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William R. Sutton, Jitendra P. Srivastava,
and James E. Neumann

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Foreword

The global climate is already changing, and the Europe and Central Asia (ECA) Region is vulnerable to these changes. This is one of the central messages of the flagship report, *Adapting to Climate Change in Eastern Europe and Central Asia*, published by the World Bank in 2010. The ECA Region will not be immune to these changes. In fact, the degree of warming from climate change is generally expected to be higher at more northerly latitudes, and this warming is projected to result in many more frequent and more severe extreme weather events. Numerous examples of such events and their effects on European and Central Asian economies and livelihoods have been witnessed in recent years, including droughts, floods, heat waves, untimely frosts, severe storms, and forest fires. Agriculture, which plays a crucial role in ensuring global food security, nutrition, and poverty alleviation, is highly vulnerable to the effects of climate change because of its dependence on the weather.

Globally, ensuring food security in a changing climate is one of the major challenges of the coming decades. As this book goes to print, the latest in a series of food price shocks has hit world markets, precipitated by adverse weather in many parts of the world. As a result, prices have remained at elevated levels for the past five years. Various projections suggest that food production must increase by a staggering 70–100 percent by 2050 to meet the demands of a world with nine billion people and changing diets. Experts look to the production potential of a number of ECA countries—Kazakhstan, the Russian Federation, and Ukraine, in particular—to help provide the necessary supply response for cereals. In other countries, particularly in the Balkans, the Caucasus, and other parts of Central Asia, there remain large rural populations that depend on agriculture for their own food consumption and income—often through a combination of fruit, vegetable, cereal, and livestock production.

These agricultural systems will be affected by climate change through higher temperatures, greater crop water demand, more variable rainfall, and weather extremes. Even where ECA countries have the potential to take advantage of certain opportunities that could be presented as a result of climate change—such as longer growing seasons—they are poorly positioned to do so because of the underdeveloped technological state of their agricultural sectors and their inability to cope with current climate variability. Meanwhile, growing populations of urban consumers are sensitive to any major swing in food prices. This situation is therefore one of the greatest development challenges for the World Bank's clients in the ECA Region.

Facing this challenge requires developing a new approach known as "climate-smart agriculture"—that is, agriculture that contributes to the "triple win" of increasing productivity in today's climate, building resilience to climate change, and reducing greenhouse gas emissions. But applying this approach in practice requires understanding the strengths and weaknesses of current farming systems at the grass-roots level, projecting the potential effects of climate change on these systems, and identifying practical and effective measures that can be taken to increase the resilience of these systems while minimizing greenhouse gas emissions. Ensuring the sustainability of this approach also requires building capacity within each country to carry on this work. That is a tough challenge, but one that the Regional Program on Reducing Vulnerability to Climate Change in ECA Agricultural Systems has begun to address for the first time in the ECA Region.

This book represents the culmination of the program. The authors bring together the findings and recommendations generated through in-depth quantitative and qualitative analyses carried out in four ECA countries—Albania, the former Yugoslav Republic of Macedonia, Moldova, and Uzbekistan—with important agricultural sectors that are being affected by climate change. The results of these analyses are important not only for the four countries examined in the study, but also for other European and Central Asian countries, because these four countries represent a diverse sample of ECA agro-ecological zones. Moreover, the authors provide an accessible description of the innovative methodology they developed to analyze impacts and prioritize responses, which means the approach developed here can be applied anywhere else in the world. They thereby contribute to our greater understanding of how to apply climate-smart agriculture.

As the book states, the risks of climate change cannot be effectively dealt with, nor the opportunities 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. This work shows that it is possible to develop a plan to meet these objectives—one that is comprehensive and empirically driven, yet consultative and quick to develop, as well as realistic to implement.

This volume and the accompanying country-level work represent pioneering contributions to raising awareness of the challenges and identifying practical approaches to make the transition to climate-smart agriculture in the ECA Region. Applying these approaches will also be an important step in adopting a green farming model in ECA, and potentially around the world. Given the implications of this transition for food security, poverty reduction, and greenhouse gas emissions reduction, it should be placed at the top of the development agenda.

Philippe H. Le Houérou
Regional Vice President
Europe and Central Asia Region
The World Bank

Preface

This volume presents a synthesis of the multi-country collaborative program of analytical and advisory activities titled Reducing Vulnerability to Climate Change in European and Central Asian Agricultural Systems. The program has been a collaborative effort between the World Bank and the governments of Albania, the former Yugoslav Republic of Macedonia, Moldova, and Uzbekistan. The goal of this book is to bring together the lessons learned and recommendations from the country-specific work, and provide guidance on the approach and methodology for others who wish to pursue similar analyses elsewhere in the Europe and Central Asia (ECA) region or anywhere else in the world.

Climate change and its impacts on agricultural systems and rural economies are already evident throughout the ECA region. Adaptation measures now in use in the region—largely piecemeal efforts—will be insufficient to prevent impacts on agricultural production over the coming decades. Interest is growing among governments and many of their development partners to gain a better understanding of the exposure, sensitivities, and impacts of climate change at the farm level, and to develop and prioritize adaptation measures to build resilience to the potentially adverse consequences. However, in searching for information in the literature on these themes, we were somewhat surprised to find that little or no satisfactory work had been done on the countries and agricultural systems of Europe and Central Asia. It may be that the potential implications of climate change were previously underestimated for the region. Regardless, we recognized a compelling need for original analysis based on the latest climatic and agronomic science, and this analysis had to be sufficiently comprehensive to provide overarching policy guidance to government decision makers and at the same time sufficiently detailed to address the diverse needs of their countries' key agro-ecological zones (AEZs). We also recognized a need to balance rigorous modeling of the potential impacts of climate change on farming systems with identification of practical adaptation responses on the ground and, furthermore, a desire to begin developing the capacity of beneficiary governments and scientists to carry this work forward on their own, as climate change is a long-term threat that requires long-term responses. The program of analytical and advisory activities was designed to fill these gaps.

The program broadly consisted of three components: a study, awareness-raising activities, and training for local experts. Implementation involved a series of key steps. We began by selecting the four countries mentioned above as the main beneficiaries through a consultative process, with the goal of enhancing the ability of these countries to mainstream climate change adaptation into agricultural policies, programs, and investments. We then carried out activities in each country to increase awareness of the threat, to analyze potential impacts and adaptation responses, and to build capacity among client country stakeholders and World Bank staff with respect to climate change and the agricultural sector. Although climate and impact modeling were important tools for raising awareness of the threat and for understanding the breadth of potential outcomes, the greatest emphasis was placed on identifying and prioritizing practical adaptation responses. The results were presented in a detailed country report, "Reducing the Vulnerability of Country Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options," for each of the four client countries.

Each of the country reports provides a menu of climate change adaptation options for the agriculture and water resources sectors, along with recommendations for specific adaptation actions that are tailored to distinct AEZs within each of the countries, as well as for overarching actions at the national level. The recommendations reflect the results of three interrelated activities conducted by the World Bank team in collaboration with local partners: (1) quantitative economic modeling of baseline conditions and the effects of certain adaptation options; (2) qualitative analysis conducted by the expert team of agronomists, crop modelers, and water resource experts; and (3) input from a series of participatory workshops for farmers in each of the AEZs. The results were discussed and confirmed with key stakeholders at National Dissemination and Consensus Building Conferences in each of the four countries. We further assessed the potential for each of the adaptation options to contribute to the reduction of greenhouse gas emissions. Lessons from the four countries and an initial draft of the book were shared with representatives of the countries at a regional workshop in Istanbul, Turkey, in June 2011.

We believe that a number of features of this work—taken together—make it unique. This book is one of the primary results of the regional program of analytical and advisory activities, and it contains a number of important lessons that should be of interest to policy makers, development practitioners, researchers, and farmer organizations. The full, detailed country report for each of the four countries, this volume, and related background materials are available on the program website: http://www.worldbank.org/eca/climateandagriculture.

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Peer reviewers for this study are Jane Ebinger (Manager, Climate Policy and Finance Department, the World Bank); David Lobell (Assistant Professor and Associate Director of the Center on Food Security and the Environment at Stanford University and lead author, "IPCC Fifth Assessment Report"); and Eija Pehu (Adviser, Agriculture and Environmental Services Department, the World Bank).

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Abbreviations

AAA	analytical and advisory activities
AEZ	agro-ecological zone
ATTC	Agriculture Technology Transfer Centers
B-C ratio	benefit-cost ratio
CDC	canopy decline coefficient
CGC	canopy growth coefficient
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CLIRUN	Climate and Runoff
CMI	Climate Moisture Index
DSSAT	Decision Support System for Agrotechnology Transfer
ECA	Europe and Central Asia
FAO	Food and Agriculture Organization of the United Nations
GCM	global circulation model
GDD	Growing Degree Days
GEF	Global Environment Facility
GHG	greenhouse gas
GIS	Global Information Systems
ICARDA	International Center for Agricultural Research in the Dry Areas
IEWE	Institute of Energy, Water and Environment (Albania)
IFPRI	International Food Policy Research Institute
IFSA	International Farming System Association
IPCC	Intergovernmental Panel on Climate Change
MAFWE	Ministry of Agriculture, Forestry, and Water Economy (FYR Macedonia)
MTS	machinery and technology stations
M&I	municipal and industrial (water demand)
MoEFWA	Ministry of Environment, Forests and Water Administration
NPV	net present value
O&M	operations and maintenance
PAR	photosynthetically active radiation
PET	potential evapotranspiration

PV	present value
SEI	Stockholm Environment Institute
SPAM	Spatial Production Allocation Model
SRES	Special Report on Emissions Scenarios
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VAT	value-added tax
WEAP	Water Evaluation and Planning System

Overview

Faced with significant changes in weather patterns, many countries now have a keen interest in confronting climate change, particularly as food demand is rising along with world population. With some countries facing the stark scenario of having less water, reduced irrigation, and less effective fertilization for key crops, the outlook is growing particularly alarming. 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.

This is not merely an academic exercise: climate change is already under way in the Europe and Central Asia (ECA) Region and it is accelerating. This creates a rapidly narrowing window of opportunity to take meaningful action to mitigate its impacts and to take advantage of potential benefits. Further, as the results of the present study show, building resilience in the agriculture sector has both short- and long-term benefits. As a result, many of the highest priority measures for adapting to climate change yield immediate gains in agriculture sector productivity, demonstrating that pursuit of agricultural adaptation goals is often consistent with pursuit of economic development goals.

Agricultural production is inextricably tied to climate, making agriculture one of the most climate-sensitive of all economic sectors (IPCC 2007). In many countries, such as the four examined in this work, 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. Therefore, climate impacts could undermine progress that has been made in poverty reduction and could adversely impact food security and economic growth in vulnerable rural areas.

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 with key stakeholders, particularly farmers, as well as local agricultural experts. The most effective plans for adapting the sector to climate change will involve both human capital and physical capital enhancements; but many of these investments can also enhance agricultural productivity right now, under current climate conditions.

The experiences of Albania, the former Yugoslav Republic (FYR) of Macedonia, Moldova, and Uzbekistan show that it is possible to develop a plan to meet these objectives, one that is comprehensive, empirically driven, yet consultative and quick to develop. The approach to planning for climate change is predicated on strong country ownership and participation, and it is defined by its emphasis on "win-win" or "no regrets" solutions to the challenges posed by climate change across a range of economic sectors; these are measures that boost productivity today while also increasing resilience to future climate change and current climate variability. This plan also relies heavily on rigorous modeling that recognizes the importance of temperature, precipitation, and general water availability in forecasting changes to farm output and that considers multiple crop types and also livestock. The options that result from this process address needs at both the national level and also the level of the agro-ecological zone (AEZ) within each country.

This volume, *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*, draws on the experience of applying this approach to these four nations in ECA to help each country mainstream climate change adaptation into agricultural policies, programs, and investments. The countries were selected for a variety of reasons, including the importance and diversity of their agricultural sectors, their vulnerability to climate change, the cross-country diversity represented, the potential to incorporate findings and recommendations into investment programs and strategies, and the countries' level of interest. However, an important advantage of the innovative approach developed for this assessment is that it can be applied to gauge the climate change risks and opportunities of any country's farming systems, and it can be used to define and prioritize practical adaptation options.

The approach for this project is centered on four clear 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

- Building capacity among national and local stakeholders to assess the impacts of climate change and developing adaptation measures in the agricultural sector, defined to encompass crop (including cereals, vegetables, fruits, and forage) and livestock production.

The approach also recognizes that the agriculture sector has a role to play in mitigating greenhouse gas emissions, although this will be secondary to measures taken in the energy sector. Many of the steps to improve the climate resilience of the agriculture sector also have the potential to mitigate climate change by cutting greenhouse gas emissions in agricultural production or by increasing the carbon stored in farmland. Uzbekistan is already considering projects to promote methane recovery and combustion for livestock and poultry, while Moldova has introduced new agricultural technologies that enhance carbon accumulation and storage in the soil. This work shows that the benefits of expanding this approach outside the current limited area would be considerable.

Key Findings

The findings fall into four general categories: (1) exposure of agricultural systems to forecast climatic changes, particularly changes in temperature and precipitation, at timescales that are relevant for agricultural production; (2) adaptive capacity of agricultural systems, given the national socioeconomic, technical, and institutional contexts; (3) sensitivity and vulnerability of systems to climate change, reflecting the low level of current adaptive capacity; and (4) menus of suitable adaptation measures prioritized based on multiple criteria.

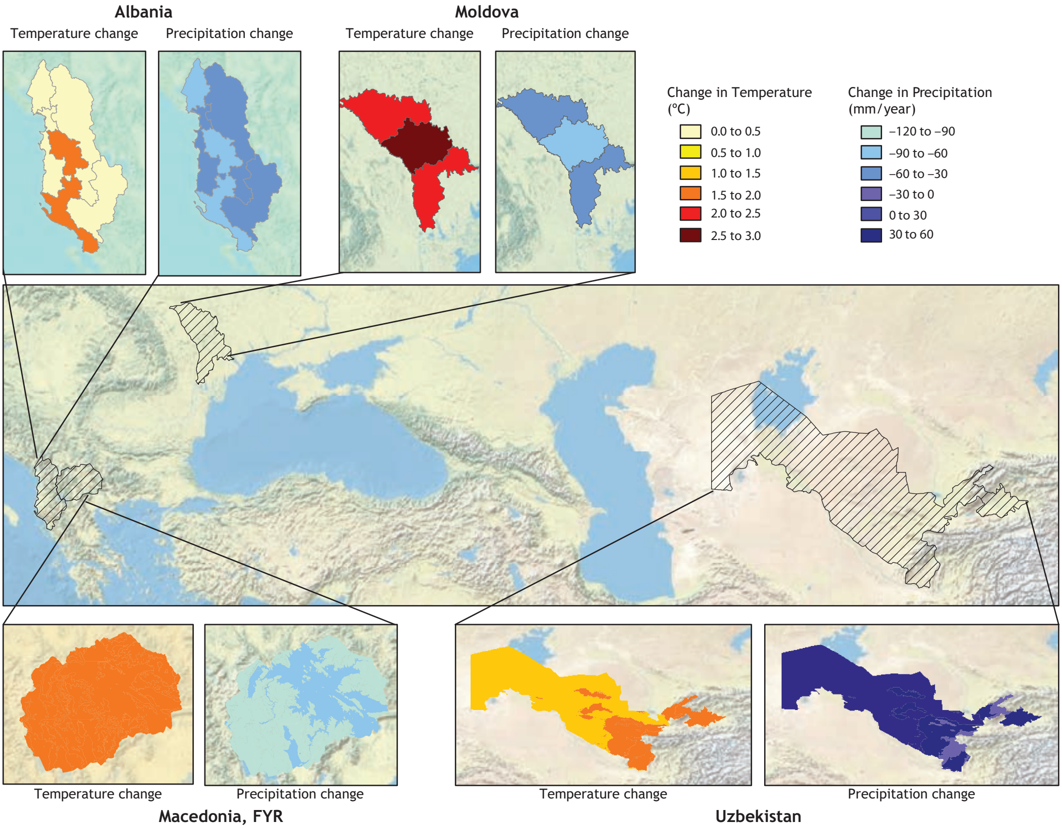
Projecting the Exposure of Agricultural Systems to Climate Change

Results for the exposure component of the findings reflect forecast changes in temperature and precipitation by scenario. Results for the medium impact climate change scenario are outlined in map O.1. Although results for the high and low impact scenarios are not displayed here, they were also analyzed in each country to ensure the adaptation options developed are robust to climate projection uncertainty.

Trends across all three scenarios are similar, with generally warmer temperatures and less rainfall in the high impact scenario, and cooler temperatures and more rainfall in the low scenario, as would be expected. As illustrated on the map, exposure varied among the four countries, particularly regarding forecast precipitation patterns. In all four countries, temperature is forecast to increase, with comparable increases of about 1.5–2.0 degrees C by 2050 throughout each country. The exceptions are Moldova, where the forecast increase is larger, up to 3.0 degrees C, and parts of coastal Albania, where the forecast increase is somewhat smaller.

Precipitation follows a different pattern in each country. In the Eastern European countries (Albania, FYR Macedonia, and Moldova), precipitation is expected to decrease, while in Uzbekistan precipitation is generally forecast to

Map O.1 Forecast Changes in Temperature and Precipitation for the Medium-Impact Climate Change Scenario by 2050



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increase, although by only a small amount—not enough to substantially alter water availability in this largely arid country. The national averages, however, are less important for agricultural production than are the seasonal distribution of temperature and precipitation. Temperature increases are likely to be higher and precipitation declines greater in July and August in all four countries. These seasonal changes in climate have clear implications for crop production if no adaptation measures are adopted beyond those that farmers already employ, with risks to crop production that result from heat and water stress.[1]

Assessing the Adaptive Capacity of Agricultural Systems

The resilience of farmers in these countries is clearly stressed by changes in overall climate. The combination of heat waves, droughts, and intense storms is especially disruptive. On-farm adaptation attempts have been numerous and partially successful, but farmers believe that larger investments in infrastructure are needed. This includes improved water storage, drainage, and irrigation systems, depending on the country. In addition, a key finding of the study's assessment of adaptive capacity was that, for most crops in most countries, farming practices are poorly adapted to current climate. Another key finding of the study is that many of the high-priority measures for adapting to future climate can also provide benefits in the short term in closing the "adaptation deficit" relative to current climate, especially where farmers have already noted some of the effects of climate change, such as shifts in growing season.

Measuring the Sensitivity and Vulnerability of Agricultural Systems to Climate Change

The impact assessment results—which considered exposure, sensitivity, adaptive capacity, and overall vulnerability to climate change, and local soil, crop yield, and water availability, varied substantially by country. These results incorporate the limited existing adaptive capacity, so they provide a baseline from which the costs and benefits of new adaptation measures can be measured. Table O.1 provides a summary of the crop yield results for a representative AEZ in each of the four countries for selected focus crops. In this table, representative AEZs were chosen as important farming regions in each country. The yield changes presented in the table incorporate only the direct effects of climate on crop yields (without considering irrigation water availability), through changes

Table O.1 Estimated "No Adaptation" Crop Yield Impacts of Climate Change before Considering Potential Irrigation Water Shortages, through 2050

	Crop (% change)	*Albania: Lowlands*	*FYR Macedonia: Continental*	*Moldova: Southern*	*Uzbekistan: Piedmont East*
Irrigated crops					
	Alfalfa	4	28	–18	22
	Maize	–4	27	–9	Not analyzed
	Wheat	Predominately rainfed	30	–34	5
	Apples	Not analyzed	13	–3	–1
	Grapes	Predominately rainfed	–23	–5	Not analyzed
	Vegetables/tomatoes[a]	–11	10	–13	–1
Rainfed crops					
	Pasture	–3	8	–19	43
	Alfalfa	–3	2	–12	Predominately irrigated
	Maize	Predominately irrigated	–54	–10	Predominately irrigated
	Wheat	7	25	–45	Predominately irrigated
	Apples	Not analyzed	–41	3	Predominately irrigated
	Grapes	–20	–32	–2	Predominately irrigated
	Vegetables/tomatoes[a]	Predominately irrigated	–9	–9	Predominately irrigated

Note: Units are percent change in 2040s yields relative to current yield. Results shown are for the medium impact climate scenario and assume no CO_2 fertilization effect. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases.

a. Tomatoes analyzed in Uzbekistan and Albania; vegetables analyzed in Moldova and FYR Macedonia.

in temperature and precipitation, and show the net effect over the full 40-year period 2010–50.

As indicated in the table, most crops are expected to experience declines in yield (shown in shades of orange). The crops that experience the most severe impacts are typically rainfed crops grown in the traditional summer season, such as maize, tomatoes/vegetables, apples, and grapes. Some crops, however, will benefit from the direct effects of climate change (those yield increases are shown in green). Typically, benefits are projected for crops grown in winter (such as winter wheat) or pasture and alfalfa, which can be grown year-round; such crops could be expected to benefit on a net basis from a longer, warmer growing season. There are also potential benefits for other irrigated crops, as higher temperatures can benefit many crops, but only if sufficient water is available.

As it turns out, assumption of irrigation water availability is critical to the crop modeling results. Table O.2 combines the results for the agriculture and water resources analyses for the medium climate scenario, providing the net crop yield effect for both the direct and indirect effects of climate change. The results in this table are for selected AEZs in Uzbekistan, Moldova, and FYR Macedonia, where future water shortages are forecasted for the agriculture sector. Comparing table O.2 to table O.1 illustrates the importance of considering both direct and indirect effects of climate change on agricultural yields. The effect of adjusting yields to reflect water shortages is most striking in the Crna basin in FYR Macedonia and in the Piedmont, Southwest region of Uzbekistan, where all the crop yield estimates show substantial declines in crop yields over the 2010–50 period, the largest a 59 percent decline in the Crna basin for grapes. These results demonstrate that where the supply of water for irrigation is expected to fall short of demand as a result of climate change, irrigated crops are in a sense more vulnerable than rainfed crops because they are more dependent on water.

Table O.2 Combined Direct and Indirect "No Adaptation" Irrigated Crop Yield Effects in Basins Where Water Shortages Are Forecast, through 2050

Crop (% change)	*FYR Macedonia: Continental, Pcinja*	*FYR Macedonia: Continental, Crna*	*Moldova: Southern, Lower Nistru*	*Uzbekistan: Piedmont, East*	*Uzbekistan: Piedmont, Southwest*
Alfalfa	18	−43	−19	1	−17
Maize	17	−44	−9	Not analyzed	Not analyzed
Wheat	20	−42	−34	−13	−28
Apples	4	−50	−3	−18	−25
Grapes	−28	−59	−5	Not analyzed	Not analyzed
Vegetables/ tomatoes[a]	1	−51	−13	−18	−24

Note: Units are percent change in 2050 yields relative to current yield. Results shown are for the medium impact climate scenario, include only irrigated crops, and assume no CO_2 fertilization effect. Declines in yield are shown in shades of orange, with darkest representing the biggest declines; increases are shaded green, with darkest representing the biggest increases).

a. Tomatoes analyzed in Uzbekistan and Albania; vegetables analyzed in Moldova and FYR Macedonia.

