ability to evaluate the effects of water stress and estimate crop water demand, both key issues in Uzbekistan currently and with climate change. The model was developed and is maintained and supported by the Food and Agriculture Organization (FAO) and is the successor of the well-known CropWat package. Other advantages of the model are its widespread use and straightforward analysis. The model is mainly parametric-oriented and therefore less data demanding. The diagram included in this box illustrates some of the main crop growth processes reflected in AquaCrop.
- *CLIRUN*: Monthly runoff in each catchment can be estimated using this hydrologic model that is widely used in climate change hydrologic assessments. CLIRUN models runoff as a lumped watershed with climate inputs and soil characteristics averaged over the watershed simulating runoff at a gauged location at the mouth of the catchment. CLIRUN can run on a daily or monthly time step. Soil water is modeled as a two-layer system: a soil layer, and a groundwater layer. These two components correspond to a quick and a slow runoff response to effective precipitation. A suite of potential evapotranspiration models is available for use in CLIRUN. Actual evapotranspiration is a function of potential and actual soil moisture state following the FAO method. CLIRUN can be parameterized using globally available data, but any local databases can also be used to enhance the data for the models. CLIRUN produces monthly runoff for each watershed.



Main processes included in AquaCrop

box continues next page

http://dx.doi.org/10.1596/978-1-4648-0000-9

Box 2.1 Impact Assessment Modeling Tools *(continued)*

- *WEAP*: The Water Evaluation and Planning System (WEAP) is a software tool for integrated water resources planning that attempts to assist rather than substitute for the skilled planner. It provides a comprehensive, flexible, and user-friendly framework for planning and policy analysis. River basin software tools such as WEAP provide a mathematical representation of the river basin encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, existing as well as potential major schemes and their various demands of water. The WEAP application proposed for this study would model demands and storage in aggregate, providing a good base for future more detailed modeling. WEAP was developed by the Stockholm Environment Institute (SEI) and is maintained by SEI-US. Although it is proprietary, SEI makes the model available for a nominal fee for developing country applications.

options are evaluated quantitatively. Methodologies for addressing each of the criteria are described below.

Criterion 1: Net Economic Benefits

The net economic benefit model evaluates a subset of the adaptation options in terms of both their net present value (NPV; total discounted benefits less discounted costs) and their benefit-cost ratio (B-C ratio; total discounted benefits divided by discounted costs) over the time period of the study. Ranking based solely on NPV would tend to favor projects with higher costs and returns; considering the B-C ratio highlights the value of smaller scale adaptation options suitable for small-scale farming operations. The economic model used here produces the optimal timing of adaptation project implementation by maximizing NPV and the B-C ratio based on different project start years. This is of particular relevance to infrastructure adaptation options such as irrigation systems and reservoir storage, whose high initial capital expenses may not be justified until crop yields are sufficiently enhanced. Lastly, the model estimates NPV and B-C ratios for yield outputs under each dimension of the analysis, namely: (1) climate scenarios, (2) AEZs or river basins, (3) crops, (4) CO_2 fertilization, and (5) irrigated versus rainfed.

Generating these metrics requires several key pieces of information, including:

- *Crop yields* with and without the adaptation option in place—these are derived from AquaCrop modeling.
- *Management multiplier* to convert from experimental to the field yields—this was developed in consultation with local experts, as part of the capacity building work.
- *Crop prices through 2050*—national crop price data from FAO for current conditions was used and price projections under two scenarios were devel-

http://dx.doi.org/10.1596/978-1-4648-0000-9

oped: one with constant prices and one based on an IFPRI global price change forecast.
- *Exchange rate* between global and local crop prices.
- *Discount rate* to estimate the present value of future revenues and costs—all analyses employ a 5 percent discount rate, consistent with recent World Bank Economics of Adaptation to Climate Change analyses.
- *Capital and operations and maintenance (O&M) costs of each adaptation input* (for example, irrigation infrastructure). Local data were requested to characterize costs of adaptation options, and in some cases they were provided. Overall, these were difficult to obtain or generalize, and as a result, in many cases estimates derived from prior work are used.

The general approach for estimating the net benefits of two of the farm management options assessed (optimizing fertilizer application, and changing crop varieties) is outlined in table 2.1. More details of these analyses are provided in chapter 4. Not all options were amenable to such quantitative analysis. In addition to optimizing fertilizer application and changing crop varieties, a quantitative assessment of the following options was also undertaken:

- Expanding extension services
- Expanding agricultural research and development activities
- Improving drainage capacity
- Developing new irrigation capacity
- Rehabilitating irrigation capacity
- Improving irrigation water application efficiency, and adjusting livestock holdings in response to climate stress.

Table 2.1 Approach for Two Quantifiable Farm-Level Adaptation Options

Adaptation option	*Description*	*Crop modeling approach*	*Economic methodology*
Optimize fertilizer application	Additional application of fertilizer may partly offset impacts of climate change on crop yields.	Redeploy AquaCrop to optimize levels of fertilizer inputs and provide resulting crop yields for each of these dimensions.	1. In the economic model, estimate the per hectare revenue increase (that is, market price times increased yield) due to implementation of the adaptation alternative, and the per hectare increase in costs, then convert these to net present value and benefit-cost ratios for each start year between 2011 and 2050. 2. Assess whether the farm management adaptation option is net beneficial, and if so, identify the optimal start year(s).
Switch to more suitable crops or crop varieties	As climate conditions change, another option would be for farmers to switch to more suitable crops or crop varieties.	The economic model employs estimates of crop yields under climate change in each of the AEZs.	

http://dx.doi.org/10.1596/978-1-4648-0000-9

Criterion 2: Robustness to Different Future Climate Conditions

All options are assessed relative to climate conditions in three alternative climate scenarios. Benefit-cost ratios and net present value calculations are developed for each of the three scenarios, both with and without the effect of carbon fertilization, providing a means for assessing robustness to future climate conditions.[3]

Criterion 3: "Win-Win" Potential

The analysis also determined whether adaptation options would be beneficial even in the absence of climate change. For options amenable to economic analysis, the net benefits of the adaptations can be analyzed relative to the current baseline. As a result, the benefits estimates implicitly incorporate both climate adaptation and non-climate related benefits of adopting the measure. For other alternatives, the win-win potential is assessed based on expert judgment.

Criterion 4: Stakeholder Recommendations

Adaptation alternatives that stakeholders recommended during the stakeholder consultation workshops carry significant weight in the menu of adaptation options. Stakeholders also provided information on impacts that they had already experienced and adaptation options that address those impacts. Adaptation options that address those impacts, such as drainage improvements to enhance adaptation to flooding, are also given a higher priority, even if those measures were not specifically mentioned in the stakeholder workshops.

Step 7: Develop Menu of Adaptation Options

The menu of adaptation options presented in chapter 6 synthesizes the results of the three components of the adaptation assessment: quantitative analysis (described in chapter 5); qualitative assessment of potential net benefits to farmers (also summarized in chapter 5); and farmer recommendations (summarized in chapter 4). Tables in chapter 6 provide a prioritized list of national- and AEZ-level options, with a justification for the option based on these three components of the assessment. In addition, the tables identify whether the option has win-win potential.

Other components of the option include a qualitative assessment of the time needed to implement each of these adaptation options. This characteristic of the option may be a key consideration for farmers and potential investors. For example, reservoir construction requires much more time than changing crop varieties from one season to the next. This information is not used to assign priority, but instead is designed to provide guidance about measures that could have an immediate versus delayed impact. The assessment is based on available information on each option along with expert judgment.

A key consideration in the quantitative analysis is assessing whether the option yields benefits across the range of possible future climate outcomes. These include the quantitative and qualitative projections of net benefits of adaptation options across three climate change scenarios, two CO_2 fertilization scenarios, multiple crops, and four decades. For some adaptation options, robustness is assessed based on expert assessment.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Assessing Risks to Livestock

Although the direct effects of heat stress on livestock have not been studied extensively, warming is expected to alter the feed intake, mortality, growth, reproduction, maintenance, and production of animals. Collectively, these effects are expected to have a negative impact on livestock productivity (Thornton et al. 2009).

In an effort to assess the effects of climate change on livestock, a broad literature review was conducted to identify existing models on the effect of climate change, particularly changing temperature, on livestock. Ideally, a "process" model similar to the AquaCrop crop model would be employed. A model of this type could be deployed to simulate effects on livestock for various climate scenarios, and also evaluate the impact of taking adaptive actions. The only extensive analysis of this type was a structural Ricardian model of livestock developed by Seo and Mendelsohn based on studies in 10 countries in Africa (2006). This model measures the interaction between temperature and livestock and considers the adaptive responses of farmers by evaluating which species are selected, the number of animals per farm and the net revenue per animal under changes in climate. The study relies on a survey of over 5,000 livestock farmers in 10 African countries. In this dataset, the variation in livestock productivity and expected incomes in different regions demonstrates a clear relationship to regional climate, which provides a mechanism, through spatial analogue, to statistically analyze how climate change may affect livestock incomes.[4]

The general results of the study are that, relative to the baseline, the probability of choosing beef cattle and chickens will decline with rising temperatures, but that the probability of selecting dairy cattle, goats, and sheep will increase. Expected income per animal falls across all livestock types, but changes are most dramatic for beef cattle, goats, and chickens, which fall 19 percent, 21 percent, and 29 percent respectively with a temperature increase of 2.5°C. Rising temperatures, in general, lead to a response to reduce the predicted number of beef cattle and chickens on each farm, but increase the number of the other livestock types.

The Mendelsohn and Seo results are consistent with other work in this area. In prior studies, beef cattle have been found to experience increases in mortality, reduced reproduction and feed intake, and other negative effects as temperatures rise (for example, Adams et al. 1999). Butt et al. (2005) found that small ruminants (that is, goats and sheep) are more resilient to rising temperatures than beef cattle. Chickens are particularly vulnerable to climate change because they can only tolerate narrow ranges of temperatures beyond which reproduction and growth are negatively affected. Further, increases in temperature caused by climate change can be exacerbated within enclosed poultry housing systems.

Ultimately, however, the Mendelsohn and Seo model was not applied in the Uzbek analysis. The main reason is that the current climate, and in particular the effect of current climate on existing management practices and current livestock varieties in the 10 African countries they studied, differs markedly from those in

Uzbekistan. The Ricardian approach does not allow for a reliable adjustment for those differences. Instead, a qualitative evaluation of both the risk of climate to livestock, and adaptive measures to consider in responding to those risks is provided.

Uncertainty and Sensitivity Analysis

A study of this breadth, conducted under time and data constraints, is necessarily limited. In particular, in order to look broadly across many crops, areas, and adaptation options, particularly options that may be relatively new to Uzbekistan, general data and characterizations of these options were relied on. While the study team has taken care to use the best available data, and has applied state-of-the-art modeling and analytic tools, analysis of outcomes 40 years into the future, across a broad and varied landscape of complex agricultural and water resources systems, involves uncertainty. As a result, this study attempts to evaluate the sensitivity of the options to one of the most important sources of uncertainty—how future climate change will unfold across Uzbekistan.

A potentially larger question that was not addressed at this time involves projecting the evolution and development of agricultural systems over the next 40 years, with or without climate change. The future context in which adaptation will be adopted is clearly important, but very difficult to project. Other important limitations involve the necessity of examining the efficacy of adaptation options for a "representative farm." The results of this study should not be interpreted as in-depth analysis of options at the farm-scale. Instead, these results may be viewed as an important initial step in the process of evaluating and implementing climate adaptation options for the agricultural sector, using the current best available methods.

Notes

1. The CMI depends on average annual precipitation and average annual potential evapotranspiration (PET). If PET is greater than precipitation, the climate is considered to be dry whereas if precipitation is greater than PET, the climate is moist. Calculated as CMI = (P/PET)-1 {when PET>P} and CMI = 1-(PET/P) {when P>PET}, a CMI of –1 is very arid and a CMI of +1 is very humid. As a ratio of two depth measurements, CMI is dimensionless.
2. For example, if a selected GCM projects that the change in January temperatures in the 2030s is two degrees and the earliest available station data are from 1994 to 2003, the January 1–31 temperatures for every year in the 2030s will be the temperatures during Januarys between 1994 and 2003 plus two degrees.
3. As noted in chapter 5, in most cases it was found that quantitative results for adaptation options are less sensitive to uncertainties in climate forecasts than to uncertainties in future prices.
4. Because the raw data from this survey were not available, it was not possible to compare the climatic conditions observed in the Seo and Mendelsohn survey to the conditions in Uzbekistan.

http://dx.doi.org/10.1596/978-1-4648-0000-9

CHAPTER 3

Impacts of Climate Change on Agriculture in Uzbekistan

This section describes the results of the climate impact assessment for the Uzbek agriculture sector. The impact assessment is an important component of developing an adaptation plan. As outlined in the section titled "Exposure of Uzbekistan's Agricultural Systems to Climate Change" in chapter 1, it reflects the potential impacts of forecast changes in temperature and precipitation on crop yields and irrigation water availability during the years 2010–50 if no actions are taken to adapt to these changes. As such, it represents a baseline from which the effects of individual adaptation options can be measured. It also provides a clear picture of the risks and opportunities presented by climate change at a detailed level, by crop, AEZ, and river basin.

This chapter reviews forecast impacts of climate change on crops and horticulture, then summarizes the results of a screening-level assessment of the direct effects of climate change on livestock, and finally reviews the effects of climate change on water available for agricultural irrigation.

The results suggest the following:

- *Overall, the effects of climate change on crops in Uzbekistan could be relatively modest, especially for wheat, alfalfa, and pasture*. There is potential for more substantial effects on cotton and vegetable and fruit crops, such as tomatoes, apples and potatoes, which could suffer from heat and drought stress, particularly during critical periods of their growth. One reason for the relatively modest effects is the widespread use of irrigation in Uzbekistan. However, to the extent water supply is reduced and irrigation infrastructure is in poor repair, water may not be available at critical times of the growing season. If this is the case, the severity of effects of future climate change for irrigated crops may be under-estimated.
- *The direct effect of temperature on livestock, reducing their productivity and farm revenues, could be considerable, especially for cattle and chickens*. The results however are qualitative in nature at this time.

http://dx.doi.org/10.1596/978-1-4648-0000-9

- *Climate change will increase irrigation water demand and reduce water supply*. The modeling results indicate that although irrigation water shortages already exist during some years, higher temperatures and lower precipitation under climate change will increase irrigation water demand and reduce river runoff during the growing season. These increases in agricultural water demand, and reductions in water supply, coupled with rising water demand in other sectors, will cause already existing shortfalls to become more severe in future years, most acutely in the western Desert and Steppe AEZ.

Climate Impacts on Crops and Horticulture

The detailed results of the team's impact assessment for individual crops—for each AEZ and climate scenario—are summarized below in tables 3.1 and 3.2. Table 3.1 shows the results for the medium scenario, and table 3.2 shows the range of results for the low-, medium-, and high-impact scenarios. As shown in table 3.1, most crops are negatively affected by climate change, except for alfalfa and grassland.

Table 3.1 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures

% change

Irrigated/rainfed	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont East*	*Piedmont Southwest*
Irrigated	Alfalfa	3	2	3	22	1
	Apples	−8	−5	−9	−1	−8
	Cotton	−6	−5	0	−2	−6
	Potatoes	−6	−4	−7	2	−7
	Tomatoes	−5	−6	0	−1	−7
	Winter wheat	2	−2	−1	13	−4
	Spring wheat	−10	−5	−13	5	−12
Rainfed	Grassland	12	15	12	43	−1

Note: Results are average changes in crop yield, assuming no adaptation and no irrigation water constraints and no effect of carbon dioxide fertilization, under medium-impact scenario. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases.

Table 3.2 Effect of Climate Change on Crop Yields through 2040s across the Three Climate Scenarios

% change

Crop	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont East*	*Piedmont Southwest*
Alfalfa	3 to 7	2 to 5	3 to 7	27	1 to 5
Apples	−22 to −4	−14 to −6	−19 to −2	−24 to 2	−19 to −3
Cotton	−10 to −3	−8 to −5	0	−9 to −2	−9 to −1
Grassland	10 to 42	−9 to 25	3 to 32	28 to 56	−5 to 32
Potatoes	−10 to −2	−11 to −5	−13 to −3	−12 to 2	−11 to −1
Tomatoes	−16 to 0	−12 to −4	0	−10 to 0	−15 to 4
Wheat	−31 to 0	−16 to 0	−30 to −1	−12 to 7	−29 to −1

http://dx.doi.org/10.1596/978-1-4648-0000-9

The high-impact climate scenario has the strongest impact, with less rainfall and higher evapotranspiration due to the higher temperature projection. For the medium-climate scenario the impact of climate change is a little less severe than the high-impact scenario, as this scenario is less pessimistic in terms of rainfall projections.

In general, the results indicate that apples, cotton, potatoes, tomatoes, and wheat decline in at least some AEZs in all three scenarios; grassland declines in only one scenario; and alfalfa increases in all three scenarios. Irrigation is critical to maintaining these yields in Uzbekistan, and to reducing yield variability.[1]

The low-impact scenario shows a net positive impact for most crops at most sites, as the plants benefit from greater water availability due to increased rainfall. The higher temperatures also result in a higher evaporative water demand, but only a part of the increased rainfall is lost through non-productive soil evaporation. Most of the crops are affected positively by the increased water availability. The yield of rainfed crops especially is enhanced by the increased rainfall amounts, as in the current situation they experience a certain amount of water-stress and growth is water-limited.

The results presented above do not incorporate the effects of higher CO_2 concentrations that are expected as a byproduct of increased CO_2 emissions. Higher CO_2 concentrations can enhance growth for some crops with a photosynthesis process that can benefit from additional ambient CO_2. The effect is difficult to accurately estimate, however, because of the difficulty in designing field experiments, and the inability in most studies to account for the countervailing effects of CO_2 on competing weeds.[2]

For the high-impact scenario, some of the crops may experience an increase in production due to the assumed CO_2 fertilization effect. This effect compensates part of the negative impact of the increased water stress caused by the higher temperatures and evaporative demand. CO_2 fertilization can mitigate some water stress, so this is particularly beneficial for crops with high increases in water requirements like apples, cotton, potatoes, and wheat. In other modeling experiments, the effect of CO_2 fertilization was found to be positive and enhance yields by about 7 percent on average.

For the irrigated crops, the climate impact on irrigation water demand was also assessed as a key input to the water resources analyses. The darker colors in table 3.3 indicate a larger magnitude of increase or decrease in crop irrigation water requirements. For all three scenarios, the overall trend is that more water is required to maintain the current yields. All crops, except possibly alfalfa, will need substantially larger amounts of water. The low- and medium-impact scenarios forecast more rainfall, including more rainfall during the cropping period, which results in a slight decrease in water demands.

Climate Impacts on Livestock

Effects on alfalfa and rainfed pasture crops summarized in the previous section present one type of climate change risk to livestock, an indirect effect. Effects of

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 3.3 Irrigation Water Requirement Changes Relative to Current Situation to 2040s under the Three Climate Scenarios, for Each Crop and AEZ (Assuming No CO_2 Fertilization)

% change

Scenario	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont East*	*Piedmont Southwest*
Low	Alfalfa	−10	−7	−10	−47	−7
	Apples	7	9	4	−8	5
	Cotton	6	9	N/A	2	3
	Potatoes	3	8	5	−2	0
	Tomatoes	−5	−2	N/A	−9	−10
	Spring wheat	7	4	4	−40	7
	Winter wheat	−2	−1	−5	1	8
Medium	Alfalfa	−2	−2	−4	−39	0
	Apples	12	7	14	−1	12
	Cotton	12	9	N/A	3	12
	Potatoes	9	7	11	−2	9
	Tomatoes	0	2	N/A	-4	4
	Spring wheat	17	9	22	−35	18
	Winter wheat	8	3	5	−12	6
High	Alfalfa	−3	−1	−2	−41	1
	Apples	32	21	30	111	26
	Cotton	18	14	N/A	25	17
	Potatoes	18	18	22	74	18
	Tomatoes	18	12	N/A	29	17
	Spring wheat	44	26	44	19	41
	Winter wheat	9	5	10	−34	19

Note: N/A = the crop is not grown in the AEZ. Orange indicates an increase in crop irrigation water requirements, while green indicates a decrease.

climate change on maize yields may also be linked to effects on livestock. As noted above, for the medium scenario, rainfed alfalfa and grassland yields are expected to increase across all AEZs, where livestock makes up a large percentage of overall agricultural productivity. Even under the high-impact scenario, effects on these crops in all regions of Uzbekistan are relatively modest, with temperature effects being a boost to yield that generally balances or outweighs the negative effects of less precipitation. As a result, the indirect effects of climate change in areas where livestock are most important would range from relatively modest in the worst case, to beneficial in the best case.

The direct effect of climate change on livestock is also important, and is linked to higher than optimal temperatures for livestock, where heat can affect animal productivity and, in the case of extreme events, may lead to elevated mortality rates related to extreme heat stress. As outlined in chapter 6, there is limited information to characterize the direct effects of climate on livestock. The currently available methodologies are far less sophisticated than the crop modeling techniques applied in the prior section, or the water resources modeling techniques in the following section, and are generally not applicable to Uzbekistan.

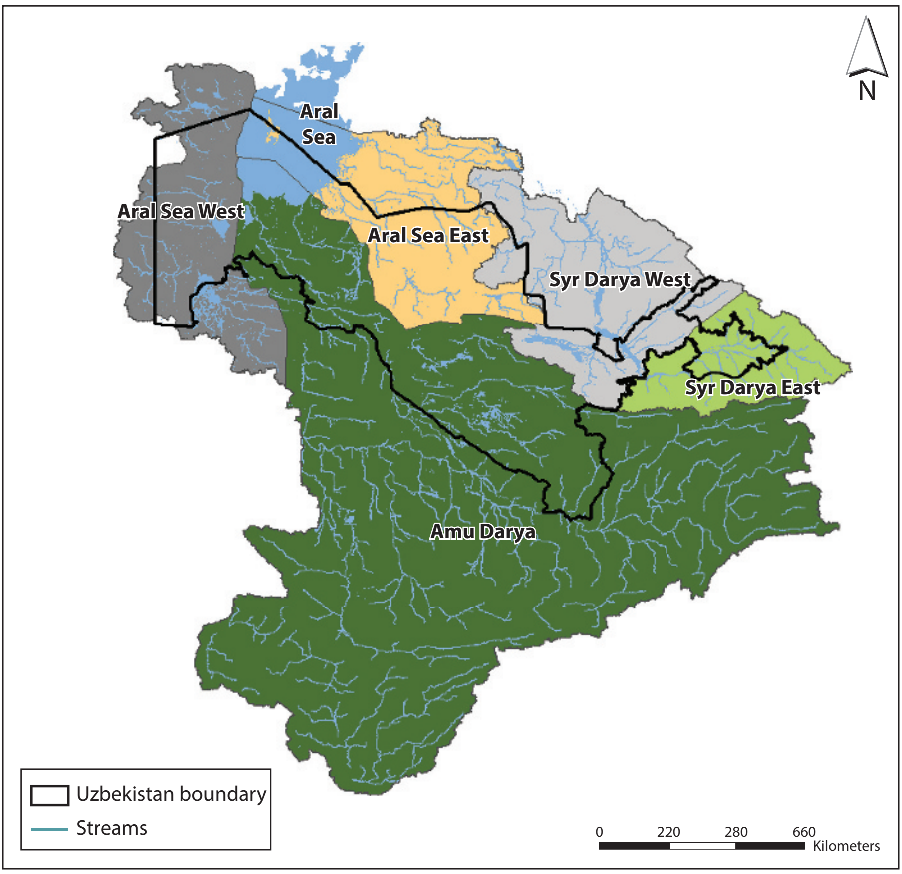
http://dx.doi.org/10.1596/978-1-4648-0000-9

A screening analysis suggests that the direct effects of climate change on most livestock, in absence of adaptation, could be negative and potentially large. For many livestock type/AEZ combinations, climate change is a major risk, with potential for as much as 35 percent loss in net revenue by the 2040s, with effects on goats and sheep being less than those for chickens and cattle.