Prioritizing Adaptation Options

The final analytical step in the study was to conduct quantitative and qualitative analyses of adaptation options to mitigate the impacts illustrated above. The key results of the overall effort are menus of high priority adaptation options for each AEZ and at the national level. The results at the AEZ level addressed mainly infrastructure or on-farm investments, while the results at the national level focused on policy measures that can facilitate more effective climate change adaptation. Placing a high priority on these options is supported by both quantitative benefit-cost analyses of adaptation options, such as improved on-farm water use efficiency and the deployment of better crop varieties, and qualitative analysis, incorporating the results of stakeholder consultations, and a consensus-building exercise conducted in each country at a National Dissemination and Consensus-Building Conference.

In addition, in each country, livestock was identified as an important component of the overall productivity of the sector, particularly among small holders, but, unlike for crops, farmers had not yet experienced many effects of climate on their livestock. The study identified a body of literature that suggested that higher temperatures over time could lead to heat stress for animals, lowering productivity. The result of conversations with local farmers was a recommendation to continuously research and improve livestock nutrition, management, and health not only to ensure that adaptive capacity was maintained, but also to place maintenance of crop productivity as a higher adaptation priority. The resulting lower priority was also consistent with the result of the crop yield impact assessment, which found that increased temperatures would most likely lead to a net increase in pasture (and in some cases alfalfa) productivity in all four countries, even if some fodder crops used at larger livestock operations (especially maize) might be negatively affected.

Table O.3 provides a cross-country summary of the highest priority adaptation measures that the study team and local stakeholders recommended to respond to the most important threats identified in the exposure and impact analyses. As with the vulnerability assessment carried out in the research project, adaptation measures are presented for both the national and local (or agro-ecological zone) levels. These are measures that participants agreed are not likely to be addressed by existing adaptive capacity or policies. The measures are listed across the column headers, and the first two columns list the key impact and exposure sources which the adaptation measures are designed to address. Table O.3 provides a summary for all four countries, but a similar table was developed for each country report (World Bank 2012a, 2012b, 2012c, 2012d) to present country-specific results.[2]

As the table shows, a key finding in all four countries is that enabling policies are urgently needed to provide farmers better access to inter-regional and global technology in a form that is accessible to them. The analysis also supports a range of agronomic practice improvements, on-farm equipment investments, and regional or basin-scale irrigation and drainage infrastructure improvements.

Table O.3 Key Impacts, Exposures, and Adaptation Measures Identified at the National and AEZ Levels

		Adaptation measure to address each impact													
		National level					*AEZ level*								
Climate change impact	*Cause of impact (exposure)*	*Improve farmer access to technologies and information*	*Investigate options for and improve crop insurance programs*[a]	*Improve dissemination of hydro-meteorological information to farmers*[b]	*Provide incentives to consolidate farm holdings*[c]	*Encourage private-sector involvement in adaptation*	*Improve crop varieties*	*Improve irrigation efficiency*[d]	*Improve irrigation infrastructure*	*Improve drainage*[e]	*Optimize agronomic practices: fertilizer application, and soil moisture conservation*	*Build new small-scale water storage facilties*[f]	*Improve irrigation water quality*[g]	*Implement floodplain land-use management measures*[g]	*Improve livestock management, nutrition, and health*
Rainfed and irrigated crop yield reductions	Higher temperatures	✓			✓	✓	✓			✓	✓				
	Increased pests and diseases	✓		✓	✓	✓	✓			✓					
Rainfed crop yield reductions	Lower 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)	✓			✓	✓	✓		✓	✓	✓	✓	✓		✓

Table O.3 Key Impacts, Exposures, and Adaptation Measures Identified at the National and AEZ Levels *(continued)*

		Adaptation measure to address each impact														
		National level					*AEZ level*									
Climate change impact	*Cause of impact (exposure)*	*Improve farmer access to technologies and information*	*Investigate options for and improve crop insurance programs*[a]	*Improve dissemination of hydro-meteorological information to farmers*[b]	*Provide incentives to consolidate farm holdings*[c]	*Encourage private-sector involvement in adaptation*	*Improve crop varieties*	*Improve irrigation efficiency*[d]	*Improve irrigation infrastructure*	*Improve drainage*[e]	*Optimize agronomic practices: fertilizer application, and soil moisture conservation*	*Build new small-scale water storage facilties*[f]	*Improve irrigation water quality*[g]	*Implement floodplain land-use management measures*[g]	*Improve livestock management, nutrition, and health*
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	✓	✓	✓	✓		✓		✓			✓			

Note: AEZ = agro-ecological zone. Adaptation measures apply to all countries except as follows:
a. For Uzbekistan and Moldova
b. For Albania, FYR Macedonia, and Moldova
c. For Albania and FYR Macedonia
d. For Albania, Moldova, and Uzbekistan
e. For Albania, FYR Macedonia, and Uzbekistan
f. For FYR Macedonia and Moldova
g. For Albania.

Figures O.1 and O.2 provide an alternative presentation of the high-priority options across the four countries. For each country in this assessment, a comprehensive list of adaptation options was considered, from which priorities were identified based on a range of considerations. These included benefit-cost criteria, expert judgments, local stakeholder and farmer evaluations and preferences, "win-win" potential, and mitigation potential. Through this process, some adaptation measures were shown to be more suitable for some countries than for others. For example, improving crop insurance was seen to be a priority in Moldova, but less so in Uzbekistan, and not at all in the other two countries. Small-capacity water storage was also regarded as an important option in FYR Macedonia and Moldova, but not in Albania or Uzbekistan. Improvements to drainage capacity were viewed as critical to addressing waterlogging issues in Albania.

However, several adaptation options were seen as high priorities across all four countries, despite their varying climates, geography, and crop focus. In particular, as indicated in figure O.1, there was a universal need to improve farmers' access to agricultural technologies and information, to broaden and improve crop varieties to make the most of the expected changes in climate and water availability, and to significantly improve water infrastructure and systems in all countries. At

Figure O.1 Summary of National Level Adaptation Measures Identified as Priorities in the Study Countries

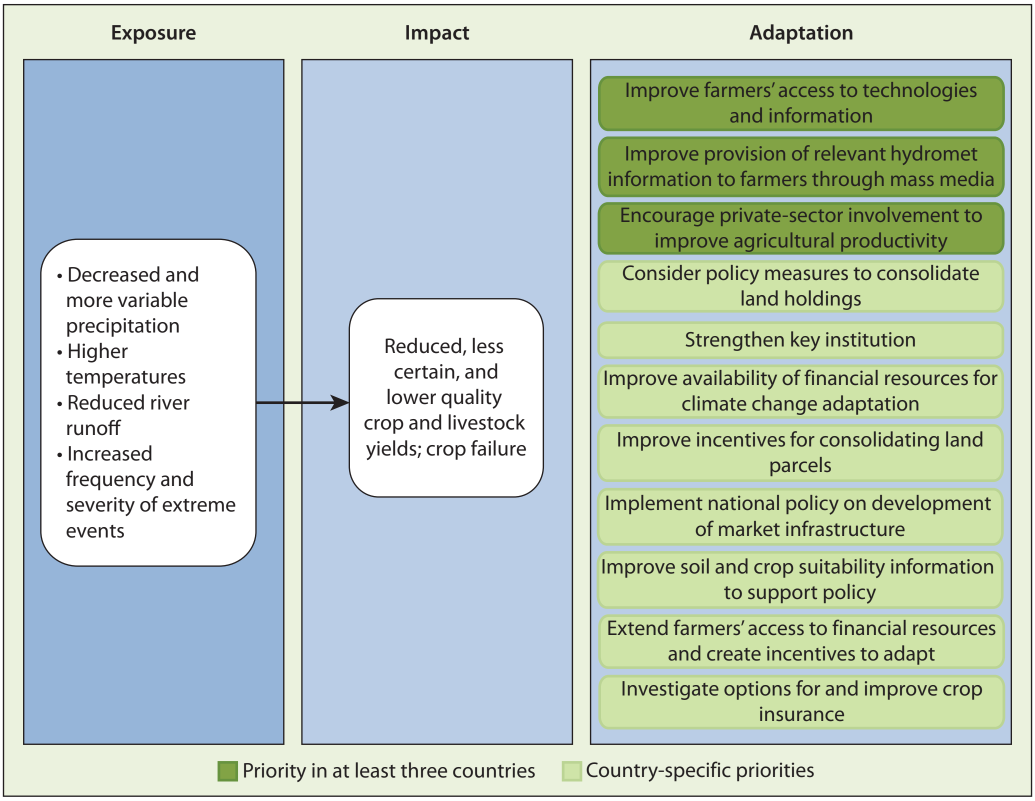
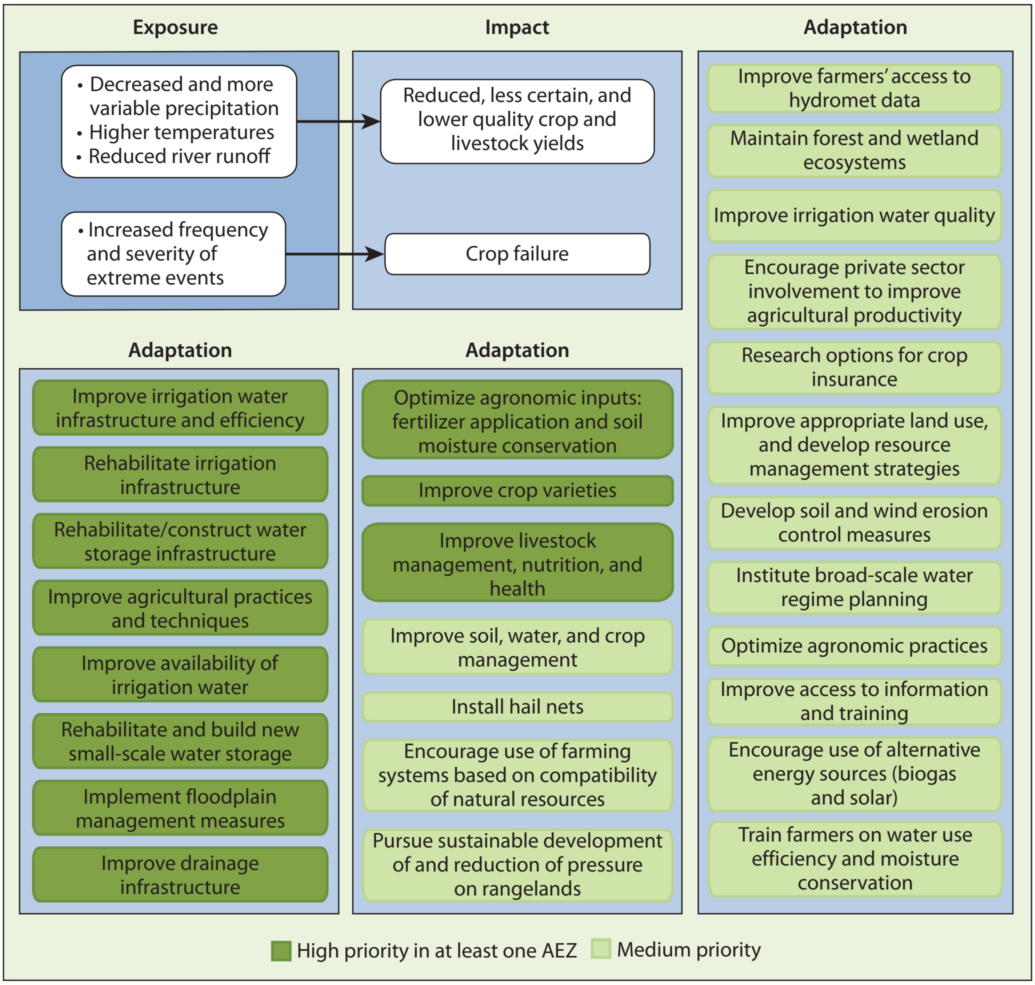


Figure O.2 Summary of AEZ-Level Adaptation Measures Identified as Priorities in the Study Countries



Note: AEZ = agro-ecological zone.

the same time, the study results also made it clear that increasing irrigation capacity is not a panacea. The results of the modeling of future water supply and demand under climate change demonstrate that in many instances there will be shortfalls in the availability of water to supply irrigation systems and that this will have a major impact on agricultural production.

Other priorities emphasized in at least three of the countries included better dissemination of hydrometeorological information to farmers, encouragement of greater private-sector participation in adaptation processes, and improvement of drainage. Additional options regarded as particular priorities in half the surveyed countries included national policy measures to consolidate farm holdings and optimized agronomic practices such as more widespread fertilizer use and better soil moisture conservation.

Overall, the study showed that farmers appear to recognize—and in some instances are already trying to respond to—climate change in their countries, but they need increased information about new technologies and more dependable forecasts for rainfall and weather patterns to better shape their responses.

Immediate Impacts of the Program

As noted, the ultimate goal of this program is to help beneficiary countries identify practical options for mainstreaming climate change adaptation into agricultural policies, programs, and investments, either on their own or with the support of development partners. Initial effects have been encouraging; each of the countries has responded to the information and options the study yielded by taking action across several fronts, highlighting the practical value of this approach as well as the urgency of the situation in each setting. Country results were as follows:

- Albania has begun incorporating the study's recommendations into a new irrigation and drainage project and is creating a new initiative with the Global Environment Facility (GEF) to pilot other recommendations.
- FYR Macedonia has incorporated several recommendations from this assessment into their new Country Partnership Strategy with the World Bank and in their agricultural development project, as well as their "Green Growth Strategy," which is under preparation.
- Moldova has already incorporated some of the findings of this study into their disaster risk mitigation and adaptation project, and more recently incorporated them into a new agricultural competitiveness project.
- Uzbekistan is also teaming with the GEF to pilot some recommendations generated by this program and is addressing other options raised through this exercise in a new agriculture competitiveness project, as well as a series of irrigation projects.
- The approach developed for this program is also being replicated in the South Caucasus countries of Armenia, Azerbaijan, and Georgia.

It is very likely that farmers will ultimately benefit from pursuit of the climate change adaptation plans developed in conjunction with the four countries in the initial study. Addressing challenges of poor access to credit, low uptake rates for available crop insurance, and poor access to modern technologies like improved seeds and equipment is important, but it is clear that one reason farmers do not take advantage of the limited existing opportunities is that they lack knowledge, resources, or both.

Going forward, while the financing of many of these adaptation measures may have to happen on a piecemeal basis, it will be critically important that countries operate on more than one front, simultaneously pushing new policies, better information provision, and enhanced on-farm and regional-scale infrastructure investments. Each of these countries has already produced a surprising number of success stories: farmers who are well-informed, connected to credit, and connected to markets. It is hoped that through efforts such as this one, those success stories can be made more widespread and, in the process, that the resiliency of agriculture to both current and future climate will be greatly enhanced.

Significant efforts have also been made to promote the sustainability of the work carried out under this program in the participating countries. On the technical level, capacity-building sessions were organized in each of the countries to train national experts on the various modeling techniques used, and modeling software was chosen so that it would be accessible and free for use by client countries. On the institutional level, the program promoted the mainstreaming of climate change into agricultural policy through a variety of actions, including working with the ministry of agriculture in each country to establish, for the first time, a climate change focal point and by bringing together policy makers from the ministries of environment (who generally take the lead in coordinating overall climate change activities at the national level) and ministries of agriculture to work together on the subject. The program also established interagency climate change and agriculture steering committees, supported the national governments in the creation of their own agricultural climate change action plans, and organized a regional knowledge exchange workshop where a community of practice was established.

Applying This Approach Elsewhere

In considering the use of the approach developed for this program in other country settings, several factors require close attention. Adaptation encompasses activities and investments in multiple realms, and not only at the farm level: adaptations can be technological, institutional, and policy based. The approach for identification and analysis of adaptation options must be context-specific and must be carried out in conjunction with local stakeholders backed by technical support and capacity-building activities, in order to ensure local ownership of the results and sustainability over time. In the course of this program, national institutions in charge of agricultural policies, agencies or individuals involved in agricultural knowledge dissemination (or “extension”) programs, research centers working on agricultural innovation, and other relevant stakeholders were continuously consulted and supported in the development of adaptation options for increasing climate change resilience and institutional effectiveness in the agricultural sector.

This volume examines the agricultural sectors and the adaptive capacities of each of the four countries; explains the process used to assess climate change scenarios, water use patterns, and crop and livestock impacts and mitigation potential; presents findings and recommendations; and explains how this approach can be applied to other countries both within ECA and in other regions.

Organization of the Book

This book is organized into five further chapters. Chapter 1 introduces the four countries that were studied—Albania, FYR Macedonia, Moldova, and Uzbekistan—and outlines their agriculture sectors, broken down into the main agro-ecological zones. It then considers the adaptive capacities of each country's agricultural sector to manage climate change, spanning the essential technical, physical, institutional, and human resources.

Chapter 2 details the methodology and techniques used to arrive at the impact assessment and the menu of options for each country for mainstreaming climate change adaptation responses tailored to their unique circumstances. It shows how the approach for this analytical and advisory program was built around rigorous biophysical and economic modeling, combined with the input of key stakeholders—particularly farmers—through a participatory process.

Chapter 3 summarizes the results of the program's efforts to identify climate risks and assess potential impacts, and to develop a menu of adaptation options for climate change management in agriculture, at both the national and the agro-ecological zone levels of the four countries. It shows how multiple criteria—including economic and qualitative assessments—were used to prioritize the adaptation options. The results provide detail about the differences in each country, particularly those related to crops at risk from climate change and limited water availability.

Chapter 4 synthesizes, compares, and contrasts the program findings across the four countries. Findings include that climate change is already under way, that the region is likely to experience a reduction in rainfall overall, and that current adaptation responses—largely piecemeal efforts at the farm level—will not constitute a sufficient response to the threat. As such, there is a risk that agricultural production and farm incomes may be undermined, threatening food security and the livelihoods of the rural poor.

Chapter 5 outlines ways that agriculture and other ministries, development agencies, researchers, and farmers worldwide can use the methodology developed by this program to help confront the daunting task of assessing the effects of climate change on agriculture, raising awareness of the threats and opportunities, and the even steeper challenge of identifying and agreeing upon adaption options. It draws lessons learned from piloting the innovative approach, explains how quantitative analysis and stakeholder consultations were paired to prioritize actions, and highlights ways the program results are already influencing activities on the ground in the four countries.

There are also two appendixes. Appendix A is a technical appendix that provides detailed information for practitioners who would like to know about the methodology and modeling techniques applied for the four countries that participated in the program. Appendix B provides a convenient glossary of technical terms.

Notes

1. Note that we adopted a broad definition of climate change, encompassing the full range of climate changes that might be experienced in the future and including but not limited to those explicitly linked to elevated changes in greenhouse gases. This broad definition of climate change may more accurately be referred to as "climate change and variability," but for brevity "climate change" is used throughout this work.
2. Note that many other potential threats and adaptation responses were considered in the course of the study, and only the most important are summarized here.

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CHAPTER 1

Agriculture and Adaptive Capacities in Albania, Moldova, the former Yugoslav Republic of Macedonia, and Uzbekistan

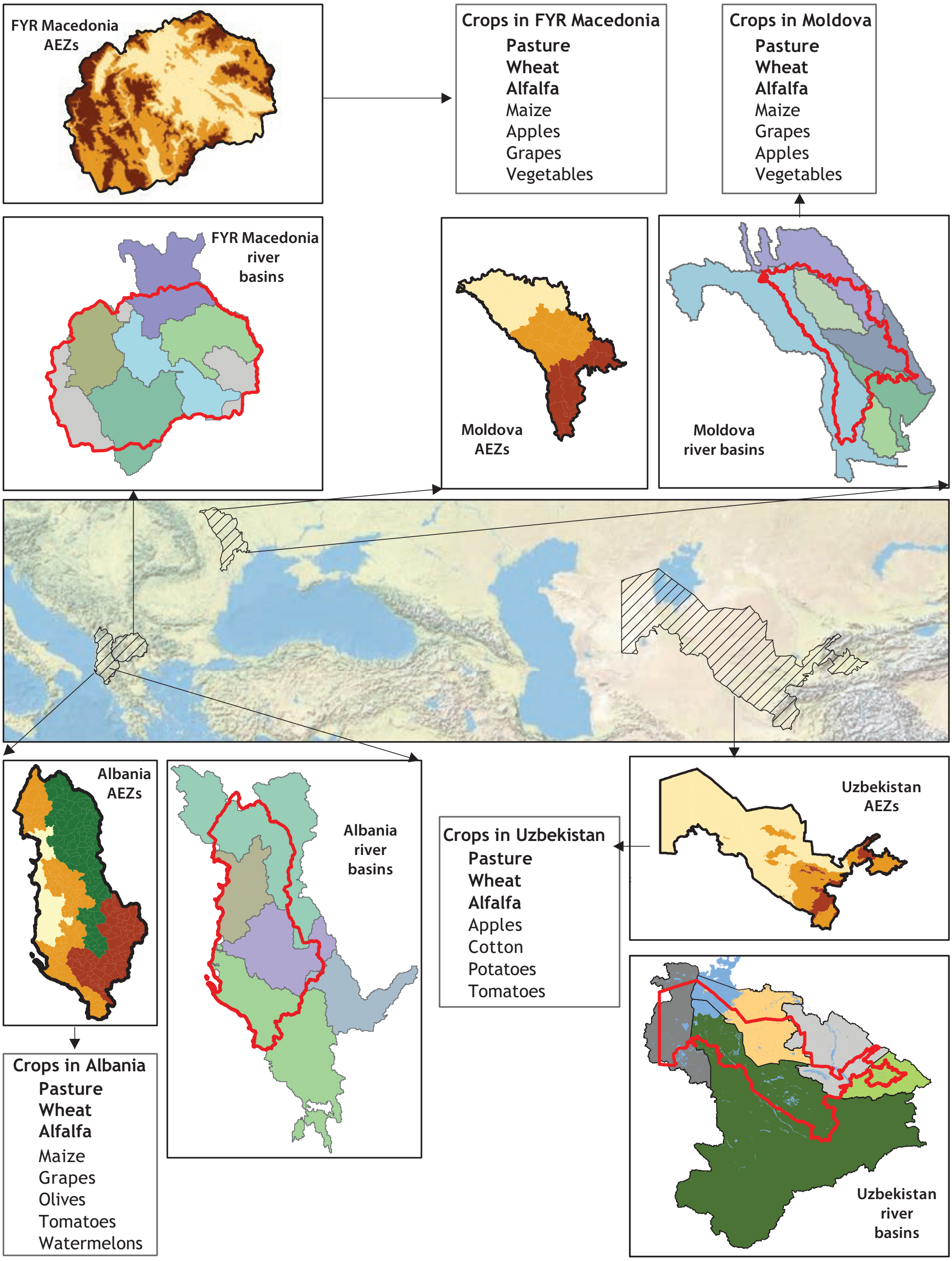
Adaptation planning is challenging because of uncertainties in climatic developments and their locally specific impacts, which makes it difficult to identify the optimal changes in agricultural systems. To be successful, adaptation planning should start early and be sufficiently flexible to address these variables. Accordingly, this work sets out to identify "win-win" or "no regrets" adaptation responses that are robust under a range of different future climate scenarios and contribute to increasing resilience to present-day climate challenges, such as droughts, floods, and increased heat stress. Wherever possible, this work also tries to identify "win-win-win" adaptation options that might also reduce greenhouse gas emissions.