Climate Impacts on Water Resources

A water availability analysis was conducted at the river basin level using the Water Evaluation and Planning System (WEAP), which compares forecasts of water demand for all sectors, including irrigated agriculture, with water supply results under climate change derived from the CLIRUN model. The five major river basins analyzed are shown in map 3.1. They include, from east to west, the Syr Darya (eastern and western) basin, the Amu Darya basin, and two other

Map 3.1 River Basins in Uzbekistan



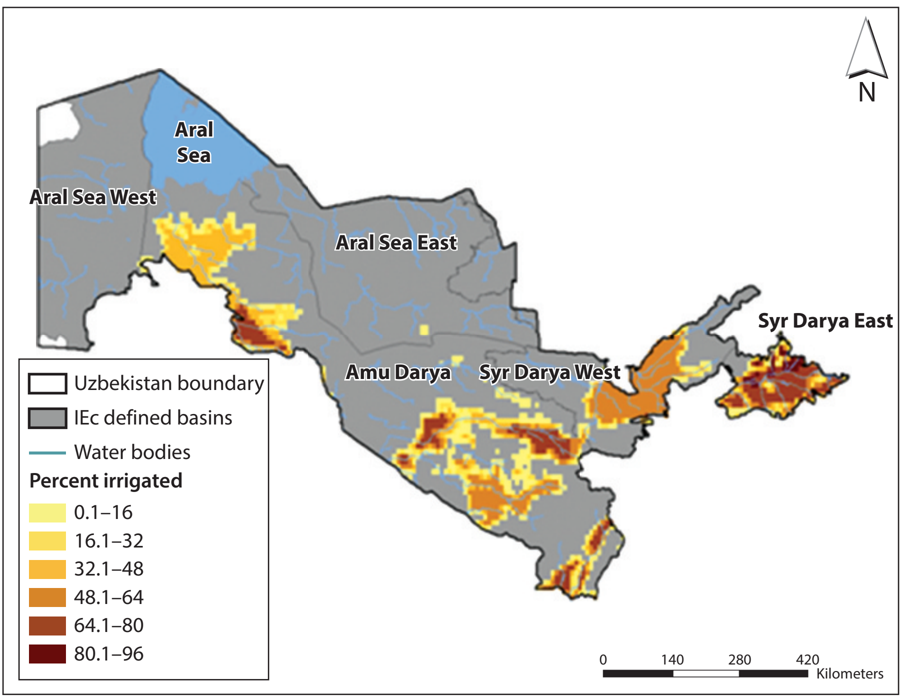
Sources: © Industrial Economics. Used with permission; further permission via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0. Basin data available from the U.S. Geological Survey Hydro1k River Basins.

basins that run into the Aral Sea (Aral Sea East and Aral Sea West). Each of these basins extends beyond Uzbekistan's border, indicated by the black line in the figure. However, the focus of this study was on changes in water supply and demand within Uzbekistan's territory.

The remainder of this section discusses: (1) the inputs to WEAP, including basin-level water demand, supply, storage, and transboundary flows, (2) analytical results, and (3) limitations of the analysis.

Total annual irrigation water withdrawals across Uzbekistan is approximately 54 km^3, representing 93 percent of water withdrawals in the country.[3] In the WEAP model, irrigation water withdrawals in each river basin were estimated based on the total hectares of irrigated land in each basin, per hectare estimates of crop irrigation requirements (discussed above), and an estimate of basin-level irrigation efficiency. The distribution of irrigated hectares across the river basins was based on FAO's Global Map of Irrigated Areas, presented for Uzbekistan in map 3.2.[4] In total, there are 4.13 million hectares of irrigation across the country, with 1.77 million hectares divided between the two Syr Darya sub-basins basin and 2.36 million hectares in the Amu Darya basin. According to Food and Agriculture Organization (FAO), very little irrigated agriculture exists in the smaller Aral Sea sub-basins.

Map 3.2 Irrigated Areas in Uzbekistan

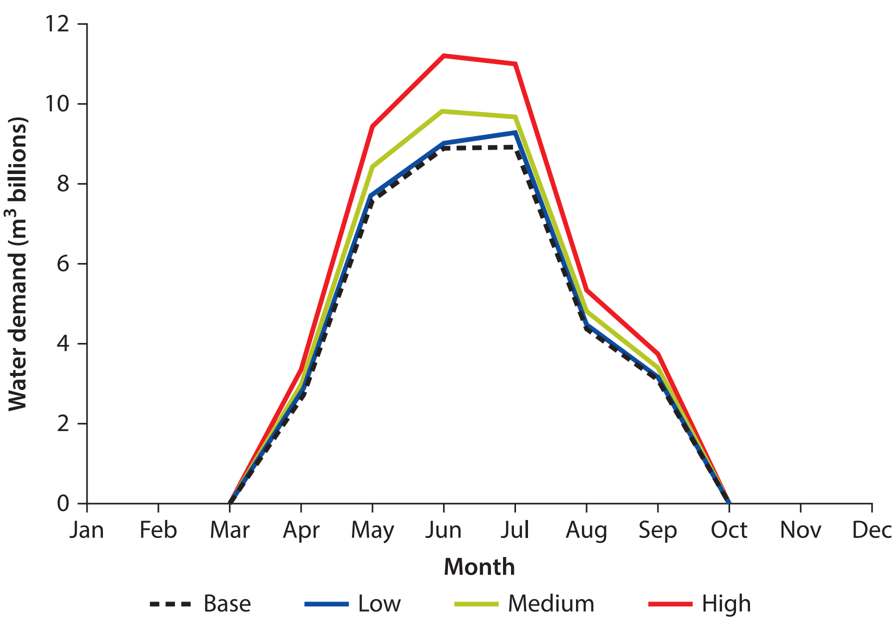


Sources: © Industrial Economics. Used with permission; further permission via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0. FAO 2011, Global Map of Irrigated Areas.

Crop irrigation requirements are affected by both temperature and precipitation, as water demand is directly linked to both crop yield and to evapotranspiration. These irrigation needs are derived from the AquaCrop model results described above. Figure 3.1 compares total monthly irrigation demands for Uzbekistan for the current baseline, and three climate scenarios for the 2040s. Note the rise in irrigation demand with climate change of up to 25 percent under the high-impact climate change scenario during the summer months.

Another key component of the modeled water demand balance is irrigation efficiency, which is the ratio of irrigation crop water demands to irrigation withdrawals. Irrigation efficiency in Uzbekistan is quite low due to several factors, including significant on-farm and conveyance losses, and saline soils that often make re-use of water unfeasible. On-farm losses result from surface runoff (over 99 percent of irrigation uses flood techniques such as furrow or border irrigation), seepage and evaporation from unlined earthen canals, operational waste, and deep percolation; these factors contribute to a farm-level efficiency in Uzbekistan of between 50 and 55 percent (see Lewis 1962). Conveyance losses, which the FAO estimates are 37 percent in Uzbekistan, result from unlined main irrigation canals (only 33 percent are lined), and operational waste.[5] Lastly, although some reuse of irrigation return flows does occur, residual irrigation water that is not lost to deep percolation or evaporation is often too saline to be reused and is typically collected in evaporation ponds. As a result of limited reuse of irrigation water, basin-level irrigation

Figure 3.1 Mean Monthly Irrigation Water Demand over All Uzbekistan Basins, 2040s



http://dx.doi.org/10.1596/978-1-4648-0000-9

efficiency is assumed to be the same as source-to-crop efficiency, at approximately 33 percent.[6]

Water demand forecasts for other sectors were incorporated into the WEAP model to account for potential conflicts between irrigation and other water uses. Specifically, World Bank forecasts for municipal and industrial (M&I) demand for water through 2050 in Uzbekistan were used (see Hughes et al. 2010). Although the M&I demands represent a small share of water use in Uzbekistan relative to agriculture, they are forecast to increase from 5.6 km^3 to 11.9 km^3 between 2011 and 2050, which is a 114 percent rise. In absence of information on the exact location of M&I water uses, these demands were allocated to each basin based on their populations, which was derived from Columbia University's Gridded Population of the World database.[7]

Modeling the effect of climate change on water supply was accomplished using CLIRUN. Water supply is measured based on runoff in rivers, which is the difference between precipitation and evapotranspiration; as a result, runoff is affected by both the temperature and the precipitation forecasts. CLIRUN is a two-layer, one-dimensional infiltration and runoff estimation tool that uses historic runoff as a means to estimate soil characteristics. In the absence of in-country station data on gauged flows, CLIRUN was calibrated for each basin using global historical gridded runoff data from the Global Runoff Data Center (GRDC), and gridded temperature and precipitation data from the Climate Research Unit (CRU) of the University of East Anglia.[8] R-squared values for the CLIRUN calibration were between 0.80 and 0.93 for the Syr Darya and Amu Darya basins, indicating a strong relationship between observed runoff and runoff modeled from precipitation and PET inputs. Once calibrated, CLIRUN uses monthly precipitation and PET projections under the three climate scenarios to project rainfall runoff in each of the five basins.

Figure 3.2 provides the annual runoff across the climate scenarios for all Uzbekistan basins between 2011 and 2050, and figure 3.3 compares the mean monthly runoff in the 2040s under the baseline and three climate scenarios. As expected, relative to current estimates, runoff declines under the high-impact scenario, increases under the low scenario, and remains close to the baseline under the medium scenario. Variability across the scenarios increases significantly after 2030. In terms of monthly effects, although annual runoff under the low-impact scenario is forecast to increase, runoff during the summer months declines under all three scenarios relative to baseline conditions. These reductions occur in months when crop water demand is highest, and when AquaCrop forecasts the most pronounced increase in crop demand under climate change.

The WEAP model utilizes these forecasts of changing water demand and supply to estimate potential irrigation water shortages under climate change. WEAP (Sieber and Purkey 2007) is a software tool for integrated water resources planning that provides a mathematical representation of the river basins encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, water demands, and reservoir storage. Computations are performed on a monthly time scale between 2011 and 2050 for a base-case

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure 3.2 Annual Runoff for All Uzbekistan Basins, 2011–50

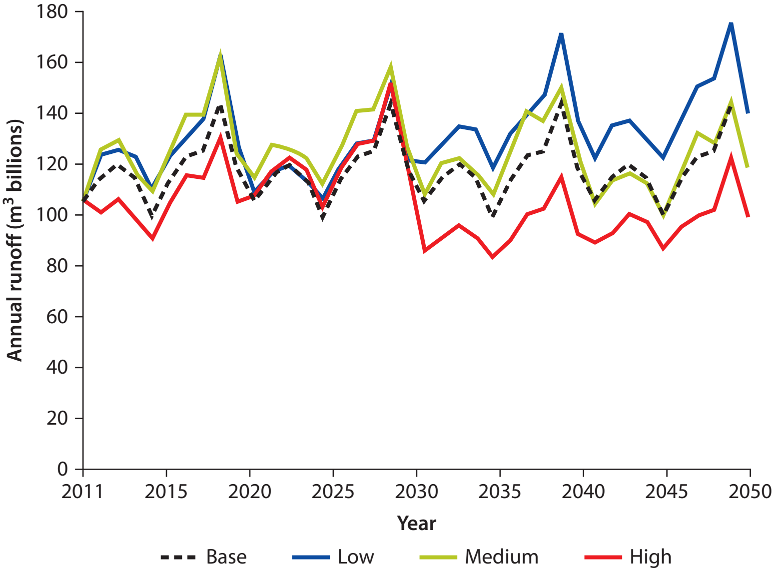
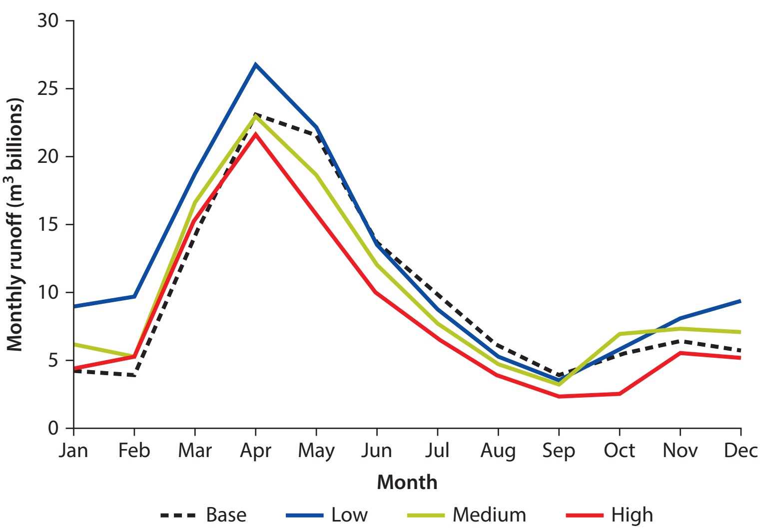


Figure 3.3 Mean Monthly Runoff for All Uzbekistan Basins, 2040s



scenario (that is, no climate change) and the three climate change scenarios, each of which is characterized by unique inflows and changing water demand. Surface water inflows from CLIRUN were used as inflows to an aggregated river in each basin modeled in WEAP. Water supplies and demands are linked between upstream and downstream basins (that is, Syr Darya East and West), and

http://dx.doi.org/10.1596/978-1-4648-0000-9

reservoirs, irrigation, and municipal and industrial demand locations were sequenced consistently with respect to their actual locations.

In addition to estimating changes in water supply and demand, the WEAP model also critically depends on information on reservoir volumes, locations and transboundary flow arrangements, and assumptions about environmental flow requirements.

- *Reservoir locations and volumes* were provided by Rakhmatullaev et al. (2010), who summarize reservoir volumes by administrative region within Uzbekistan. In total, they report that Uzbekistan has 19 km^3 of storage, of which 14.5 km^3 is usable (that is, active storage); of this usable storage, approximately 4.4 km^3 is within the Syr Darya basins, and 9.4 km^3 is in the Amu Darya basin.
- *Transboundary flow agreements* are also a critical determinant of water available in Uzbekistan, as each of the major rivers in Uzbekistan is shared with at least one other country. Although the Interstate Commission for Water Coordination (ICWC) is in the process of updating the water sharing strategy for the Aral Sea basins, current allocation is governed by agreements made during the Soviet period.[9] These agreements provided 29.6 km^3 of renewable Amu Darya flows and 11 km^3 of Syr Darya flows to Uzbekistan, which translate to 33 percent and 51 percent of the modeled mean annual runoff for these basins.[10] In the WEAP model, it was assumed that these sharing arrangements hold for all months, and that any increases or decreases in available water resulting from climate change would be shared proportionally between parties.
- *Environmental flow requirements.* A minimum flow requirement of 20 percent of Uzbekistan's water resources was assumed to be dedicated to environmental purposes. In the Amu Darya and two western Aral Sea basins, these flows enter the Aral Sea directly; in the Syr Darya basins they apply to flows entering Kazakhstan.

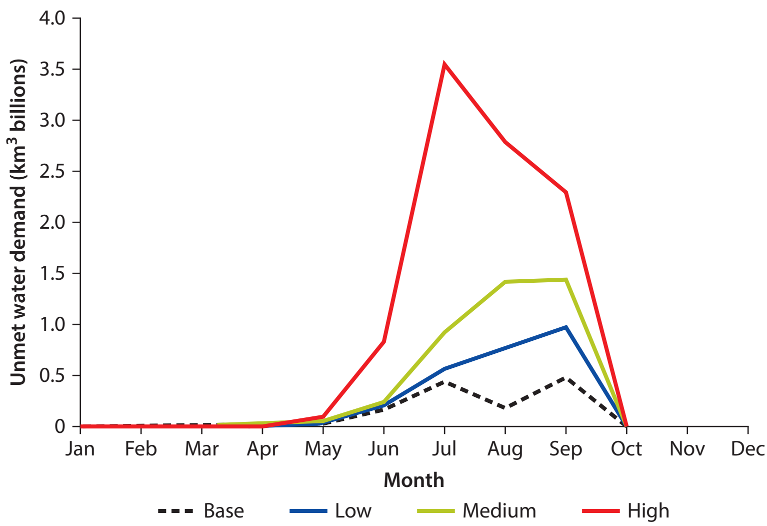
WEAP results indicate that unmet irrigation water demands already occur under the baseline, and rise significantly under climate change. Table 3.4 presents irrigation water shortages for the five basins under three climate scenarios in the 2040s. Under climate change, overall irrigation shortages are projected to increase to 8.0 percent under the low-impact scenario, 15.4 percent under the medium-impact scenario, and 33.5 percent under the high-impact scenario by the 2040s. Importantly, under the high-impact scenario, over 50 percent of irrigation demand is unmet in the Syr Darya East basin, and approximately one-third of demand in the Syr Darya West and Amu Darya is not met. Although mean annual runoff increases in the low-impact scenario, shortfalls rise in all scenarios because, as described above, irrigation demands are higher and available runoff is lower during the summer months. This effect is evident in a graph of mean monthly unmet irrigation water demands in the 2040s, which is provided in figure 3.4.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 3.4 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario

	Climate scenario (shortfall in irrigation water, m³ and percent of total irrigation demand)					
	Low impact 2040s		*Medium impact 2040s*		*High impact 2040s*	
Basin	*m³ thousands*	*% shortfall*	*m³ thousands*	*% shortfall*	*m³ thousands*	*% shortfall*
Syr Darya East	615,927	11.6	940,601	17.5	3,627,991	51.6
Syr Darya West	122,023	1.9	325,942	4.7	2,817,031	34.4
Amu Darya	2,174,069	8.7	4,807,848	17.8	8,405,243	28.9
Aral Sea East	0	0	0	0	0	0
Aral Sea West	0	0	0	0	0	0
Subtotal	2,912,019	8.0	6,074,391	15.4	14,850,265	33.5

Figure 3.4 Mean Unmet Monthly Irrigation Water Demand over All Uzbekistan Basins, 2040s



There are several important limitations to this analysis that if addressed, would improve the certainty of the results:

- *Gauged historical runoff, temperature, and precipitation data*. Although the global GRDC and CRU datasets are ultimately sourced from gauged station data, CLIRUN results could be improved with reliable gauged hydrometeorological data from in-country sources. Similarly, crop water demand projections could benefit from daily meteorological station data.

http://dx.doi.org/10.1596/978-1-4648-0000-9

- *Groundwater use*. The WEAP model does not incorporate groundwater resources in the overall water balance, based on the assumption that these resources ultimately interact with and influence either the quantity or quality of surface water supplies (see Winter et al. 1998). Assuming that these withdrawals are truly separable from surface water resources and that groundwater mining is not occurring, including these resources in the model would increase water availability.
- *Water quality*. Insufficient information was available to assess the implications of deteriorating water quality and increasingly saline soils on water demands in future years. Lessening quality is likely to either further reduce reuse of irrigation water, or cause yields to decline. To the extent that increasing soil salinity causes certain irrigated hectares to fall out of production, irrigation water demand would decline.
- *Basin spatial boundaries*. Because GRDC gridded runoff data are measured in millimeters, the total volumetric runoff estimates are highly dependent upon basin area (that is, total monthly runoff is basin area multiplied by runoff depth). For example, the high modeled relative to measured mean annual runoff in the Amu Darya may reflect too large a basin area. Such discrepancies are partly adjusted for based on the transboundary flow allocations described above.
- *Future irrigation and storage projects*. The analysis assumes that no new reservoirs or irrigation projects will be constructed through 2050. If the construction schedule for any such projects were known with certainty, they could be incorporated into the WEAP baseline and would affect the overall water balance.
- *Reservoir sedimentation*. Reservoir volumes are assumed to remain constant at reported levels and that sedimentation does not cause substantial reductions in storage capacity. This assumption may overestimate storage availability over the next 40 years.

Effect of Irrigation Water Shortages on Crop Yields

As a final step in evaluating impacts of climate on agriculture, the results of the crop and water impact analyses were combined to evaluate how crop yields may be affected by reductions in basin-level water availability. To adjust mean changes in crop yields reported above (tables 3.1 and 3.2) for changes in water availability projected by WEAP, information from FAO on crop sensitivity to water availability was combined with basin-level water deficits from WEAP. To do so, it was first assumed that each farm will receive the percentage of water that WEAP projects will be available at the basin level (table 3.4). For example, WEAP projects an irrigation water deficit of 4.7 percent in the Syr Darya West basin under the medium-climate scenario in the 2040s; from this it can be assumed that each farm in the Syr Darya West receives 95.3 percent of the water necessary to meet all irrigation needs. With less water available, an irrigator can either evenly distribute the remaining water over the field so that each crop

http://dx.doi.org/10.1596/978-1-4648-0000-9

receives less water (that is, deficit irrigation), or meet all irrigation needs of a fraction of the crops, leaving the remaining fraction unirrigated.

Determining which approach will produce higher yields depends on the sensitivity of the particular crop planted. For crops that are highly sensitive to water application, deficit irrigation would result in disproportionately lower yields relative to the irrigation deficit, so the second approach (that is, 100 percent of water to a fraction of crops) will generate higher farm-level yields, even though this approach would cause complete loss of production on a portion of the land. On the other hand, deficit irrigation will generate higher farm-level yields for crops that are relatively less sensitive to water application.

The relationship, or elasticity, between relative crop yield and relative water deficit is called the yield response factor (K_y); FAO has developed crop-specific yield response factors for each stage of the growing season. In general, the decrease in yield due to water deficit is relatively small during the vegetative period, whereas it is large during the flowering and yield formulation periods.[11] FAO has aggregated these seasonal factors into a single coefficient for the entire growing season. For K_y values less than one, deficit irrigation causes crop yields to fall less than the water deficit, whereas K_y values greater than one result in higher yield losses relative to the water deficit. For example, If K_y for a particular crop is 0.9 and the water deficit is 10 percent, the resulting yield loss will be 9 percent (that is, 0.9*10 percent). If the K_y value for another crop is 1.1, the resulting yield loss will be 11 percent.

Table 3.5 presents the growing season K_y values for each crop from FAO's CropWat decision support tool. Note that only cotton has an overall growing season K_y value less than one, so deficit irrigation will reduce yield losses for only that crop. A response factor was not available for apples, but because response factors for other fruit trees were greater than one, it was assumed that the factor for apples would be above one as well.

These factors are used to estimate the change in yield resulting from a reduction in water availability for each crop, unique AEZ-basin area, and climate scenario. At the high end of yield impacts, crops have K_y values greater than one

Table 3.5 FAO Crop Response Factors

Crop	K_Y	*FAO crop name*
Alfalfa	1	Alfalfa 1
Apples	>1	Assumed; other fruit trees are 1 or greater
Cotton	0.85	Cotton
Grassland	1	Turf Grass
Potatoes	1.1	Potato
Tomatoes	1.05	Tomato
Winter wheat	1	W. Wheat
Spring wheat	1.15	Wheat

Source: FAO 2010, CropWat 8.0. Accessed March 22, 2011, from http://www.fao.org/nr/water/infores_databases_cropwat.html.
Note: K_y = yield response factor (the elasticity between relative crop yield and relative water deficit).

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 3.6 Effect of Climate Change on Irrigated Crop Yields 2040–50 under the Three Impact Scenarios, Including Effects of Reduced Water Availability

% change

Scenario	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont East*	*Piedmont Southwest*
Low impact	Alfalfa	−2	−13	−12	24	−13
	Apples	−13	−23	−19	0	−20
	Cotton	−11	−19	−15	−3	−16
	Potatoes	−11	−22	−20	0	−19
	Tomatoes	−8	−21	−18	−2	−14
	Winter wheat	−1	−13	−14	19	−17
	Spring wheat	−9	−18	−18	5	−18
Medium impact	Alfalfa	−2	−16	−15	1	−17
	Apples	−12	−22	−25	−18	−25
	Cotton	−10	−20	−15	−17	−21
	Potatoes	−10	−21	−24	−16	−23
	Tomatoes	−9	−23	−18	−18	−24
	Winter wheat	−2	−20	−18	−7	−21
	Spring wheat	−14	−22	−28	−13	−28
High impact	Alfalfa	−33	−28	−27	−39	−28
	Apples	−49	−39	−43	−63	−42
	Cotton	−36	−31	−25	−49	−32
	Potatoes	−41	−37	−38	−57	−37
	Tomatoes	−45	−38	−29	−56	−40
	Winter wheat	−40	−32	−31	−42	−43
	Spring wheat	−55	−41	−50	−57	−49

Note: Results are average changes in crop yield, assuming no effect of carbon dioxide fertilization. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases.

and no deficit irrigation will take place. As a result, less area will be irrigated and farm-level crop yield will fall by the water deficit percentage. At the low-end, crops have K_y values less than one and crop yields fall by the water deficit percentage multiplied by the K_y value. The resulting mean decadal changes in irrigated crop yields, adjusted for 2040s water availability, are presented in table 3.6.

Notes

1. The results in tables 3.1 and 3.2 provide summary yield changes relative to current yields, expressed as average percent change per decade for the full 40-year study period. In table 3.1, orange indicates a decrease in yield, compared to the current situation, while green denotes an increase in yield. The results were calculated by taking the average percentage change for each of the four periods (2010s, 2020s, 2030s and 2040s) relative to the current situation. These percentage changes in many cases cannot be summed to reach to a total percentage over 40 years, because for some crops, AEZs and scenarios, the changes do not show a linear trend.

http://dx.doi.org/10.1596/978-1-4648-0000-9

2. A full accounting of indirect effects of climate change on crops would also incorporate the effects of higher ambient ozone, which also limits most crop yields.
3. FAO. AQUASTAT: Uzbekistan (accessed January 14, 2011), http://www.fao.org/nr/water/aquastat/countries/uzbekistan/index.stm.
4. FAO. AQUASTAT. Global Map of Irrigated Areas (accessed December 14, 2010), http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm.
5. FAO. AQUASTAT: Uzbekistan (accessed January 14, 2011), http://www.fao.org/nr/water/aquastat/countries/uzbekistan/index.stm.
6. See Lewis (1962). Basin level irrigation efficiency is total crop irrigation water requirements in a basin divided by total net basin irrigation withdrawals (that is, less reuse). For all of Uzbekistan, dividing average annual baseline irrigation water requirements from AquaCrop of 11.9 km^3 by 49.8 km^3 of net irrigation withdrawals (that is, 54.3 km^3 of irrigation withdrawals less 4.5 km^3 of reuse) yields an efficiency of 0.24, which is a lower value than that employed in this analysis.
7. SEDAC, Columbia University. 2011. Gridded Population of the World (accessed January 15, 2011), http://sedac.ciesin.columbia.edu/gpw/.
8. For more information on the GRDC data, see the supporting documentation at http://www.grdc.sr.unh.edu/html/paper/index.html (accessed on January 15, 2011). Information on the Climate Research Unit can be found at http://www.cru.uea.ac.uk/.
9. FAO. AQUASTAT: Uzbekistan (accessed January 14, 2011), http://www.fao.org/nr/water/aquastat/countries/uzbekistan/index.stm.
10. Rysbekov. 2004. Analysis of Water Management Organizations in Chirchik-Akhangaran River Basin (Central Asia) (accessed January 20, 2011), http://www.cawater-info.net/rivertwin/documents/pdf/rysbekov_e.pdf.
11. FAO. 1998. "Crop Evapotranspiration—Guidelines for Computing Crop Water Requirements." FAO Irrigation and Drainage Paper 56 (accessed March 22, 2011) http://www.fao.org/docrep/x0490e/x0490e00.htm#Contents.

http://dx.doi.org/10.1596/978-1-4648-0000-9

CHAPTER 4

Identification of Adaptation Options for Managing Risk to Uzbekistan's Agricultural Systems

Options for Consideration

This section describes the qualitative approach to identifying and evaluating adaptation options, with a focus on those adaptation options that are not amenable to the quantitative assessment. The qualitative analyses are based on the judgment of three sets of individuals: (1) Uzbek in-country agricultural experts who have been consulted throughout the study process; (2) farmers who shared their insights in consultation workshops; and (3) international experts engaged by the World Bank to conduct the analytical work for this study.