Key geographic, crop, and river basin dimensions that define the scope of this work are represented on map 1.1. The program of analytical and advisory activities on which this volume is based focused on four countries in the Europe and Central Asia (ECA) region, from west to east, Albania, the former Yugoslav Republic of Macedonia, Moldova, and Uzbekistan. For each of the countries, analyses were conducted at the agro-ecologic zone level, with representative crop modeling for three-to-four regions in each country. Agro-ecological zones (AEZs) were defined based on a combination of elevation, soil type, and cropping patterns.

Given the important role of water resources in the study, another dimension of the geography of the analyses was the definition of river basins. In most cases, river basins cross country boundaries, presenting important challenges in data collection and analysis; the red lines in the river basin map insets represent the country border. Also shown in the figure are the crop focuses for each country.

Assessments of climate impacts on wheat, pasture, and alfalfa (the latter two important as livestock feed) were undertaken in all four countries, and these were augmented by impact assessments on select cereal, fruit, and vegetable

Map 1.1 Overview of Geography, Crop Focus, and River Basins in Study Countries



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Note: AEZ = agro-ecological zone. For each country the pair of inset maps shows AEZs. The red lines indicate the borders of the country within transboundary river basins. The lists show the crops modeled in the study; boldface text shows common crops across all four countries.

crops, chosen in conjunction with in-country counterparts to reflect the majority of the value of agricultural production in each country. The consultations to select crop focus also referenced the prevalent water use regime (whether irrigated or rain-fed), to ensure these were represented in the modeling. The countries themselves represent a wide range of irrigation dependence, from a 5–10 percent reliance on irrigation in FYR Macedonia and Moldova, to over 80 percent in Uzbekistan. These percentages also vary by crop, with higher value vegetables and fruits more likely to be primarily irrigated.

This assessment employed three future climate scenarios, representing low-, medium-, and high-impact scenarios, selected to reflect a range of future climate outcomes specific to each country. The scenarios reflect a range of projected outcomes in 2050 for a measure of soil moisture known as the climate moisture index. This measure incorporates both temperature and precipitation and also provides a rough correspondence with climatic influence on rain-fed crops. Projected results were reported for each decade from 2010 to 2050.

Economic baselines mostly reflect current conditions, implying that the results of the climate impact assessment represent a pure agronomic effect of climate change (that is, no adaptations are planned). For the economic analysis, the baseline was supplemented with analysis of an increased agricultural price trajectory based on forecasts generated through 2050 by the International Food Policy Research Institute (IFPRI).

A key goal of the project was to include actively managed agriculture systems within the scope of the assessment, including selected cereal crops, vegetables, fruit trees, vineyards, and livestock. Unfortunately, because of the lack of readily available quantitative tools for livestock impact and adaptation analyses well suited to the ECA region, the livestock component of the work was largely qualitative in nature, aside from the impacts on pasture and fodder production.[1] The scope excluded forestry and fisheries production—although World Bank support of these countries sometimes has included initiatives that address silviculture and aquaculture—and in some cases sustainable practices suggest that these sectors and their adaptation options are interrelated with traditional agriculture. But for this study, the choice was made to focus on crops and livestock, because they constitute the largest share of the agricultural economy in the four countries.

The ambition of the three Central European countries to achieve membership in the European Union (EU) was one notable motivating factor in their development of climate change adaptation plans. FYR Macedonia, Albania, and Moldova stand at different milestones on the path to accession, a path that requires certain economic, political, and institutional reforms as early markers. Along with these needed reforms, the EU encourages specific action toward climate change preparedness and adaptation. As outlined in a 2009 EU white paper on the topic, these actions could include systematic assessment of climate risks, development of outreach initiatives to train farmers in such areas as improving water use efficiency, and identification of needs for financing of adaptation measures (Commission of the European Communities 2009b).[2]

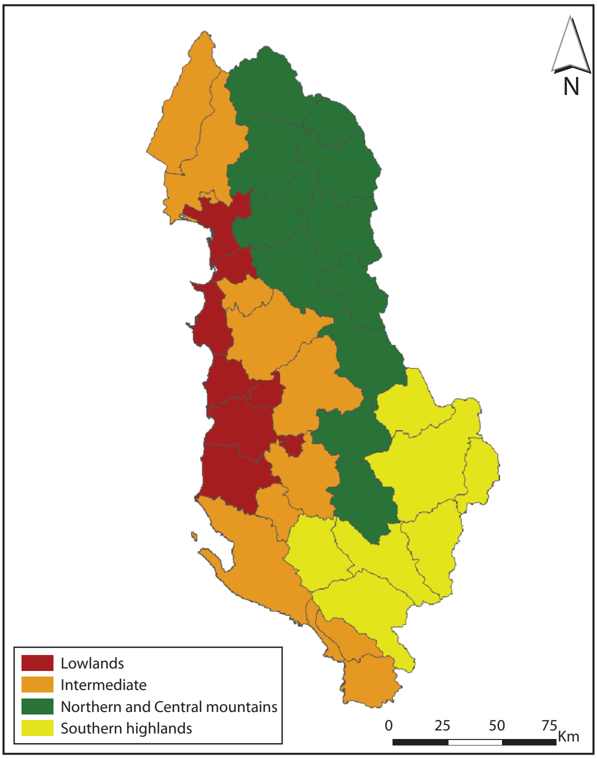
Albania

Albania is located in southeast Europe, on the western side of the Balkan Peninsula, bordering the Adriatic and Ionian Seas. It has a surface area of 28,745 km^2 and is bordered by Montenegro and Kosovo to the north, FYR Macedonia to the east, and Greece to the south. Administratively, Albania is divided into 12 prefectures, 36 districts, 315 communities, and 2,900 villages.

For this study, Albania was divided into four AEZs, as shown on map 1.2. The area within each of these AEZs shares some of the same characteristics in terms of terrain, climate, soil type, and water availability; as a result, baseline agricultural conditions, climate change impacts, and adaptive options are similar within each AEZ, with differences between AEZs that are important for developing a specific adaptation plan.

Albania's terrain is primarily mountainous, with 77 percent of the country's territory hilly or mountainous. On map 1.2 these areas are shown in green, indicating the Northern and Central Mountains AEZ, and in yellow, the Southern Highlands AEZ. There is also a highly productive coastal plain, shown in red, comprising the Lowlands AEZ, and parts of the Intermediate AEZ, shown in

Map 1.2 Albania Agro-Ecological Zones



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Note: AEZ = agro-ecological zone.

orange. Overall, the average elevation of the country at 708 meters above sea level is double the European average. The terrain and change in relief from the mountains to the coast result in high rates of soil degradation, and water resources are characterized by powerful, highly erosive river flows. This power has been converted into electricity, with over 95 percent of the country's power supply sourced from hydroelectric infrastructure.

Rural Population Has Low Income, High Vulnerability

Agriculture traditionally has been the backbone of the Albanian economy. Although the sector has been growing, the pace of growth has been outstripped by other sectors such that the agricultural contribution to GDP has declined from 56 percent in 1997 to 21 percent in 2007. Although waning in economic importance, the agriculture sector provided between 55 and 60 percent of total employment between 2003 and 2005. However, with almost three-quarters of the rural population earning less than US$5 a day, the vast majority are poor and highly vulnerable to any adverse event that affects the agricultural sector.

The value of agricultural production in 2008 was a combined US$1.9 billion, including livestock, field crops, and fruit production. Table 1.1 shows that the livestock sector accounts for more than half of the value of production, field crops account for about one-third, and fruit production makes up the remainder.

Although cereal field crops such as wheat and maize are grown extensively and occupy a large percentage of the cropping land (see figure 1.1), the value of their contribution is less than 50 percent of the contribution made by vegetable field crops, which command a higher price. Note that the spatial variability of soils and climate, as well as access to water, infrastructure, and other inputs, makes many areas of Albania outside the coastal plain unsuitable for high-value vegetable production. In the more mountainous areas there is a reliance on more resilient, less input-intensive crops, such as wheat, maize, and forage.

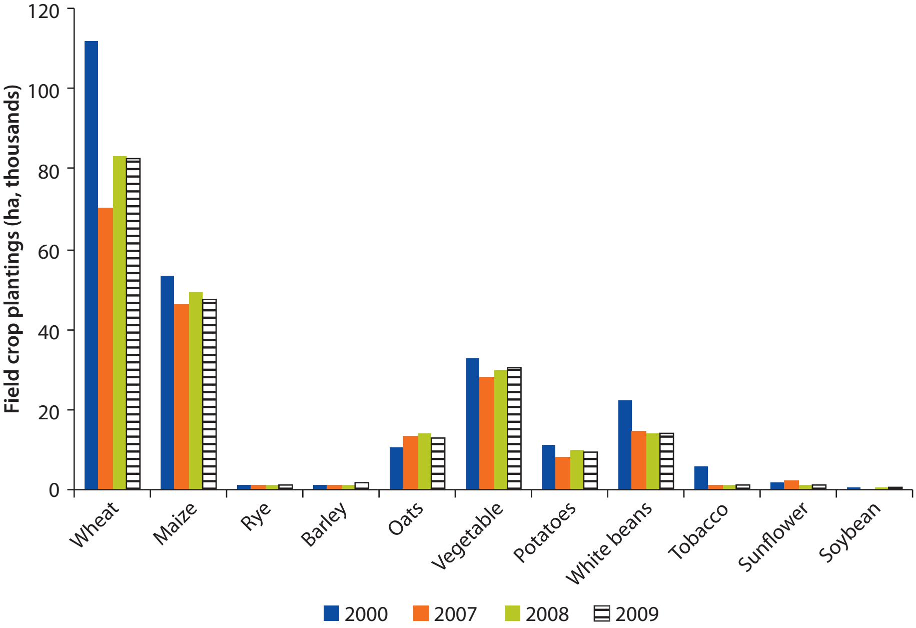
Trends within the field crop sector over the last decade indicate a decline in areas planted overall, with a substantial decline in the area planted in wheat from the beginning of the current decade (figure 1.1). Total crop area declined 4.2 percent from 2000 to 2009, while high-value vegetable crop areas remained roughly constant, with only a slight decline.

Table 1.1 Value of Agricultural Products in Albania, 2008

Description	*Value (US$ millions, 2008[a])*	*% of Sectors Listed*
Cereals	546	28.6
Fibers	0	0.0
Fruit and tree crops	275	14.4
Livestock	1,036	54.3
Vegetables	51	2.7
Total	1,908	100

Sources: Food and Agriculture Organization Statistical Database; Albanian Institute of Statistics.
a. Used an exchange rate for 2008 of Lek 83.842/US dollar.

Figure 1.1 Area Planted by Crop in Albania, 2000–09



Source: Ministry of Agriculture, Food and Consumer Protections, Republic of Albania, 2009.
Note: ha = hectare.

Livestock has long been an important component of the Albanian agricultural economy. After privatization of agriculture in the early 1990s, livestock increased by 90 percent and peaked in 1995 (with 840,000 cattle and 4.1 million sheep) as a result of growing demand for livestock products and the sector's low capital requirements. Consequently, the production of forage crops, especially alfalfa, increased throughout the country. Since 1995, the number of livestock has started to decrease, partly as a result of people abandoning farm land in the mountains to move to urban areas. However, livestock production still contributes a large share of agricultural output and more than half of farmers' net income.

Scarce Resources, Poor Water Infrastructure Hinder Adaptive Capacity

At the national level, some aspects of Albania government policies reflect high adaptive capacity, but most functions that would increase resiliency in the agriculture sector are currently inadequate, which can be seen in the following:

- *Agricultural policy is well-planned, but resources for implementing these plans are limited*. The Ministry of Agriculture, Food, and Consumer Protection oversees the agricultural sector. Farmland management, irrigation and drainage, and immovable property registration fall under the responsibility of the ministry. Local Land Administration and Protection units in each district report directly to the local government. A key strategic document, the National Environmental Action Plan, was prepared in 1994 and revised in 2001 with the ultimate goal of meeting the constitutional right to live in an ecologically healthy environment. The plan identified several priority investment programs, including watershed management, forestry, and flood control. The National Strategy on Agriculture and Food and the National Strategy Plan for Rural Development, both covering the period 2007–13, were developed as part of the overall National Strategy on Social and Economic Development. These plans provided the framework for integrated rural development programs and are designed to enhance synergies among all related public institutions. Poverty reduction and sustainable management of natural resources (including land, water, and biodiversity) are among the objectives. However, strategies and legislation are not always translated into programs and projects, mainly because most of the activities included in these strategies require investments that are too high for the state budget. Implementation is also hindered by the limited professional capacities of relevant institutions. Hence, continuous international development support is a crucial element for ensuring and expanding implementation.

- *The ability to collect, generate, and provide meteorological data to farmers is very limited.* The main hydrometeorological institute in Albania is the Institute of Energy, Water and Environment, a center in the University of Tirana. This institutional arrangement has left the institute with an acute funding shortage. Although the institute has in the past contributed to global data clearinghouses, such as those maintained by the UN, it was unable to provide data for this study. It has no or very limited means of collecting and sharing data from electronic stations in real time. As a result, farmers rely solely on privately funded or neighboring country sources for meteorological information.

- *The current agricultural extension (or knowledge sharing) service is institutionally far-reaching but not oriented toward ameliorating risks from climate.* Extension in Albania employs 250 service personnel who work in 100 small offices throughout the country. The overall budget for extension is €1 million, but less than €200,000 is available for operations. While it seems that virtually all farmers are aware of the extension service, and indeed roughly 70–80 percent of them make use of these services, the current extension service has little or no capacity to advise on adapting agricultural systems to the climate risks outlined in this study.

- *Agricultural research capabilities are expanding but have few connections to extension.* The Agricultural Technology Transfer Centers conduct agricultural research and maintain information. There is a clear and rational scheme to the division of research responsibilities by crop and region across these five institutions, and there is some effort devoted to livestock varieties as well. These agricultural research institutes, however, have not yet focused on climate change as a major risk to agricultural production, nor are they as effectively coordinated with the extension service as they could be. Further, research could be better focused on leveraging advances in seed varieties and farming practices shown to be effective in other countries, and coordinating with the extension service to demonstrate these results locally, particularly for small-scale farmers.

- *Many farms are small and have limited resources for adaption investments*. An early priority for agricultural reforms during the transition from the Soviet era was land privatization. During 1990–2004, 564,000 hectares (ha) of agricultural land—equal to 98.9 percent of land planned for distribution—were privatized, resulting in the creation of about 450,000 private farms with an average size of 1.3 ha. The total number of farms is gradually decreasing, mainly due to migration and farm mergers, but the average size remains small and ownership of parcels can be fragmented. Production on most small farms cannot be mechanized due to financial constraints.

- *Agricultural markets are limited*. Farms in Albania are mostly subsistence farms that produce for family consumption and have no market links. Most farmers operate as individuals, and organized activities in marketing and other areas are very limited. A few entrepreneurial landowners are developing businesses (vegetable and fruit production, especially grapes) aimed at wholesale markets, and the number of such producers is gradually increasing.

At the AEZ level, the project team carried out a series of in-depth consultations with Albanian farmers about their own level of adaptive capacity relative to climate change risks. In general, Albanian farmers expressed concerns that the current extension service was not adequate to help them address climate risks. Other common themes that emerged from the farmer meetings in terms of current adaptive capacity were as follows:

- *Water infrastructure remains in poor repair*. Two World Bank Projects (1993–2004) helped to rehabilitate irrigation and drainage infrastructure; secondary and tertiary irrigation facilities were transferred to water user associations; and primary canals and headworks to the Farmer Federations. The two projects together have rehabilitated irrigation infrastructure on 180,000 ha and drainage on 120,000 ha, or about 40 and 50 percent, respectively, of the area originally equipped for irrigation and drainage. Although these projects were successful and have made Albania a model of decentralized irrigation management for the region, problems remain with irrigation and drainage infrastructure. Depending on the specific climate related risk faced by each AEZ, the priority infrastructure was for either irrigation or drainage. For example, a good deal of land in the lowlands region lies below sea level. One farmer who farms 10 ha with a partner says that the roots of his plum trees rot during especially wet seasons, a phenomenon that occurs with increasing frequency. If drainage channels were functioning properly this would not be an issue.

- *Extension and hydrometeorological institutional capacity are low*. The need for capacity building to enhance adaptive capacity was universally mentioned by the farmers; in particular they suggested increasing the reach of extension services. Other capacity building recommendations included technical training, seed and crop selection, and increasing the availability of region-specific hydrometeorological information. Due to the lack of available Albanian services, some farmers reported relying on Italian weather forecasts.

- *Market structure is inadequate*. Farmers emphasized that overall market effectiveness would assist in making farms more productive and provide a win-win adaptive response. Farmers expressed frustration with the absence of logistical support in the country, such as processing and storage facilities. They also expressed frustration at the small size of their farms.

Moldova

Moldova is a landlocked country in Eastern Europe. It has a surface area of 33,843 km^2 (Expert Grup 2009), and is bordered by Romania to the west, and Ukraine to the north, east, and south. Administratively, Moldova is divided into 32 districts, three municipalities, and two autonomous regions.

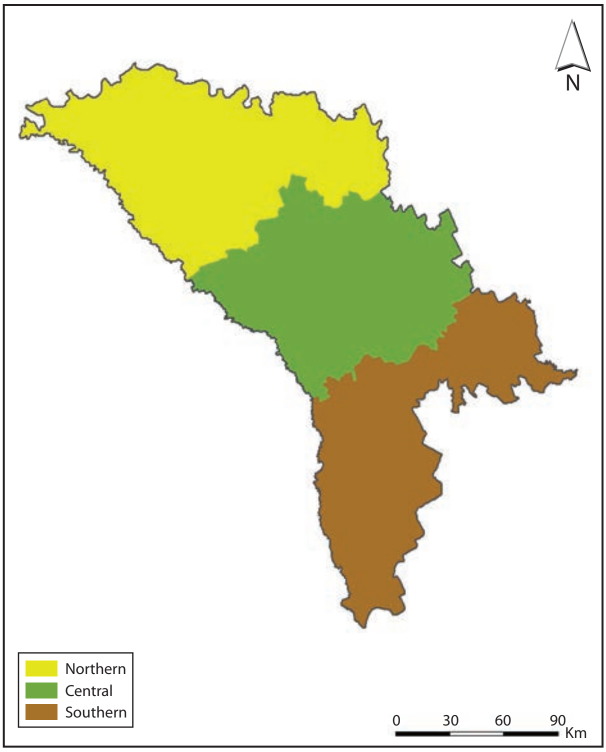
For the study, Moldova was divided into three AEZs, as shown on map 1.3. Each of these AEZs shares some characteristics in terms of terrain, climate, soil type, and water availability, resulting in similar baseline agricultural conditions, climate change impacts, and adaptive options within each AEZ and differences between AEZs that are important for developing a specific adaptation plan.

Open, undulating plains with fertile chernozem soils and productive agricultural land primarily characterize Moldova's terrain. The country's territory is 75 percent agricultural land and 13 percent forest (Ministry of Environment and Territorial Development 2000). The regions on map 1.3 reflect differences in key landscape characteristics important for agriculture. The northernmost region is the Northern AEZ, which is a hilly zone with forests, steppe, and meadow vegetation. It has the most fertile soil with a high water holding capacity, which makes the zone best for field crops. The middle region is the Central AEZ, which is hilly and has deep valleys, has less fertile soil, and is best for perennial crops such as orchards and vineyards. The southernmost region is the Southern AEZ, which has terrain from steppes to meadows, with both highly fertile and less degraded soil types. Due to higher temperatures and lower rainfall, the zone has only marginal production in the absence of irrigation.[3] Overall, the elevation of the country ranges from 5 to 429 meters above sea level, with the highest areas mostly in central and northern Moldova (Ministry of Environment and Territorial Development 2000). The hilly terrain results in high rates of soil erosion, especially in the Northern and Central AEZs.

Weather Extremes Hurt Agriculture and the Economy

Agriculture has traditionally been the backbone of the Moldovan economy, but the sector has been shrinking and its growth has been outstripped by other

Map 1.3 Moldova Agro-Ecological Zones



Sources: © Industrial Economics. Used with permission; reuse allowed via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). *AEZs* adapted from Daradur et al. 2007; National Agency for Rural Development 2007; administrative boundaries based on GADM databases of Global Administrative Areas and used via CC BY 3.0.

sectors such that the agricultural contribution to GDP has declined from 28 percent in 1999 to 11 percent in 2009 (World Bank 2010b). The agriculture sector provided 33 percent of total employment in 2007 (World Bank 2009a). However, much as with Albania, with nearly 91 percent of the rural population earning less than US$5 a day (World Bank 2009e), the vast majority are poor and highly vulnerable to any adverse event that affects the agricultural sector. Production declines in the agricultural sector due to natural hazards (including droughts, floods, hail, frosts, and severe storms) translate into estimated annual losses of 3.5–7.0 percent of Moldova's GDP (World Bank 2007b). Following particularly severe events, such as the drought of 2006–07, yields of major crops like wheat, maize, and sunflowers have diminished by 50–75 percent.

The combined value of agricultural production in 2008 was US$1.27 billion, excluding agribusiness and services (National Bureau of Statistics 2009). As shown in table 1.2, the plant sector accounts for more than half the value of production. Plant production accounts for about 69 percent of the value of production, and livestock production makes up the remainder.

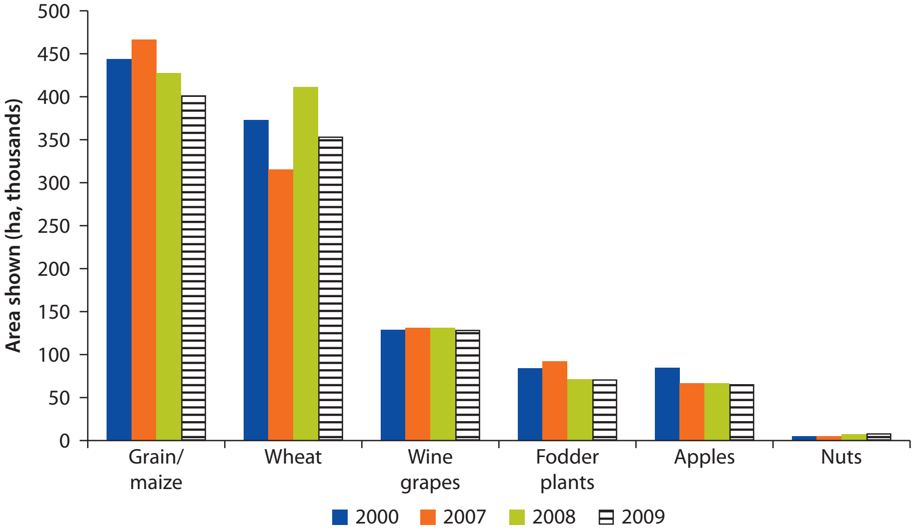
Although cereal field crops such as wheat and maize are grown extensively and occupy about 65 percent of the cropping land (see figure 1.2),

Table 1.2 Value of Agricultural Products in Moldova, 2008

Description	*Value (US$ millions, 2008[a])*	*% of Sectors Listed*
Cereals	384	30.3
Fibers	2	0.1
Fruit and tree crops	309	24.4
Livestock	385	30.5
Vegetables	186	14.7
Total	1,266	100

Source: National Bureau of Statistics 2009.
a. Used an exchange rate for 2008 of MDL 10.34/US dollar.

Figure 1.2 Area Planted by Crop in Moldova, 2000–09



Source: National Bureau of Statistics 2009.
Note: ha = hectare.

their contribution by value is comparable to that for grapes and apples, which garner a higher price. Trends within the field crop sector over the last decade indicate a slight decline in areas planted overall. Total crop area declined 4.1 percent from 2000 to 2009. Many high-value vegetable crop areas saw significant declines, although a few such as soybeans had large increases (National Bureau of Statistics 2009).

Limited Budget, Poor Implementation Curb Adaptive Capacity

The study's national level assessment of Moldova found the following areas where adaptive capacity is currently inadequate:

- *Agricultural policy is well-planned, but constrained by limited resources*. The Ministry of Agriculture and Food Industry oversees the agricultural sector and is administratively linked to the major research institutions. Further, the hydrometeorological institution in Moldova has a high level of capability, is well run, and appears eager to support decision-making by farmers. However, constrained budgets hinder the translation of strategies and legislation into new projects; implementation is also hindered by the limited professional capacities of some relevant institutions. Hence, continuous international development support is a crucial element for ensuring and expanding implementation.

- *Agricultural research capabilities are limited.* Agricultural research institutions have a long history in Moldova but are not oriented toward climate change adaptation and may have a poor connection to farmer extension. Technical expertise varies widely within the Moldovan agricultural research community; its ability to provide comprehensive and high-quality data to support this study, for example, was an indicator that this community in Moldova is well-informed and is capable of generating policy-relevant results. Agricultural research institutions, however, have not yet focused on climate change as a major risk to agricultural production and are not effectively coordinated with the extension service. Further, research could be better focused on leveraging advances in seed varieties and farming practices shown to be effective in other countries and on coordinating with the extension service to demonstrate these results locally, particularly for small-scale farmers. (See the following section on seed policy.)
- *Many farms are small and have limited resources*. Resources are limited for adaption investments. Production on most small farms cannot be mechanized due to financial constraints, which limits adaptive capacity. Farm holdings were also fragmented as a result of the privatization process.
- *Agricultural markets are limited.* Many farms in Moldova are subsistence farms that produce for family consumption and have no market links. Many farmers operate as individuals, and organized activities in marketing and other areas are limited. A few entrepreneurial landowners are developing businesses (such as vegetable and fruit production, especially grapes) aimed at wholesale markets, and the number of such producers is gradually increasing. During the project consultations, however, farmers stressed that they have a shortage of information on agricultural market conditions that hamper their decision making. Regional political developments over the past decade have also resulted in the loss of traditional markets in both the east and the west.
- *Crop insurance is available to farmers, but has been poorly subscribed.* In 2004 a law in Moldova introduced a subsidized insurance scheme through Moldasig, a state-owned company and the first of 30 insurance companies that offer insurance policies covering agricultural risks. In 2006, Moldasig issued policies worth MDL 3 million to 80 large farmers, with 70 percent insuring against hail and the rest against winter frost. No policies were provided for drought because in order to make a claim, a drought had to be excessive as defined by Moldovan

law. In 2006 the government financed 80 percent of the premium cost of insurance and planned to finance 50–60 percent of premium costs in the following years. As Moldasig grows, the government will take on contingent liabilities and will provide increasing subsidies into the future. The agricultural insurance market in Moldova is still very small and the World Bank has recommended the piloting of alternative approaches such as weather index insurance to mitigate extreme weather events like hail, frost, and droughts.

- *Current agricultural subsidies are inefficiently implemented*. Most agricultural subsidies in Moldova are recurrent subsidies rather than investment subsidies and are provided to larger corporate farmers rather than smaller household-based producers. After 2001, subsidies in Moldova increased, especially in the cereal and oil seed markets, despite the World Bank's advice to improve the quality of taxation and customs rather than increase revenue levels. These subsidies are generally inefficient and fail to help the poor (World Bank 2006a). There has been no evidence that subsidizing agricultural inputs, such as fertilizer, irrigation operations, energy, and pesticides, promotes long-term growth (World Bank 2006b). Additionally, large farms in Moldova are generally less efficient than individual family farms, so directing subsidies at large-scale corporate farms is not the best use of scarce resources. (World Bank 2006b). These inefficiencies are reflected in the stagnation of the agricultural sector despite a period of increased subsidies. In 2004, MDL 236 million, or 37 percent, of total public expenditure went to farm subsidies and a growing number of subsidy schemes. Most subsidies from the Ministry of Agriculture and Food Industry between 2001 and 2004 were credit incentives to stimulate participation in credit programs through grants to farmers who repaid agricultural loans (World Bank 2006c). In 2006 plans included reducing inefficient subsidies, such as machinery and technology stations (MTS) subsidies, and directing agricultural subsidies at producer cooperatives rather than large farmers (World Bank 2006c). Recently, the World Bank suggested that Moldova redirect agricultural subsidies toward more efficient investment grants and reduce agricultural subsidies by MDL 350 million, especially for larger farms, as part of budget consolidation and tighter fiscal policy. In the 2006 Agriculture PER report (World Bank 2006b), World Bank personnel also recommended that subsidies be more streamlined and optimized to support increased productivity. Historically, the largest and least efficient subsidies were for the value-added tax (VAT) paid on fertilizers and pesticides and for VAT charged on outputs. These subsidies benefit larger commercial farmers and encourage overuse of fertilizers and pesticides (World Bank 2010c). Changing the types of subsidies and their recipients may enable subsidies to promote agricultural growth.
- *Policy on seed provision should be improved*. Appropriate seeds and seedlings are one way for farmers to be prepared for severe weather (World Bank 2007b). Improved seed varieties are also a crucial part of creating a high-value export market (World Bank 2005). In 2004 the total expenditure for

> agricultural services was MDL 19.0 million, of which MDL 3.7 million was for seeds and variety testing (World Bank 2006c). The World Bank has proposed a variety of measures to improve seed varieties: import advanced agricultural technology, including seeds (World Bank 2006c); improve access to seeds by simplifying the seed certification process (World Bank 2005); provide direct loan inputs for seeds (World Bank 2009a); and initiate structural reform that includes liberalizing the use of EU seeds and seedlings (World Bank 2010c). Seed improvement can increase agricultural production, boost rural incomes, improve the rural economy, and contribute to the country's food security, among other benefits (World Bank 2009a). These recommendations by the World Bank suggest the importance of appropriate seed varieties to agricultural growth and stability.

At the AEZ level, as part of the study's stakeholder consultation process, Moldovan farmers and other local experts outlined several adaptive responses they are already taking to adapt to climate change and severe climate events, including the following:

- Expand water supply for irrigation by building small-scale storage reservoirs, harvesting rainwater, and making greater use of local water sources for irrigation, such as creeks and groundwater;
- Apply protective measures, such as moving vegetable production to greenhouses, using mulch or other plant protection on soil, installing plant protection belts, or using hail nets; and
- Change agronomic practices, such as planting patterns, crop rotation and intercropping, chemical soil augmentation, and using drought-resistant varieties.

Farmers also noted at least three key impediments to effective adaptation to the effects of climate change:

- The lack of timely meteorological information to respond effectively, especially to extreme events such as droughts;
- Limited access to alternative crop varieties (particularly seeds) and know-how to make best use of these varieties, through enhanced extension; and
- Poor or limited access to irrigation water and to technologies to make the most efficient use of irrigation infrastructure.

The adaptive capacity of farmers in Moldova is clearly stressed by changes in overall climate. The combination of heat waves, droughts, and intense storms is especially disruptive. On-farm adaptation responses have been numerous and partially successful, but farmers' responses have been largely ad hoc, with little support, and they believe that larger investments in infrastructure are needed. These needs include improved water storage, drainage and irrigation systems, and improved extension and training services.

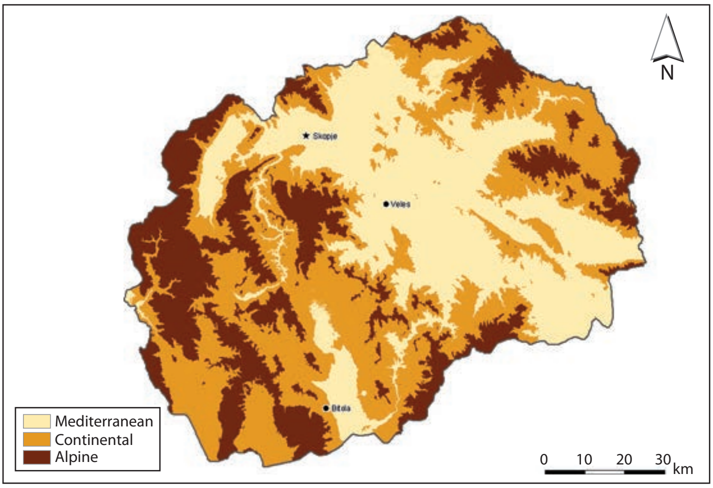
FYR Macedonia

FYR Macedonia is located in southeast Europe, on the western side of the Balkan Peninsula. It has a surface area of 25,713 km^2 and is bordered by Albania to the east, Serbia to the north, Bulgaria to the west, and Greece to the south. Administratively, FYR Macedonia is divided into 84 local municipalities, and eight major regions.

For the purposes of this study, FYR Macedonia is divided into three AEZs, as shown on map 1.4.

FYR Macedonia's geography is characterized by rugged terrain, with 79 percent of the country's territory hilly or mountainous. The plains, the richest agricultural area, comprise 19.1 percent of total land area, and water covers 1.9 percent (MEPP 2008). Approximately 20 percent of the country is cultivated land, 19 percent is pasture (SSO 2010), and about 37 percent is covered by forests (European Commission 2007). On map 1.4, the lightest shading represents the Mediterranean zone at 50–600 meters above sea level, medium shading shows the Continental zone at 600–1,000 meters above sea level, and the darkest shading shows the Alpine zone, covering 1,000 meters to greater than 2,250 meters above sea level. The Mediterranean zone is characterized by floodplains and undulating hills, with generally productive conditions and a high degree of irrigation; the Continental zone comprises highland plains to undulating hills and mountain slopes and is also relatively productive; the Alpine Zone is characterized by mountainous terrain and harsh climate, with restricted productivity and high poverty rates.[4] The terrain and change in relief coming down from the mountains results in high rates of soil erosion in some locations.

Map 1.4 FYR Macedonia Agro-Ecological Zones



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; European Environment Agency; GADM databases of Global Administrative Areas; Environmental Systems Research Institute.

Macedonian Crop Area Declining Significantly

Agriculture has traditionally been a significant and stable part of the Macedonian economy and has slowly grown in value over time at an annual rate of 0.2 percent from 1990 to 2000 and at a rate of 1.3 percent from 2000 to 2007 (World Bank 2009e). Agriculture's contribution to the nation's GDP has slightly declined, from 13.3 percent in 1994 to 11.3 percent in 2009, as its growth has been outpaced by that of other sectors (World Bank 2010a). While slightly waning in economic importance, the agriculture sector provided 18.2 percent of total employment in FYR Macedonia in 2007 (World Bank 2009e), although some local sources suggest the figure is much higher.[5] Population and income distribution show much of Macedonia's population is poor and highly vulnerable to any adverse event that affects the agricultural sector, with 34 percent of the population living in rural areas and 36 percent of this group earning less than US$5 a day.

The total output of agricultural production was more than US$1.6 billion, and the net value-added of agricultural production in 2008 was US$839 million for the agricultural industry (SSO 2010). As shown in table 1.3, the livestock sector accounts for about 35 percent of the value of production. Crops account for about two-thirds of the value of production.

Although cereal field crops like wheat and maize are grown extensively and occupy 24 percent of cultivated land (figure 1.3) (FAOSTAT 2009; SSO 2010), their contribution by value is only 11 percent of total crop output (SSO 2010). Note that given the spatial variability of soils and climate, and access to water, infrastructure, and other inputs, many areas of FYR Macedonia outside of the lower elevations are unsuitable for high-value vegetable production. This explains in part the reliance on more resilient and less input-intensive crops such as wheat, maize, and forage in the more mountainous areas.

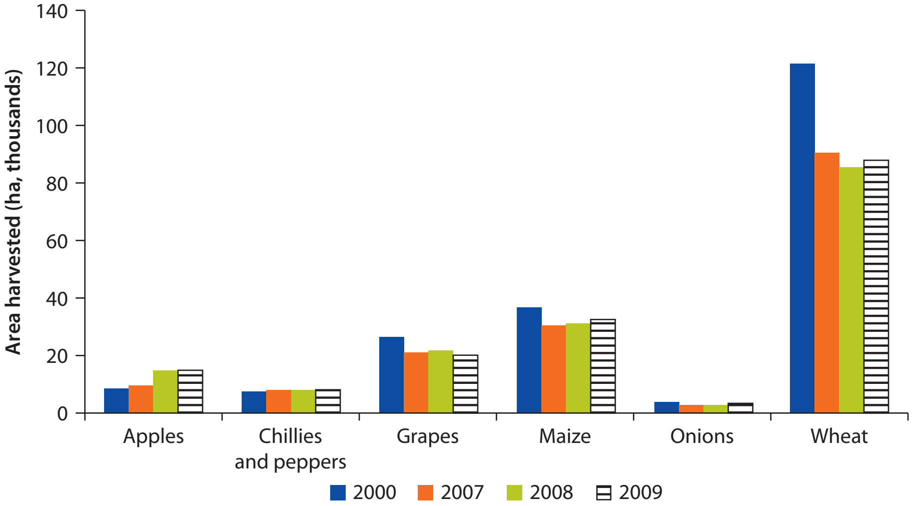
Trends within the field crop sector over the last decade indicate a decline in areas planted overall, with a substantial decline from the beginning of the current decade in the area devoted to wheat (figure 1.3). Total crop area declined by about 13 percent from 2000 to 2008, while fruit crop areas increased by 8 percent (FAOSTAT 2009).

Table 1.3 Value of Agricultural Products in FYR Macedonia, 2008

Description	*Value (US$ millions, 2008[a])*	*% of sectors listed*
Cereals	179	11.3
Fibers	1	0.0
Fruit and tree crops	448	28.2
Livestock	552	34.8
Vegetables	408	25.7
Total	1,588	100

Source: Republic of Macedonia State Statistical Office.
a. Used an exchange rate for 2008 of 41.94 MDen/US dollar.

Figure 1.3 Area Planted by Crop in FYR Macedonia, 2000–09



Source: Republic of Macedonia State Statistical Office.
Note: ha = hectare.

FYR Macedonia's Focus on EU Accession Overshadows Adaptation Needs

In FYR Macedonia, adaptive capacity at the national level is hampered by the following factors.

- *Agricultural policy appears to be focused on EU Accession demands, but climate change adaptation is not currently part of the EU Accession strategy.* The Ministry of Agriculture, Forestry, and Water Economy (MAFWE) oversees the agricultural sector, including farmland management and irrigation and drainage. Efforts are under way to modify the existing National Agricultural and Rural Development Strategies, and the Ministry of Agriculture has indicated a strong interest in integrating the results of this and other studies in the planning process. Overall, however, the national government policies are most concerned with meeting requirements of EU Accession—in particular, building the necessary institutions, information systems, food safety capacity, and farm subsidy programs—and climate change adaptation as a result is not yet emphasized (MAFWE 2009).
- *The ability to collect, generate, and provide meteorological data to farmers could be improved*. Farmers have noted that limited meteorological information is available to support their decision-making. In addition, the study team found monthly historical data difficult to work with: daily data appear to be available but were not provided in time for this analysis. Local counterparts lacked familiarity with techniques to make use of data from global circulation models such as those used in this study.
- *The current agricultural extension service is not oriented toward ameliorating risks from climate change*. While many farmers were aware of the extension

service, the study estimated that only a small proportion make use of their services. Additionally, the current extension service has little or no capacity to advise on adapting agricultural systems to the climate risks outlined in this study. This is a common finding among the countries included in the broader program of analytical and advisory activities in the Europe and Central Asia Region, and is also not uncommon in many other countries.

- *Agricultural research capabilities are expanding, but have few connections to extension*. Agricultural research institutes, mostly located in Skopje, have not yet focused on climate change as a major risk to agricultural production, and they could be more effectively coordinated with the extension service. Further research could be better focused on leveraging advances in seed varieties and farming practices shown to be effective in other countries, as well as on coordinating with the extension service to demonstrate these results locally, particularly for small-scale farmers.
- *Many farms are small and have little means to fund adaption investments*. Both local data and interactions with farmers support this finding. Migration and farm mergers are paring the total number of farms, yet the average size remains small and ownership of parcels is fragmented.
- *Agricultural markets are limited*. Many farms in FYR Macedonia are subsistence farms without access to markets. Many farmers operate as individuals and a small but growing number of enterprising landowners are developing businesses aimed at wholesale markets.

Farmers Seek Assistance with Climate Issues

At the AEZ level, farmers expressed concerns that the current extension service was not adequate to help them address climate change risks to agriculture. Farmer meetings resulted in the list of concerns specific to regions as follows.

- *Mediterranean AEZ*: Flooding is the primary climate issue in this region, and farmers have noticed an increase in the frequency of torrential rainfalls. They report that high rainfalls cause riverbank overflow and clogged drainage channels, and therefore reduce water quality. Droughts are the next most significant issue. Farmers specifically mentioned their crops being buffeted by a cycle that seems to comprise one year of flood followed by a year of drought. Extremely high temperatures and hail were also mentioned as significant issues in this AEZ. The farmers in this region state that they need support institutions and wish to see better cooperation among farmers themselves as part of that.
- *Continental AEZ*: In this region, farmers confirmed that climate change is negatively affecting agriculture. The greatest risk is declining water availability as reflected in low reservoir levels and drought. Hail, heat stress, and wind are also concerns, and farmers say they feel poorly equipped to respond effectively

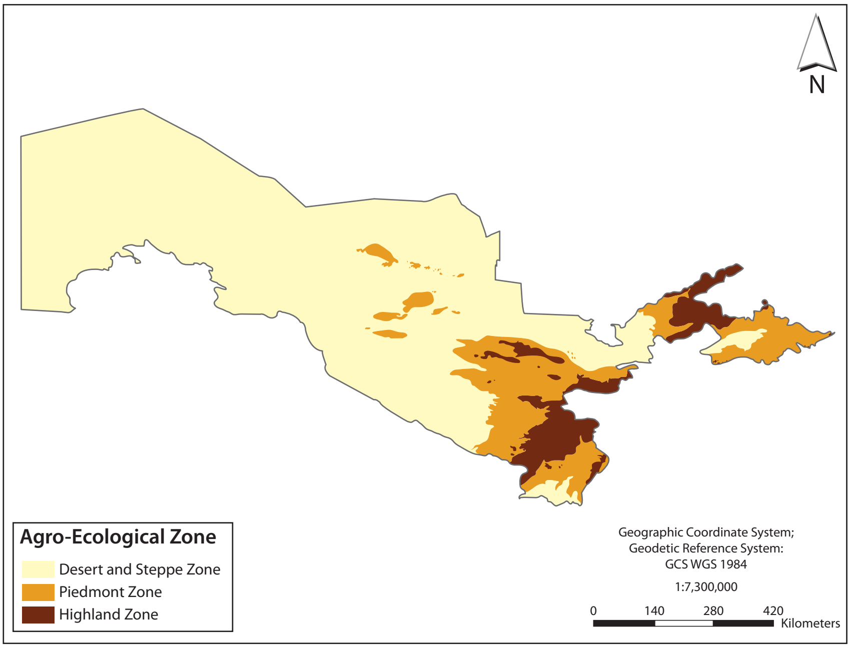
to these events. Although 28,000 ha of land in the area are potentially irrigable, only 15,000 ha are currently irrigated.

- *Alpine AEZ*: Heat waves are cited as the climate issue posing the greatest risk to crops for which farmers have limited capacity to adapt. Risks are most prominent in low elevation areas and when there is a southern wind. Farmers have very limited capacity to adapt to the regular droughts and heat waves that occur in this AEZ. Although insufficient water in reservoirs and reductions in frost at higher elevation are also problems, they are of secondary concern. Farmers indicate that they need better water storage infrastructure and more widespread information on nets to protect grapes from hail and sunshine, as well as better guidance on crop suitability.

Uzbekistan

Uzbekistan is a landlocked country in central Asia with a surface area of 448,900 km^2 and shared borders with Kazakhstan to the west and north, Kyrgyzstan and Tajikistan to the east, and Afghanistan and Turkmenistan to the south. Administratively, Uzbekistan is divided into 12 provinces, one autonomous republic, and one independent city. Map 1.5 shows Uzbekistan divided into three AEZs for purposes of this study.

Map 1.5 Uzbekistan Agro-Ecological Zones



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.

Desert plains dominate Uzbekistan's geography, with about 20 percent of the territory comprising mountains and foothills in the eastern and northeastern sections (Centre of Hydrometeorological Service 2008). Map 1.5 shows these primary desert plains with lightest shading, comprising the desert and steppe AEZ at 60–150 meters above sea level. The country's most fertile areas are shown in medium shading, comprising the Piedmont AEZ at 400–1,000 meters above sea level, and hilly mountainous areas are shaded darkest, comprising the highland AEZ at over 1,000 meters above sea level.[6] 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.