This section attempts to apply the same overall framework for identifying options as were used in the quantitative analyses (see chapter 5). In practice, that means attempting to identify options for which economic benefits (to farmers, primarily) seemingly exceed costs (regardless of who bears the costs: the Uzbekistan government, donors, cooperatives, farmers themselves, or some combination). To the extent possible, a clear rationale and a time frame for implementing the options are also identified. Finally, to the extent possible, to the recommendations are specific to Uzbekistan AEZs.

Table 4.1 provides the overall scope for the adaptation assessments in this chapter and in the quantitative analysis. The table includes four categories of options: (A) infrastructural adaptations, which are "hard" adaptation options that involve improvements of agriculture sector infrastructure, including water resource infrastructure improvements or expansions that are specifically targeted toward water available for irrigation; (B) programmatic adaptations, which strengthen existing programs or create new ones; (C) farm management adaptations, which are farm-level measures, and make up the largest portion of the list; and (D) indirect adaptations, which are options not directly aimed at the agriculture sector, but which would benefit agriculture. Options that were evaluated quantitatively in chapter 1 are highlighted in bold in the table.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 4.1 Adaptation Options for Consideration

Category	*Adaptation measures and investments*	*Adaptation option reference number*
A. Infrastructural adaptations		
Farm protection	**Hail protection systems (nets)**	**A.1**
	Install plant protection belts	A.2
	Lime dust on greenhouses to reduce heat	A.3
	Vegetative barriers, snow fences, windbreaks	A.4
	Move crops to greenhouses	**A.5**
	Smoke curtains to address late spring and early fall frosts	A.6
	Build or rehabilitate forest belts	A.7
Livestock protection	Increase shelter and water points for animals	A.8
	Windbreak planting to provide shelter for animals from extreme weather	A.9
Water management	Enhance flood plain management (for example, wetland management)	A.10
	Construct levees	A.11
	Drainage systems	**A.12**
	Irrigation systems: new, rehabilitated, or modernized	**A.13**
	Water harvesting and efficiency improvements	**A.14**
B. Programmatic adaptations		
Extension and market development	Demonstration plots and/or knowledge sharing opportunities	B.1
	Education and training of farmers via extension services (new technology and knowledge-based farming practices)	**B.2**
	National research and technology transfer through extension programs	**B.3**
	Private enterprises, as well as public or cooperative organizations for farm inputs (for example, seeds, machinery)	B.4
	Strong linkages with local, national, and international markets for agricultural goods	B.5
Livestock management	Fodder banks	B.6
Information systems	Better information on pest controls	B.7
	Estimates of future crop prices	B.8
	Improve monitoring, communication, and distribution of information (for example, early warning system for weather events)	B.9
	Information about available water resources	**B.10**
Insurance and subsidies	Crop insurance	B.11
	Subsidies and/or supplying modern equipment	B.12
R&D	**Locally relevant agricultural research in techniques and crop varieties**	**B.13**
C. Farm management adaptations		
Crop yield management	Change fallow and mulching practices to retain moisture and organic matter	C.1
	Change in cultivation techniques	C.2
	Conservation tillage	C.3
	Crop diversification	C.4

table continues next page

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 4.1 Adaptation Options for Consideration *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*
	Crop rotation	C.5
	Heat- and drought-resistant crops/varieties/hybrids	C.6
	Increased input of agro-chemicals and/or organic matter to maintain yield	**C.7**
	Manual weeding	C.8
	More turning over of the soil	C.9
	Strip cropping, contour bunding (or plowing) and farming	C.10
	Switch to crops, varieties appropriate to temp, precipitation	**C.11**
	Optimize timing of operations (planting, inputs, irrigation, harvest)	**C.12**
Land management	Allocate fields prone to flooding from sea level rise as set-asides	C.13
	Mixed farming systems (crops, livestock, and trees)	C.14
	Shift crops from areas that are vulnerable to drought	C.15
	Switch from field to tree crops (agro-forestry)	C.16
Livestock management	Livestock management (including animal breed choice, heat tolerant, change shearing patterns, change breeding patterns)	C.17
	Match stocking densities to forage production	C.18
	Pasture management (rotational grazing, etc.) and improvement	C.19
	Rangeland rehabilitation and management	C.20
	Supplemental feed	C.21
	Vaccinate livestock	C.22
Pest and fire management	Develop sustainable integrated pesticide strategies	C.23
	Fire management for forest and brush fires	C.24
	Integrated pest management	C.25
	Introduce natural predators	C.26
Water management	Intercropping to maximize use of moisture	C.27
	Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night)	**C.28**
	Use water-efficient crop varieties	**C.29**
D. Indirect adaptations		
Market development	Physical infrastructure and logistical support for storing, transporting, and distributing farm outputs	D.1
Education	Increase general education level of farmers	D.2
Water management	Improvements in water allocation laws and regulations	D.3
	Institute water charging or tradable permit schemes	D.4

Note: Adaptation options in bold are those that are evaluated quantitatively in chapter 5.

Recommendations from Farmers

An important component of the study is to inform and consult stakeholders—farmers and farmers' associations—on the impact of climate change on agriculture and water resources. The team first met with farmers for structured workshops in Tashkent in December 2010, for a two-day stakeholder consultation.

http://dx.doi.org/10.1596/978-1-4648-0000-9

For the first day, a formal consultation was organized at the Farmer Association in Tashkent. A total of over 50 farmers from the region attended the workshop. On the second day, farmers in the Tashkent region (Yangibozor) were visited on their farms. The objectives of these stakeholders' consultations were to solicit input from stakeholders as to their reactions and concerns around a list of potential climate impacts, and to record their thoughts and concerns about proposed adaptation responses.

The team also met with farmers in Urgench and again in Yangibozor in March 2011, just prior to the National Conference. Farmers, ministry personnel, and Extension Service workers were in attendance. A total of roughly 40 individuals attended the two conferences.

Below is first a description of the outcomes of the first stakeholder workshops, followed by a review of outcomes from the second workshops.

First Stakeholder Workshops—December 2010

Farmer Assessment of the Impacts of Climate Change to Agriculture

Farmers were first asked whether they had experienced the impact of climate change and whether they thought farming will be influenced, now and in the future, by this climate change. The following topics were identified as most relevant to the farmers:

- The number of pests and diseases has increased substantially over the last few years. Mainly wheat and vegetables, and to a certain extent cotton, were hit hard by various diseases. Some of these diseases are new to Uzbekistan.
- Snow cover and cold temperatures during wintertime are essential for winter wheat, but have been limited over recent years.
- Many complaints were raised about the level of support farmers received from the government, centered on the need for enhanced technical knowledge from agronomists, fertilizer specialists, and crop disease experts.
- Most farmers were from the Tashkent region and their crops suffered from air pollution from factories, specifically from the aluminum industry.
- Cotton yields were very low this year. In recent years, about 3.5 tons per hectare could be obtained, but in 2010 yields decreased to 1.5 to 1.8 tons per hectare. The main reasons farmers cited for the yield decline were diseases and very erratic rains.
- Wheat has experienced serious heat stress in the low elevation areas. Wheat also required about two times as much irrigation over the last three years owing to the shortage of rainfall. In general, farmers believed that the year 2008 marked the beginning of a period of unusually low rainfall.
- In general, farmers believed that overall yields had declined by 5–10 percent over the last decade, with the last three years showing the steepest decreases in yields owing to shortage of rainfall and high temperatures.

At the conclusion of this discussion, a set of eight most likely impacts of climate change on agriculture, based on international experience, were presented

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 4.2 Farmers' Rankings of the Relevance of Eight Risks of Climate Change to Agriculture (1 to 5 Scale, with 5 Being Most Relevant)

Climate change impact	*Relevance to Tashkent region*	*Relevance to Uzbekistan*
Crop area changes due to decrease in optimal farming conditions	1	1
Decreased crop productivity	2	2
Increased risk of agricultural pests, diseases, and weeds	3	3
Increased risk of floods	1	1
Increased risk of drought and water scarcity	2	4
Increased irrigation requirements	3	4
Soil erosion, salinization, desertification	2	5
Deterioration of conditions for livestock production	1–2	1–2

to the stakeholders. These eight issues were discussed in detail and farmers were asked to rank their relevance for their own situations using a 1 to 5 scale, with 1 meaning not relevant and 5 very relevant (table 4.2).

Farmer Assessment of Adaptation Options

Secondly, famers were exposed to a list of potential adaptation options to respond to these impacts and were also asked to mark these between 1 (not relevant) and 5 (extremely relevant). Farmers were asked to consider the entire country, but for some items the emphasis was put on the region of origin (mainly Tashkent and surroundings). Items marked with an "X" in table 4.3 were not mentioned in the discussion.

Summarizing the discussions and results from the ranking the following conclusions can be drawn. First, farmers are mainly concerned about (1) air

Table 4.3 Farmers' Ranking of Relevance of Climate Change Adaptation Options for Uzbekistan as a Whole and the Tashkent Region in Particular, December 2010 (1 to 5 Scale, with 5 Being Most Relevant)

Climate change impact	*Agricultural adaptation*	*Ranking*
Crop area changes due to decrease in optimal farming conditions	Changing cropping mix	2–3
	Changing application of inputs, such as water	4
	Switching to alternative crops	X
	Investing in irrigation infrastructure	4
	Extensification: enhance carbon management and zero tillage	X
	Precision agriculture: improve soil and crop management	X
	Increase investment in crop genetics	X
	Regional or nationwide crop insurance programs	5
Decreased crop productivity	Change in cropping mix	2–3
	Increased input of agro-chemicals to maintain yields	2
	Investing in irrigation infrastructure	4

table continues next page

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 4.3 Farmers' Ranking of Relevance of Climate Change Adaptation Options for Uzbekistan as a Whole and the Tashkent Region in Particular, December 2010 (1 to 5 Scale, with 5 Being the Most Relevant) *(continued)*

Climate change impact	*Agricultural adaptation*	*Ranking*
	Invest in cultivar and other agricultural research	4
	Enhance technology transfer through improved extension services	5
Increased risk of agricultural pests, diseases, and weeds	Use new pest-resistant varieties	5
	Introduction of natural predators	4
	Vaccinate livestock	X
	Develop sustainable integrated pesticides strategy	5
Increased risk of floods	Create/restore wetlands	X
	Enhance flood plain management	1
	Increase rainfall interception capacity	1
	Reduce grazing pressures to protect against soil erosion	3
	Contour plowing and increasing drainage	X
	Regional or nationwide flood insurance program	X
	Construct levees	1
Increased risk of drought and water scarcity	Shift crops from areas that are vulnerable to drought	3
	Increase water use efficiency	3
	Installation of small-scale reservoirs on farmland	1
	Alter crop rotations to introduce crops more tolerant to heat/drought	4
	Use of precision farming: tillage and timing of operations	X
	Water charging or tradable permit schemes	1
	Regional or nationwide drought insurance program	5
	Construction of large scale reservoirs	3
Increased irrigation requirements	Investing in irrigation infrastructure	4
	Investing in water saving infrastructure (for example, drip irrigation)	5
	Irrigating at night	1
	Installation of small-scale reservoirs on farmland	1
	Construction of large-scale reservoirs	3
Soil erosion, salinization, desertification	Change cropping mix	2–3
	Change fallow and mulching practices to retain moisture and organic matter	2–3
	Use intercropping to maximize use of moisture	1
	Reduce grazing pressures to protect against soil erosion	1
	Contour plowing and increasing drainage	X
	Allocate fields prone to flooding from sea level rise as set-asides	1
Deterioration of conditions for livestock production	Increase shelter for animals	X
	Windbreak planting to provide shelter for animals from extreme weather	X
	Change breeding and shearing patterns for sheep production	2
	Supplemental feeding	X
	Change the timing of operations	2
	Introduction of more heat tolerant species/breeds	5
	Match stocking densities to forage production	X

http://dx.doi.org/10.1596/978-1-4648-0000-9

pollution, (2) lack of support in terms of extension services, and (3) large increase of pests and diseases. In terms of climate change farmers are mainly concerned about the following issues:

- Increased risk of drought, water scarcity, and higher irrigation requirements
- Increased risk of agricultural pests, diseases, and weeds
- Soil erosion, salinization, and desertification.

The most relevant adaptation strategies to climate change for farmers were:

- Technology transfer and improved extension services
- Improved crop varieties focusing on heat, drought, and pest resistance
- Improved insurance schemes to compensate for drought losses
- Investments in improved irrigation techniques
- Investments in irrigation infrastructure.

Second Stakeholder Consultations—March 2011

The second of two rounds of agricultural stakeholder meetings was held in Uzbekistan March 7–9, 2011. Climate change outreach events were held in the cities of Urgench and Tashkent with farmers and other stakeholders. Farmers from these locations come from the three agro-ecological zones of Uzbekistan: the Desert/Steppe, Piedmont, and Highlands. Farmers, ministry personnel, and Extension Service workers were in attendance.

Stakeholders confirmed that the impacts presented have been felt on local farms. Although farmers are becoming more flexible in their response to climate change through education, their adaptive capacity is still quite limited. This is mainly because of inefficient and poorly maintained irrigation and drainage systems, limited access to the best technologies and seed varieties, and minimal support from extension services.

The ranked list in table 4.4 provides the top three AEZ-level and national adaptation options that farmers made across all AEZs.

Below, information is provided for each of the consultations regarding the participants, adaptive capacity, and ranked adaptation recommendations.

Desert and Steppe AEZ: Urgench, March 7, 2011

Participants. A total of 33 individuals participated in the Urgench consultation, including farmers, farmers' association representatives, and regional representatives from the Department of Agriculture and Water Resources. Twenty-six of the participants were farmers from farms ranging in size from less than 2–200 hectares. Generally crops grown on the farms were wheat and cotton, usually in equal proportions. Other crops included fruit trees, vegetables, melons, and fodder. Two of the farmers also kept cattle, totaling about 180 head.

Recommendations. The most significant effects in this AEZ are droughts, heat waves, and wind. The wind deposits salts and sediments from the receding Aral Sea. Farmers' capacity to adapt to climate change is especially stressed during

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 4.4 Ranked AEZ- and National-Level Stakeholder Recommendations

AEZ or national level	*Recommendation*	*Description*
AEZ level	1. Water use efficiency	The efficient use of water was foremost in the minds of farmers. Drip irrigation and sprinkler irrigation most often mentioned. Water capture and storage techniques, such as small holding reservoirs were also suggested.
	2. Increase access to seed variety and new information	Farmers mentioned the need for better research and development regarding modern seed varieties, and increased availability of newly developed seeds. When asked about farmer interaction with extension services, they said they had none.
	3. Irrigation and drainage infrastructure	Generally, these recommendations focused on rehabilitating existing irrigation and drainage canals and installing more water conserving technologies such as drip irrigation. Traveling within the region, the consultants noticed significant visible damage to irrigation delivery systems and blocked drainage canals.
National level	1. Increase farmer access to technology and information through extension services	This option was strongly supported.
	2. Investigate options for improved crop insurance schemes especially for drought and pests	This option was supported, though there was some discrepancy regarding insurance schemes. Many farmers cited the government quotas and contracts as functioning as "insurance."
	3. Encourage private sector adaptation	This option was strongly supported.

the summer growing months when water availability is low. In response to these concerns, farmers ranked the following adaptation responses in order of importance:

1. *Water savings technologies:* For example, some farmers have already started to use drip irrigation, providing high yields especially for tomatoes. Specific recommendations on water savings technologies included the following:

   - Concrete-line irrigation channel: Need a resin-based barrier beneath the concrete. (This was considered a higher priority than drip irrigation, or should take place before drip irrigation.)
   - Drip irrigation.

2. *Drainage system improvement:* Specific recommendations included:

   - Vertical drainage systems (open and tile drains that lower the water table)
   - Bio-drainage systems. This is done by planting trees (Mulberry trees were mentioned specifically) over underground drainage channels. In addition

http://dx.doi.org/10.1596/978-1-4648-0000-9

to drainage the process prevents wind erosion (though it does nothing to remove salt).

3. *Improved access to newer varieties and information:* Specific recommendations included:

   - Strengthen field crop, horticulture, and vegetables research.
   - Improve availability of good quality seeds, by improving seed production and distribution system.
   - Increase knowledge and expertise of extension staff.

4. *Improved varieties* (especially for pest, heat, drought, and salt tolerance).

Highlands and Piedmont AEZs: Tashkent, March 9, 2011

Participants. A total of twenty individuals participated in the stakeholder consultations. Of the attendees fifteen were farmers, four were district representatives of the Ministry of Agriculture and Water Resources, and one was the chairman from the Water Users Association in the district. Most managed large farms of between 90 and 200 hectares; however, there were also a few present who had small fruit and vegetable farms of one or two hectares. Cotton and wheat represented most of the crops in equal measure; and nearly all the fields were irrigated. There were also two cattle and sheep ranchers.

Recommendations. Unlike the salinity issues of the Desert/Steppe AEZ, the most significant climate impact experienced in this region is water shortages during the growing season. They also mentioned hot, easterly winds that damaged crops, and increased pests. In a previous consultation farmers mentioned inadequate snow cover for winter wheat, dry conditions that necessitated 2–3 times normal irrigation amounts, and decreased yields of 5–10 percent during the past five years. To adapt to these impacts, water-use efficiency was foremost on their minds. As a result, improved irrigation techniques such as drip irrigation and vertical drainage ranked highest on the list, followed closely by access to modern seed varieties. Farmers also stressed the need for rehabilitated infrastructure. During field travel the consultants noticed significant damage to irrigation delivery systems resulting in water loss. Farmers ranked all adaptation options as follows:

1. *Water saving technologies:*

   - Install drip irrigation (drawing from surface water if possible: ground water is very deep, 160–200 meters, and expensive to access).
   - Construct small reservoirs for retaining water.

2. *Improved drainage:*

   - Install vertical drainage system (open and tile).

http://dx.doi.org/10.1596/978-1-4648-0000-9

3. *Improved access to newer varieties and information:*

   - Improve seed development (especially drought- and pest-resistant varieties) and the distribution system.
   - Improve access to and quality of extension services (when asked about extension farmers replied that they had no contact).

4. *Use of greenhouses, especially for vegetables.*

The adaptive capacity of farmers in Uzbekistan has recently been stressed by climate change. The primary concerns are a lack of available water during the growing season, and winds in the west that carry salt from the dry bed of the Aral Sea. Pests are also becoming more of a problem given the warmer temperatures. The combination of these factors heightened their awareness of climate change and increased their motivation to both discuss, and presumably implement these options and others. While on-farm adaptation responses have been numerous and partially successful, larger investments in infrastructure are needed. This includes improved water delivery systems, drainage and assorted water efficiency strategies. Finally, improved access to modern crop varieties and new information was seen as invaluable.

Options Offered by the Team

Concerning crops, the team arrived at a general conclusion that the adaptation deficit, or the difference between current Uzbekistan yields and potential yields for current climate, may be larger than the incremental gains that can be made to better adapt the Uzbekistan system to the projected effects of climate change. Closing the adaptation deficit should be accomplished with future climate change explicitly considered, especially for larger capital/infrastructural projects such as drainage infrastructure construction and/or rehabilitation. Every large investment project should include analyses of climate change in the design phase, because it is much less expensive to incorporate adjustments in the design phase than as a retrofit option after the system is built.

The most critical need in Uzbekistan, however, concerns irrigation water availability. Climate change will increase water demand for agriculture and decrease water supply, even with higher precipitation, requiring Uzbekistan to improve water use efficiency for on-farm and water distribution systems. Recommended options include the following:

- *Optimize use of irrigation water (for example, irrigation at critical stages of crop growth) and optimize timing of operations (planting, inputs, irrigation, harvest) (Options C.12 and C.28)*. Training of farmers to make better use of existing inputs is a high priority.
- *Invest in irrigation systems: new, rehabilitated, or modernized (Option A.13)*. The existing irrigation system is extensive, suggesting that rehabilitation will

http://dx.doi.org/10.1596/978-1-4648-0000-9

be much more cost-effective. Lining of irrigation channels to improve water use efficiency is likely to have a high benefit-cost ratio.

- *Improve water allocation laws and regulations (Option D.3)*. Currently, it appears there are few incentives for farmers to use water efficiency. A water allocation system that provides better signals about the importance of conserving scarce water would improve on-farm water use efficiency.
- *Improve drainage infrastructure and educate on drainage practices at farm level (Options A.12, B.2, and C.13)*. Drainage is necessary in Uzbekistan to reduce soil salinity. Drainage infrastructure is evaluated quantitatively in chapter 5, but to realize the full benefits of that infrastructure option better farmer education is needed.
- *Increase general education level of farmers (Options B.1, B.2, and B.3; possibly coupled with B.14)*. More specifically, this option involves improving the existing extension agency capacity overall to support better agronomic practices at the farm level, and strategic implementation of a plan for more widespread demonstration plots. This option could also be coupled with investment in research focused on the testing of varieties that are better tuned for future climate.
- *Switch to crops and varieties appropriate to future climate regime (Options C.11, C.6, and B.2)*. This option, assessed quantitatively in chapter 5, requires a combination of increased knowledge at the national level and effective extension to advise farmers on those varieties best suited to the emerging temperature and precipitation trends. This option has both a medium-term and a long-term component.
- *Consider modifying existing crop insurance programs (Option B.11)*. The Uzbekistan Country Note prepared for this study states that crop insurance is available to farmers, but is not widely subscribed. Nonetheless, during consultations farmers placed a high priority on accessible crop insurance. Crop insurance is a risk-spreading instrument that provides more stable farmer income over time and across geography. If the goal in Uzbekistan is to avoid farmers facing severe income loss and/or bankruptcy, the available options include crop insurance (which in most countries is provided by a private entity but subsidized by the government) and direct government disaster relief. The choice will be based on whether government payouts on crop insurance subsidies are lower than disaster relief payouts. Crop insurance could cover all forms of natural disasters, including droughts, floods, heat waves, or hail events. If actuarially fair, most crop insurance is too expensive for farmers because the insurance pool is often not wide enough and participation is low. Although more attention has been paid to crop insurance in the United States and EU recently because of concerns about climate change, and some elements of this study provide information that might be useful in redesigning crop insurance programs, the development of crop insurance schemes is complex and requires much more detailed analysis than can be completed within the scope of this assessment. Additional information on a specific measure to improve the affordability of crop insurance, an index-based system, is included in box 4.1.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Box 4.1 Index-Based Insurance

Crop insurance is one adaptation that addresses increasing occurrences of extreme weather events that are predicted with climate change. Increased losses with natural disasters have been observed globally, with economic losses from natural events increasing ten-fold from 1950 to 1999 (Munich Re 2000). Classic crop insurance, which makes up the majority of crop insurance around the world, is not optimal for rural small-scale farmers in developing countries. Traditionally, insurance requires large expenses for assessment of damages. Index-based insurance products instead use meteorological measurements to determine indemnity payments, as opposed to assessing damages at the individual farm level, allowing for a lower premium cost. Additionally index-based insurance reduces adverse selection, where those most at risk are the only ones who purchase policies, and moral hazard, where insured farmers do not try to avoid or minimize loss (Roberts 2005).

This new type of insurance is particularly useful for damages that impact areas relatively evenly. For example, weather types that can be measured to estimate monetary damages include minimum or maximum temperatures over a period of time, quantities of rainfall in a certain time period (either excess or lack of rainfall), or certain wind speeds. Payments can either be determined through temperature, precipitation and wind speed thresholds, or on a graduated scale. Certain devastating events are difficult to assess using index-based insurances such as hail and non-native pest damage. Additionally, it can be difficult to assess damages from hurricanes, as hurricanes vary in size and wind strength, and tracking a hurricane's path is only an approximation of the actual path, which can lead to an unfair distribution of indemnity payments (Roberts 2005).

Index-based insurance is relatively new; however, implementation of both pilot and country-wide projects are fairly widespread. Two examples include crop insurance in Malawi and livestock insurance in Mongolia. Through FAO tools, effective weather-based crop yield indices for crop insurance were created for Malawi. A weather-based maize yield index for crop insurance for any point in Malawi can be determined every ten days, starting from the time of planting (FAO Data Tools). Additionally, the World Bank recommended an Index-Based Insurance Program based on livestock mortality rate by species and county in 2005 for Mongolia. The program has increased in popularity, with more than 14,000 insurance policies sold and indemnity payments made to the 2,117 herders who were eligible with livestock losses (World Bank 2010).