Rural Population Increasing as Agricultural Growth Lags

Agriculture is important to rural areas of Uzbekistan, comprising 20–35 percent of GDP since 1995. While this percentage has decreased over the past few years, the proportion of the rural population has increased[7] and now accounts for about two-thirds of Uzbekistan's population (World Food Programme 2008). The pace of agricultural growth has been outstripped by other sectors such that agriculture's contribution to GDP has declined from 32 percent in 1997 to 21 percent in 2009 (World Bank 2009b). Even so, the agriculture sector provides 34 percent of the country's employment (Sutton et al. 2008). While economic growth has averaged 5 percent per year, it has not significantly increased living standards: a quarter of the population is still poor (World Bank 2007a). In 2003, 47 percent of the population was living beneath the absolute poverty line of US$2.15 per day, and 86 percent was living under the high international poverty line of US$4 per day, representing the third-highest poverty rate in Central Asia. The poverty rate was also generally higher among rural communities than in urban areas (World Food Programme 2008). This leaves a significant portion of the population highly vulnerable to any adverse climatic or economic event that affects the agricultural sector.

In 2009, agriculture made up 21 percent of Uzbekistan's US$33-billion GDP (World Bank 2009b). The annual and perennial crop sectors make up about 60 percent of the value of agricultural production in 2008, while the livestock sector accounts for the remaining 40 percent, as shown in table 1.4.

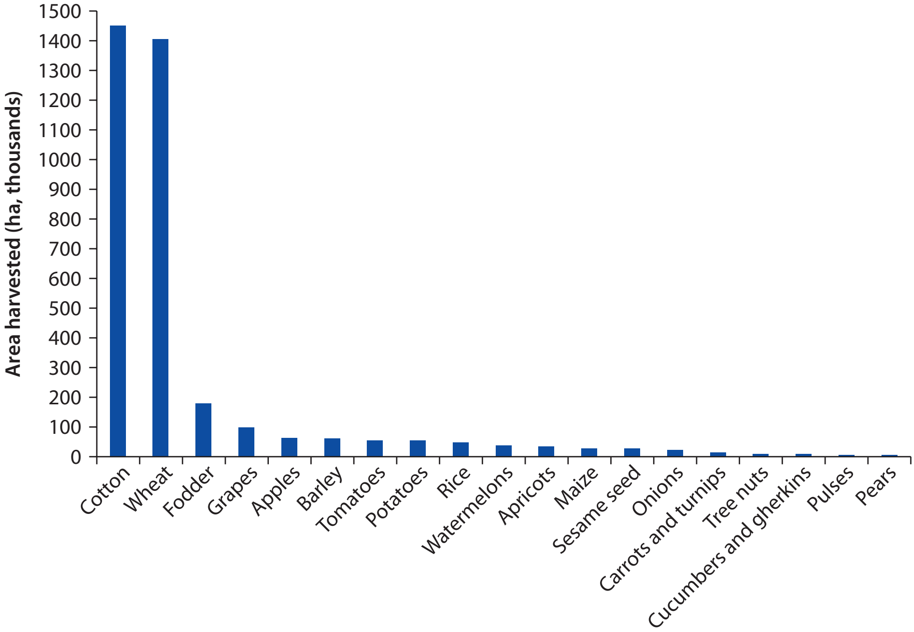
Although field crops like wheat and cotton are grown extensively, occupying 80 percent of irrigated land in 2007 (World Bank 2009b) (figure 1.4), they provide a relatively small percentage of revenues, indicating a low valued-added. Cotton accounts for 40 percent of cultivated lands and represents about 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$1160/ton compared to cotton at US$340/ton and wheat at US$140/ton (State Statistics Committee of Uzbekistan 2010). From 2000 to 2007, cotton and fodder areas declined and wheat areas increased. Additionally, the planted area of

Table 1.4 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

Source: State Statistics Committee of Uzbekistan 2010.
a. Used an exchange rate for 2008 of Sum 1319/US dollar.

Figure 1.4 Average Area Harvested by Crop in Uzbekistan, 2006–08



Sources: FAOSTAT 2009; World Bank 2009b.
Note: ha = hectare.

potatoes, vegetables, and melons increased from 6 to 7 percent (World Bank 2009b). Note that given the spatial variability of soils and climate and access to water, infrastructure, and other inputs, many areas of Uzbekistan outside the Piedmont zone are unsuitable for high-value vegetable production; hence, farmers rely 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 percent and total arable land declined

16 percent from 2000 to 2007, while high-value vegetable crop areas remained roughly constant, with a slight increase in 2009 (FAOSTAT 2009).

Farm Reforms Shape Nation's Adaptive Capacity

In Uzbekistan some conditions enhance adaptive capacity, such as relatively well-established institutions for irrigation provision, but others are currently inadequate, as described in the following examples.

- *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. However, in consultations farmers noted that the agricultural extension service is not oriented toward ameliorating climate risks, and suggested it could provide better integration with hydrometeorological data provision, particularly related to short-term precipitation forecasts and seasonal water availability for irrigation. They also noted that the extension service might 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.* Along with these research efforts, the presence of the International Center for Agricultural Research in the Dry Areas (ICARDA) in Tashkent is also an advantage, but the penetration of high-yield varieties for the key wheat and cotton crops could be expanded. The study team was unable to evaluate agricultural research capabilities with several Ministry of Agriculture and Water Resources crop institutes during visits to Tashkent, but did observe that in some areas, such as with vegetable crops, these institutes appear to be well-integrated with the ICARDA office in Tashkent. In general, however, agricultural research institutes appear not to have focused as yet on climate change as a major risk to agricultural production; it was noted that they could be more effectively coordinated with the extension service. In addition, research by institutes could be better focused on leveraging advances in seed varieties and farming practices shown to be effective in other countries, particularly in cotton production, as well as on coordinating 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"). They functioned in addition to the traditional household plots, renamed "dekhan" farms. Since 2001, seeing that most of the 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. Currently the agricultural sector comprises mainly 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). Dekhan farms tend to specialize in vegetables and livestock, providing what appears to be the majority of food crops and the vast majority of livestock. The private farms also appear to be focused on cotton and wheat production and receive inputs from supplying organizations, which means they have less flexibility in crop choice. Small numbers of private farms are engaged in cultivation of vegetables, melons, orchards, grapes, and livestock production. A key remaining issue is providing greater flexibility for private farms to choose cropping patterns.

- *Farm size is increasing, but ownership/land tenure is lacking.* In 2008, reforms led to an increase in the size of farms, yielding an average crop area of all farms after reform of about 56 ha, with vegetable and melon farms at just over 20 ha. Farmland is leased for a period of 50 years, with ownership retained by the state. Farmers are required to meet a state production quota for cotton and wheat, restricting the ability of farmers to adapt by switching to higher value or more drought-resistant crops, for example. Reforms have encouraged crop rotation and have provided access to loans for private farms. At the same time, however, the lack of long-term land ownership hampers farmer incentives 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 by most accounts they are much lower than optimal, with only about one quarter of the distribution channels equipped with antiseepage lining, for example. Pumping infrastructure is relatively old and, as a result, less energy-efficient than newer infrastructure. Few incentives exist for application of water-saving technologies because farmers do not see direct costs of water provision. Instead, water costs are covered by an overall land tax and are not tied to use of inputs. Water user associations are thus far not well-established. Overall, water usage per kilogram of production appears low for raw cotton and wheat compared to international standards. Some recent reforms appear promising, however. The announced Program on Land Development and Soil Fertility Improvement, scheduled to run 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), and the introduction of new irrigation practices and water saving technologies may also be considered.

- *Integration of agricultural sector in international markets is incomplete*. Uzbekistan is one the world's largest exporters of cotton, and has applied for accession to the World Trade Organization. However, some high-value crops with export potential, such as vegetables and potatoes, currently appear to be restricted to domestic market use. Most of the production of these crops occurs at dekhan farms, where the state is the main buyer of agricultural produce.
- *Crop diversity is at a low level*. The dominance of cotton and wheat leaves Uzbekistan's agricultural sector highly vulnerable to price fluctuations in these commodities. The high concentration around two crops, combined with restrictions on exports of other crops, means that farmers have limited means to adapt to changing yield and price conditions. Participation is also low in the crop insurance programs currently available.

The importance of Uzbek agriculture to the nation's economy makes agriculture a continuing focus for domestic and international policy and finance initiatives. The announcement in 2009 of a "Year of Rural Development" spurred several domestic and international efforts to improve the financial and environmental sustainability of the Uzbek agricultural sector. For example, the World Bank is currently engaged in a US$68 million Uzbekistan Rural Enterprise Support Project—Phase 2. The project helps independent farmers increase the productivity and financial and environmental sustainability of agriculture and the profitability of agribusiness. This initiative is also designed to increase farmers' access to nongovernment sources of finance, improve irrigation and drainage provision, and provide rural training and advisory services. One focus of the effort is on providing water users associations with capacity building and training, as well as developing demonstration plots for improved agricultural management practices. Investments will be made in on-farm and inter-farm drainage and irrigation infrastructure.

At the local AEZ level, farmers' adaptive capacity is still quite limited, 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. When asked about measures that could be taken to address these issues, the farmers recommended the following three adaptation measures.

1. *Improve water use efficiency*. The efficient use of water was foremost in the minds of farmers, with 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. *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 study team noticed significant visible damage to irrigation delivery systems and blocked drainage canals.

At the national level, the farmers recommended the following three adaptation measures:

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 disagreement 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.

Notes

1. Note that the Seo and Mendelsohn (2007) Ricardian livestock model was considered to estimate impacts of climate on livestock revenues—as in the World Bank Economics of Adaptation to Climate Change country studies for Ghana, Ethiopia, and Mozambique—but the geographic focus of that work on the African continent severely limited its applicability and transferability to the climate and animal stocking patterns of the ECA region.
2. See also Commission of the European Communities 2009a, a Commission Staff Working Document accompanying the White Paper.
3. Based on Daradur et al. 2007; National Agency for Rural Development 2007; Iglesias et al. 2007; World Bank team analysis of climate change implications.
4. Based on Iglesias et al. 2007; Mitkova and Mitrikeski 2005; Filipovski, Rizovski, and Ristevski 1996; World Bank team analysis of climate change implications.
5. For example, the Macedonia State Statistical Office (SSO 2010) notes that 629,901 workers were employed in agriculture, hunting, and forestry in 2009, which is 30.8 percent of the total population of 2,046,898, and 68 percent of the total 2009 labor force of 978,775.
6. Based on Makhmudovich 2001; Centre of Hydrometeorological Service 2007; Iglesias et al. 2007; World Bank team analysis of climate change implications.
7. This article is an outgrowth of analytical work carried out June 2007–May 2008 under the auspices of UNDP (United Nations Development Programme)/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.

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CHAPTER 2

Framework and Program Design

The main goals of the assessment that shaped the design of the analytic framework for this study were as follows:

- Combine rigorous analytic work with participatory input from key stakeholders, including local farmers, to shape the results and, in some cases, the methods applied.
- Integrate agricultural sector analysis with in-depth modeling of water supply and demand, with the understanding that climate change will affect the agriculture sector both directly and indirectly through its effects on the availability of irrigation water.
- Combine biophysical modeling with economic analysis.
- Allow flexibility for local tailoring of the approach to focus on particular crops or adaptation measures of interest.
- Generate results that answer the question: What measures should be the highest priority for adapting local agricultural systems to future climate change?

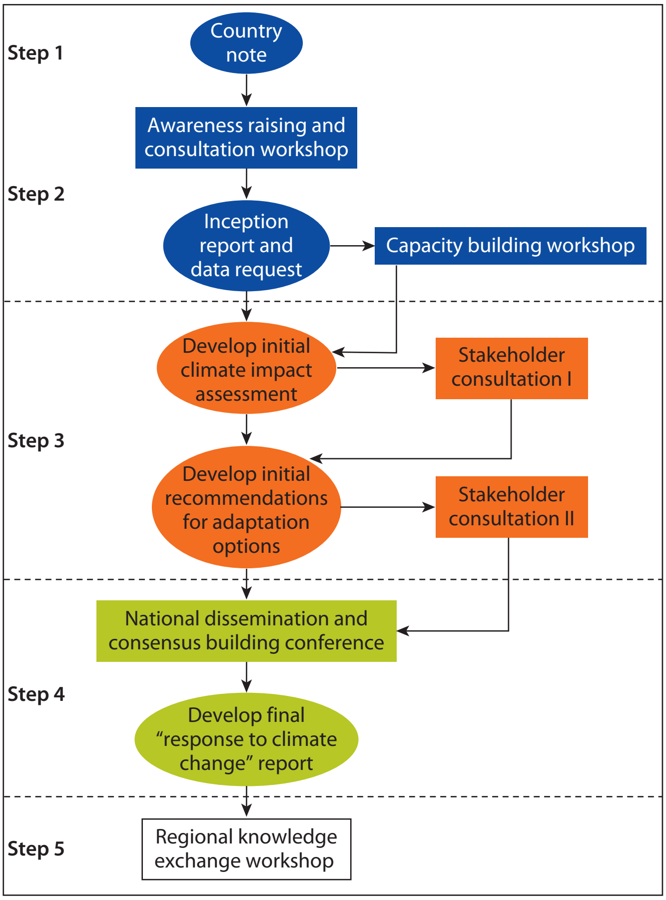
Study Approach: Action Steps

To accomplish these aims and achieve the overarching goal of integrating consideration of climate change in agricultural policy, planning, and development, the study team designed the program with three objectives: raising awareness, conducting analysis in conjunction with building capacity, and achieving consensus on priority measures to improve resiliency. The program, therefore, comprised five main action steps, as follows and outlined in figure 2.1.

Action Step 1: Country Notes on Climate Change and Agriculture

The team developed a "Country Note on Climate Change and Agriculture" for each country as a background document for all stakeholders and to serve as an engagement tool for awareness raising and consultation. The country note provided a summary of available country-specific information with a focus on

Figure 2.1 Flow of Major Study Action Steps



climate and crop projections, adaptation options, policy development, and institutional involvement in agriculture and climate change.

Action Step 2: Awareness Raising and Consultation Workshop

The World Bank team organized an initial country-level awareness raising and consultation workshop in each country in consultation with key stakeholders at the technical level, including local experts from national, private-sector, and nongovernmental institutions, as well as representatives of other development organizations. The objectives of the workshops were to raise stakeholder awareness of agriculture and climate change issues, discuss the country note, identify any other relevant analytical work in the country, elicit ideas on potential adaptation responses, agree on information gaps and needs for additional analysis, and identify local partners to engage in the development and implementation of country-specific analytical approaches for climate change impact assessment and analysis of adaptation options, including data collection, analysis, and dissemination follow-up activities. After the Awareness Raising and Consultation Workshop was completed, an Inception Report was developed, which served as a work plan for the subsequent steps.

Action Step 3: Country-Specific Agriculture and Climate Change Impact Assessment and Menu of Adaptation Options at the AEZ Level

The initial climate impact assessment, which built on the awareness raising and consultation workshop, provided the basis for assessing the impacts of climate change on agricultural sector resources in each country. The team then focused on analyzing those crops and impacts agreed to be most important for the country and developing an initial menu of adaptation options, which served as the heart of the study.

First, the team conducted a quantitative analysis at the national and agro-ecological zone (AEZ) levels to estimate the potential physical impacts of climate change on the agricultural sector. At this stage, the quantitative analysis focused on crop and pasture yield impacts that could occur without planned adaptation to improve resiliency.

Concurrent with development of the impact assessment, a capacity building event was conducted in each country that focused on the crop and water resource modeling tools that were to be applied in that country, as agreed in the inception report.

Second, the team then presented draft results of the impact assessment to farmers in each AEZ and to local experts at the first stakeholder consultations. This provided an opportunity for local stakeholders to learn about the potential impacts of climate change and to provide feedback on the draft results. It also gave the team a chance to collect information on existing adaptive capacity at the farm level.

Third, the results of the impact assessment and stakeholder consultation were combined with an assessment of the country's existing adaptive capacity and additional economic modeling to generate the first draft of a menu of adaptation options tailored to each AEZ in each country. These results were vetted with farmers at the second stakeholder consultations, again held in each AEZ. The first draft of adaptation options combined crop modeling, water resource supply modeling, basin-level water balance modeling (to identify potential shortages of irrigation water), and benefit-cost analysis of adaptation options based on farm-level economic modeling.

Action Step 4: National Dissemination and Consensus-Building Conference

A high-level National Dissemination and Consensus Building Conference was organized for each country with the following objectives:

- Discuss and raise awareness of the results of the impact assessment and recommendations of the draft menu of adaptation options;

- Build consensus on the priorities for action;
- Explore ways to integrate adaptation recommendations into country policies, programs, and investments; and
- Discuss financing opportunities and other potential contributions from development partners.

The conferences were co-hosted by the ministers of agriculture and environment along with World Bank offices in each country. The organizers sought high-level representation from agencies with national policy-making responsibility, such as ministries of finance and economics. Representatives of farmers and other civil society organizations also participated, and development partners who could help support adaptation actions were invited. Following the conference, the country-specific menu of adaptation options was finalized and disseminated. More important, the results were used by the countries to develop their own climate change adaptation action plans for the agricultural sector.

Action Step 5: Regional Knowledge Exchange

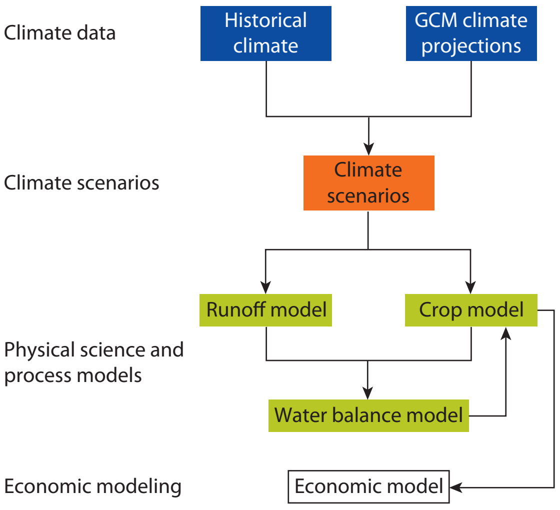
Upon completion of the country-specific menus of adaptation options, the program sponsored a regional knowledge exchange activity in which the four beneficiary countries participated. The activity included a regional knowledge exchange workshop, in which participants from each country presented their draft adaptation action plans and received feedback from other participants and from the World Bank team experts. It also provided an opportunity to present a draft of the synthesis report. The objectives of the regional knowledge exchange were to:

- Share country-level experiences and results across the region,
- Synthesize the lessons learned from the country-specific work,
- Explore a scope for greater regional collaboration on activities such as weather forecasting and early warning systems and disaster insurance programs,
- Establish a regional community of practice, and
- Identify participants' interest in additional collaboration with the World Bank on climate change adaptation in agriculture.

Analytic Tools: Model Choices and Workflow

Overall, within Action Step 3, seven analytic steps were required to develop the menu of adaptation options. As illustrated in figure 2.2, these analytic steps were carried out sequentially from top to bottom, with the exception of the interaction between the crop and water balance modeling, which is discussed below. The first four analytic steps are needed to complete the initial impact assessment, as follows: (1) identify major agricultural growing regions in each country, (2) gather baseline data, (3) develop climate projections, and (4) use baseline and climate projection data to conduct the impact assessment. Building on the four

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



Note: GCM = global circulation model.

analytic steps of the impact assessment, there are three additional analytic steps necessary to develop the adaptation menu: (5) select and categorize a set of adaptation options to be considered for each AEZ in each country, (6) conduct qualitative and quantitative assessments of those options, and (7) develop a ranked order menu of adaptation options based on multiple criteria.

Achieving the goals outlined at the beginning of this chapter dictated certain aspects of the modeling approach. For example, the project team immediately identified that a simulation modeling approach to the quantitative work would be most appropriate. Simulation modeling can be demanding; simulating the processes of crop growth and water resource availability requires extensive data inputs and careful calibration. In addition, simulation modeling can present difficult issues in modeling a future economic baseline that incorporates innovation over time in those situations where it may be important to the analysis to do so.[1] The payoff is that the modeling system can estimate the incremental change in crop output and water supply in response to changes in climatic conditions and agricultural and water resource management techniques. Other approaches, such as econometric and statistical models of crop yield, often are unable to incorporate adaptation or, if they do incorporate adaptation, cannot estimate the incremental effects of specific measures.[2] A further advantage of the simulation approach is that it provides an opportunity for stakeholder involvement at several stages of the analytic process: designing scope, adjusting parameters, selecting inputs, calibrating results, and incorporating adaptation measures of specific local interest (for example, in half of the countries, hail nets, crop insurance, water storage, and improved drainage capacity were major issues, in each case involving a different pair of countries).

Analytic Step 1: Identify Agricultural Growing Regions

Determining agro-ecological zones in each country was a process that was largely complete before the Awareness Raising and Consultation Workshops were held. The Country Notes proposed a "draft" set of AEZs, and although there were some revisions suggested during the workshops, these were relatively minor. The unit of analysis agreed on in each country was "representative farms" in each of the major agricultural production regions, at least one of which was located in each of the three or four relevant AEZs. Presenting the results at this spatial scale allowed the use of baseline data from meteorological stations that are co-located with agricultural regions, avoiding the need to either interpolate data between stations or rely upon global sources of gridded data (which have already used interpolation).[3]

Analytic Step 2: Gather Baseline Data

Baseline meteorological, soils, and water resources data were provided from in-country and global sources. Data requirements included the following:

- *Meteorological:* The crop modeling methodology required at least 10 years of daily historical data in the major agricultural regions of each country.[4]
- *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 or monthly (daily preferred) historical river flow data for gauging stations along the main stem rivers of each major drainage basin. These data were provided by in-country sources. In addition, the study obtained locations and active storage volumes of each major reservoir from in-country sources.

The station-level meteorology data provided by local sources varied in quality and comprehensiveness. While some countries had excellent data and shared the data readily with the project team, institutional capacities prevented others from providing useful data. In some cases, therefore, there was a need to rely on global sources of data (details are provided in each of the supporting country reports (World Bank 2012a, 2012b, 2012c, 2012d)).

Analytic Step 3: Develop Climate Projections

Climate change analyses require some forecasts of how temperature, precipitation, and other climate variables of interest might change over time. Because of the great uncertainty in climate forecasts, it is best in a study such as this to attempt to characterize a range of alternatives as well as a "central case" forecast. In this study the guiding principle used to select future climate scenarios was based on measures most likely to be relevant to negative or positive impacts of climate change on the agricultural sector. Because both temperature and precipitation affect agricultural productivity, scenarios were selected based on an index of soil moisture—the "climate moisture index" that is believed to be well-correlated with potential agricultural production. The climate projections combine information from the baseline datasets with projections of changes in climate obtained from global circulation model (GCM) results prepared for the United Nations *Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report*. (IPCC 2007b). As noted in box 2.1, for each country three climate scenarios were developed, defined by the Climate Moisture Index (CMI), which measures the aridity of a region.[5] Using CMI values for each country, of the team selected driest, wettest, and a "medium" scenario from among 56 future climate change forecast scenarios developed by IPCC. Then, both daily and monthly temperature and precipitation forecasts were generated to be used in the subsequent crop and water resources models.

Analytic Step 4: Impact Assessment

The goal of the impact assessment was to develop a rigorous quantitative assessment of the biophysical risks of climate change to agriculture if no adaptation

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Box 2.1 Developing a Range of Climate Scenarios

Climate change analyses require forecasts of how temperature, precipitation, and other climate variables of interest might change over time. Because of the great uncertainty in climate forecasts, it is best in a study like this to attempt to characterize a range of alternatives as well as a "central case" forecast.

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 were selected based on a climate moisture index, or CMI. The CMI is based on the combined effect of temperature and precipitation, and as it is linked to soil moisture, so it is believed to be well-correlated with potential agricultural production.

Each scenario in the study corresponds to a specific global circulation model (GCM)/greenhouse gas (GHG) emissions scenario combination. These SRES scenarios were among those used by the IPCC in its fourth assessment of the science of climate change ("Special Report on Emissions Scenarios," or SRES, IPCC 2000, also IPCC 2007a, 2007b).

The study team relied on the three most commonly used GHG emissions scenarios: B1, A1b, and A2. A "wet" CMI scenario means that the location experienced the smallest impact (or change in) CMI—that is, the "low impact" scenario. A dry scenario corresponds to high potential impact. The specific global general circulation model selected for the medium scenario is the closest in consistency with the model mean CMI from a total of 56 readily available emission scenario–GCM combinations.

The advantages of this approach are that it provides a representation of a full range of available scenarios for future climate change in a manageable way and that all climate scenarios are based on distinct GCM results. These results are themselves internally consistent in terms of the key GCM outputs the team used as inputs to the crop, livestock, and water resource impact modeling.

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were conducted. Subsequently the same model set was applied to estimate the marginal effect of individual adaptation measures on yields, which could then be valued and compared to the costs of those measures to assess the economics of alternative adaptation responses. As shown in figure 2.2, three general categories of biophysical models were used to develop the impact and adaptation assessments: crop models, a hydrological river runoff model, and a water balance model. The specific model choices within those categories were as follows:

- *Crop models analyze changes in crop yields and crop water and irrigation requirements.* Different crop models were used in various combinations across the study countries to assess which models could best provide a reasonable degree of confidence in the crop yield results; incorporate the effects of changes in temperature, precipitation, and irrigation water availability simultaneously; and be practically applied under multiple conditions to assess the marginal effect of individual adaptation measures needed to support benefit-cost analyses. Although three different models were used in different situations (DSSAT, AquaCrop, and in some cases, CropWat), the team ultimately concluded that FAO's AquaCrop model provided the best combination of high confidence in yield results, flexibility, and the ability to estimate marginal effects of adaptation measures.

- *River runoff models are used to estimate the effects of climate change on the quantity of surface water available for irrigation and other uses.* Both temperature and precipitation changes affect river runoff volumes. The CLIRUN model was used to analyze changes in water runoff.

- *Water balance models combine information about the spatial layout of the water supply system with water demand and supply projections to assess whether certain uses might result in water shortages.* Using the inputs from the river runoff model to characterize water supply, the crop modeling to characterize changes in irrigation water demand, and other analyses that project water demand from other users (such as hydropower and municipal water supply),[6] the water balance model's primary purpose in this analysis is to identify potential shortages in water available for agriculture under climate change. The WEAP (Water Evaluation and Planning System) model was used in this analysis.

It is important to note that the analysis also included a critical "loop-back" from the results of the water balance modeling to the crop yield analysis, for any basin in which a water shortage for agricultural irrigation was noted (as illustrated in figure 2.2). The feedback loop was performed to estimate the yield of irrigated crops that would result if available water was insufficient for irrigation. The general increase in irrigation demands due to higher temperatures proved to be a very important part of the analysis. The various modeling tools used in this analytic step are briefly described in box 2.2.

Box 2.2 Impact Assessment Modeling Tools

The five models used in Analytic Step 4 of this study are: DSSAT, AquaCrop, CropWat, CLIRUN, and WEAP. The characteristics of each model are as follows.

- *DSSAT.* The Decision Support System for Agrotechnology Transfer (DSSAT) is used to facilitate simulations of crop responses to climate and management. DSSAT software includes more than 20 models for the main food and fiber corps; many of the models were specifically developed for climate change impact studies with funding provided by international agencies (USAID, UNEP, and UNDP, among others) and have been calibrated and validated in a few hundred sites in all agroclimatic regions. The DSSAT models have been widely used for evaluating climate impacts in agriculture at levels ranging from individual sites to wide geographic areas.
- *AquaCrop*. The strengths of this process model are that it is simple to evaluate the impact of climate change and evaluation of adaptation strategies on crops, and it can evaluate the effects of water stress and estimate crop water demand, both key issues in several of the study countries. The model was developed and is maintained and supported by the Food and Agricultural Organization (FAO) and is the successor of the well-known CropWat package. The model is mainly parametric-oriented and therefore less data demanding than DSSAT.
- *CropWat.* CropWat was developed by FAO as simple one-dimensional crop model as a tool for use by poor farmers to plan irrigation patterns in arid to semi-arid regions. The application requires very limited input and assumes no vertical differences in soil moisture and that the soil moisture cannot exceed field capacity. CropWat simulates water stress on crops, but does not incorporate nutrient or solar stresses on a daily time-step. As a result, while it can generate both yield and water demand estimates under climate change, it cannot estimate any positive effects from longer growing seasons, and does incorporate the effects of waterlogging or daily precipitation patterns.
- *CLIRUN.* This Climate and Runoff hydrologic model can be used to estimate monthly runoff in each catchment using 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. The application can run on a daily or monthly time step. Soil water is modeled as a two-layer system (a soil layer and groundwater layer) corresponding to a quick and a slow runoff response to effective precipitation. 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.
- *WEAP.* The Water Evaluation and Planning system (WEAP) is a software tool for integrated water resources planning that assists rather than substitutes for the skilled planner. It provides a comprehensive, flexible, user-friendly framework for planning and policy

box continues next page

Box 2.2 Impact Assessment Modeling Tools *(continued)*

analysis. WEAP produces 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, as well as existing as well as potential major schemes and their various demands of water. The WEAP application for this project modeled 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 a proprietary product, SEI makes the model available for a nominal fee for developing country applications.

Sources: DSSAT: Dinar and Mendelsohn 2011; AquaCrop: Raes et al. 2009; CropWat: http://www.fao.org/nr/water/infores_databases_cropwat.html; CLIRUN: World Bank (2010); WEAP: http://www.weap21.org/.

If provided with less irrigation water than he demands, a farmer can either evenly distribute the remaining water over his cropland so that each crop receives less water (that is, deficit irrigation), or meet all the irrigation needs of a fraction of the crops, leaving the remaining fraction unwatered. The sensitivity of each crop planted to water shortages determines which approach will produce higher yields. For this important step in the analysis, information from FAO on the relationship between relative crop yield and relative water deficit—called the yield response factor (Ky)—was used to estimate the change in yield resulting from a reduction in water availability for each crop, relevant AEZ-basin area, and climate scenario (FAO 1998).

Analytic Step 5: Select and Categorize Adaptation Options for Each AEZ and Country

A set of adaptation alternatives was defined and categorized for each country of the four study countries. This list was supplemented by stakeholder recommendations from the consultation workshops (described below). The types of adaptation options are as follows:

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

Categorized adaptation options are listed in appendix A.

Analytic Step 6: Conduct Adaptation Assessment

The adaptation options are evaluated primarily on the basis of five criteria: (1) the net economic benefits (quantified where possible; based on expert assessment otherwise); (2) the robustness to a range of future potential climate outcomes; (3) the potential to aid farmers with or without climate change, otherwise referred to as "win-win" potential; (4) a favorable evaluation by stakeholders; and (5) the potential for GHG emission reductions. Because of data limitations, not all options are evaluated quantitatively. Methodologies for addressing each of the criteria are described below.

Criterion 1: Net Economic Benefits

These assessments, conducted at the farm level on a per hectare basis, considered available estimates of the incremental cash costs for implementing the option, as well as the revenue implications of increasing crop yields. 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 that 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 the NPV and the B-C ratio based on different project start years. This is particularly relevant to infrastructural 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 (in the case of water supply options) river basins, (3) crops, (4) with and without CO_2 fertilization, and (5) irrigated versus rainfed.

Generating these metrics requires several key pieces of information,[7] which include the following:

- *Crop yields* with and without the adaptation option in place, which are derived from the crop modeling. Changes in yields are modeled based on adaptations such as those that increase water availability, open irrigation in currently rainfed areas, optimize application of inputs, or result in more optimal use of crop varieties.[8]
- *Management multiplier* to convert from experimental to field yields—agronomic and crop modeling experts developed these estimates, in consultation with local experts, as part of their capacity building work.
- *Crop prices through 2050* were derived using national crop price data from FAO for current conditions and as a baseline to develop price projections under one scenario with constant prices and another based on

the International Food Policy Research Institute (IFPRI) global price change forecast.

- *Exchange rates* between global and local crop prices were factored in.
- *Discount rate* to estimate the present value of future revenues and costs. The base case analyses employ a 5 percent discount rate consistent with recent World Bank Economics of Adaptation to Climate Change analyses, but sensitivity tests using a 10 percent discount rate were also employed.
- *Capital and operations and maintenance costs of each adaptation input* (for example, irrigation infrastructure). Local data were sought to characterize costs of adaptation options, and in some cases they were provided. Overall, these can be difficult to obtain or generalize, and as a result, in many cases estimates they were derived from prior World Bank work or broader research.

The quantitative cost-benefit analyses of adaptation options address in detail seven of the most important adaptation options as follows:

1. Adding new irrigation capacity;
2. Rehabilitating existing irrigation infrastructure;
3. Improving water use efficiency in fields;
4. Adding new drainage capacity;
5. Rehabilitating existing drainage infrastructure;
6. Changing crop varieties; and
7. Optimizing agronomic inputs (particularly fertilizer use).

Two of these options—improving water use efficiency and changing crop varieties—include costs for extension programs, because enhanced extension is necessary to achieve the full benefits of the adaptation option. In addition, screening level analyses were made for four other options: expanding research and development, improving basin-level water use efficiency, adding new water storage capacity, and installing hail nets for selected crops.[9] These other analyses were more limited because of the lack of benefit information (requiring a "break-even" approach) or the inability to conduct the analysis at a crop-specific, model-farm level (for example, expanding research and development).

Criterion 2: Robustness to Different Future Climate Conditions

A key consideration in the quantitative analysis was assessing whether the option yields benefits across the range of possible future climate outcomes. These outcomes include 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. All options were assessed relative to climate conditions in three alternative climate scenarios: low, medium, and high impact. Benefit-cost ratios and NPV calculations were 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.[10]

Criterion 3: "Win-Win" Potential

The project team identified whether adaptation options would be beneficial even in the absence of climate change. For options amenable to economic analysis, the team analyzed the net benefits of the adaptations 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 was assessed based on expert judgment.

Criterion 4: Stakeholder Recommendations

Adaptation alternatives recommended by stakeholders during the stakeholder consultation workshops, at both the AEZ and national levels, carried significant weight in the results. Stakeholders also provided information on impacts that they had already experienced and adaptation options that address those impacts. Adaptation options that addressed those impacts, even if those measures were not specifically mentioned in the stakeholder workshops, were also given a higher priority.

Criterion 5: Greenhouse Gas Mitigation Potential

Once an initial set of options was identified as high priority, the team then also analyzed the GHG mitigation potential of adaptation options. The significance of this assessment and how it was conducted are explained in box 2.3. For this study, adaptation effectiveness for agriculture was the highest priority criterion, with GHG mitigation potential identified as an ancillary benefit once the option

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Box 2.3 Evaluating GHG Mitigation Potential of Adaptation Options

Many of the adaptive measures recommended to improve the climate resilience of the agricultural sector also have the potential to mitigate climate change. Particular adaptive practices such as manure management present promising opportunities to lower emissions by either reducing the amount of gases emitted in agricultural production processes or increasing the carbon stored in agricultural soils.

Table 2.1 provides a summary of the mitigation potential of various adaptive measures considered in this study. This evaluation was primarily based on each measure's contribution to climate change as described in table 5-14 of Albania's "Second National Communication (SNC) to the Conference of Parties under the United Nations Framework Convention on Climate Change" (Islami et al. 2009). Albania's SNC estimates a "score" for each adaptive measure according to its potential to reduce GHG emissions and mitigate the economic impacts of climate change. These measures were ordered by the GHG emission reduction potential score and assigned a "high" potential to the top third, a "medium" potential (two checks) to the middle third, and a "low" potential (one check) to the last third (shown by 3, 2, or 1 checkmarks in table 2.1).

box continues next page

Box 2.3 Evaluating GHG Mitigation Potential of Adaptation Options *(continued)*

The study team mapped the adaptive practices discussed in Albania's SNC to those listed in table 2.1 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 this analysis, a comprehensive review was 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.

was established as cost-effective, highly desired by stakeholders, or possessing "win-win" potential. In this manner, the potential for "win-win-win" alternatives (indicated by three checkmarks) were identified as shown in table 2.1.

Analytic Step 7: Develop Menu of Adaptation Options

The first six analytic steps were used to develop an initial menu of ranked adaptation options. The options were then presented in a draft report and at the National Dissemination and Consensus Building Conference in each country. Rankings for each of the five criteria under Analytic Step 6 were developed, and the top-ranked options within each category were put forward for further consideration at the conference. Participants at the conference then considered these results and in small groups developed their own set of priorities for adoption, which often included additional adaptation measures that had not been analyzed or presented as well as greater specificity on the nature and focus of the measure. Small groups were formed for each AEZ and for a set of national policy recommendations. The potential for a measure to mitigate GHG emissions also influenced the results in the final reports.

Finally, the results included 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 crops varieties from one season to the next. This information was not used to assign priority, but instead was designed to provide guidance about measures that could have an immediate versus delayed impact. The assessment was based on available information on each option along with expert judgment.

Limitations and Key Challenges

The approaches developed and applied in this assessment need to be as robust and accurate as possible; at the same time they needed to be consistent with local

Table 2.1 Greenhouse Gas Mitigation Potential of Adaptation Options

Adaptation measure	*GHG mitigation impact*	*Mitigation potential*
Irrigation systems: new, rehabilitated, or modernized (including drip irrigation; irrigation using less power)	Minimizes 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	Increases carbon inputs to soil and promotes soil carbon sequestration, reduces energy used in transportation, and reduces energy consumption for production of agrochemicals.	✓✓
Conservation tillage	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; and reduces emissions from use of heavy machinery.	✓✓
Crop rotation	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 increase carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Strip cropping, contour bunding (or ploughing), and conservation farming	Increases carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Optimize timing of operations (planting, inputs, irrigation, harvest)	More efficient fertilizer use reduces nitrogen losses, including $N0_2$ 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	Increases soil carbon stocks, especially in highly degraded soils that are at risk of erosion.	✓✓
Switch from field to tree crops (agro-forestry)	Retains nutrients in soil and reduces emissions of GHG by fixing atmospheric nitrogen, reducing losses of soil N, and increasing carbon soil sequestration.	✓✓
Livestock management (including animal breed choice, increase heat tolerance, change shearing practices, change breeding patterns)	Reduces CH_4 emissions.	✓
Match stocking densities to forage production	Reduces CH_4 emissions by speeding digestive processes.	✓
Pasture management (e.g., rotational grazing) and improvement	Degraded pastureland may be able to sequester additional carbon by boosting plant productivity through fertilization, irrigation, improved grazing, introduction of legumes, or use of improved grass species.	✓✓
Rangeland rehabilitation and management	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	Increases carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Optimize use of irrigation water (e.g., irrigating at critical stages of crop growth, irrigating at night)	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓
Use water-efficient crop varieties	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓

Note: CH_4 = methane, CO_2 = carbon dioxide, GHG = greenhouse gas. ✓✓✓: hiigh potential; ✓✓: medium potential; ✓: low potential.

data availability and local conditions and avoid unnecessary complexity to achieve the goals of in-country capacity building and involvement of local experts in the application of the methodology and the dissemination of the results. The framework was designed to be suitable for a wide range of specific crops (for example, maize, wheat, tomato, wine grapes, apple, alfalfa, and cotton) selected for focus in the early stages of each country analysis. The resulting methodology provides a good initial level of predictive ability and is suitable to simulate and evaluate a range of adaptation options for various climate change scenarios, cropping systems, and agricultural water regimes.

A study with this broad scope, nonetheless, necessarily involves significant limitations. For example, assumptions must be made about many important aspects of agricultural and livestock production in each country; the limits of simulation modeling techniques for forecasting crop yields and water resources must be considered; and time and resource constraints must be factored in. The overall methodology was designed to yield results sufficiently precise to ensure that the adaptation measures will yield benefits in excess of costs and are robust to future climate change. Some of the options will require additional, more detailed examination and analysis to ensure that specific adaptation measures are implemented in a manner that maximizes their value to agriculture in each country. Nevertheless, while more detailed modeling could yield more precise impact and benefit-cost results, pursuing a more detailed approach would not necessarily alter the ranking of options or suggest that options evaluated to be highly cost-effective might instead be poor investments.

In order to look broadly across many crops, areas, and adaptation options, however—particularly for adaptation options that may be relatively new to each of the countries supported in the study—it was necessary to develop general data and characterizations of these options. While the study team took great care to use the best available data and applied state-of-the-art modeling and analytic tools, they recognize that 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, the team attempted to evaluate the sensitivity of results to one of the most important sources of uncertainty—how future climate change will unfold—through the use of the multiple climate scenarios.[11]

Other costs and benefits that do not affect farm expenditures or revenues are excluded from the quantitative analysis, mainly owing 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 very difficult to quantify those effects without consideration of the site-specific characteristics that may be unique to individual farms.

A potentially larger question, more difficult to address, 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 forecast. Other important limitations involve the necessity of examining the efficacy of adaptation options for a "representative farm." The result is an important initial step in the process of evaluating and implementing climate adaptation options for the agricultural sector using the current best available methods.

The researchers hope, 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 agricultural institutions of the basis of the results, but also an enhanced capability to conduct the required, more detailed assessment that will be needed to further pursue the most promising adaptation measures.

Notes

1. In this analysis, the economic and physical baseline is current yields, which represents a simplification of the expectation for these countries, but it is a reasonable expectation for agricultural productivity without planned adaptation interventions. Because the purpose of this study is to evaluate measures that might enhance resilience to both current and future climate, it is not clear whether modeling of an alternative baseline that includes agricultural innovation (and adoption) is appropriate or important. Using a baseline of increasing yield, for example, implies that some adaptive actions (such as new varieties) would be adopted as "autonomous" adaptations, at some cost to either the country or the farmers. This study examines marginal gains in crop yields and farm-level revenue from this baseline for individual measures that we believe are unlikely to be adopted without additional adaptation plans and investments. It is certain that projecting a baseline of future crop yields that differs from the constant yield assumption used here adds significant complexity and uncertainty to the results.
2. Some might argue that simulation modeling is so demanding of inputs that it yields less precise or even inaccurate estimates. The difficulties of simulation modeling make calibration of the models to current conditions, wherever possible, most important. The Ricardian approach is sometimes put forward as an alternative method for estimating the impacts of climate change on yields and revenue in response to climate change. However, the Ricardian approach, which relies on an econometric estimation of a climate response function based on current data, implicitly reflects adaptive responses in the current system and therefore lacks the ability to estimate the incremental benefits of specific adaptation options. Further, only currently practiced adaptive measures are reflected in the estimation—whereas in many cases in developing countries agricultural systems are poorly adapted to current climate, reflecting an "adaptation deficit"—and new measures should be introduced.
3. Note that the overall approach used in this instance focuses the analysis on regions that are currently in agriculture and does not evaluate regions that may become newly suitable for agriculture as the climate changes.
4. Both DSSAT and AquaCrop require daily inputs. CropWat is also used, which requires only monthly data.
5. 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.

6. Water demands for other sectors were projected based on the results of the World Bank "Economics of Adaptation to Climate Change Study" (World Bank 2009).
7. All parameters used in the analysis are described in greater detail in appendix A.
8. For changes in varieties, the team looked not at the yield benefits of newly developed seed varieties, but rather at adopting currently available varieties either that are not used at present or that would optimize yields for future conditions. A separate analysis reviews possible returns from investment in research to develop new varieties and technologies.
9. Note that some analysts have suggested that improving water use efficiencies, such as lining irrigation channels, may have little value if both surface water and groundwater are used for irrigation, because losses from the channels would be gains to the groundwater aquifers. There is, however, a cost of collecting and delivering the water to the fields, so while the water may not be lost to the hydrologic system, additional pumping costs would be incurred to recover water lost from irrigation channels.
10. An interesting finding is that in most cases quantitative results for adaptation options were less sensitive to uncertainties in climate forecasts than to uncertainties in future prices. This was also true for CO_2 fertilization effects on yield.
11. The next chapter, which shows the climate projections for each country, demonstrates that using multiple climate scenarios is a critical step—use of only one scenario would suggest more certainty in climate forecasts than is warranted, particularly for precipitation projections that are critical for agriculture.