Greenhouse Gas Mitigation Potential of Adaptation Options

Many of the adaptive measures recommended here to improve the climate resilience of Uzbekistan's agricultural sector also have the potential to mitigate climate change now and in the future. Particular adaptive practices, like manure management, present promising opportunities to lower greenhouse emissions by either reducing the greenhouse gases emitted in agricultural production processes or increasing the carbon stored in agricultural soils. This section discusses the potential for greenhouse gas mitigation in Uzbekistan's agricultural sector and highlights the specific adaptive measures that demonstrate the greatest opportunities for emissions reductions. A summary of the mitigation potential of various adaptive measures is provided in table 4.5.

Table 4.5 Greenhouse Gas Mitigation Potential of Adaptation Options

Adaptation measure	*Adaptation option reference number*	*Mitigation impact*	*Mitigation potential*
Irrigation systems: new, rehabilitated, or modernized (including drip irrigation; irrigation using less power)	A.13	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓
Change fallow and mulching practices to retain moisture and organic matter	C.1	Increases carbon inputs to soil and promotes soil carbon sequestration; reduces energy used in transportation; reduces energy consumption for production of agrochemicals.	✓✓
Conservation tillage	C.3	Minimizes the disturbance of soil and subsequent exposure of soil carbon to the air; reduces soil decomposition and the release of CO_2 into the atmosphere; reduces plant residue removed from soil thereby increasing carbon stored in soils; reduces emissions from use of heavy machinery.	✓✓
Crop rotation	C.5	Rotation species with high residue yields help retain nutrients in soil and reduces emissions of GHG by carbon fixing and reduced soil carbon losses. Also increases carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Strip cropping, contour bunding (or plowing) and farming	C.10	Increases carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Optimize timing of operations (planting, inputs, irrigation, harvest)	C.12	More efficient fertilizer use reduces N losses, including NO_2 emissions; more efficient irrigation minimizes CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓✓
Allocate fields prone to flooding from sea level rise as set-asides	C.13	Increases soil carbon stocks; especially in highly degraded soils that are at risk erosion.	✓✓
Switch from field to tree crops (agro-forestry)	C.16	Retains nutrients in soil and reduces emissions of GHG by fixing atmospheric N, reducing losses of soil N, and increasing carbon soil sequestration.	✓✓
Livestock management (including animal breed choice, heat tolerant, change shearing practices, change breeding patterns)	C.17	Reduces CH_4 emissions.	✓
Match stocking densities to forage production	C.18	Reduces CH_4 emissions by speeding digestive processes.	✓

table continues next page

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 4.5 Greenhouse Gas Mitigation Potential of Adaptation Options *(continued)*

Adaptation measure	*Adaptation option reference number*	*Mitigation impact*	*Mitigation potential*
Pasture management (rotational grazing, etc.) and improvement	C.19	Degraded pastureland may be able to sequester additional carbon by boosting plant productivity through fertilization, irrigation, improved grazing, introduction of legumes, and/or use of improved grass species.	✓✓
Rangeland rehabilitation and management	C.20	Degraded rangeland may be able to sequester additional carbon by boosting plant productivity through fertilization, irrigation, improved grazing, introduction of legumes, and/or use of improved grass species.	✓✓
Intercropping to maximize use of moisture	C.27	Increases carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night)	C.28	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓
Use water-efficient crop varieties	C.29	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓

Sources: Islami et al. 2009; Medina and Iglesias 2010; Ososkova 2008; Paustian et al. 2006; Smith et al. 2005, 2008; Weiske 2007.
Note: CH_4 = methane, CO_2 = carbon dioxide, GHG = greenhouse gas; ✓✓✓ = high potential, ✓✓ = medium potential, ✓ = low potential.

The relative mitigation potential of the various adaptive measures described in table 4.5 is primarily based on each measure's contribution to climate change (Islami et al. 2009). Albania's SNC was relied on to estimate mitigation potential because Uzbekistan's SNC (Ososkova 2008) lacks a quantitative assessment of mitigation potential across adaptive agricultural practices. In particular, Albania's SNC estimates a "score" for each adaptive measure according to its potential to reduce greenhouse gas emissions and mitigate the economic impacts of climate change. The measures were classified by the greenhouse gas emission reduction potential score and assigned a high potential (three checks in table 4.5), a medium potential (two checks), and a low potential (one check).

The adaptive practices discussed in Albania's SNC were then mapped to those listed in table 4.5 based on similarities across qualitative descriptions. For example, Albania's SNC estimates the mitigation potential of "perennial crops (including agro-forestry practices), and reduced bare fallow frequency," which is attributed to "change fallow and mulching practices to retain moisture and organic matter" and "switch from field to tree crops (agro-forestry)." To supplement the analysis, a comprehensive review was also conducted of the economic and scientific literature related to the mitigating impacts of agricultural adaptation in Europe (Medina and Iglesias 2010; Paustian et al. 2006; Smith et al. 2005, 2008; Weiske 2007). The results of this review were used to corroborate the mitigation potentials identified in Albania's SNC and to provide additional mitigation potentials for adaptive measures that were not explicitly quantified in Albania's SNC.

Each year Uzbekistan's agricultural sector accounts for approximately 8 percent—or 16.1 million tons CO_2-equivalent—of the country's total greenhouse gas emissions which are generated by CO_2, nitrous oxide, and methane (Ososkova 2008). Mitigation of CO_2 emissions is primarily enabled by adaptive crop yield and cropland management practices that increase soil carbon content. Soil carbon content is augmented either by enhancing the uptake of atmospheric carbon in agricultural soils or by reducing carbon losses from agricultural soils. Specific adaptive practices that promote carbon soil sequestration include changing fallow season and mulching practices to retain moisture and organic matter and introducing cropping systems that promote high residue yields (that is, crop rotation, strip cropping, intercropping, cover cropping, etc.). Adaptive practices that slow rates of soil decomposition and reduce soil carbon losses include reduced till and no till farming.

Adaptive practices also have the ability to significantly reduce nitrous oxide and methane emissions. Nitrous oxide emissions are largely driven by fertilizer overuse and misuse, which increases soil nitrogen content and generates nitrous oxide losses. By improving fertilizer application techniques, specifically through more efficient allocation, timing, and placement of fertilizers, nitrous oxide emissions can be reduced while maintaining crop yields. Mitigation of methane emissions, on the other hand, is largely achieved by increasing the efficiency of livestock production. Optimizing breed choices, for example, serves to increase livestock production per animal thereby reducing overall methane emissions. Improved feed quality quickens digestive processes and also leads to reduced methane emissions. Finally, adaptive measures may also reduce the emissions associated with agricultural production processes. In particular, conservation tillage and manual weeding will reduce emissions generated by heavy machinery use. Similarly, increased irrigation efficiency reduces energy required to pump groundwater.

While climate change mitigation in Uzbekistan largely focuses on reducing greenhouse gas emissions in the energy sector, the mitigation potential of adaptive agricultural practices has also garnered some attention. For example, efficient irrigation systems, modernized water pumping units, and lightweight machinery have been identified as ways to maintain agricultural productivity and reduce greenhouse gas emissions. Furthermore, numerous projects have been proposed that promote improved methane recovery and combustion for livestock and poultry; together these projects may reduce annual emissions by 75,000 tons CO_2-equivalent (Ososkova 2008).

http://dx.doi.org/10.1596/978-1-4648-0000-9

CHAPTER 5

Cost-Benefit Analysis

Scope and Key Parameters

The quantitative cost-benefit analyses of adaptation options described in this chapter address seven of the most important adaptation options in a detailed fashion:

1. Adding new drainage capacity
2. Rehabilitating existing drainage infrastructure
3. Adding new irrigation capacity
4. Rehabilitating existing irrigation infrastructure
5. Improving water use efficiency in field
6. Changing crop varieties and species
7. Optimizing fertilizer use

These options may include costs for extension programs, as appropriate, if enhanced extension is necessary to achieve the full benefits of the adaptation option. This is true for two of these options, improving water use efficiency, and changing crop varieties. It is expected that farmers will incur some costs from these changes in farming practice, such as drip irrigation for improved water efficiency, and new seeds if varieties are change, but in the current situation, many aspects of these good farming practices are presumably not currently pursued because of a lack of knowledge at the farm level. This has been confirmed by at least some of the farmers in the consultations. Therefore, a component of additional costs that would be incurred to enable these measures is to improve the capacity of extension services and availability of new varieties and breeds.

In addition, less detailed analyses of three other options were conducted: improving and expanding extension services, separate from other adaptation options; improving basin-wide water efficiency; and expanding water storage capacity.[1]

The assessments were conducted at the farm level, on a per hectare basis, and consider available estimates of the incremental cash costs for implementing the option as well as the revenue implications of increasing crop yields. All the

http://dx.doi.org/10.1596/978-1-4648-0000-9

estimates are conducted for representative "model" farms, located in each of the three Uzbekistan AEZs, for farms that cultivate each of the key crops. With seven key crops, and three AEZs, there are a total of 21 model farms in the analyses.

The results presented here are useful as a first order assessment of actions that are likely to yield positive returns for farmers. No conclusions are however made in this analysis about farmers' ability to pay for these measures. For example, it may be concluded that irrigation infrastructure would increase farm-level revenue for certain crops and in certain locations, and the revenue increase would be greater than the per-hectare cost, that does not mean that the study recommends that farmers attempt to construct and pay for this infrastructure themselves. In fact, few farmers would actually be able to obtain individual farm-level irrigation infrastructure at the price per hectare used, which reflects construction of a broader irrigation infrastructure project with potentially significant economies of scale. In many cases, national policies and/or funding are needed to enable these adaptations to occur.

While some measures (for example, additional fertilizer) could be pursued with limited or no government or donor involvement, most could be more cost-effectively pursued as sector- or regional-scale programs. The results are therefore useful for decision-making at the national or regional scale, with the target decision-making audience being Uzbek government policymakers and donor communities with interest in financing agricultural sector investments.

The analyses reported here have limited scope and not all adaptation options considered with the Uzbek farmers and in-country experts could be assessed quantitatively for their effects on crop yields (the key element of the benefits side of the cost-benefit analysis). Also, for some options it was difficult to assess the overall costs. For those options that were not amenable to quantitative cost-benefit analysis, a qualitative assessment of benefits and costs was provided, based on evaluation by farmers and the team and summarized in chapter 4.

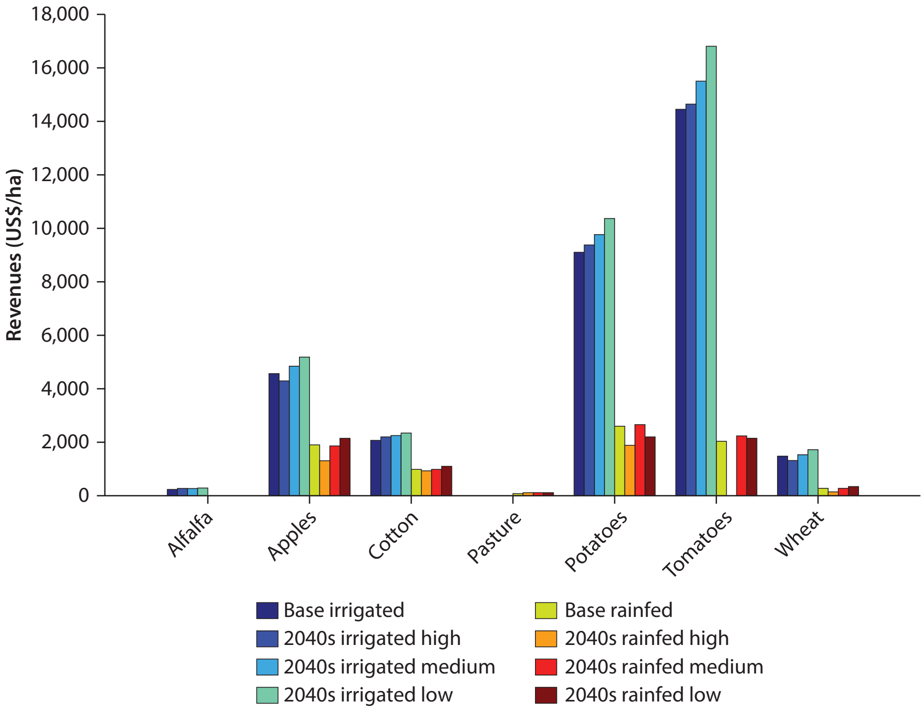
Other costs and benefits that do not affect farm expenditures or revenues were excluded from the quantitative analysis, mainly due to lack of available data. For example, while increasing fertilizer use may lead to social costs in terms of negative effects on nearby water quality, it is difficult to quantify those effects without consideration of the site-specific characteristics that may be unique to individual farms. While excluding those costs from the scope of the quantitative cost-benefit assessment, and focusing only on cash expenditures and revenues, social costs and other considerations were brought back into consideration qualitatively in the final chapter, as part of the overall menu of adaptation options.

Figure 5.1 presents the revenue per hectare for crops, comparing current conditions with those with climate change in the 2040s, but before adaptation actions are taken. For comparison purposes across years, the price forecasts incorporated in this figure are current prices rather than the "high" 2040 price forecasts.

In this figure it is clear that tomatoes provide the greatest yield per hectare.[2] What is not apparent is that tomatoes also require appropriate soil suitability and terrain, relatively intensive inputs of labor and nutrients, and also that irrigation

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure 5.1 Estimated Crop Revenues per Hectare for the 2040–50 Decade before Adaptation Actions Are Taken



water needs to be available to support tomato production at these yield levels. Potatoes are also a high-revenue crop. A general conclusion from figure 5.1 is that climate change alters yields and revenue estimates for all crops examined here, in the range of up to about a 10 percent decline in yields. As seen in the next section, implementing adaptation measures has on the other hand the potential to enhance yield more than 10 percent. This is because adaptation can both address current yield deficits relative to full yield potential (i.e., closing the adaptation deficit), and enhance farmers abilities to both minimize risks and exploit opportunities presented by climate change.

Results of Quantitative Analyses: Cost-Benefit and Present Value Assessments

This section presents sample results for each of the options analyzed. The quantitative results for each AEZ are summarized and ranked later in the chapter.

Adding New Drainage Capacity and Rehabilitating Existing Drainage Infrastructure

The results of an analysis of improving drainage are presented in figures 5.2 and 5.3, for the Desert and Steppe AEZ.

Figure 5.2 Benefit-Cost Analysis Results for Improved Drainage in the Eastern Portion of the Desert and Steppe AEZ—New Drainage Infrastructure

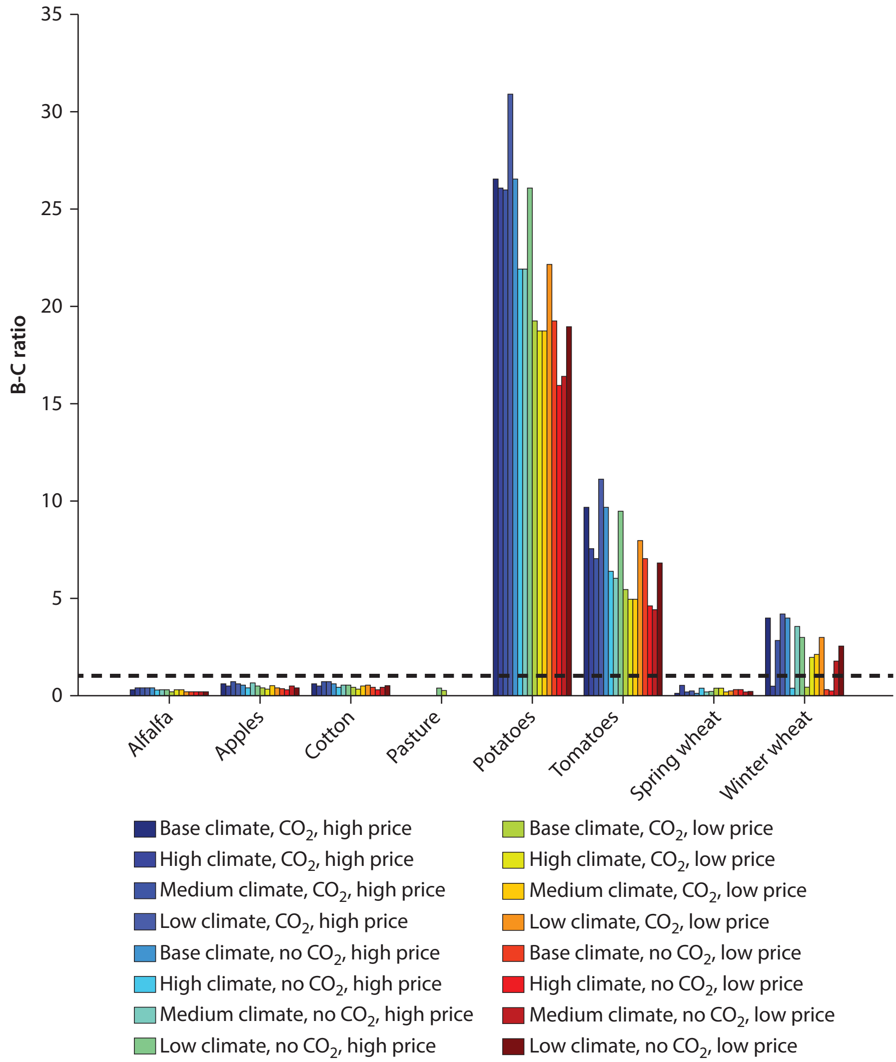
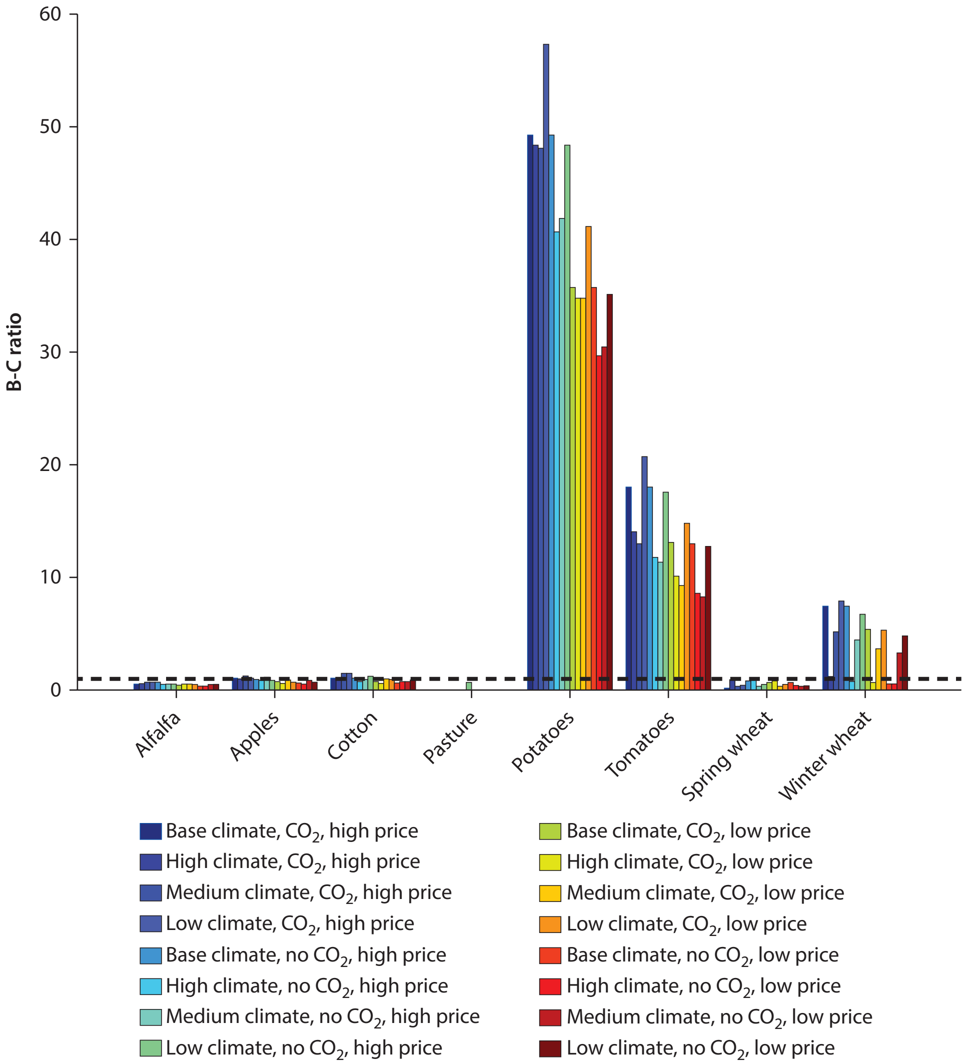


Figure 5.2 is for new drainage infrastructure, and figure 5.3 is for rehabilitated drainage infrastructure. This option involves a farm-level improvement of drainage conditions similar to that which would result from the difference between poorly drained and well-drained soils, and entails both capital and ongoing maintenance costs, estimated on a per hectare basis. Costs are higher for new drainage infrastructure than for rehabilitated infrastructure, but the estimated yield increase is the same, so benefit-cost ratios are higher where it is possible to rehabilitate existing infrastructure. The yield effect in these calculations is based on the estimated effect of drainage on reducing soil salinity and, in the process, increasing yields.

Figure 5.3 Benefit-Cost Analysis Results for Improved Drainage in the Eastern Portion of the Desert and Steppe AEZ—Rehabilitated Drainage Infrastructure



The figures show benefit-cost ratios for all crops, under each of the climate scenarios, for both assumptions regarding carbon dioxide fertilization (with and without the yield effect), and for two alternative future price forecasts. The dashed line near the bottom of each graph shows a B-C ratio of one. Bars that extend above this line represent crop/condition combinations where benefits exceed costs.

The results for all three AEZs are similar in that enhanced drainage is most advantageous for the higher-value crops. The tallest bars are for potatoes and tomatoes. B-C ratios for other crops have relatively low B-C ratios. As a result, drainage for those crops should be a much lower priority.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Adding New Irrigation or Rehabilitating Existing Irrigation Infrastructure

Figures 5.4 and 5.5 illustrate the results for adding irrigation capacity, and for rehabilitating existing irrigation capacity. The option is modeled as a switch from rainfed to irrigated crops on the model farms in each of the three AEZs. The graphs represent B-C ratios for these crops in the Piedmont AEZ. In practice, the feasibility of this option is likely quite limited, as there are very few situations where crops are rainfed in Uzbekistan. Even in areas where formerly irrigated land has been removed from cultivation, the reason for its removal is likely high salinity or un-economic irrigation due to high pumping costs.