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CHAPTER 3

Risks, Impacts, and Adaptation Menus for Study Countries

This chapter summarizes the results of efforts to develop an adaptation menu in each of the four countries in the study. The results at the country level provide more detail about the differences among the four countries, particularly with regard to crops at risk from climate change and water availability. This chapter focuses on three aspects of the country-level results:

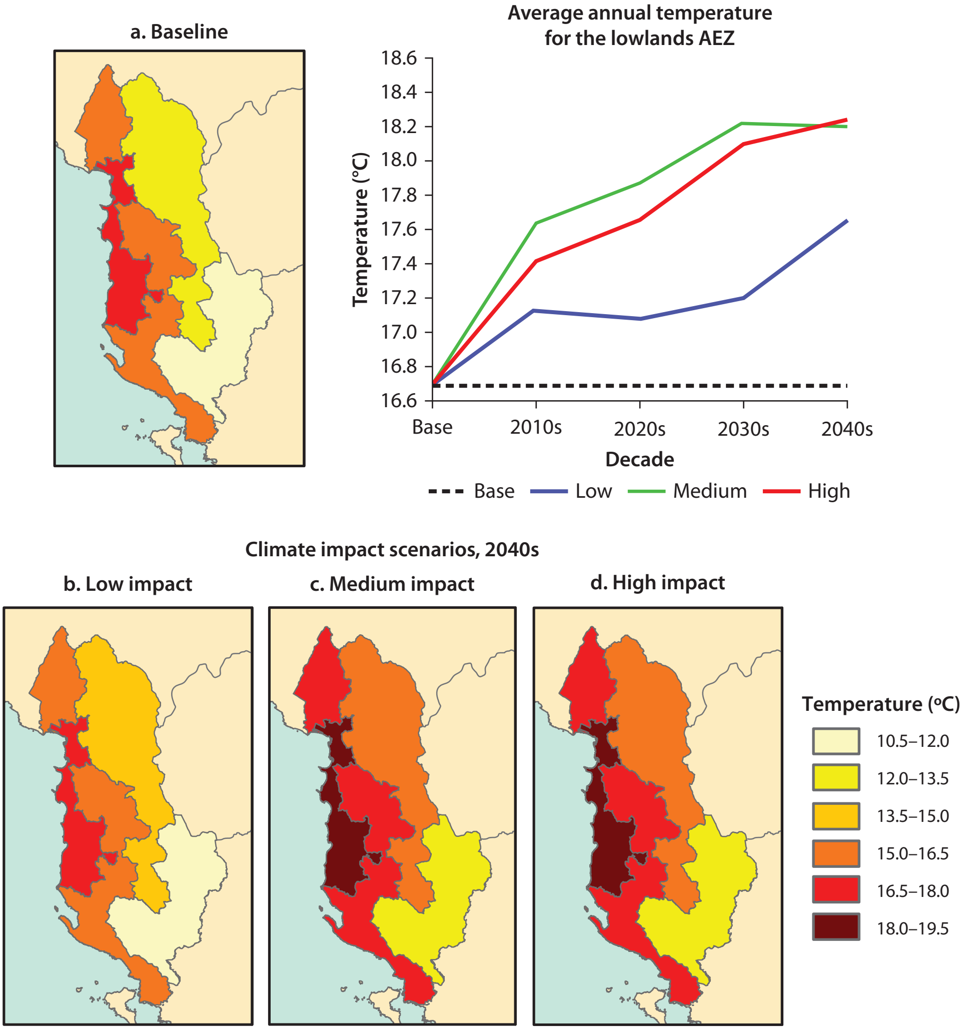
- The climate hazard to the agricultural sector, in particular, annual and seasonal changes in temperature and precipitation;
- The impact assessment results, which combine climate stress, baseline adaptive capacity, and detailed simulation modeling in the crop and water resources sectors; and
- The resulting menu of adaptation options for each country.

Albania Climate Risk

Analysis of recent climate data and information gathered from the study's farmer workshops support the finding of an increasing trend in temperature in Albania. Farmers also observed an increasing trend in extreme heat events. Analysis indicates this trend will accelerate in Albania in the near future, as indicated in map 3.1. Although uncertainty remains as to the degree of warming that will occur in Albania, the overall warming trend is clear and evident in all four agro-ecological zones (AEZs), with average warming over the next 40 years of about 1.5°C, much greater than the increase of less than 0.5°C observed over the last 50 years.

Changes in precipitation are much more uncertain than temperature changes, as demonstrated in map 3.2. The medium impact forecast indicates a decline in average annual precipitation for Albania of about 50 mm by 2050, most of this decline occurring in the lowlands AEZ. The range of outcomes across the low and

Map 3.1 Albania: Effect of Climate Change on Temperature through 2050 for the Three Climate Impact Scenarios



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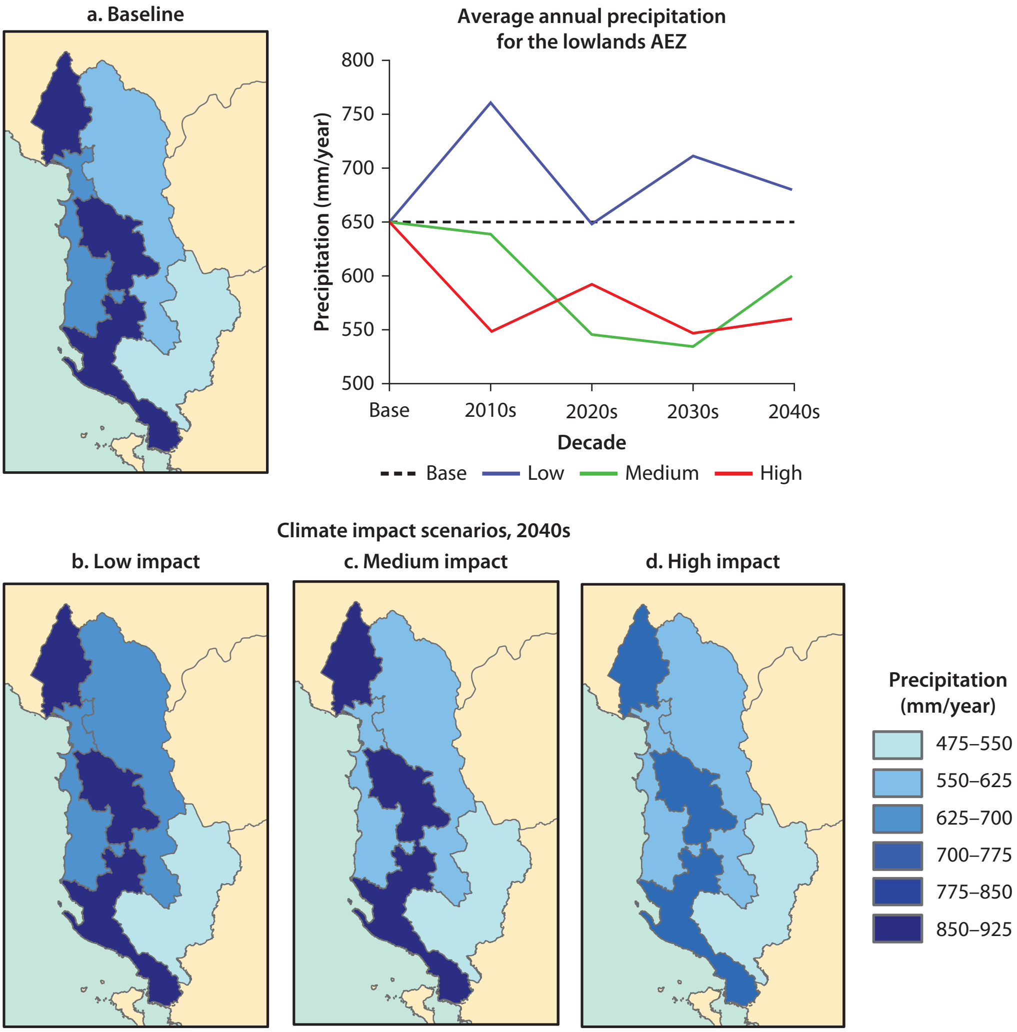
high impact alternative scenarios, however, encompasses an increase in annual precipitation of 30 mm for low impact and a decrease of 90 mm for high impact.[1] Uncertainty at the regional level is even higher: annual precipitation declines in the lowlands and intermediate AEZs, including areas around Lushnje, Vlores, Fushe-Kruje, and Shkodra, could be as large as 150 mm per year. Most models show that the mountainous areas of Albania, particularly around Korce, should experience only modest declines in annual precipitation.

Map 3.2 Albania: Effect of Climate Change on Precipitation through 2050 for the Three Climate Impact Scenarios



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Albania also has a history of relatively frequent flooding, especially in the last two decades. Flood events occur on a daily to weekly timescale, so the monthly data presented above does not reflect the risk that climate change can lead to more extreme precipitation and flooding events. During a large flood in December 2010, 14,000 hectares of Shkodra were submerged due to heavy rains and high water levels of the River Drin (Lowen 2010). Flooding is a particular problem in the northwest, a region with minimal watershed management and poor infrastructure. Most prevalent in May–December, the floods have worsened in recent decades most likely due to deforestation, overgrazing, and erosion, combined with a lack of maintenance of drainage canals and pumping stations. In addition, river control programs were discontinued and reservoirs became silted. These disruptions led to a worsening of the hydroelectric and irrigation systems (Kodderitzsch 1999).

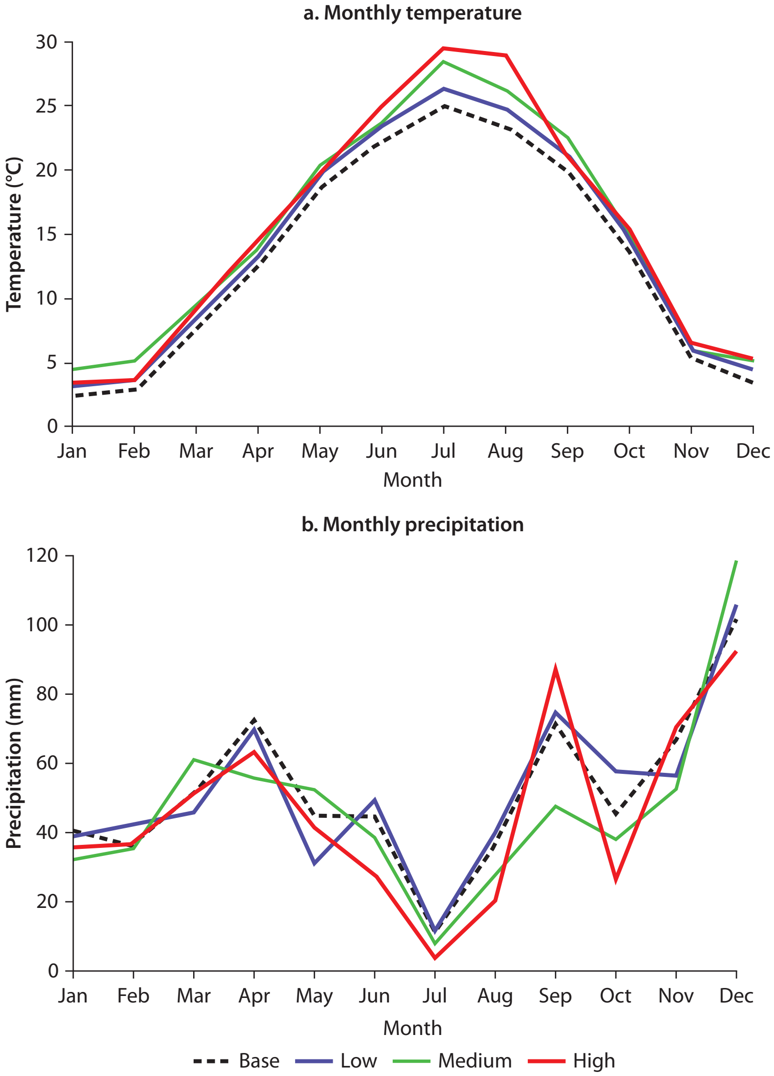
Climate change could potentially increase the frequency and magnitude of flooding. While precipitation is only expected to increase in the low impact scenario by the 2040s (see map 3.2), rainfall events in all scenarios are likely to be larger and less frequent. Additionally, increasing sea level rise and storm surges are expected to increase flooding in coastal areas. For the agriculture sector in Albania, floods are particularly problematic in the spring, when flooding can delay or prevent planting of summer crops, and during late summer, when flooding can destroy the entire year's growth and prevent timely harvesting. Less serious flood events can reduce productivity through water logging of roots.

The seasonal pattern of changes in climate are, however, more important for crop and livestock production than annual averages, particularly if no adaptation measures are adopted beyond those that farmers already employ (such as changing planting dates in response to temperature changes). Figure 3.1 provides the monthly temperature and precipitation results for Albania, showing that temperature increases are higher and precipitation declines greater in July and August relative to current conditions. The summer temperature increase can be as much as 4–5°C in the northern mountains of Albania. In addition, forecast precipitation declines are greatest in the key May–September period when precipitation is already lowest, particularly in the southern and northern mountains.

Impact Assessment Results for Albania

The monthly projections in figure 3.1 are further translated to daily projections for use in the crop models. These models provide results for climate change impacts to crops if no adaptation is implemented; the crop yield impacts are summarized in table 3.1. The results show that grapes and olives will be most affected by climate change, with declining grape yield in all AEZs and with olives particularly affected in the lowlands AEZ. Winter wheat yields could increase, however, as climate change will likely result in an extended growing season, more moderate fall and winter temperatures, and greater precipitation and water availability during the wheat growing season. Alfalfa production should also increase in most regions. The expected effects on maize vary by region, with yield increases in the southern highlands and decreases in other regions, probably because current temperatures are quite moderate in the mountainous southern highlands and a temperature increase could enhance yields. The other crops analyzed in this study should

Figure 3.1 Albania: Effect of Climate Change on Temperature and Precipitation Patterns for Northern Mountains AEZ, 2040–50



Note: AEZ = agro-ecological zone.

experience relatively modest crop yield changes compared with current yields.

The study team also conducted a water availability analysis in Albania at the river basin level. They modeled the effect of climate change on water runoff in rivers for each basin and then used a second model to compare water supply results with forecasts of water demand for all sectors, including agriculture. Agricultural water demand for irrigation is derived from the crop model results

Table 3.1 Albania: Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium Impact Scenario

% change

Irrigated/ rainfed	*Crop*	*Intermediate*	*Lowlands*	*Northern Mountains*	*Southern Highlands*
Irrigated	Alfalfa	6	4	6	13
	Maize	−3	−4	−11	1
	Tomatoes	0	−11	−8	−4
	Watermelon	N/A	−6	N/A	N/A
	Alfalfa	−6	−3	−2	7
Rainfed	Grapes	−17	−20	−21	−18
	Grassland	−5	−3	−7	10
	Olives	−3	−21	N/A	N/A
	Wheat	10	7	24	20

Note: Results are average changes in crop yield, assuming no effect of carbon dioxide fertilization, under medium impact scenario (no adaptation and no irrigation water constraints). Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases. N/A = the crop is not grown in that AEZ, according to local stakeholders.

summarized in table 3.1. This comparison of water demand and water supply (or runoff) identifies the potential for shortages of water to meet future demands. In Albania, overall results suggest that water supply will decrease under the high and medium impact scenarios, and increase under the low impact scenario. Irrigation water demand is higher for all scenarios, particularly in the summer months. Nonetheless, in each of the four river basins of the country, because the baseline supply of water is so high, the analysis indicates there is no unmet water demand through 2050, indicating there will continue to be ample water available for both current levels of irrigation and expansion of irrigated areas, as necessary.

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 climate change on maize yields may also be linked to effects on livestock. As noted, for the medium scenario alfalfa and grassland yields are expected to increase in the northern mountains and southern highlands AEZs, where livestock makes up a larger percentage of overall agricultural productivity. Even under the high impact scenario, the effects on these crops in the higher elevation regions of Albania are relatively modest, with the temperature effects providing 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, can lead to elevated mortality rates related to extreme heat stress. As noted in chapter 2, there is very limited information to characterize the direct effects of climate on livestock because the currently available methodologies are far less sophisticated than the crop modeling techniques or the water resource modeling techniques.

Adaptation Options Menu for Albania

The project team developed an extensive list of potential adaptation options that might be considered to reduce risks of climate change to crops and livestock in Albania (see appendix A). The team conducted a detailed quantitative benefit-cost (B-C) analysis of adaptation options selected from this list to address seven adaptation issues in Albania, including the following:

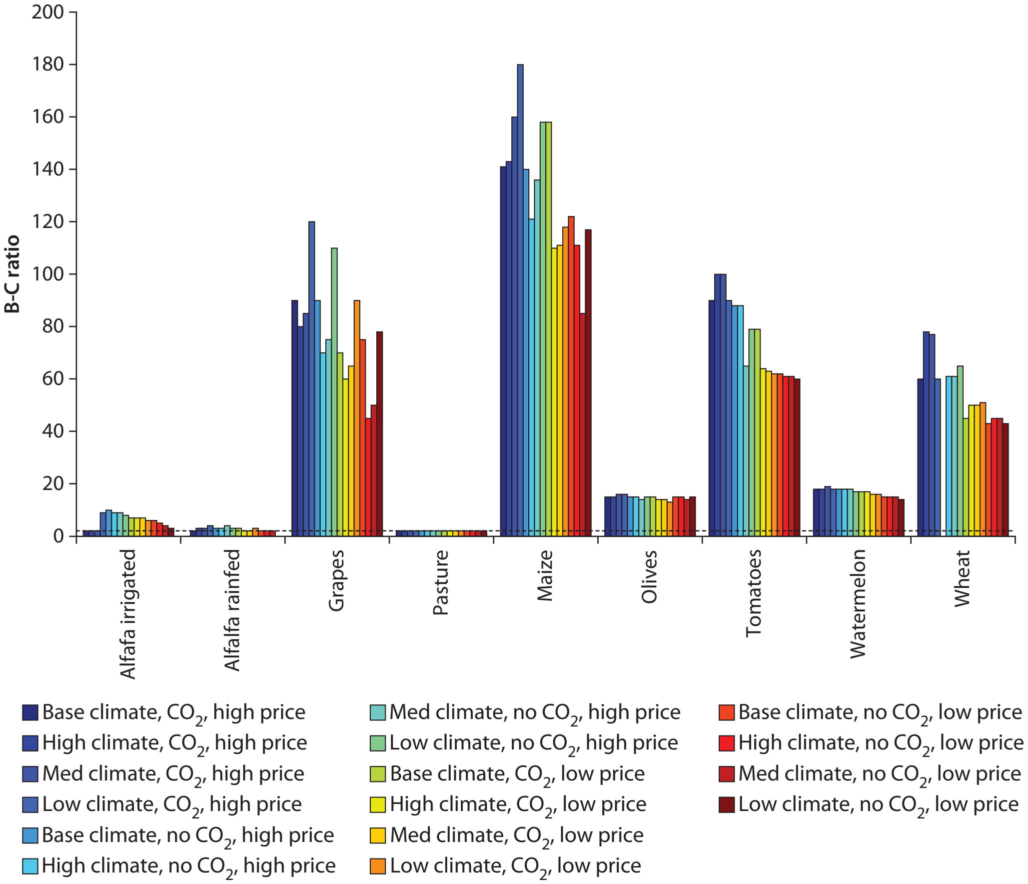
1. adding new drainage capacity;
2. rehabilitating existing drainage infrastructure;
3. adding new irrigation capacity;
4. rehabilitating existing irrigation infrastructure;
5. improving water use efficiency in fields;
6. changing crop varieties; and
7. optimizing fertilizer use.

Some of these options included costs for extension programs, as appropriate, if enhanced extension was determined to be necessary to achieve the full benefits of the adaptation option. This is true for two of the selected options—improving water use efficiency and changing crop varieties. In addition, less detailed analyses were conducted of two other options: improving the hydrometeorological network and installing hail nets for selected crops. The assessments were conducted at the farm level on a per hectare basis and considered available estimates of the incremental cash costs for implementing the option as well as the revenue implications of increasing crop yields.

The results of benefit-cost (B-C) analysis for one of these measures, rehabilitating existing drainage infrastructure, are illustrated in figure 3.2. The analysis was conducted for multiple climate, CO_2 fertilization, and price scenarios, to evaluate robustness of the results. As indicated, for this measure, benefit-cost ratios are very high for virtually all crops and all scenario analyses, suggesting that the yield benefits of this measure are much higher than the estimated costs.

An overall set of high-priority policy, institutional capacity building, and investment measures to improve the resiliency of Albanian agriculture to climate change were derived from this review. The study analysis considered adaptive capacity, identification of the risk of climate change to agricultural yields, the results of the farmer and expert evaluation of adaptation options, and quantitative benefit-cost evaluation of adaptation measures, coupled with the results of the National Dissemination and Consensus Building Conference held in Tirana in March 2011 and, finally, the mitigation potential of the measure. These results

Figure 3.2 Benefit-Cost Analysis Results for Improved Drainage in Albania's Lowlands AEZ—Rehabilitated Drainage Infrastructure



Note: The 16 scenarios for which benefit-cost (B-C) ratios are shown include combinations of four climate scenarios (base, low, medium, and high impact); two carbon fertilization assumptions (with and without); and two price projections (low and high).

were arrayed for national policy measures and for each AEZ in a tabular form—an example for national-level adaptation measures is shown in table 3.2 and for the lowlands AEZ in table 3.3. Results for adaptation measures at both the national and AEZ level are summarized in table 3.4. The results for Albania are similar to those for the other three countries in the program, but recent experiences with flooding made drainage measures a much higher priority in Albania than for other countries.

Tables 3.2 and 3.3 are summary tables that list only the highest-ranked options. Such tables were used in the National Dissemination and Consensus Building Conference to focus participants on the draft recommendations. Other options were also evaluated, however; for example, virtually all of the measures listed in Appendix A were evaluated in either a quantitative or qualitative

Table 3.2 Albania: National-Level Adaptation Options

		Ranking criteria			
Adaptation measure	*Specific focus areas*	*Net economic benefit: quantitative analysis*	*Net economic benefit: expert assessment*	*"Win-Win" potential*	*Favorable evaluation by local farmers*
Improve farmer access to technology and information	Seed varieties; more efficient use of water	High	High	High	High
Improve farmer access to relevant hydrometeorological information	Short-term temperature and precipitation forecasts	High (based on "break-even" analyses)	High	High	High
Improve agricultural information for policy support	Soils (types and drainage qualities), general crop suitability	Not evaluated	High	High	Not mentioned
Provide incentives to consolidate farm holdings	None identified	Not evaluated	Not mentioned	Potentially high	High
Encourage private sector involvement in efficient adaptation	Seeds, livestock options, particularly on international market	Not evaluated	Potentially high	High	Not mentioned

manner. In the interest of space, those options that were ranked low against the study criteria are not listed in the summary tables in this chapter.

Moldova Climate Risk

Overall, Moldova has dry and mild winters with little snow and warm summers that begin with intense periods of rainfall followed by lengthy dry periods. Analysis of recent climate data, as well as information gathered from farmer workshops, support an increasing trend in temperature in Moldova. Farmers also have observed an increasing trend in extreme heat events. Analysis indicates this trend will accelerate in Moldova in the near future, as indicated in map 3.3.

Although uncertainty remains as to how much warmer Moldova will get, the overall warming trend is clear and evident in all three AEZs, with average warming over the next 50 years greater than 2°C, much greater than the increase of less than 0.6°C observed over the last 50 years.

Precipitation changes are much more uncertain than temperature changes, as indicated in map 3.4. The medium impact forecast indicates a decline in average annual precipitation for Moldova of about 120 mm per year by 2050. The range of outcomes across the low and high impact scenarios is consistent with a drop in precipitation by 2050, but the decadal pattern of forecast precipitation reflects uncertainty in the modeling of climate over the next 50 years. Uncertainty at the AEZ level is even higher, and annual precipitation declines could be as large as 9.9 mm per month, with all AEZs significantly affected.