Figure 5.4 Benefit-Cost Analysis Results for New Irrigation Infrastructure in the Southwest Portion of the Piedmont AEZ

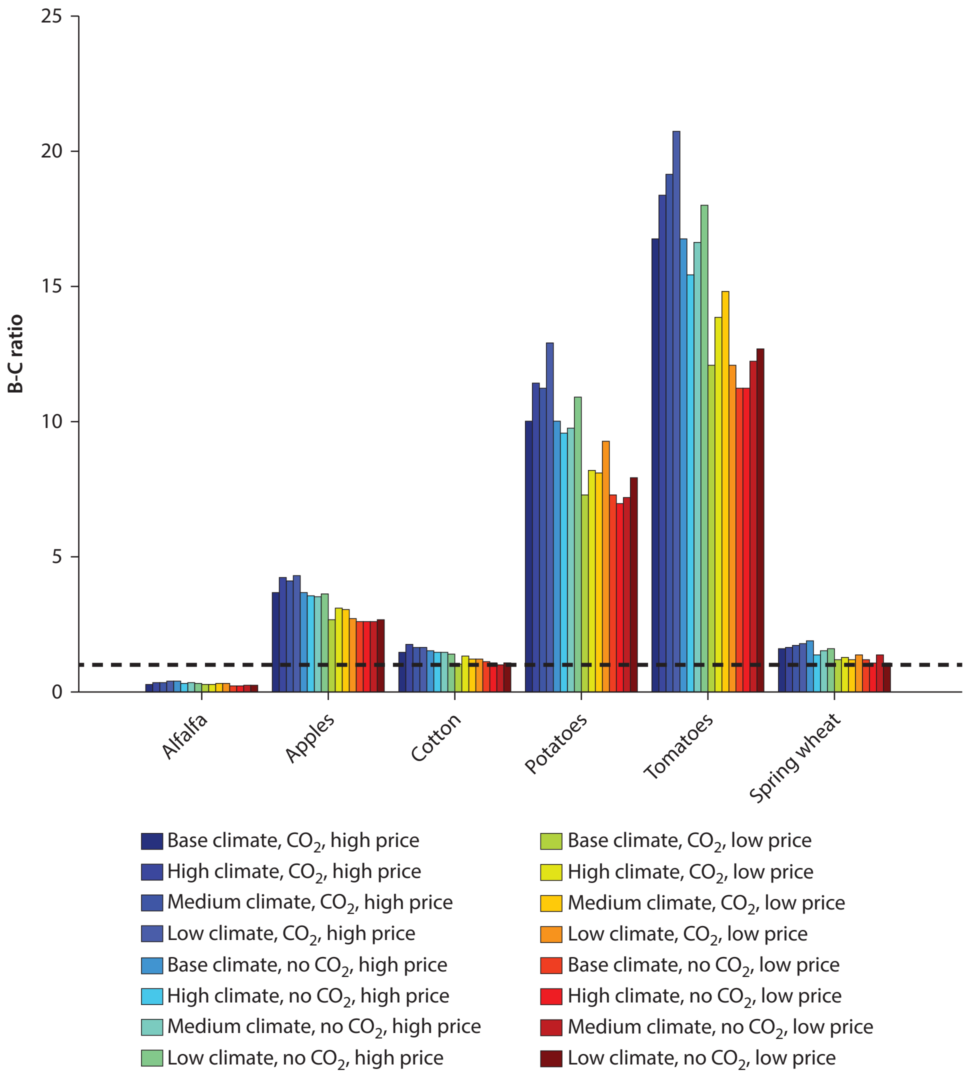
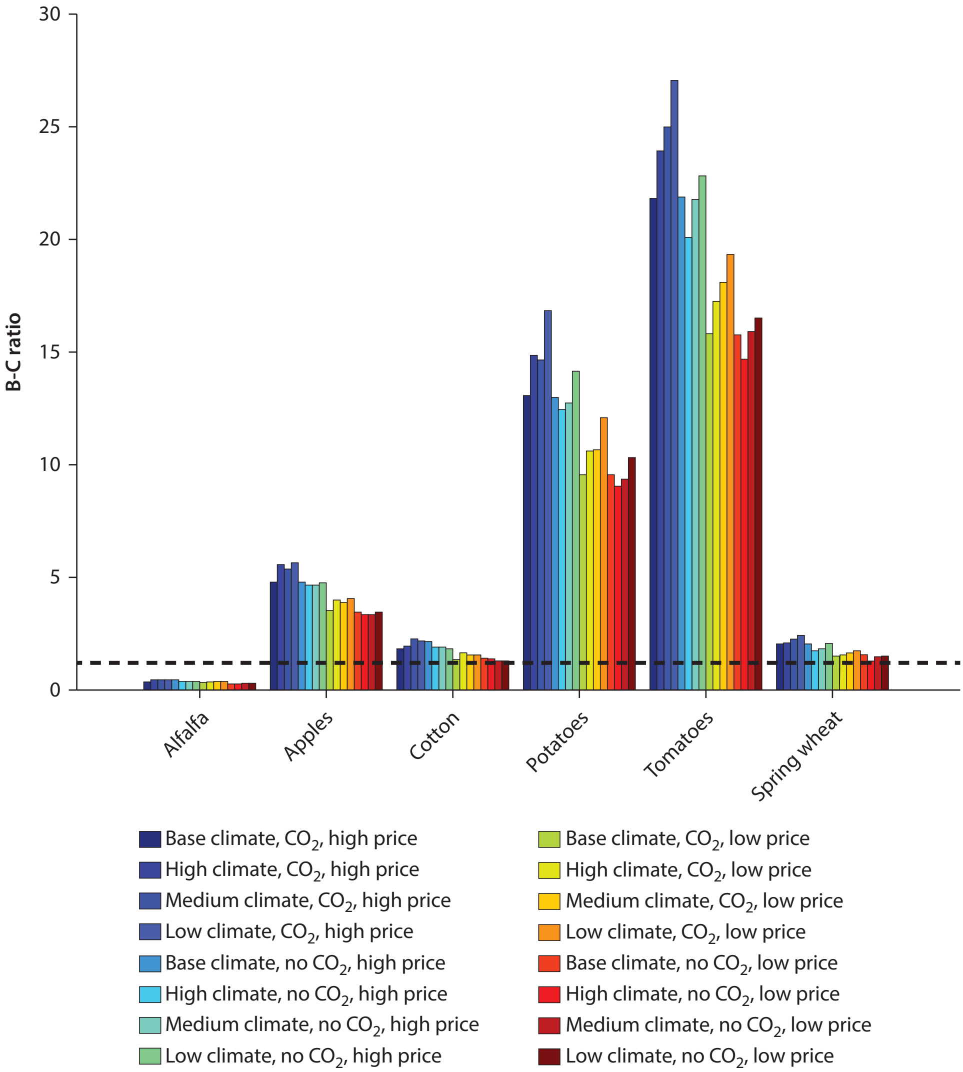


Figure 5.5 Benefit-Cost Analysis Results for Rehabilitated Irrigation Infrastructure in the Southwest Portion of the Piedmont AEZ



The results in these figures indicate that B-C ratios are relatively high in the Piedmont AEZ for tomatoes, potatoes, and apples, but lower for wheat, cotton, and alfalfa. Because rehabilitating irrigation infrastructure is less expensive than new infrastructure but benefits are the same, B-C ratios for rehabilitated infrastructure are higher than for new infrastructure. As expected, for alfalfa, apples, cotton, and wheat, both the new and rehabilitated irrigation capacity options have the lowest B-C ratio for the low-impact scenario, which has the highest precipitation and therefore the lowest estimated incremental yield benefit for increased irrigation water. On the other hand, potatoes and tomatoes show the opposite pattern because precipitation between 2015 and 2050 during key

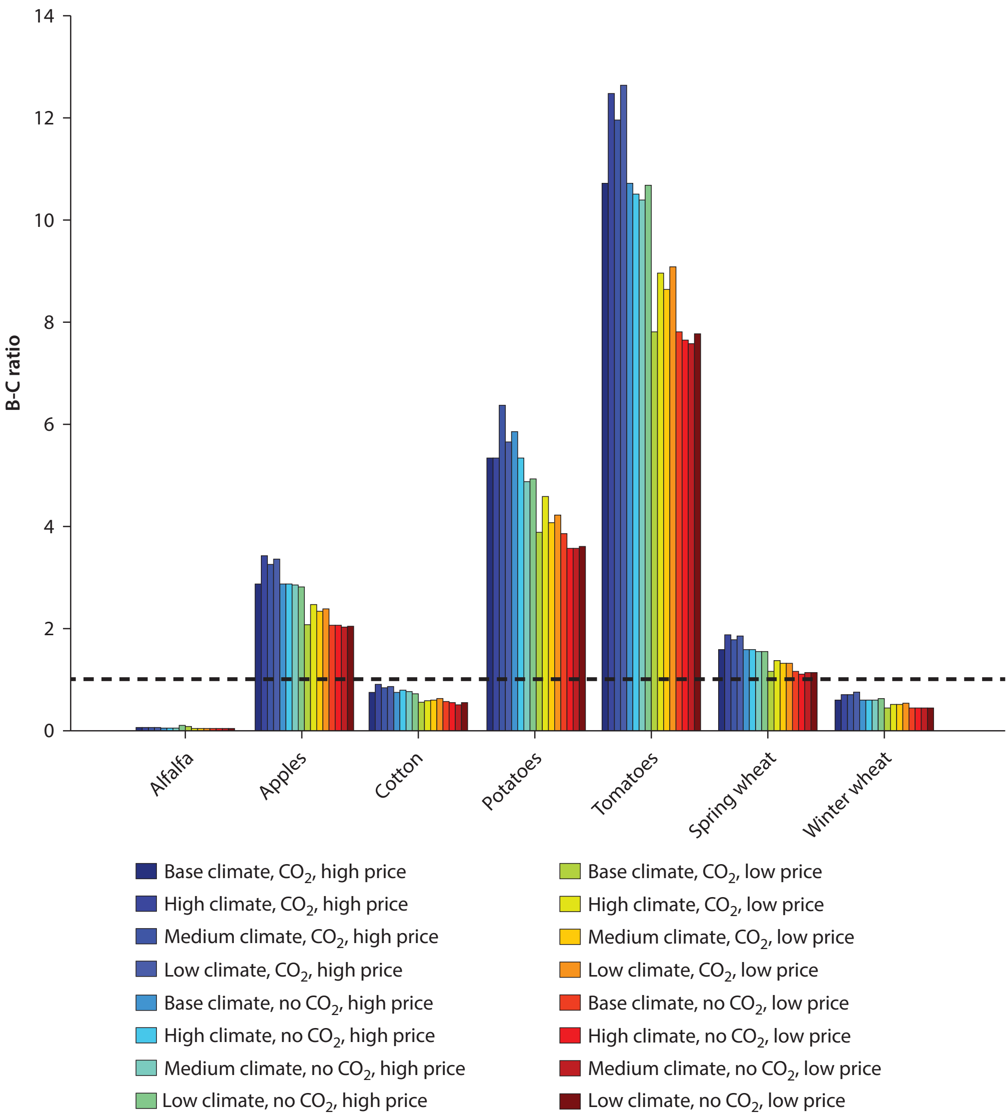
http://dx.doi.org/10.1596/978-1-4648-0000-9

months of their growing seasons is projected to be lowest under the low-impact scenario. In all cases, B-C ratios under the high-, medium-, and low-climate scenarios are approximately equal to or higher than if the adaptation options are adopted under base climate conditions.

Improving Water Use Efficiency in Fields

Figure 5.6 shows the B-C ratios for improving water use efficiency in fields, for the western portion of the Desert and Steppe AEZ. The main costs for this

Figure 5.6 Benefit-Cost Analysis Results for Improved Water Use Efficiency in the Western Portion of the Desert and Steppe AEZ



http://dx.doi.org/10.1596/978-1-4648-0000-9

option include drip irrigation, an enhanced hydrometeorological network (to provide better precipitation forecasts for farmers), and enhanced extension to provide better training for farmers to make better use of existing water resources to optimally irrigate. The results for the Desert and Steppe AEZ indicate high B-C ratios for the high-value crops tomatoes, potatoes, and apples, but also for wheat. The wheat result is somewhat surprising, as drip irrigation seems unfeasible for the large areas of wheat that are cultivated. Nonetheless, the high B-C ratio provides a strong indication the efforts to optimize water inputs are quite valuable in Uzbekistan. Ratios for cotton are, not surprisingly, less than one, indicating that costs exceeds of benefits. Also, B-C ratios for alfalfa are much less than one. In general, the results across scenarios appear to be most sensitive to price projections and the presence or absence of carbon dioxide fertilization effect, and less sensitive to the climate scenario, confirming the "win-win" nature of this adaptive measure.

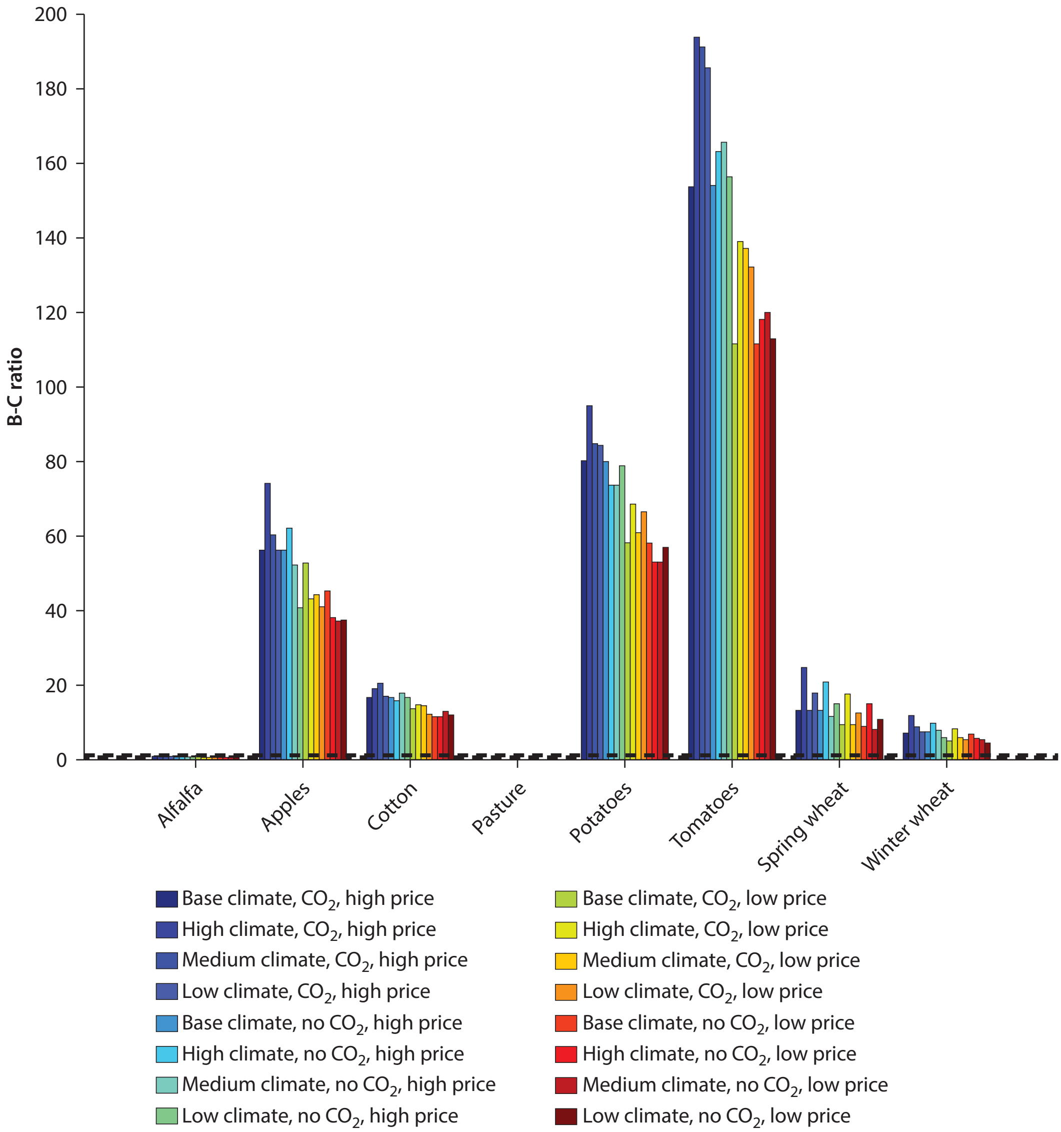
Changing Crop Varieties

Figure 5.7 shows the results for changing crop varieties for the eastern portion of the Piedmont AEZ, with results being similar for the other AEZs. For this option, the main cost is estimated to be enhanced research and development at the regional level, most likely funded through public expenditures although potentially funded privately by farmer cooperatives or agribusiness enterprises. The value of yield benefits is estimated for a change from current to optimal crop varieties, as feasible within the options available within the AquaCrop database of crop varieties. B-C ratios are highest for tomatoes, with extraordinarily high ratios of up to 200 to 1. B-C ratios for other crops are lower but still significantly greater than one for potatoes, apples, wheat, and cotton, but are very low for alfalfa and pasture. In most cases, the benefits of optimizing crop varieties also reflects the current adaptation deficit in that better varieties could result in substantial yield gains regardless of the change in climate. Costs for this adaptation option may however be underestimated since there may be additional costs to farmers for more expensive varieties, and possibly other direct costs for fertilizer and water inputs to achieve the highest yields.

Optimizing Fertilizer Application

Figure 5.8 illustrates the results for optimized organic fertilizer application, relative to current use of fertilizer, for the eastern portion of the Piedmont AEZ. The graph shows a wide range of B-C ratios by crop, from as high as 35 to 1 for potatoes, and 15 to 1 for tomatoes, but with lower ratios for other crops. As noted above, however, the costs for fertilizer in this framework include only the direct expenditures, and do not reflect indirect costs and effects of fertilizer application for the surrounding environment, or the possibility that enhanced fertilizer application could in some cases also increase greenhouse gas emissions that contribute to climate change. As a result, the full social cost of increased use of fertilizer is likely to be underestimated.

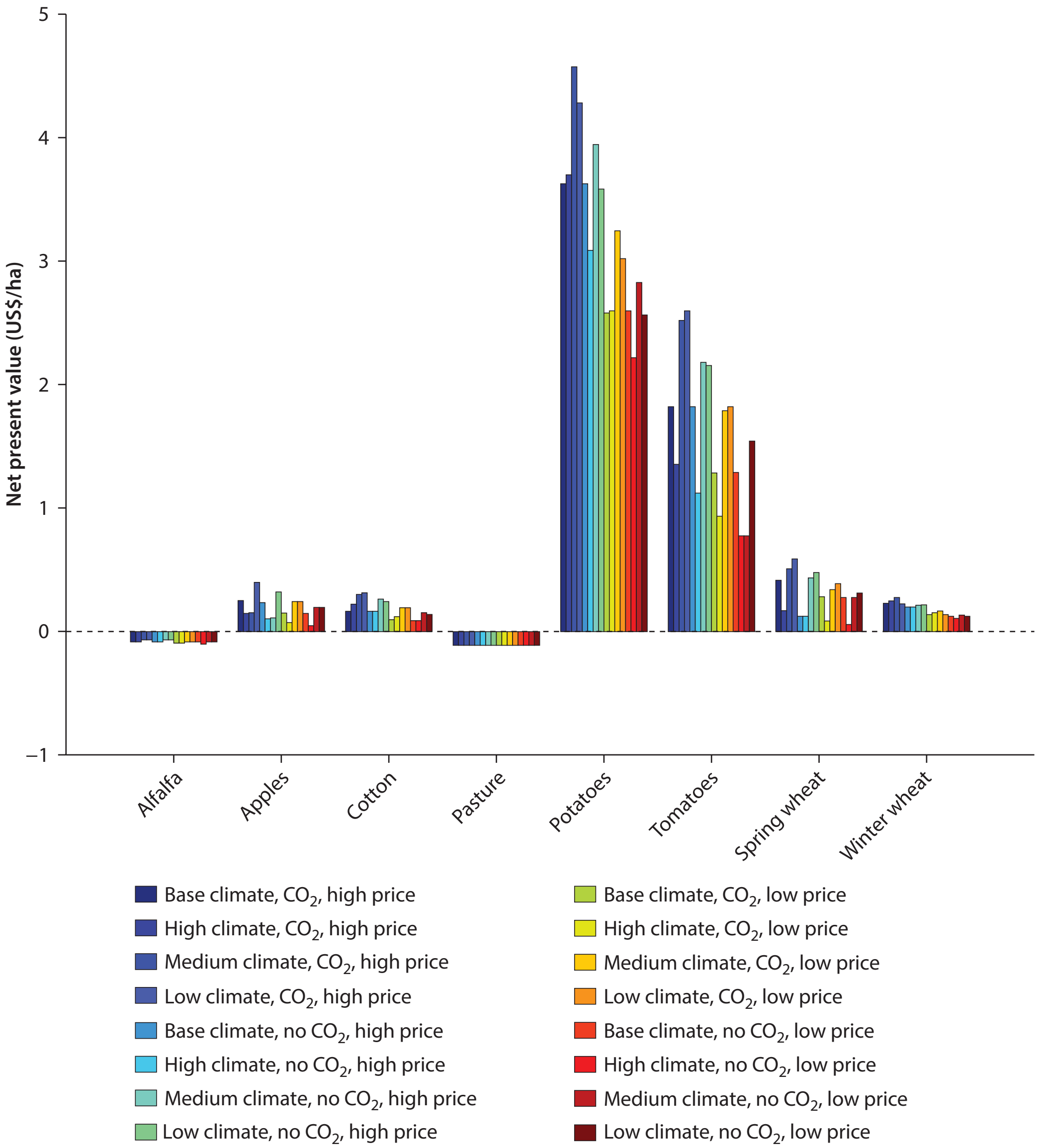
Figure 5.7 Benefit-Cost Analysis Results for Optimizing Crop Varieties in the Eastern Portion of the Piedmont AEZ



Other Economic Analyses

In addition to the detailed economic analyses described above, analyses were conducted of the potential benefits and costs for three additional options that were of interest to farmers, but for which data were sparser, or for which the methods are more uncertain: expanding extension services; improving basin-wide water efficiency; and expanding water storage capacity. These other economic analyses are informative for ranking options but provide less certainty than the more detailed analyses in the prior section.

Figure 5.8 Benefit-Cost Analysis Results for Optimized Fertilizer Use in the Eastern Portion of the Piedmont AEZ



Expanding Extension Capabilities and Services

The costs of enhanced extension services are already included in B-C analyses of the optimized fertilizer application and improved irrigation water application options presented above. A break-even analysis was also conducted for expanding extension services as a stand-alone adaptation measure.

The total cost for an enhanced extension service was estimated based on the experience with other countries in this study, which suggests an annual cost per hectare of US$6.44. The average break-even yield increase required to justify this cost, across all crops, AEZs, and scenarios, is about 1 percent. Extension appears to be most cost-effective for tomatoes, potatoes, apples, cotton, and wheat, where the break-even yield increase required to justify the program is less than 0.5 percent, and is much less cost-effective for alfalfa and pasture crops, where break-even yield requirements can be as high as 17 percent.

The yield increase required to justify the program seems plausible when compared to other estimates in the literature on the likely yield benefits of enhanced extension. For example, a meta-analysis of 294 studies of research and development rates of return (IFPRI 1998) found a 79 percent rate of return to extension services. The Inter-American Development Bank also found enhanced extension services increase yields by the lowest producing grape farmers, and increase grape productivity (2008). Another study (Pesticide News 2007) found that farmer field schools reduced pesticide use on cotton by 34–66 percent. In a project to reform the Indian agriculture extension system, IFPRI found that Farmer Field School increased graduates' cotton yields by 4–14 percent (2010).

Improving Basin-Wide Water Efficiency

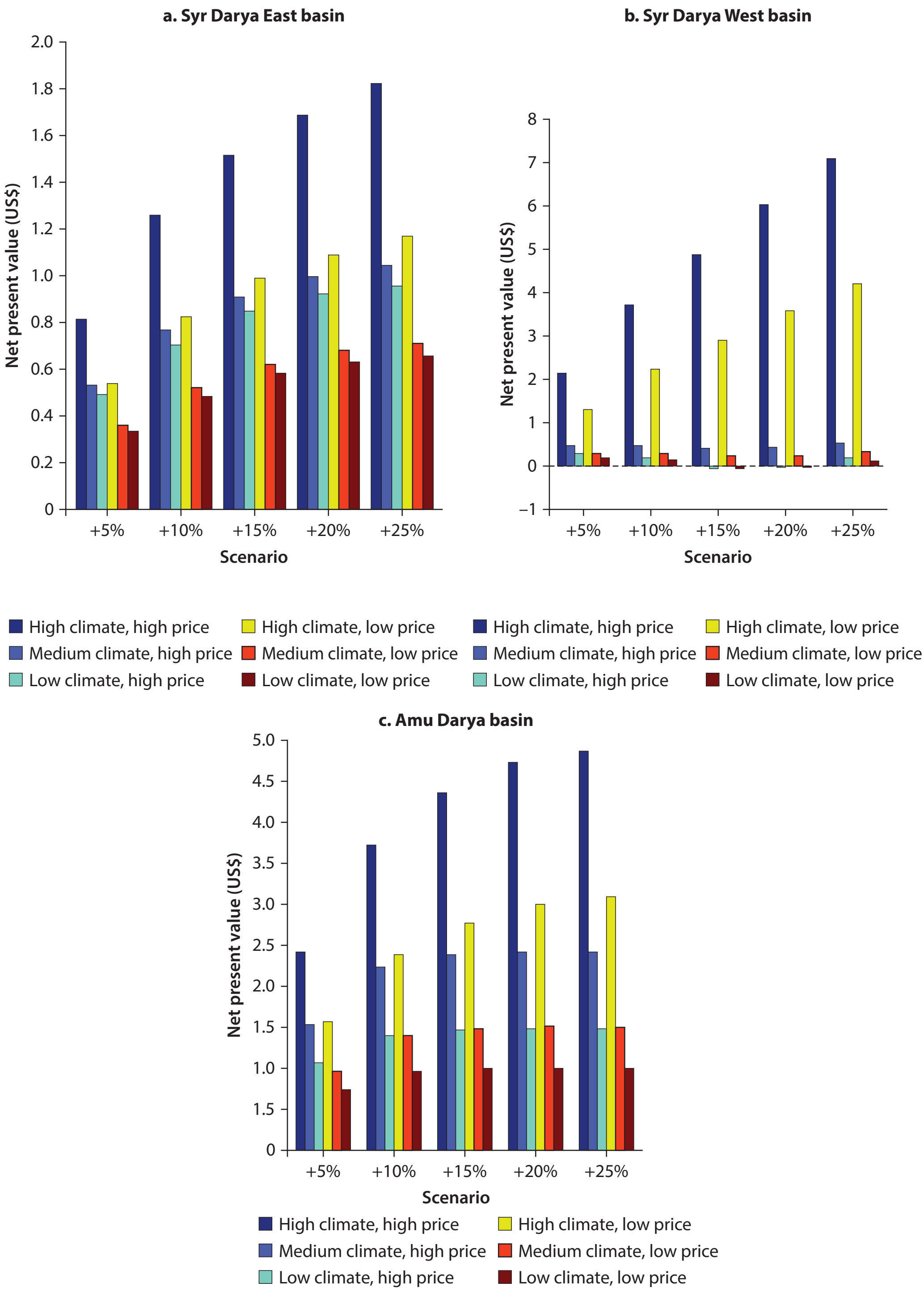
A screening analysis was conducted of the benefits of improving water efficiency in each of three basins where water shortages are likely: the Amu Darya, the Syr Darya East, and the Syr Darya West. The analysis examined improving irrigation efficiency from the baseline of 33.4 percent in 5 percent increments, up to a high of 58.4 percent, in all three basins simultaneously. The benefit is increased profit (not revenue) from additional irrigation water to bring back to cultivation additional acreage. For example, under the high-impact climate change scenario in the Amu Darya basin, a 5 percent increase in efficiency allows an additional 225,000 hectares to be irrigated. The results are presented in figure 5.9, with one panel for each of the three basins.

The Syr Darya West basin generally benefits less from these improvements, partly because the Syr Darya West is downstream of Syr Darya East, and more irrigated hectares in the East basin results in less water actually delivered to the West basin. But overall, the total cumulative benefits of improving efficiency over the period 2015 to 2050 are considerable.

There is no cost estimate for these water efficiency improvements, though they ought to be accomplished through repair of leaking conveyance channels or other leak repair. In another World Bank project in Armenia, project analysts found that by reducing leaks and mechanical losses in main, secondary, and tertiary canals, 150 million m^3 of water was saved (World Bank 2007b, 2009c). In total, 261 kilometers were repaired at a cost of US$21.9 million, or US$83,900 per kilometer. Additionally, 2,145 water measurement devices were installed for a total cost of US$3.54 million, or US$1,650 per unit. Overall, the anticipated cost of this project was 17 US cents per cubic meter of water, but ultimately the cost was evaluated to be 22 US cents per cubic meter. These costs seem fairly high, and correspond roughly to the middle of the range of cost estimates for construction of new water storage capacity.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure 5.9 Impact of Improving Basin-Wide Irrigation Efficiency



http://dx.doi.org/10.1596/978-1-4648-0000-9

Expanding Water Storage Capacity

A screening analysis was also conducted of the costs and benefits of building new storage capacity, to provide additional water during times of low water supply. The limitations of the approach used here are substantial since it was not possible to conduct detailed studies of basin dynamics, and the implications of storage for transboundary flows and compliance with international water treaties have not been analyzed. Estimated costs of constructing storage are from Ward et al. (2010), and are between 12 and 30 US cents per cubic meter, varying based on the size of storage structure and the average slope of the basin. The benefits of storage are in reducing unmet water demand, and therefore providing additional net revenues of cultivating crops. The value of additional crop cultivation is net revenue from a mix of crops identical to those currently cultivated in the basin, though in practice this may overstate benefits because, as water shortages manifest, water might be diverted to higher-value crops. There is no clear mechanism for diverting water from private to dekhan farms, however, where a large proportion of the more valuable crops are grown.

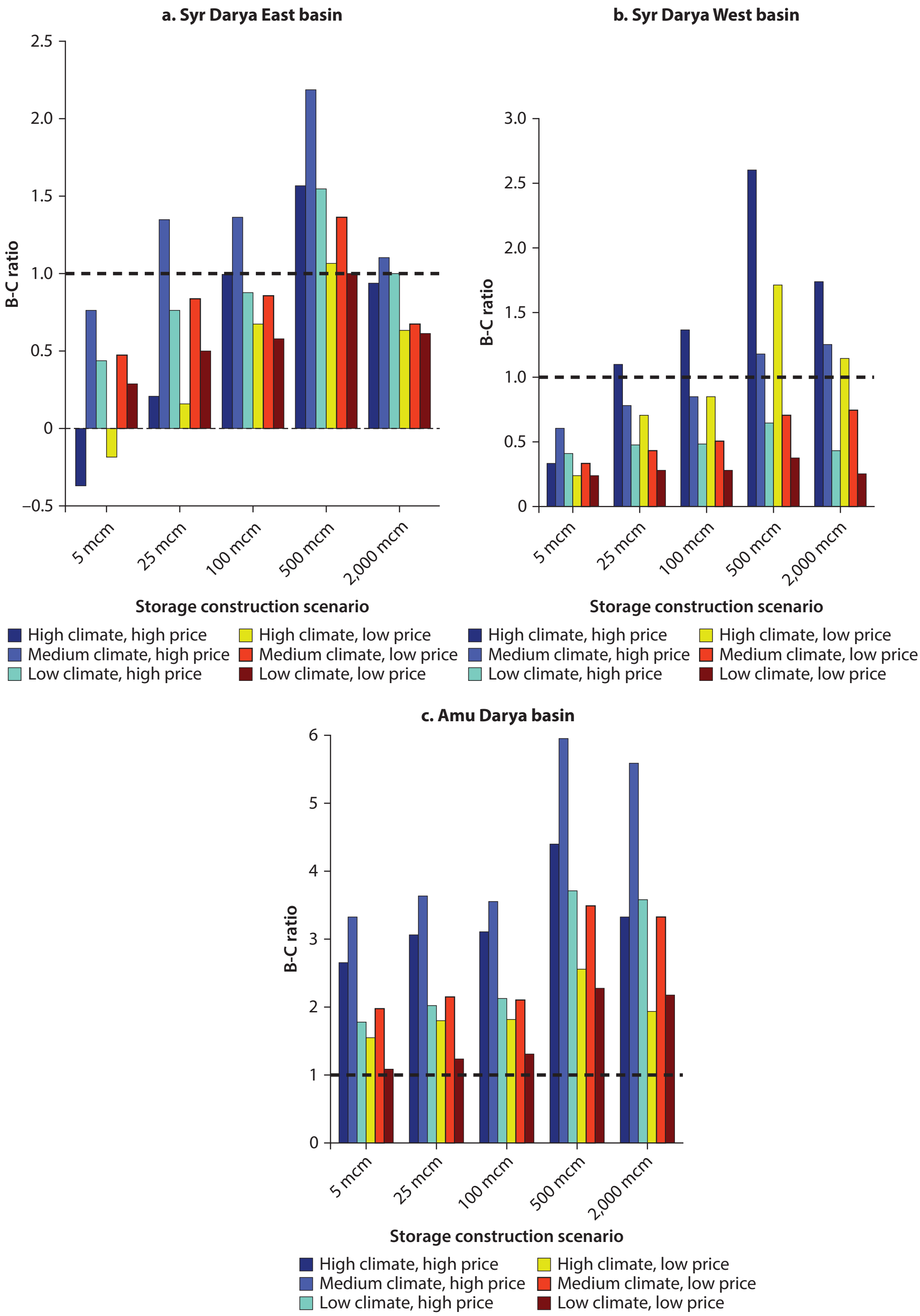
The three panels of figure 5.10 illustrate the range of results for the three basins where continued water shortages are forecast with climate change. Benefit-cost ratios for storage vary substantially by the amount of storage, along the horizontal axis, and the climate scenario, represented by the individual bars, and by basin, with storage generally showing favorable benefit-cost ratios in Syr Darya basins only under certain scenarios, but having a favorable benefit-cost ratio in the Amu Darya basin under all scenarios. These results should be considered with caution, however, as they reflect only a zero-order analysis of the viability of storage across the basin, at a very coarse resolution, without the benefit of detailed study of the feasibility of constructing additional storage.

Sensitivity Analyses

As indicated above, the sensitivity of the B-C ratio and present value of benefits across 12 (3×2×2) scenarios was examined, including the three climate scenarios (low-, medium-, and high-impact), two carbon dioxide fertilization assumptions (no effect and full effect), and two price projections (low forecast, which holds prices constant, and high forecast, which incorporates a gradual upward trend in prices based on IFPRI published projections). The results are generally most sensitive to the price projections, which yield relatively larger changes in revenues in later years of this analysis (near 2050), though some of those differences are tempered by application of a 5 percent discount rate.

The effect on the results of using a 10 percent rather than 5 percent discount and cost-of-capital rate was also examined. Overall, use of a higher discount rate results in present value benefits of the adaptation options falling by between 44 and 54 percent (across crops, AEZs, and climate/CO_2/crop price scenarios). This narrow range reflects the fact that increases in revenue over the 2015–50 time period are relatively constant, particularly in the near term when the majority of

Figure 5.10 Preliminary Analysis of the Benefits and Costs of Water Storage



Note: mcm = million cubic meters.

http://dx.doi.org/10.1596/978-1-4648-0000-9

present value benefits accrue. On the other hand, present value costs fall between 29 and 47 percent, where the low end of the range reflects adaptation options with large initial loans for capital expenditures and relatively low O&M costs (for example, new irrigation or drainage infrastructure). The effect on present values varies and depends on relative magnitudes of the costs and benefits, but the overall average effect on present values is a reduction of 48 percent. In approximately 5 percent of instances, the use of a 10 percent discount rate causes net present values (NPVs) of the adaptation options to change signs. The vast majority of these sign changes (99 percent) are from positive NPVs to negative NPVs, and occur under adaptation scenarios with near-zero NPVs at a 5 percent discount rate (for example, many options for alfalfa and pasture). Because options are not recommended unless B-C ratios are much greater than one or NPVs are much greater than zero, the higher discount rate of 10 percent does not alter the options or the priority ranking.

More detailed sensitivity analyses are possible, including analysis of the optimal start date for specific options for each crop and AEZ, as illustrated in figures 5.11 and 5.12.[3] Figure 5.11 shows that, under all scenarios and start dates, new irrigation infrastructure for potatoes in the Highlands AEZ has a B-C ratio greater than one. Figure 5.12, on the other hand, for new drainage capacity for irrigated cotton in the Piedmont AEZ, shows that only some ratios and start dates yield B-C ratios greater than one. For figure 5.12 the price trajectory is critical, with low-price scenarios exhibiting B-C ratios less than one, and high price ratios exhibiting B-C ratios greater than one. In this case, price is clearly more important than climate in determining the B-C ratios, although climate is also a key factor. One conclusion from figure 5.12 might be that, rather than ruling out implementation of new drainage for cotton in the Piedmont AEZ, it would be prudent to wait to implement this option, and to monitor price trends as well as the unfolding of climate scenarios.

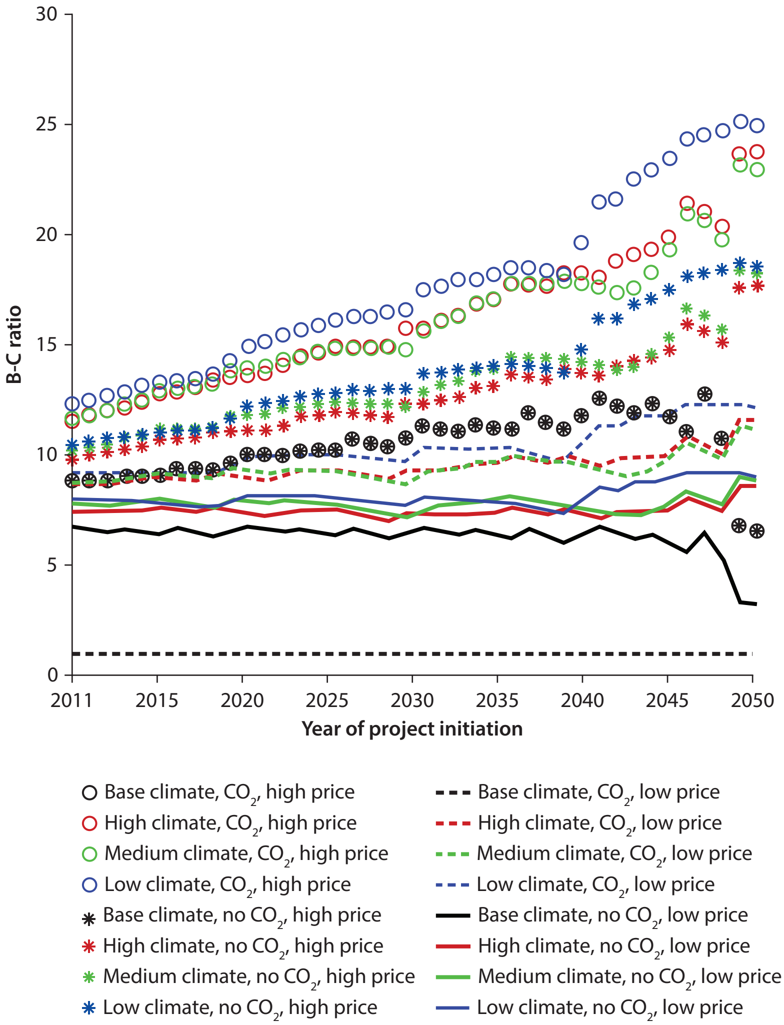
A general finding across almost all option, crop, and AEZ combinations is that there are upward sloping B-C ratio curves. That in turn suggests that implementation of these options grows more beneficial over time, either because of changes in prices, changes in climate that widens the increment in yield (that is, increasing resiliency over time), or both. For options with B-C ratios greater than one in the early period of analysis, short-term implementation is warranted, and benefits can be expected to grow over time. For others, the option can be part of a long-term plan, or at least a "wait-and-see" approach can be adopted, with monitoring of both price and climate outcomes to assess whether uncertainty in these parameters narrows as time progresses.

Analysis of Livestock Sector Adaptation

In the absence of a process model that can simulate the effects of climate change and adaptation measures on livestock productivity, it is difficult to evaluate livestock sector adaptation options. As a result, the livestock sector options are based on a literature review and qualitative analysis. These include options such

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure 5.11 Detailed Sensitivity Analyses: New Irrigation Infrastructure for Potatoes in the Highlands AEZ

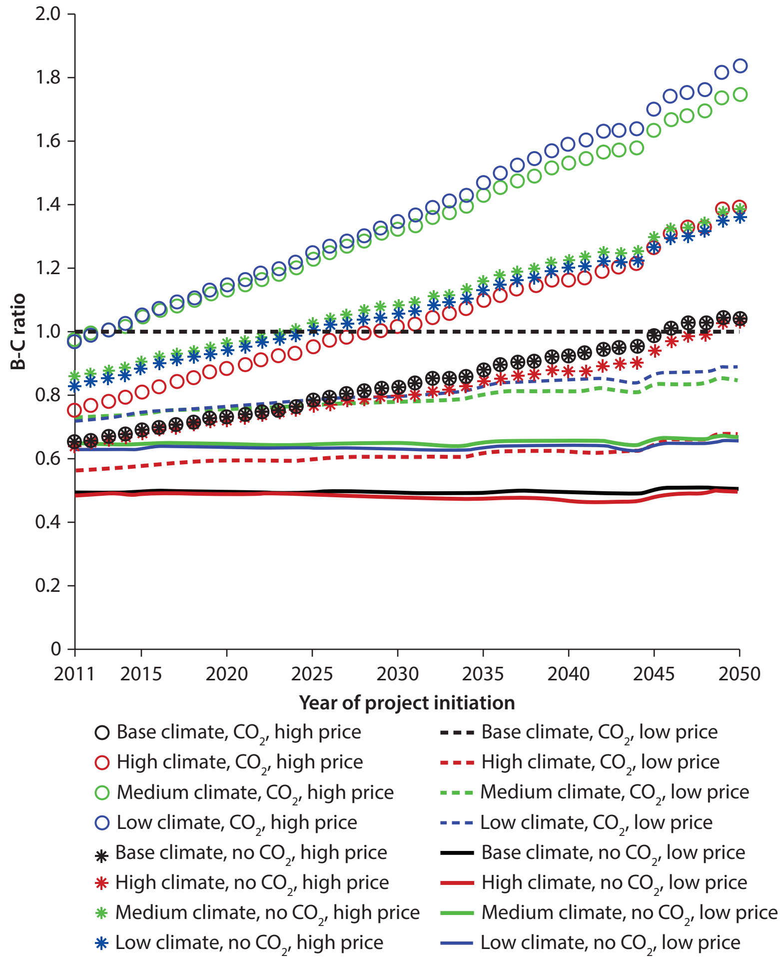


as providing better protection for livestock during heat waves (ranging from better shade to air-conditioned barn space) modifying feedstocks, providing vaccinations, and transitioning livestock varieties. Chapter 6 recommends a national policy to devote greater attention to evaluating the suitability of gradually introducing heat-tolerant breeds for stocking Uzbekistan livestock herds.

Summary of Quantitative Results in AEZs

The previous section highlights selected results for benefit-cost ratios for the each of the options that is analyzed quantitatively. Benefit-cost ratios are useful, but another useful measure is net present value benefits, which indicates the per

Figure 5.12 Detailed Sensitivity Analyses: New Drainage Capacity for Irrigated Cotton in the Eastern Portion of the Piedmont AEZ



hectare farm revenue benefits minus the per hectare costs over the full period of the analysis, starting in 2015 and ending in 2050. Ranges of results reflect variation across climate, CO_2 fertilization, and price scenarios.

Tables 5.1 and 5.2 summarize the net benefit estimates for two AEZs, the Piedmont and the Desert-Steppe. The results for the Highlands AEZ are similar to those for the Piedmont, but generally somewhat lower. The tables list what can be considered to be the five adaptation measures with the highest overall net benefits. More detailed results from the background report indicate that the same five measures have the highest overall rankings in all AEZs, but the crop emphasis differs by AEZ and sub-basin. Note that only those crops with a positive net benefit are listed; for all other crops not listed it the table, a negative net benefit for the measure is estimated for at least one scenario, suggesting the measure is not robust to alternative climate or other input assumptions.

Table 5.1 Five Adaptation Measures with High Net Benefits: Piedmont AEZ

		Illustrative present value economic results per hectare (000 2009$)			
Adaptation measure	*Crop focus for Piedmont AEZ*	*Estimated revenue gain*	*Estimated costs*	*Net revenues*	*Notes*
Improve varieties	Tomatoes: Potatoes: Apples: Wheat: Cotton:	\$33 to 73 \$18 to 35 \$11 to 26 \$3 to 9 \$4 to 7	\$0.35	\$32 to 72 \$18 to 35 \$11 to 26 \$3 to 8 \$3 to 6	Costs are for R&D
Use irrigation water more efficiently	Tomatoes: Potatoes:	\$27 to 97 \$18 to 47	\$8.5	\$19 to 88 \$10 to 38	Costs are drip irrigation, extension & hydromet
Rehabilitate or build new irrigation infrastructure	Tomatoes: Potatoes:	\$130 to 336 \$31 to 209	\$12 to 16	\$114 to 323 \$15 to 196	Low-end cost is for rehabilitation, high for new
Rehabilitate or build new drainage infrastructure	Potatoes: Tomatoes:	\$14 to 35 \$3 to 20	\$0.6 to 1.0	\$13 to 35 \$2 to 20	Low-end cost is for rehabilitation, high for new
Optimize fertilizer application	Potatoes: Tomatoes: Cotton:	\$18 to 7 \$4 to 27 \$1.3 to 4.3	\$1.2	\$17 to 46 \$3 to 26 \$0.1 to 3	Costs do not include environ. damages

Table 5.2 Five Adaptation Measures with High Net Benefits: Desert and Steppe AEZ

		Illustrative present value economic results per hectare (000 2009$)			
Adaptation measure	*Crop focus for Desert and Steppe AEZ*	*Estimated revenue gain*	*Estimated costs*	*Net revenues*	*Notes*
Improve varieties	Tomatoes: Potatoes: Apples: Wheat: Cotton:	\$36 to 68 \$19 to 36 \$11 to 21 \$5 to 9 \$3 to 7	\$0.35	\$36 to 68 \$18 to 35 \$11 to 21 \$4 to 9 \$3 to 7	Costs are for R&D
Use irrigation water more efficiently	Tomatoes: Potatoes: Apples: Wheat:	\$41 to 107 \$21 to 54 \$15 to 29 \$10 to 17	\$8.5	\$33 to 99 \$12 to 46 \$7 to 20 \$1 to 9	Costs are drip irrigation, extension & hydromet
Rehabilitate or build new irrigation infrastructure	Tomatoes: Potatoes: Apples: Wheat:	\$194 to 352 \$105 to 221 \$42 to 78 \$17 to 32	\$12 to 16	\$178 to 340 \$89 to 209 \$26 to 66 \$1 to 16	Low-end cost is for rehabilitation, high for new
Rehabilitate or build new drainage infrastructure	Potatoes: Tomatoes:	\$16 to 32 \$3 to 12	\$0.6 to 1	\$15 to 32 \$1 to 11	Low-end cost is for rehabilitation, high for new
Optimize fertilizer application	Potatoes: Tomatoes:	\$21 to 43 \$3 to 16	\$1.2	\$20 to 42 \$2 to 14	Costs do not include environ. damages

http://dx.doi.org/10.1596/978-1-4648-0000-9

The ranking of benefits also considers that some benefit and cost estimates are incomplete, as indicated in the "Notes" column. For example, the estimated costs for optimizing fertilizer application include only the costs for the fertilizer input and extension service to advise farmers—these costs leave out the potentially very significant environmental costs to surface and ground water quality, as well as potential greenhouse gas emissions, that could result from added fertilizer loads on fields. For this reason, fertilizer application is the lowest-ranked of the five options listed here.

This ranking of measures by their net benefits is carried through to the next chapter, where the results of the quantitative and qualitative evaluations are combined to arrive at an overall menu of climate adaptation options for Uzbekistan's agriculture.

Notes

1. Although it is not reported here, the team also conducted a screening analysis of the application of hail nets for apple and tomato crops, and found that they would not be economic adaptation options in Uzbekistan unless climate change caused an increase in the frequency of damaging hail storms a factor of five or more, which seems implausible based on current literature. As farmers did not mention hail as one of their main concerns from climate change, that analysis is not reported here.
2. These findings, based on in-country data provided by Uzbekistan counterparts, are confirmed in a recent analysis of farm-level net revenue in Uzbekistan—see Hasanov and Nommen (2011). Note that, while rainfed yields are included in figure 5.1 to illustrate the potential difference in irrigated versus rainfed yields, in practice only pasture and about 5 percent of field crops are rainfed in Uzbekistan.
3. Benefit-cost ratios over time, however, are influenced by an inability to estimate benefits after 2050—in many cases, the study may be underestimating benefits of options that have a continued useful life after 2050, and may have higher benefits as climate changes accelerate after 2050.

CHAPTER 6

Options to Improve Climate Resilience of Uzbekistan's Agriculture Sector

This chapter combines the review of current adaptive capacity (chapter 1), the identification of the risk of climate change to agriculture (chapter 3), the results of the farmer and evaluation of adaptation options (chapter 4), and the quantitative evaluation of adaptation measures (chapter 5), and the results of the National Dissemination and Consensus Building Conference held in Tashkent on March 10, 2011, to arrive at an overall set of high-priority policy, institutional capacity building, and investment measures to improve the resiliency of Uzbekistan's agriculture to climate change.

Below is a summary of the high-priority options at the national level, followed by recommendations specific to each AEZ. The discussions below include summaries of the ranked lists developed at the National Conference.

Options at the National Level

Measures that are most appropriate for consideration at the national level focus on policy and institutional capacity measures that have value on their own, or which are essential to ensure that farm-level and private sector actions are applied to their best advantage.

Three measures were identified for adoption at the national level. The basis for the ranking of these options is the qualitative analysis of potential net benefits by the team, combined with recommendations from farmer stakeholder groups. These national-level recommendations are the following:

1. *Increase the access of farmers to technology and information through farmer education, both generally and for adapting to climate change.* The Bank team recommends that the capacity of the existing extension agency be improved in two areas: (1) to support better agronomic practices at the farm level, including implementation of more widespread demonstration plots and access to better information on the availability and best management practices of high-yield crop varieties, with a particular focus on pest-resistant varieties for wheat and

http://dx.doi.org/10.1596/978-1-4648-0000-9

apples; and (2) to support the same measures but with a focus on maintaining yields during extreme water stress periods that are likely to be more frequent with climate change. The first part of this option is a measure to close the adaptation deficit, and the second part is a measure to ensure yield gains are not undermined by future climate change. Investing in extension has a high benefit-cost ratio in the quantitative analysis.

2. *Investigate options for crop insurance, particularly for drought*. The Uzbekistan Country Note observes that crop insurance, while presently available in Uzbekistan, is not viable for the vast majority of agricultural producers. This conclusion was supported in farmer workshops, but farmers remain eager to explore insurance options. The Country Note also suggests that a possible way to expand coverage could be via the piloting of a privately run index-based weather insurance program. This approach has many potential advantages over traditional multiple-peril crop insurance, including simplification of the product, standardized claim payments to farmers in a district based on the index, avoidance of individual farmer field assessment, lower administrative costs, timelier claim payments after loss, and easier accommodation of small farms within the program. The program may be particularly suitable for Uzbekistan, where the institutional hydrometeorological capacity is relatively sophisticated and could support an index-based approach. The drawback of an index-based approach may be the inability to readily insure coverage of damage from pests. In addition, insurance systems need to be carefully designed to maintain incentives for farmers to invest in damage mitigation, such as through better water use efficiency.
3. *Encourage private sector involvement to most efficiently adapt to climate change*. There might be a tendency to assume that adaptation to climate change is a public sector function, but as the economic analysis in this study demonstrates, there is strong private sector incentive—with economic benefits greatly exceeding costs—for measures that will improve the resiliency of Uzbekistan agriculture to climate change. The national government should focus on putting in place policies that enable the private sector to effectively assist in adaptation. For example, allowing farmers greater flexibility to choose cropping patterns to adapt to local conditions, conducting testing of seed and livestock varieties for their suitability for Uzbek climate, terrain, and soil conditions, and making recommendations through extension of the best varieties, but allowing the private sector to provide those varieties. Perhaps most important, it should provide financial incentives where possible to conserve water and otherwise practice agricultural land stewardship, though reform of water quota systems and similar policy measures.

At the National Conference, the national breakout group developed the following ranked list of adaptation options:

1. Build capacity for variety development, agronomic technologies and knowledge dissemination (extension).

2. Enhance insurance in agricultural systems (encourage private sector and competition; increase extreme event coverage).
3. Encourage farmer adaptation at the dekhan farm level. Conference participants emphasized that small farmers in Uzbekistan are the most vulnerable to changes in climate.
4. Improve information availability to farmers by Uzbekistan's hydrometeorological service through mass media.

The above options are summarized in table 6.1. Options in italics indicate overlap between these options and the National Conference recommendations (all three options overlap).

Combining the above priorities with the options emerging from the National Conference generates an overall set of adaptation measures at the national level. Figure 6.1 links the climate change exposures to impacts, and then these impacts to the national-level adaptation options. Measures shaded in darker green represent options that were recommended by both the consultants' assessment and the National Conference group.

Options at the AEZ Level

Tables 6.1 through 6.3 present the results of the adaptation modeling (chapter 5), qualitative analysis, and farmer consultations (chapter 4), which form the basis

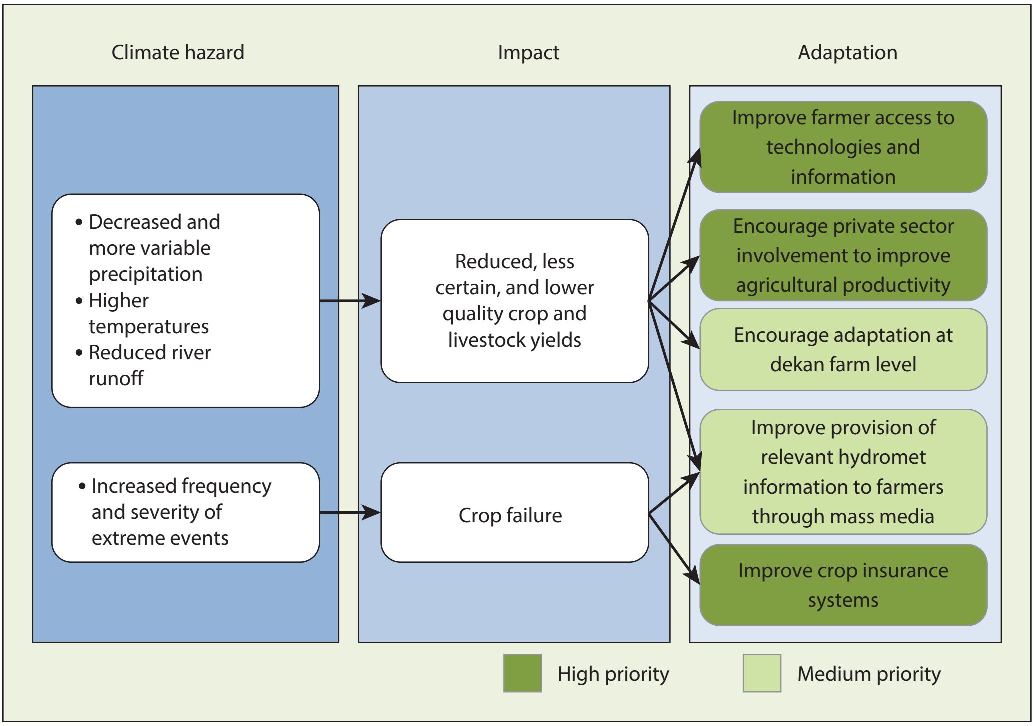
Table 6.1 Adaptation Measures at the National Level Based on Team Assessment

		Ranking criteria			
Adaptation measure	*Specific focus areas*	*Net economic benefit: quantitative analysis*	*Net economic benefit: expert assessment*	*Potential to aid farmers with or without climate change*	*Favorable evaluation by local farmers*
Improve farmer access to technology and information	*Seed varieties; more efficient use of water*	*High*	*High*	*High*	*High*
Improve crop insurance affordability and streamline implementation	*Drought damage; pest damage*	*Not evaluated*	*High*	*High*	*High*
Encourage private sector involvement in efficient adaptation	*Improve flexibility in farmer choice of cropping patterns; transparent costs of water provision; land tenure; improve access to seeds, particularly from the international market*	*Not evaluated*	*Potentially high*	*High*	*Not yet mentioned*

Note: Rows in italics indicate measures that were prioritized both by the expert analysis and by the stakeholders participating in the National Conference.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Figure 6.1 Adaptation Measures at the National Level Based on Team and National Conference Assessment



for the overall ranking of options to improve the resilience of Uzbekistan's agricultural sector to climate change. The tables reflect four ranking criteria, and assessment of the measure on a five-point scale for net economic benefits, with all measures on that scale representing a favorable economic evaluation; and a three-point scale (high, medium, or low) for other criteria:

- *Net economic benefits* (benefits minus costs)
- *Expert assessment of ranking* for those options that cannot be evaluated in economic terms
- *"Win-win" potential.* A Measure with a high potential for increasing the welfare of Uzbekistan's farmers, with or without climate change
- *Favorable evaluation by the local farming community.* In this draft, these results are based on the results of both stakeholder consultations.

The following sections summarize the results of the individual, AEZ-specific small groups that met at the National Conference on March 10, 2011. The purpose of those groups was to rank adaptation options most advantageous for each AEZ. The synthesized menus of high- and medium-priority adaptation options for each AEZ are summarized in figures 6.2 and 6.3.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Desert and Steppe AEZ

At the National Conference, the Desert and Steppe AEZ breakout group developed the following ranked list of adaptation options for rangeland areas:

1. Promote sustainable development of rangeland rehabilitation and rain water harvesting for livestock in arid regions.
2. Reduce pressure on rangelands (including overgrazing).
3. Reduce soil and wind erosion (for example, with windbreaks).
4. Increase the use of alternative energy sources (biogas and solar). These alternative energy sources could be used for heating in regions where other sources of fuel are not available.
5. Promote adaptable livestock breeds and improved livestock management.
6. Strengthen institutional capacity for rangeland and livestock management.
7. Focus on capacity building, both human resources and capital.
8. Improve veterinary services and access to markets.

Another breakout group at the National Conference focused specifically on irrigation issues across Uzbekistan. This group developed the following ranked list:

1. Improve water use efficiency—delivery of water (at farm level as well).
2. Improve irrigation infrastructure.
3. Improve access to improved crop varieties, production technologies, and information to farmers.
4. Improve drainage systems/sustainable use of groundwater and wastewater.

Four options emerge from the quantitative and qualitative evaluation as most advantageous for adapting to climate change in the Desert and Steppe AEZ. Where these options overlap with recommendations from the National Conference, they are italicized in table 6.2.

- *Improve access to higher yield, drought-tolerant, and/or pest-resistant crop varieties.* The team evaluated the possible yield increases if farmers were to change varieties in the short term to higher yield alternatives. Farmers stressed the need for both drought tolerance and pest resistance in new varieties. Further, qualitative assessment of current adaptive capacity suggests that new cotton varieties may improve productivity in this AEZ. To achieve the higher yields, experts note that this measure needs to be combined with extension services on management practices. Expanding extension capacity is discussed below under national measures, but the costs of an extension program are also reflected in the benefit-cost calculations for this measure at the AEZ-level.
- *Enhance irrigation water use efficiency.* Water shortages are clearly a major current challenge for Uzbekistan agriculture, which the assessment indicates will worsen with climate change, perhaps substantially. The quantitative benefit-cost analysis evaluates three measures for improving irrigation in some

http://dx.doi.org/10.1596/978-1-4648-0000-9

Table 6.2 Adaptation Measures for the Desert and Steppe AEZ

		Ranking criteria			
Adaptation measure	*Crop and livestock focus*	*Net economic benefit: Quantitative analysis*	*Net economic benefit: expert assessment*	*Potential to aid farmers with or without climate change*	*Favorable evaluation by local farmers*
Improve crop varieties	*Tomatoes, Potatoes, Apples, Wheat, Cotton Cattle?*	*1st*	*High*	*High*	*3rd*
Improve irrigation efficiency	*On-farm systems for: Tomatoes, Potatoes*	*2nd*	*High*	*High*	*1st*
Improve irrigation infrastructure	*Tomatoes, Potatoes, Wheat*	*3rd*	*Medium, dependent on water availability*	*High*	*1st*
Improve drainage infrastructure	*Potatoes, Tomatoes*	*4th*	*Not mentioned*	*High*	*2nd*
Optimize agronomic inputs: fertilizer and soil moisture conservation	Potatoes, Tomatoes	5th	Medium	High	Not mentioned

Note: Rows in italics indicate measures that were prioritized both by the expert analysis and by the stakeholders participating in the National Conference. The measure not in italics was prioritized only by the expert analysis.

detail: improving on-farm water efficiency, rehabilitating existing irrigation capacity, and adding new irrigation capacity. In addition, basin level efficiency improvements (such as lining conveyance channels to reduce leakage) were evaluated, and a preliminary assessment of the benefits and costs of increasing storage capacity was conducted. The least expensive measure, by far, is to improve on-farm irrigation capacity, which involves both investment in on-farm technology and improved extension (and should also involve national water quota system policy reform). Improvement of basin-level efficiency also shows promise, but cost estimates for a Desert and Steppe AEZ program were not available. The analysis for storage, while preliminary, shows costs exceed benefits, and raises feasibility issues. The other infrastructure measures implicitly assume that additional irrigation water will be available; with the forecast for more extreme water shortages, with or without climate change, those options are only viable in portions of the Desert and Steppe AEZ.

- *Improve drainage capacity.* The main benefit of improving drainage capacity is reducing salinity in soils, which is a major issue in this AEZ. An ancillary benefit may be enhanced water efficiency, if drainage can reduce the need for water used to leach soils.
- *Optimize agronomic inputs, including fertilizer application and soil moisture conservation.* High to very high benefit-cost ratios were found for optimizing fertilizer application, based on the enhanced yields indicated by the team's

http://dx.doi.org/10.1596/978-1-4648-0000-9

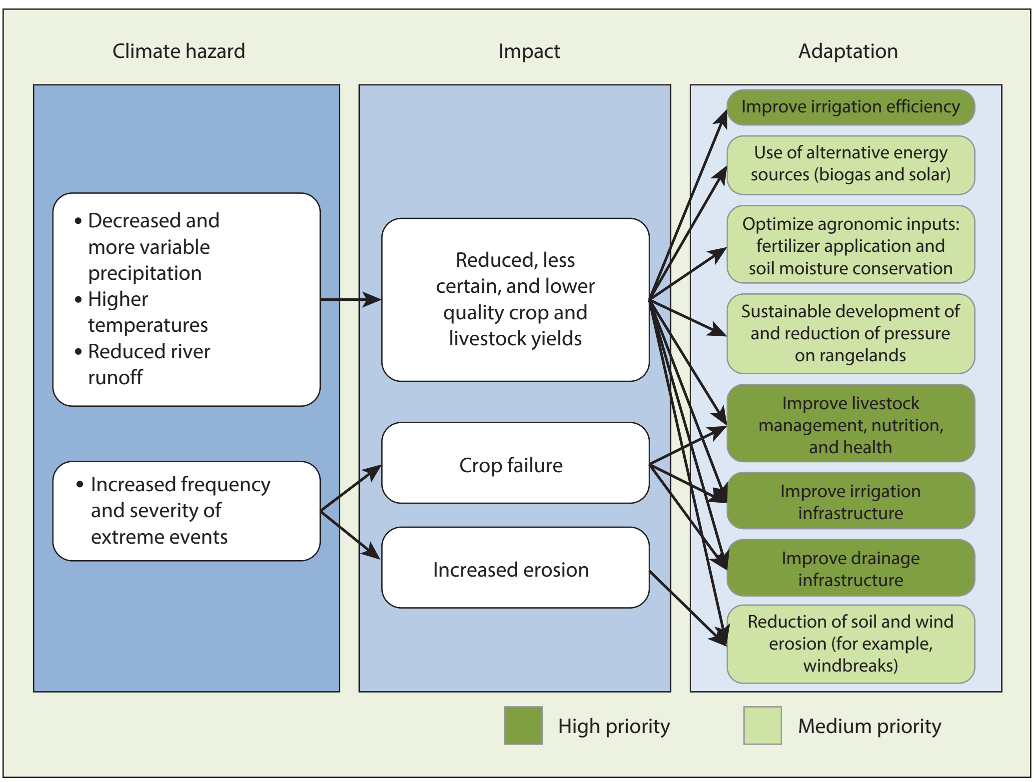
crop modeling. However, when combined with the omission of other costs of fertilizer application, such as reduced water quality, there is a significant potential that a full cost analysis could yield costs in excess of yield benefits for some crops where lower benefit-cost ratios were found. This measure would need to be coupled with the national measure to enhance extension capacity noted above.

Figure 6.2 presents an overall set of prioritized adaptation options based on the National Conference recommendations and the options considered by the team. Measures shaded in darker green represent options that were recommended by both the Bank assessment and the National Conference groups.

Piedmont and Highlands AEZs

Many of the measures identified in the Piedmont and Highlands AEZs are similar to those in the Desert and Steppe AEZ, but water availability issues are less acute in most parts of these AEZs, and many of the crops grown in other AEZs are not viable in the Highlands AEZ. In general, climate change should present opportunities in the Highlands AEZ, particularly in the livestock sector.

Figure 6.2 Adaptation Measures for the Desert and Steppe AEZ Based on Team and National Conference Assessment



http://dx.doi.org/10.1596/978-1-4648-0000-9

The Piedmont and Highlands AEZ breakout group at the National Conference developed the following ranked list of adaptation options:

1. Improve appropriate land use (for example, apples and pistachio orchards, vegetables, alfalfa, grazing land, pasture).
2. Develop soil, water, and crop-management strategy, including consideration of diseases and pests.
3. Improve water use efficiency—using both modern and traditional methods (including rain water-harvesting).
4. Promote agro-processing and private sector participation.
5. Improve access to technology and information.

Where these National Conference recommendations overlap with the original consultant team priorities in table 6.3, they are listed in italics.

Table 6.3 Adaptation Measures for the Piedmont and Highlands AEZs

		Ranking criteria			
Adaptation measure	*Crop and livestock focus*	*Net economic benefit: Quantitative analysis*	*Net economic benefit: Expert assessment*	*Potential to aid farmers with or without climate change*	*Favorable evaluation by local farmers*
Improve crop varieties	*Tomatoes, Potatoes, Apples, Wheat (Both), Cotton (Piedmont only)*	*Piedmont: 1st, Highlands: 2nd*	*High*	*High*	*3rd*
Improve irrigation efficiency	*On-farm systems for: Tomatoes (Piedmont), Potatoes (Both), Apples and Wheat (Highlands)*	*Piedmont: 2nd, Highlands: 3rd*	*High*	*High*	*1st*
Improve irrigation infrastructure	*Tomatoes (Piedmont), Potatoes (Both), Apples and Wheat (Highlands)*	*Piedmont: 3rd, Highlands: 1st*	*Medium to high, dependent on water availability*	*High*	*1st*
Research options for crop insurance	All	Not evaluated	Depends on level of participation; government subsidy, and effectiveness of risk spreading	Medium to high, depending on affordability	1st in initial meetings, not mentioned in second meeting
Optimize agronomic inputs: fertilizer and soil moisture conservation	Potatoes (Both), Tomatoes (Piedmont)	Piedmont: 5th, Highlands: 4th	Medium	High	Not mentioned
Research and improve livestock management, nutrition, and health	Beef cattle, Chickens	Unknown	Not mentioned	Low	Not mentioned

Note: Rows in italics indicate measures that were prioritized both by the expert analysis and by the stakeholders participating in the National Conference. Measures not in italics were prioritized only by the expert analysis.

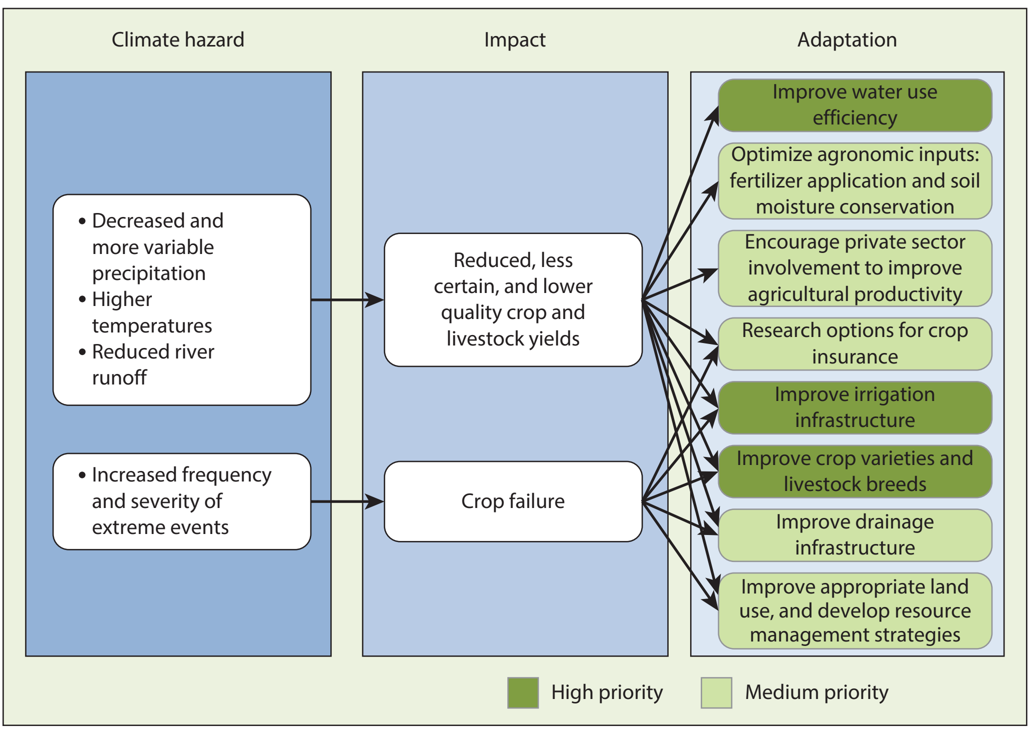
http://dx.doi.org/10.1596/978-1-4648-0000-9

Merging the above priorities with the options from the National Conference generates an overall menu of adaptation measures for the Piedmont and Highlands AEZs. In generating this summary list, measures recommended by the irrigation breakout group at the National Conference (see above) are also included. Figure 6.3 summarizes exposures, impacts, and adaptation options, where measures shaded in darker green represent options that were recommended by both the World Bank assessment and the National Conference groups.

Categorization of Short-, Medium-, and Long-Term Options

The measures outlined above will need to be implemented over differing time scales to ensure they have maximum effect and cost-effectiveness. As part of the quantitative analysis, several sensitivity tests were conducted to assess whether, as climate changes, certain of the options analyzed here might be more cost-effectively implemented at a certain point in time. For the options analyzed, it was found that time was not an important factor in determining B-C ratios. In other words, options with B-C ratios greater than one exhibited positive net benefits from the start of the simulations, in 2015, and exhibited continued net benefits throughout the period of analysis, through 2050, regardless of the

Figure 6.3 Adaptation Measures for the Piedmont and Highlands AEZs Based on Team and National Conference Assessment



http://dx.doi.org/10.1596/978-1-4648-0000-9

simulated start date.[1] The opposite was also true—options with B-C ratios less than one exhibited low B-C ratio values for all simulated start dates.

As a result, categorization of short-, medium-, and long-term options is mainly based on qualitative assessment. Short-term options are those that would be implemented within 1–3 years; medium-term options would be implemented in 4–10 years; and long-term options in 10 years or more.

Short-Term Options

The following should be implemented or at least initiated within 1–3 years of the completion of the study:

- Implement policy reforms to encourage more efficient use of water and clear incentives for land stewardship.
- Improve farmer access to technologies and information, through improved farmer education capacity.
- Improve on-farm water use through farmer education.
- Evaluate options for revised crop insurance schemes.
- Optimize agronomic inputs, including fertilizer application and soil moisture conservation.

Medium-Term Options

The following should be implemented or at least initiated within 4–10 years of the completion of the study. These measures will require lead time to ensure they are designed with consideration of the effects of future climate change on the potential for episodic drought, for example. Prior to implementing these options, therefore, more detailed engineering feasibility studies will be needed for these long-term investments, but those studies must consider the effects of climate change. However, these measures are not long-term options, because they clearly will yield benefits based on current climate conditions, even before the climate changes significantly:

- Implement on-farm drip irrigation for high-value crops.
- Develop more detailed plans for improving basin-level water efficiency.
- Rehabilitate irrigation water infrastructure as necessary.
- Improve on-farm vertical drainage infrastructure to reduce soil salinity.

Long-Term Options

The following options require long lead time to implement, and also are best pursued as climate scenarios unfold:

- Fully implement basin-level water efficiency measures, such as lining of conveyance channels.
- Continue to develop and offer farmer education in the management of drought-resistant and pest-resistant varieties.
- Transition to more heat-tolerant livestock breeds.

http://dx.doi.org/10.1596/978-1-4648-0000-9

A study with this broad scope necessarily involves significant limitations. These include the need to make assumptions about many important aspects of agricultural and livestock production in Uzbekistan, the limits of simulation modeling techniques for forecasting crop yields and water resources, and time and resource constraints. Some of the options will require more detailed examination and analysis than could be accomplished here, to ensure that specific adaptation measures are implemented in a manner that maximizes their value to Uzbekistan agriculture.

It is hoped, however, that the awareness of climate risks and the analytic capacities built through the course of this study provide not only a greater understanding among Uzbekistan agricultural institutions of the basis of the options presented here, but also an enhanced capability to conduct the required more detailed assessment that will be needed to further pursue these actions.

Note

1. Note that the preliminary water storage assessment assumes more lead time for construction, so the expected operational date is 2030. That option is currently not part of this study's recommended suite of measures, however.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Glossary

The source of these definitions is the IPCC AR4 Working Group II report, Appendix I: Glossary, unless otherwise noted. Italics indicate that the term is also contained in this glossary.

Adaptation. Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous, and planned adaptation:

- *Anticipatory adaptation*—Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
- *Autonomous adaptation*—Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in human systems. Also referred to as spontaneous adaptation.
- *Planned adaptation*—Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

Adaptation assessment. The practice of identifying options to adapt to *climate change* and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility.

Adaptation—"hard" vs. "soft". "Hard" adaptation measures usually imply the use of specific technologies and actions involving capital goods, such as dikes, seawalls and reinforced buildings, whereas "soft" adaptation measures focus on information, capacity building, policy and strategy development, and institutional arrangements. (World Bank 2011)

Adaptive capacity (in relation to climate change impacts). The ability of a system to adjust to climate change (including climate variability and extreme to moderate potential damages), to take advantage of opportunities, or to cope with the consequences.

Agroforestry. A dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. (World Agroforestry Centre 2011).

http://dx.doi.org/10.1596/978-1-4648-0000-9

Aquaculture. The managed cultivation of aquatic plants or animals, such as salmon or shellfish, held in captivity for the purpose of harvesting.

Arid region. A land region of low rainfall, where "low" is widely accepted to be less than 250 millimeters precipitation per year.

Baseline/reference. The baseline (or reference) is the state against which change is measured. It might be a "current baseline," in which case it represents observable, present-day conditions. It might also be a "future baseline," which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines. Economic baselines reflect current conditions, and climate baselines reflect the decade 2000–09.

Basin. The drainage area of a stream, river, or lake.

Benefits of adaptation. The avoided damage costs or the accrued benefits following the adoption and implementation of *adaptation* measures.

Biophysical model. Biophysical modeling applies physical science to biological problems, for example, in understanding how living things interact with their environment. In this report, biophysical modeling is used in conjunction with economic modeling.

Capacity building. In the context of *climate change*, capacity building is developing the technical skills and institutional capabilities in developing countries and economies in transition to enable their participation in all aspects of *adaptation* to, *mitigation* of, and research on *climate change*, and in the implementation of the Kyoto Mechanisms.

Carbon dioxide (CO_2). A naturally occurring gas fixed by photosynthesis into organic matter. A by-product of fossil fuel combustion and biomass burning, it is also emitted from land-use changes and other industrial processes. It is the principal anthropogenic *greenhouse gas* that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured, thus having a Global Warming Potential of 1.

Carbon dioxide fertilization. The stimulation of plant photosynthesis due to elevated CO_2 concentrations, leading to either enhanced productivity and/or efficiency of primary production. In general, C_3 plants show a larger response to elevated CO_2 than C_4 plants.

Catchment. An area that collects and drains water.

Climate. Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO).

http://dx.doi.org/10.1596/978-1-4648-0000-9

Climate change. Climate change refers to any change in *climate* over time, whether due to natural variability or as a result of human activity. This usage differs from that in the *United Nations Framework Convention on Climate Change* (UNFCCC), which defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." See also *climate variability*.

Climate model. A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity (that is, for any one component or combination of components a hierarchy of models can be identified), differing in such aspects as the number of spatial dimensions; the extent to which physical, chemical, or biological processes are explicitly represented; or the level at which empirical parameterizations are involved. Coupled atmosphere/ocean/sea-ice *General Circulation Models (AOGCMs)* provide a comprehensive representation of the climate system. More complex models include active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but also for operational purposes, including monthly, seasonal, and interannual climate predictions.

Climate Moisture Index (CMI). CMI is a measure of aridity that is based on the combined effect of temperature and precipitation. The CMI depends on average annual precipitation and average annual potential evapotranspiration (PET). If PET is greater than precipitation, the climate is considered to be dry, whereas if precipitation is greater than PET, the climate is moist. Calculated as CMI = (P/PET) –1 {when PET > P} and CMI = 1– (PET/P) {when P > PET}, a CMI of –1 is very arid and a CMI of +1 is very humid. As a ratio of two depth measurements, CMI is dimensionless.

Climate projection. The calculated response of the *climate system* to *emissions* or concentration *scenarios* of *greenhouse gases* and aerosols, or radiative forcing scenarios, often based on simulations by *climate models*. Climate projections are distinguished from climate predictions, in that the former critically depend on the emissions/concentrations/radiative forcing scenarios used, and therefore on highly uncertain assumptions of future socio-economic and technological development.

Climate risk. Denotes the result of the interaction of physically defined hazards with the properties of the exposed systems—that is, their sensitivity or social vulnerability. Risk can also be considered as the combination of an event, its likelihood and its consequences—that is, risk equals the probability of climate hazard multiplied by a given system's vulnerability (UNDP 2005).

Climate (change) scenario. A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use

http://dx.doi.org/10.1596/978-1-4648-0000-9

as input to climate change impact models. A "climate change scenario" is the difference between a climate *scenario* and the current climate.

Climate variability. Climate variability refers to variations in the mean state and other statistics (such as standard deviation, statistics of extremes, and so on) of the *climate* on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variation in natural or anthropogenic external forcing (external variability). See also *climate change*.

Costs of adaptation. Costs of planning, preparing for, facilitating, and implementing *adaptation* measures, including transition costs.

Crop modeling. Determines characteristics of crops such as yield and irrigation water requirements. Examples of inputs to crop models include changes in conditions, such as soil type, soil moisture, precipitation levels, and temperature, and changes in inputs, such as fertilizer and irrigation levels.

Deficit irrigation. A type of irrigation meant to maximize water-use efficiency (WUE) for higher yields per unit of irrigation water applied: the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other crops. The grower must have prior knowledge of crop yield responses to deficit irrigate (Kirda 2000).

Desert. A region of very low rainfall, where "very low" is widely accepted to be less than 100 millimeters per year.

Discount rate. The degree to which consumption now is preferred to consumption one year from now, with prices held constant, but average incomes rising in line with GDP per capita.

Drought. The phenomenon that exists when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that often adversely affect land resources and production systems.

Evaporation. The transition process from liquid to gaseous state.

Evapotranspiration. The combined process of water evaporation from the Earth's surface and transpiration from vegetation.

Exposure. A description of the current climate risk within the priority system (that is, the probability of a climate hazard combined with the system's current vulnerability; UNDP 2005).

Extreme weather event. An event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called "extreme weather" may vary from place to place. Extreme weather events typically include floods and *droughts*.

Food security. A situation that exists when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development, and an

http://dx.doi.org/10.1596/978-1-4648-0000-9

active and healthy life. Food insecurity may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level.

Forecast. See climate projection.

Global circulation model (GCM). Computer model designed to help understand and simulate global and regional climate, in particular the climatic response to changing concentrations of greenhouse gases. GCMs aim to include mathematical descriptions of important physical and chemical processes governing climate, including the role of the atmosphere, land, oceans, and biological processes. The ability to simulate subregional climate is determined by the resolution of the model.

Greenhouse gas (GHG). Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapor (H_2O), *carbon dioxide* (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. As well as CO_2, N_2O, and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

Hydrometeorological data. Information on the transfer of water between land surfaces and the lower atmosphere, especially in the form of precipitation. This type of data can provide insight on effects on agriculture, water supply, flood control, and more.

(Climate change) Impact assessment. The practice of identifying and evaluating, in monetary and/or non-monetary terms, the effects of *climate change* on natural and human systems.

(Climate change) Impacts. The effects of *climate change* on natural and human systems. Depending on the consideration of *adaptation*, one can distinguish between potential impacts and residual impacts:

- *Potential impacts*—all impacts that may occur given a project change in climate, without considering adaptation.
- *Residual impacts*—the impacts of climate change that would occur after adaptation.

Index-based insurance. A type of crop insurance that uses meteorological measurements to determine indemnity payments, as opposed to assessing damage at the individual farm level, allowing for a lower premium cost. This type of insurance is particularly useful for damages that affect areas relatively uniformly (Roberts 2005).

Infrastructure. The basic equipment, utilities, productive enterprises, installations, and services essential for the development, operation, and growth of an organization, city, or nation.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Integrated water resources management (IWRM). The prevailing concept for water management which, however, has not been defined unambiguously. IWRM is based on four principles that were formulated by the International Conference on Water and Environment in Dublin in 1992: (1) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; (2) Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels; (3) Women play a central part in the provision, management, and safeguarding of water; and (4) Water has an economic value in all its competing uses and should be recognized as an economic good.

Irrigation water-use efficiency. Irrigation *water-use efficiency* is the amount of biomass or seed yield produced per unit of irrigation water applied, typically about 1 tonne of dry matter per 100 millimeters water applied.

Mitigation. An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce *greenhouse gas* sources and emissions and enhancing greenhouse gas sinks.

Multiple-peril crop insurance (MPCI). A type of insurance that is geared toward a level of expected yield, rather than to the damage that is measured after a defined loss event. MPCI policies are best suited to perils where individual contribution to a crop loss are difficult to measure and peril impacts last over a long period of time. Yield shortfall may be determined on either an area or individual farmer basis (Roberts 2005).

Net present value (NPV). Total discounted benefits less discounted costs.

Projection. The potential evolution of a quality or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions—concerning, for example, future socioeconomic and technological developments, that may or may not be realized—and are therefore subject to substantial uncertainty.

Rangeland. Unmanaged grasslands, shrublands, savannas, and tundra.

Reservoir. A component of the climate system, other than the atmosphere, that has the capacity to store, accumulate, or release a substance of concern (for example, carbon or greenhouse gas). Oceans, soils, and forests are examples of carbon reservoirs. The term also means an artificial or natural storage place for water, such as a lake, pond, or aquifer, from which the water may be withdrawn for such purposes as irrigation or water supply.

Resilience. The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

Runoff. That part of precipitation that does not *evaporate* and is not transpired.

Scenario. A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from *projections*,

http://dx.doi.org/10.1596/978-1-4648-0000-9

but are often based on additional information from other sources, sometimes combined with a "narrative storyline." See also (*climate change) scenario*.

Sector. A part or division, as of the economy (for example, the manufacturing sector, the services sector) or the environment (for example, water resources, forestry) (UNDP 2005).

Semi-arid regions. Regions of moderately low rainfall, which are not highly productive and are usually classified as *rangelands*. "Moderately low" is widely accepted as 100–250 millimeters precipitation per year. See also *arid region*.

Sensitivity. Sensitivity is the degree to which a system is affected, either adversely or beneficially, by *climate variability* or change. The effect may be direct (for example, a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (for example, damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Silviculture. Cultivation, development, and care of forests.

Special Report on Emissions Scenarios (SRES). The storylines and associated population, GDP, and emissions scenarios associated with the Special Report on Emissions Scenarios (SRES) (Nakićenović et al. 2000), and the resulting *climate change* and sea-level rise scenarios. Four families of socioeconomic scenarios—A1, A2, B1, and B2—represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns and global versus regional development patterns.

Stakeholder. A person or organization that has a legitimate interest in a project or entity or would be affected by a particular action or policy.

United Nations Framework Convention on Climate Change (UNFCCC). The convention was adopted in 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community; it entered in force in March 1994. Its ultimate objective is the "stabilization of *greenhouse gas* concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." It contains commitments for all "parties, which under the convention, are those entities included in Annex I that aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000.

Vulnerability. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Water stress. A country is water-stressed if the available freshwater supply relative to water withdrawals acts as an important constraint on development. Withdrawals exceeding 20 percent of renewable water supply have been used as an indicator of water stress. A crop is water-stressed if soil-available water, and thus actual *evapotranspiration*, is less than potential evapotranspiration demands.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Water-use efficiency (WUE). Carbon gain in photosynthesis per unit water lost in *evapotranspiration*. It can be expressed on a short-term basis as the ratio of photosynthetic carbon gain per unit transpirational water loss or on a seasonal basis as the ratio of net primary production or agricultural yield to the amount of available water.

Win-win options. "Win-win" options are measures that contribute to both *climate change mitigation* and *adaptation* and wider development objectives; for example, business opportunities from energy efficiency measures, sustainable soil, and water management, among others. They constitute *adaptation* measures that would be justifiable even in the absence of climate change. Many measures that deal with *climate variability* (for example, long-term weather forecasting and early warning systems) may fall into this category (World Bank 2011).

Win-win-win options. "Win-win-win" options are measures that contribute to *climate change mitigation*, development objectives, and *adaptation* to *climate change*.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Bibliography

Adams, R. M., B. A. McCarl, K. Segerson, C. Rosenzweig, K. J. Bryant, B. L. Dixon, R. Connor, R. E. Evenson, and D. Ojima. "The Economic Effects of Climate Change on US Agriculture." In *Impact of Climate Change on the United States Economy*, edited by R. Mendelsohn and J. E. Neumann, 74–98. Cambridge, UK: Cambridge University Press.

Alston, J. M., M. C. Marra, P. G. Pardey, and T. J. Wyatt. 1998. "Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D." IFPRI, Environmental and Production Technology Division, Washington, DC (accessed February 1, 2011), http://www.ifpri.org/sites/default/files/publications/eptdp38.pdf.

Butt, T. A., B. A. McCarl, J. Angerer, P. T. Dyke, and J. W. Stuth. 2005. "The Economic and Food Security Implications of Climate Change in Mali." *Climatic Change* 68 (3): 355–78.

Centre of Hydrometeorological Service, Cabinet of Ministers. 2008. Second National Communication of the Republic of Uzbekistan under the United Nations Framework Convention on Climate Change, Tashkent.

Cerdán-Infantes, P., A. Maffioli, and D. Ubfal. 2008. "The Impact of Agricultural Extension Services: The Case of Grape Production in Argentina." Inter-American Development Bank, Office of Evaluation and Oversight. Working Paper OVE/WP-05/08 (accessed February 1, 2011), http://www.iadb.org/intal/intalcdi/pe/2009/03159.pdf.

ClimateWizard. The Nature Conservancy, University of Washington, and The University of Southern Mississippi. http://www.climatewizard.org.

Dixon, J., H.-J. Braun, P. Kosina, and J. Crouch, eds. 2009. *Wheat Facts and Futures 2009*. Mexico, D.F.: CIMMYT.

FAO (Food and Agriculture Organization). *Data Tools Methods for Climate Impact Assessment in Agriculture and Planning of Climate Change Adaptation Practices*. Rome, Italy: Climate, Energy and Tenure Division (NRC), Food and Agriculture Organization of the United Nations (FAO) (accessed April 1, 2011), http://www.fao.org/climatechange/20976-0381c1f0c1b89be3ea31a467ad5fd74dc.pdf.

———. 2006. "Forestry: Country Report on the Republic of Uzbekistan." AgroWeb, FAO.

FAO AQUASTAT. Uzbekistan (accessed January 14, 2011), http://www.fao.org/nr/water/aquastat/countries/uzbekistan/index.stm.

———. Global Map of Irrigated Areas (accessed December 14, 2010), http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm.

http://dx.doi.org/10.1596/978-1-4648-0000-9

FAOSTAT. 2005. Predicted Global Livestock Densities 2005 Converted for Unsuitability, adjusted to match FAOSTAT totals for the year 2005 (accessed September 27, 2010), http://www.fao.org/ag/againfo/resources/en/glw/glw_dens.html.

———. 2009. http://faostat.fao.org/.

———. 2010. PriceStat (accessed December 20, 2010), http://faostat.fao.org/site/570/default.aspx#ancor.

Glendenning, C. J., S. Babu, and K. Asenso-Okyere. 2010. "Review of Agricultural Extension in India: Are Farmers' Information Needs Being Met?" IFPRI Discussion Paper 01048, Eastern and Southern Africa Regional Office (accessed February 1, 2011), http://www.ifpri.org/sites/default/files/publications/ifpridp01048.pdf.

Gu, S., and J. Chism. 2010. "Greenhouse and High Tunnels in Vegetable Production." University of Missouri Extension and Lincoln University Cooperative Extension (accessed February 3, 2011), http://www.greatplainsgrowers.org/2010%20information/2010%20powerpoints/beginners%27%20vegetable%20-%20greenhouse%20-%20high%20tunnels%20-%20sanjun%20gu.pdf.

Hasanov, Shavkat, and Ahmed Mirza Nomman. 2011. "Agricultural Efficiency Under Resources Scarcity in Uzbekistan: A Data Envelopment Analysis." *Business and Economic Horizons* 4 (1): 81–87.

Hughes, G., P. Chinowsky, and K. Strzepek. 2010. "The Costs of Adaptation to Climate Change for Water Infrastructure in OECD Countries." *Utilities Policy* 18 (3): 142–53.

Iglesias, A., K. Avis, M. Benzie, P. Fisher, M. Harley, N. Hodgson, L. Horrocks, M. Moneo, J. Webb. 2007. *Adaptation to Climate Change in the Agricultural Sector.* Report to European Commission Directorate-General for Agriculture and Rural Development. ED05334.

Iglesias, I., and Simó Alegre. 2006. "The Effect of Anti-Hail Nets on Fruit Protection, Radiation, Temperature, Quality and Profitability of 'Mondial Gala' Apples." *Journal of Applied Horticulture* 8 (2): 91–100.

Islami, B., M. Kamberi, E. D. Bruci, and E. Fida. 2009. "Albania's Second National Communication to the Conference of Parties under the United Nations Framework Convention on Climate Change." Republic of Albania Ministry of Environment, Forestry and Water Administration, Tirana.

Jiggins, J. 2007. "Farmer Field Schools Reap Long-Term Rewards." Pesticide News 78 (accessed February 1, 2011), http://www.pan-uk.org/archive/projects/fairness/pn/pn78pp6-7.pdf.

Kirda, C. 2000. "Deficit Irrigation Scheduling Based on Plant Growth Stages Showing Water Stress Tolerance." FAO Water Report 22, UN Food and Agriculture Organization, Rome, Italy (accessed June 16, 2011), http://www.fao.org/docrep/004/Y3655E/Y3655E00.HTM.

Lerman, Zvi. 2008. "Agricultural Development in Central Asia: A Survey of Uzbekistan, 2007–2008." *Eurasian Geography and Economics* 49 (4): 481–505. doi:10.2747/1539-7216.49.4.481. http://bellwether.metapress.com/content/x06m0123v5635358/?p=bdc729471c494bd8911049fec55f5f35&pi=5.

———. 2009. "Agricultural Development in Uzbekistan: The Effect of Ongoing Reforms." Discussion Paper No. 7.08, The Hebrew University of Jerusalem, The Center for Agricultural Economic Research.

Lewis, R. A. 1962. "The Irrigation Potential of Soviet Central Asia." *Annals of the Association of American Geographers* 52 (1): 99–114.

Medina, F., and A. Iglesias. 2010. "Agricultural Practices with Greenhouse Mitigation Potential in Mediterranean Countries: Evaluation and Policy Implications." 9th Europeans IFSA Symposium, July 4–7. Vienna.

Munich Re. 2000. *Review of Natural Disasters, 1999*. Munich Re, Report No. 2946-M-e.

National Cotton Council of America http://www.cotton.org/.

Odame, H., P. Musyoka, and J. Kere. 2008. "How National Public Policies Encourage or Impede Agribusiness Innovation: Cases of Maize, Tomato and Dairy in Kenya." World Bank Institute and the Governments of Denmark and Ireland (accessed February 3, 2011), http://info.worldbank.org/etools/docs/library/243695/kyagribusinessreport.pdf.

Ososkova, T. 2008. "Uzbekistan's Second National Communication to the Conference of Parties under the United Nations Framework Convention on Climate Change." Centre of Hydrometeorological Service under the Cabinet of Ministers of the Republic of Uzbekistan, Tashkent.

Parry, M. L, C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer. 2004. "Effects of Climate Change on Global Food Production under SRES Emissions and Socio-economic Scenarios." *Global Environmental Change* 14: 53–67.

Paustian, K., J. Antle, J. Sheehan, and E. Paul. 2006. *Agriculture's Role in Greenhouse Gas Mitigation*. Washington, DC: Pew Center on Global Climate Change.

Rakhmatullaev, S., F. Huneau, P. Le Coustumer, M. Motelica-Heino, and M. Bakiev. 2010. "Facts and Perspectives of Water Reservoirs in Central Asia: A Special Focus on Uzbekistan." *Water* 2: 307–20.

Roberts, R. A. J. 2005. "Insurance of Crops in Developing Countries. Food and Agriculture Organization." FAO Agricultural Services Bulletin 159. UN Food and Agriculture Organization, Rome, Italy (accessed April 1, 2011), ftp://ftp.fao.org/docrep/fao/008/y5996e/y5996e00.pdf.

Rysbekov. 2004. Analysis of Water Management Organizations in Chirchik-Akhangaran River Basin (Central Asia) (accessed January 20, 2011), http://www.cawater-info.net/rivertwin/documents/pdf/rysbekov_e.pdf.

SEDAC, Columbia University. 2011. Gridded Population of the World (accessed January 15, 2011), http://sedac.ciesin.columbia.edu/gpw/.

Seo, S. N., and R. Mendelsohn. 2006. "The Impact of Climate Change on Livestock Management in Africa: A Structural Ricardian Analysis." Center for Environmental Economics and Policy in Africa (CEEPA). Printed by the University of Pretoria.

Sieber, J., and D. Purkey. 2007. *Water Evaluation and Planning (WEAP) Model User Guide.* Stockholm, Sweden: Stockholm Environment Institute. www.weap21.org.

Smith, P., P. Andren, T. Karlsson, P. Perala, K. Regina, M. Rounsevell, and B. V. Wesemael. 2005. "Carbon Sequestration Potential in European Croplands Has Been Overestimated." *Global Change Biology* 11: 2153–63.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J. Smith. 2008. "Greenhouse Gas Mitigation in Agriculture." *Philosophical Transactions of the Royal Society* 363 (1492): 789–813.

State Committee on Land and Cadastre of the Republic of Uzbekistan (former Goscomzem). 2009. "Impact of Recent Agricultural Reform Policy of Uzbekistan (Draft)." World Bank, Tashkent.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Sutton, W. R., J. P. Srivastava, and J. E. Neumann. 2013. *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*. Directions in Development. Washington, DC: World Bank. doi:10.1596/978-0-8213-9768-8.

Sutton, W. R., P. Whitford, E. M. Stephens, S. P. Galinato, B. Nevel, B. Plonka, and E. Karamete. 2008. *Integrating Environment into Agriculture and Forestry: Progress and Prospects in Eastern Europe and Central Asia*. Washington, DC: World Bank.

Thornton, P. K., J. van de Steeg, A. Notenbaert, and M. Herrero. 2009. "The Impacts of Climate Change on Livestock and Livestock Systems in Developing Countries: A Review of What We Know and What We Need to Know." *Agricultural Systems* 101: 113–27.

Trapp, R. J., N. S. Diffenbaugh, H. E. Brooks, M. E. Baldwin, E. D. Robinson, and J. S. Pal. 2007. "Changes in Severe Thunderstorm Environment Frequency during the 21st Century Cause by Anthropogenically Enhanced Global Radiative Forcing." *PNAS* 104 (50): 19719–23.

UNDP. 2005. "Adaptation Policy Frameworks for Climate Change." United Nations Development Programme, New York (accessed June 15, 2011), http://www.undp.org/climatechange/adapt/apf.html.

UNFCCC. 1992. *United Nations Framework Convention on Climate Change.* Geneva: United Nations.

Ward, Philip J., Kenneth M. Strzepek, W. Pieter Pauw, Luke M. Brander, Gordon A. Hughes, and Jeroen C. J. H. Aerts. 2010. "Partial Costs of Global Climate Change Adaptation for the Supply of Raw Industrial and Municipal Water: A Methodology and Application." *Environmental Research Letters* 5: 044011.

Weiske, A. 2007. Potential for Carbon Sequestration in European Agriculture: Impact of Environmental Agreements on the CAP. Specific Targeted Research Project SSPE-CT-2004-503604, MEACAP, European Union, Geneva.

Winter, T. C., J. W. Harvey, O. L. Franke, and W. M. Alley. 1998. "Groundwater and Surface Water A Single Resource." USGS Circular 1139, Denver, Colorado.

World Agroforestry Centre (accessed June 16, 2011), http://www.worldagroforestry-centre.org/.

World Bank. 2004. "Project Performance Assessment Report Armenia Irrigation Rehabilitation Project (Credit 2667-AM)." World Bank, Sector and Thematic Evaluation Group, Operations Evaluation Department.

———. 2007a. "Integrating Environment into Agriculture and Forestry Progress and Prospects in Eastern Europe and Central Asia. Volume II." Uzbekistan, Country Review. Report No. 28847, World Bank, Washington, DC.

———. 2007b. "Project Paper on a Proposed Additional Financing Credit in the Amount of SDR 3.3 million to the Republic of Armenia for the Irrigation Development Project." Sustainable Development Department, South Caucasus Country Unit, Europe and Central Asia Region. Report No. 40171-AM. World Bank, Washington, DC.

———. 2009a. Data and Statistics for Uzbekistan (accessed February 15, 2011), http://www.worldbank.org.uz/wbsite/external/countries/ecaext/uzbekistanextn/0,,menupk:294213~pagepk:141132~pipk:141109~thesitepk:294188,00.html.

———. 2009b. Impact of Recent Agricultural Reform Policy of Uzbekistan (Draft). Tashkent.

———. 2009c. "Implementation Completion and Results Report on a Credit in the Amount of SDR19.8 million and the Additional Financing Credit in the Amount of SDR3.3 million to the Republic of Armenia for the Irrigation Development Project." Sustainable Development Department, South Caucasus Country Unit, Europe and Central Asia Region. Report No. ICR00001145, World Bank, Washington, DC.

———. 2009d. *World Development Indicators*. Washington, DC: World Bank. http://data.worldbank.org/products/data-books/WDI-2009.

———. 2010. IDA at Work: Mongolia, Index Based Livestock Insurance Program (accessed April 1, 2011), http://www.worldbank.org/en/news/feature/2009/09/23/index-based-livestock-insurance-project.

———. 2011. Adaptation Guidance Notes—Key Words and Definitions (accessed June 15, 2011), http://climatechange.worldbank.org/climatechange/content/adaptation-guidance-notes-key-words-and-definitions.

World Food Programme. 2008. Poverty and Food Insecurity in Uzbekistan (accessed February 16, 2011), http://documents.wfp.org/stellent/groups/public/documents/ena/wfp179011.pdf.

http://dx.doi.org/10.1596/978-1-4648-0000-9

Environmental Benefits Statement

The World Bank is committed to reducing its environmental footprint. In support of this commitment, the Publishing and Knowledge Division leverages electronic publishing options and print-on-demand technology, which is located in regional hubs worldwide. Together, these initiatives enable print runs to be lowered and shipping distances decreased, resulting in reduced paper consumption, chemical use, greenhouse gas emissions, and waste.

The Publishing and Knowledge Division follows the recommended standards for paper use set by the Green Press Initiative. Whenever possible, books are printed on 50 percent to 100 percent postconsumer recycled paper, and at least 50 percent of the fiber in our book paper is either unbleached or bleached using Totally Chlorine Free (TCF), Processed Chlorine Free (PCF), or Enhanced Elemental Chlorine Free (EECF) processes.

More information about the Bank's environmental philosophy can be found at http://crinfo.worldbank.org/wbcrinfo/node/4.

green press INITIATIVE

http://dx.doi.org/10.1596/978-1-4648-0000-9

Reducing the Vulnerability of Uzbekistan's Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options is part of the World Bank Studies series. These papers are published to communicate the results of the Bank's ongoing research and to stimulate public discussion.

Agriculture is one of the most climate-sensitive of all economic sectors. Uzbekistan is one of the many countries where the majority of the rural population depends on agriculture—directly or indirectly—for their livelihood. The risks associated with climate change pose an immediate and fundamental problem in the country.

The study proposes a clear and comprehensive plan for aligning agricultural policies with climate change; developing the capabilities of key agricultural institutions; and making needed investments in infrastructure, support services, and on-farm improvements. Developing such a plan ideally involves a combination of quality quantitative analysis; consultation with key stakeholders, particularly farmers and local agricultural experts; and investments in both human and physical capital. The experience of Uzbekistan, highlighted in this work, shows that it is possible to develop an initiative to meet these objectives, one that is comprehensive and empirically driven as well as consultative and quick to develop.

The approach of the study is predicated on strong country ownership and participation, and is defined by its emphasis on "win-win" or "no regrets" solutions to the multiple challenges posed by climate change for farmers in Uzbekistan. The solutions are measures that increase resilience to future climate change, boost current productivity despite the greater climate variability already occurring, and limit greenhouse gas emissions—also known as "climate-smart agriculture."

Reducing the Vulnerability of Uzbekistan's Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options applies this approach to Uzbekistan with the goal of helping the country mainstream climate change adaptation into its agricultural policies, programs, and investments. The study projects impacts of climate change on agriculture across Uzbekistan's three agro-ecological zones through forecast variations in temperature and rainfall patterns so crucial to farming. It offers a map for navigating the risks and realizing the opportunities, outlined through a series of consultations with local farmers. A detailed explanation of the approach is provided for those who want to implement similar programs in other countries of Europe, Central Asia, and anywhere else in the world.

The study is one of four produced under the World Bank program "Reducing Vulnerability to Climate Change in European and Central Asian Agricultural Systems." The other countries included in this series are Albania, the former Yugoslav Republic of Macedonia, and Moldova. The results from the four studies are consolidated in the book *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*.

World Bank Studies are available individually or on standing order. This World Bank Studies series is also available online through the World Bank e-library (www.worldbank.org/elibrary).

ISBN 978-1-4648-0000-9

SKU 210000

THE WORLD BANK