Table 3.3 Adaptation Measures for Albania's Lowlands 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*	*Mitigation potential*
Improve drainage infrastructure	Tomatoes, maize, grapes, wheat	Ranked 3 for rehabilitation, 4 for new drainage	High	High	High	Unknown
Optimize agronomic inputs: fertilizer and soil moisture conservation	Tomatoes, olives, wheat	Ranked 5	Not mentioned	High	Medium	Medium
Improve irrigation water quality	Tomatoes, maize, watermelon	Ranked 2, but only indirectly evaluated	Not mentioned	High	High	Low
Improve crop varieties	Tomatoes, grapes, wheat, maize, watermelon	Ranked 1	Medium	Medium	High	Low
Research and improve livestock management, nutrition, and health	Beef cattle, chickens	Unknown	Not mentioned	Low to Medium	High	Low

The national averages, however, are less important for agricultural production than are the seasonal distributions of temperature and precipitation. Temperature increases are likely to be higher and precipitation declines greater in July and August relative to current conditions—the summer temperature increase could be as much as 7°C in the southern AEZ of Moldova. In addition, forecast precipitation declines are greatest in the June–September period, when thirsty summer crops need water most. Figure 3.3 presents the monthly baseline and forecast temperatures and precipitation for the southern AEZ.

Impact Assessment Results for Moldova

These seasonal changes in climate have clear implications for crop production. If no adaptation measures are adopted beyond those farmers are already attempting, and reduced water availability is taken into account, climate change is likely to have significant impacts on agriculture in Moldova, with potential yield reductions of 10–30 percent by 2050 for nearly all crops. First, estimations of impacts on crops if no adaptation is implemented, but before reductions in irrigation water

Table 3.4 Albania: Key Climate Hazards, Impacts, and Adaptation Measures at National and AEZ Levels

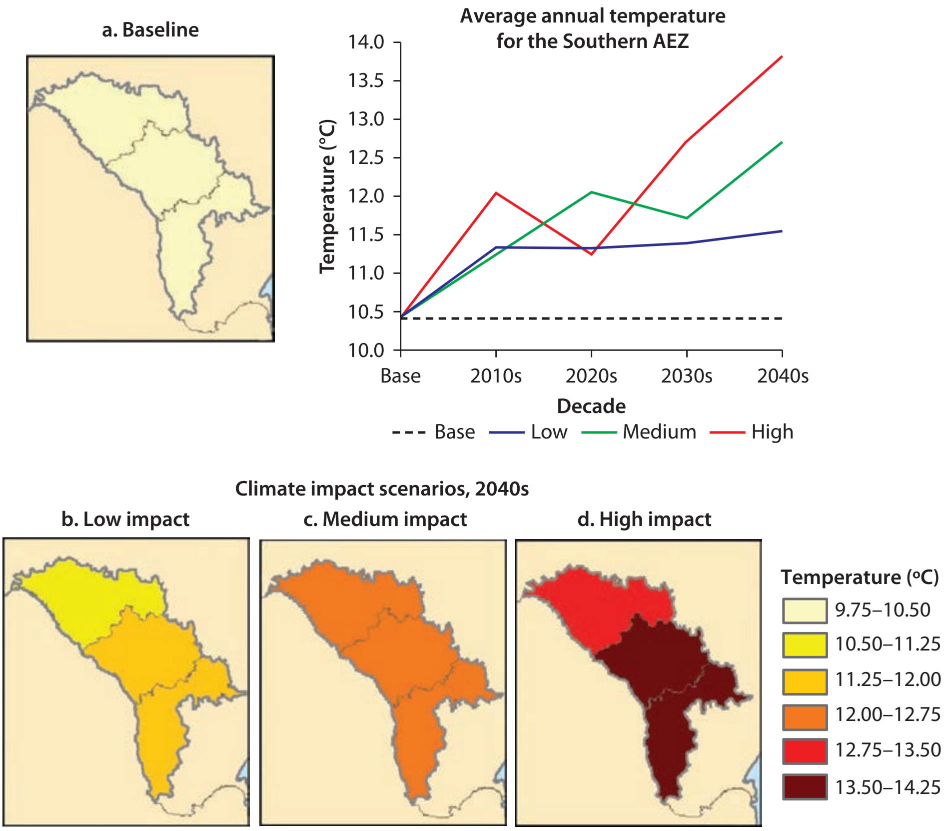
		Adaptation measure to address impact											
		National level				*AEZ level*							
Climate change impact	*Cause of impact (climate hazard)*	*Improve farmer access to technologies and information*	*Provide timely hydro-meteorological forecasts through mass media*	*Initiate national policy measures to consolidate farm holdings*	*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 irrigation water quality*	*Implement floodplain land-use management measures*	*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)	✓		✓	✓	✓		✓	✓	✓	✓		✓

table continues next page

Table 3.4 Albania: Key Climate Hazards, Impacts, and Adaptation Measures at National and AEZ Levels *(continued)*

		Adaptation measure to address impact											
		National level				*AEZ level*							
Climate change impact	*Cause of impact (climate hazard)*	*Improve farmer access to technologies and information*	*Provide timely hydro-meteorological forecasts through mass media*	*Initiate national policy measures to consolidate farm holdings*	*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 irrigation water quality*	*Implement floodplain land-use management measures*	*Improve livestock management, nutrition, and health*
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	✓	✓	✓		✓		✓					

Map 3.3 Moldova: Effect of Climate Change on Average Annual Temperature through 2050 for the Three Climate Impact Scenarios


a. Baseline

b. Low impact

c. Medium impact

d. High impact

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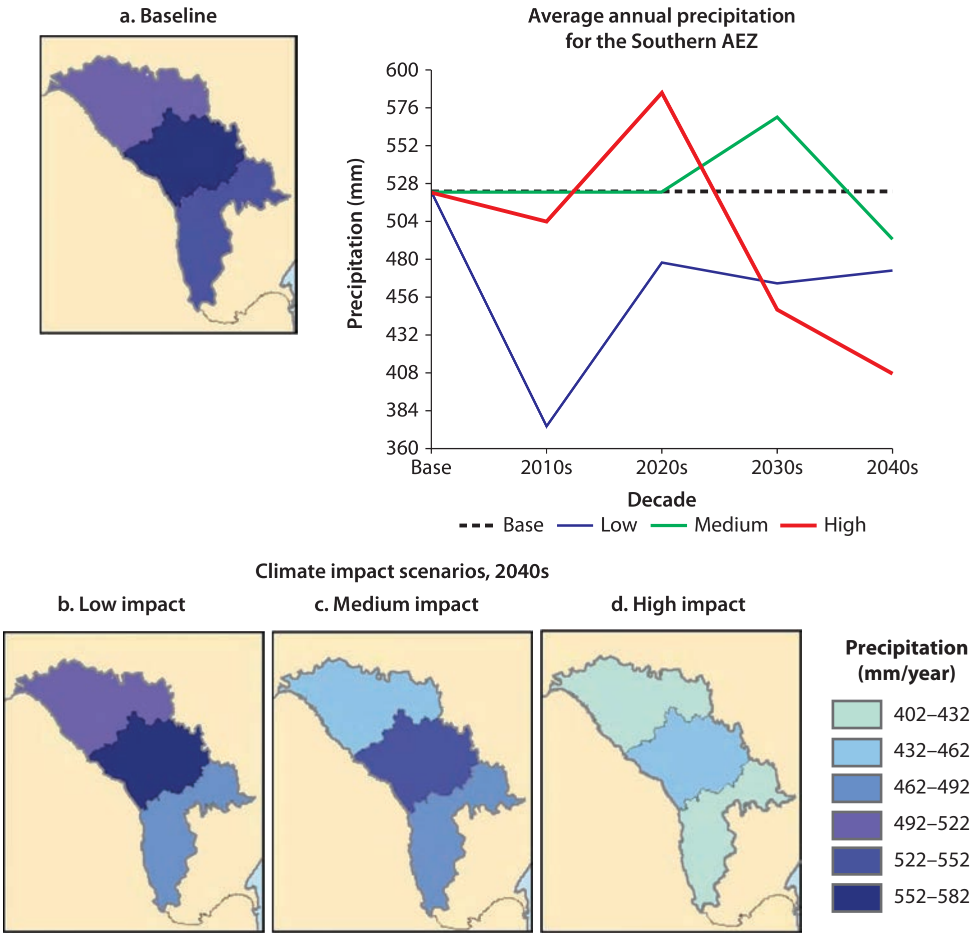
availability are taken into account, are summarized in table 3.5. The results show that yields of all crops in Moldova's agricultural sector except for apples will decrease under the medium-impact scenario, mainly as a result of heat and water stress.

Crop yields decline across AEZs under the medium impact scenario. Particularly severe declines can be seen for wheat and alfalfa. Apple yields, on the other hand, remain relatively consistent, with irrigated yields in the southern AEZ and rainfed yields in the central AEZ declining slightly, and rainfed yields in the southern AEZ increasing slightly.

The water resource management implications of climate change should also be of great concern in Moldova, because climate change both increases irrigation water demand and decreases overall water supply. For example, irrigation water demand increases for all scenarios and all crops relative to historical conditions by roughly 10–15 percent overall and to a greater degree during the summer months. At the same time, overall water availability declines because

Map 3.4 Moldova: Effect of Climate Change on Average Annual Precipitation through 2050 for the Three Climate Impact Scenarios



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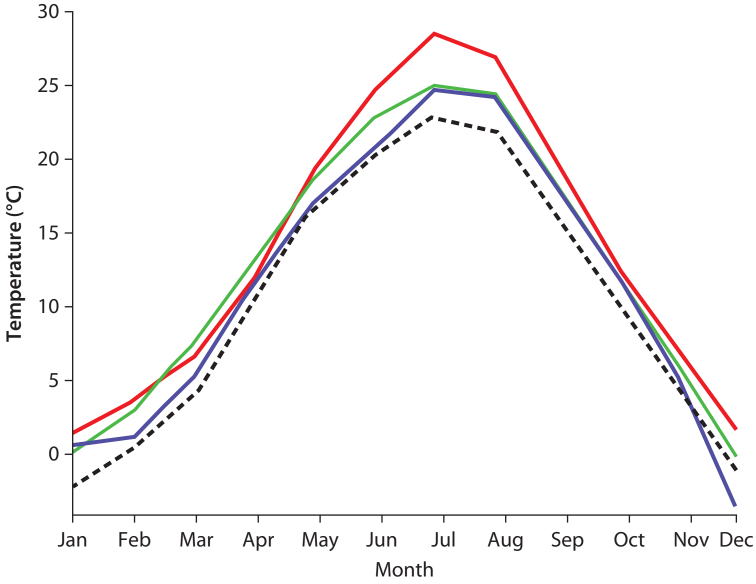
of increased heat and lower summer precipitation, as shown in figure 3.4. For all scenarios, the overall trend is that more water is required to maintain the current yields. Grapes, apples, and vegetables in particular will need substantially greater amounts of water. In addition, all Moldovan water basins across each scenario show reduced mean runoff during the irrigation season. In the Reut basin in particular, river flows fall over 60 percent in the high impact scenarios relative to the historical baseline. It should be noted, however, that currently only a small portion of the crops in Moldova, about 10 percent, are irrigated—nonetheless, there are plans to double that proportion, making the water resources analysis important.

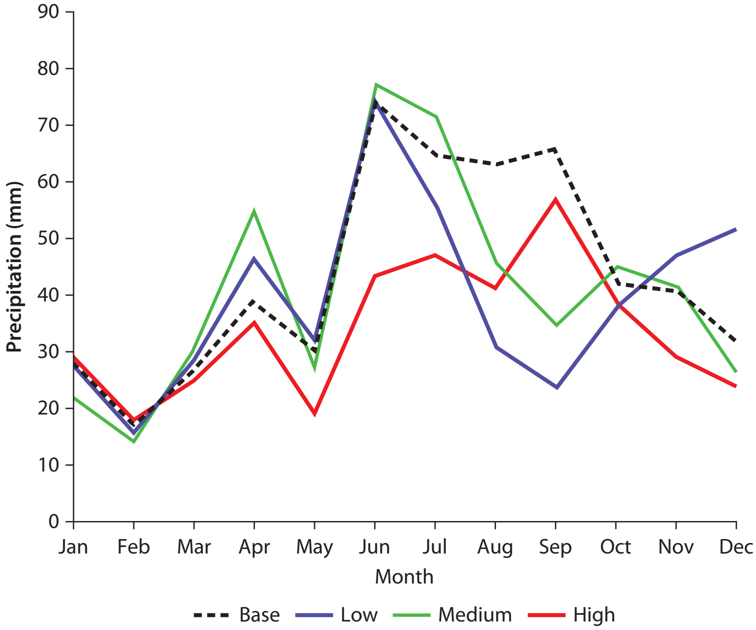
The net effect of falling water supply and rising irrigation demands, combined with the forecast for increased water demands from the municipal and industrial

Figure 3.3 Moldova: Effect of Climate Change on Temperature and Precipitation Patterns for the Southern AEZ

a. Monthly temperature



b. Monthly precipitation



Note: AEZ = agro-ecological zone.

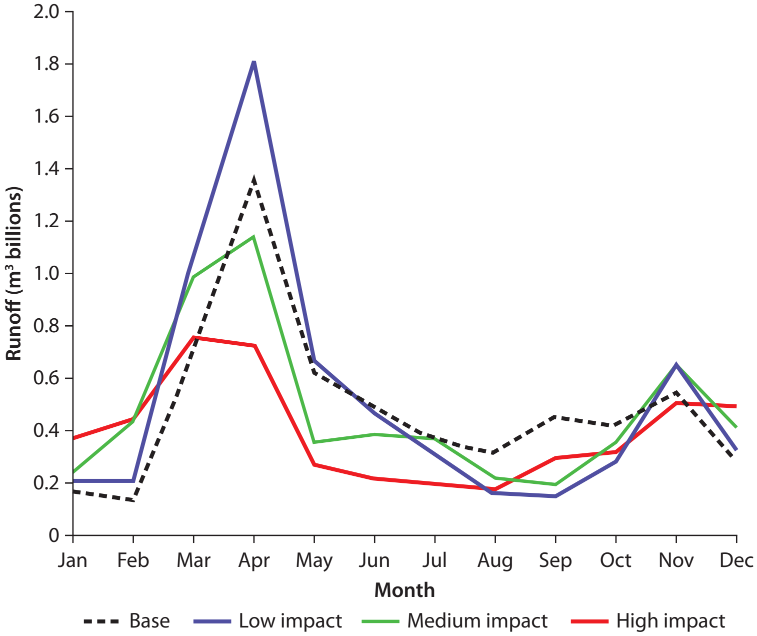
Table 3.5 Moldova: Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium Impact Scenario, No Irrigation Water Constraints

% change

Irrigated/rainfed	*Crop*	*Northern*	*Central*	*Southern*
Irrigated	Maize	–8	–6	–9
	Wheat	–14	–30	–34
	Alfalfa	–7	–13	–18
	Grapes	–4	–3	–5
	Apples	0	0	–3
	Vegetables	–5	–9	–13
Rainfed	Maize	–9	–3	–10
	Wheat	–36	–38	–45
	Pasture	–17	–22	–19
	Alfalfa	–13	–18	–12
	Grapes	–4	–3	–2
	Apples	–2	–4	3
	Vegetables	–9%	–13%	–9%

Note: Results are average changes in crop yield, assuming no adaptation, no irrigation water constraints, and no effect of CO_2 fertilization, under a medium impact scenario. Shading is darker the larger the decline in crop yield.

Figure 3.4 Moldova: Estimated Climate Change Effect on Mean Monthly Runoff



sectors due to overall economic growth, is a significant reduction in water available for irrigation. The forecast indicates that these factors could result in water shortages occurring within the next decade, with severe water shortages in the 2040s under all climate scenarios, but especially under the high impact scenario. Water shortfalls for the irrigation sector are outlined in table 3.6—the estimates presented are the amounts and percentage shortfalls relative to total water amounts demanded in the basin for irrigation purp. The most severe irrigation water shortages by the 2040s are forecast to occur in the Reut basin, an area where irrigation is prevalent and most agricultural production is highly reliant on irrigation to maintain current yields. Shortages are also forecast for the Upper and Lower Nistru basins, though these are not likely to be as severe as in the Reut basin. No shortage of irrigation water is forecast for the Kogilnic and Prut basins.

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

1. The direct effect of temperature and precipitation changes;
2. The increased demand for irrigation water even as yields decline; and
3. The fall in water supply associated with higher evaporation and lower rainfall.

All of these effects worsen during the summer growing season. The net effect of these three factors on irrigated agriculture is illustrated in table 3.7. The table shows that all crops in all AEZs and basins and across all scenarios are negatively affected by climate change.

Adaptation Options Menu for Moldova

The review of adaptive capacity, identification of the risk of climate change to agricultural yields, the results of the farmer and expert evaluation of adaptation options, and a quantitative benefit-cost evaluation of adaptation measures, coupled with the results of the National Dissemination and Consensus Building

Table 3.6 Moldova: Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario

	Climate scenario (shortfall in irrigation water relative to total irrigation water demand)					
	Low impact 2040s		*Medium impact 2040s*		*High impact 2040s*	
Basin	*m^3thousands*	*% shortfall*	*m^3thousands*	*% shortfall*	*m^3thousands*	*% shortfall*
Lower Nistru	79	0.2	62	0.2	318	0.7
Reut	213	0.6	2,000	5.6	8,360	21.5
Upper Nistru	26	0.3	37	0.4	162	1.5
Kogilnic	0	0	0	0	0	0
Prut	0	0	0	0	0	0
Total	318	0.2	2,099	1.5	8,840	5.6

Table 3.7 Moldova: Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields for Irrigated Crops, Including Effects of Reduced Water Availability

% change

		AEZ/river basin					
		Northern		*Central*			*Southern*
Scenario	*Crop*	*Reut*	*Upper Nistru*	*Lower Nistru*	*Reut*	*Upper Nistru*	*Lower Nistru*
Low impact	Maize	−23	−23	−21	−21	−21	−17
	Wheat	−6	−5	−29	−29	−29	−32
	Alfalfa	−20	−20	−24	−24	−24	−23
	Grapes	−13	−13	−12	−12	−12	−10
	Apples	−7	−7	−6	−6	−6	−5
	Vegetables	−14	−14	−17	−18	−17	−16
Medium impact	Maize	−13	−8	−6	−12	−7	−9
	Wheat	−19	−14	−30	−34	−31	−34
	Alfalfa	−12	−7	−13	−17	−13	−19
	Grapes	−9	−4	−3	−8	−3	−5
	Apples	−6	0	0	−5	0	−3
	Vegetables	−10	−5	−9	−14	−9	−13
High impact	Maize	−18	3	0	−21	−1	−10
	Wheat	−39	−23	−42	−54	−42	−43
	Alfalfa	−21	0	−13	−31	−13	−22
	Grapes	−16	2	0	−18	−1	−6
	Apples	−18	3	1	−20	0	−4
	Vegetables	−21	0	−9	−28	−10	−16

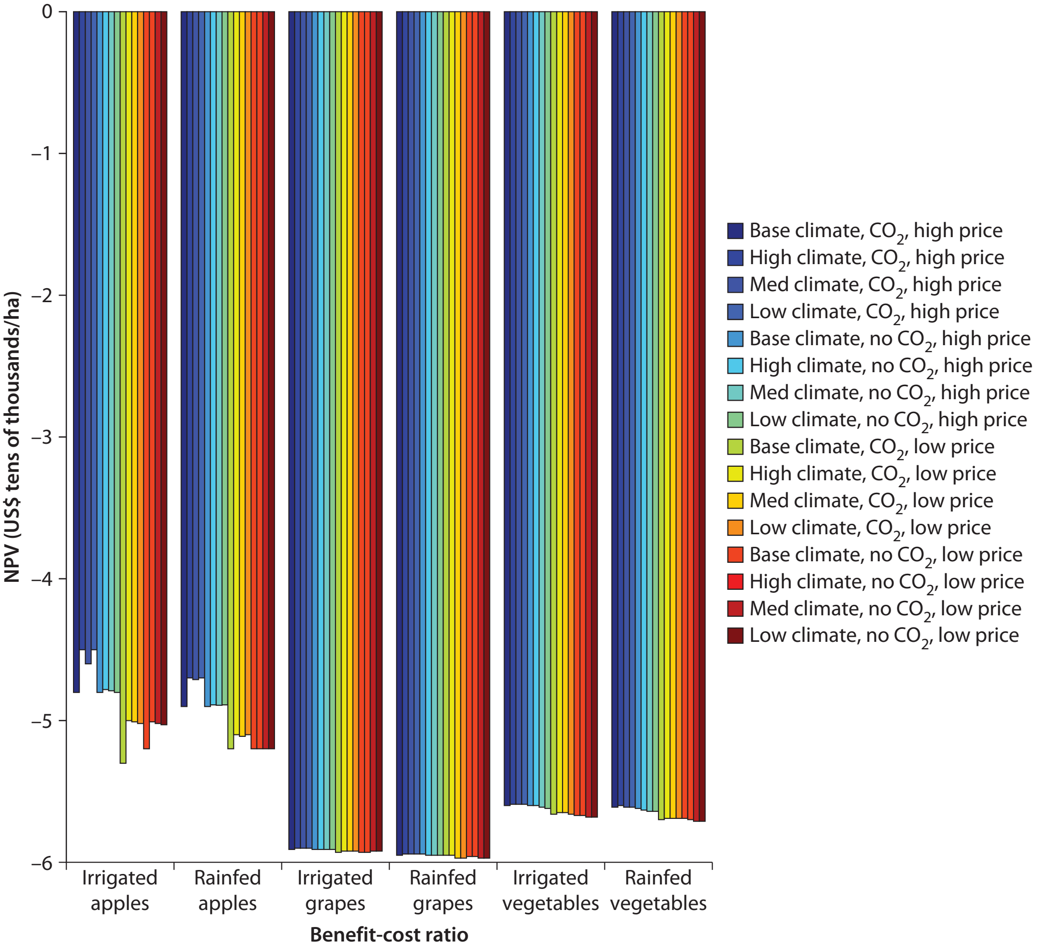
Note: Shading is darker the larger the decline in yield.

Conference held in Chisinau in May 2011 and GHG mitigation potential, were combined to arrive at an overall set of high priority measures. A wide range of adaptation measures were evaluated by quantitative and qualitative means. Some of these quantitative analyses were benefit-cost analyses as were conducted for Albania, but in other cases where information was more limited, the analyses were quantitative but reflected available information. Installation of hail nets for apple orchards and other crops was one such measure evaluated in Moldova.

Hail nets were mentioned by farmers in all three Moldova AEZs as a measure that some had already adopted in response to the threat of hail damage in the current climate. Emerging literature indicates that climate change will lead to more frequent and more severe hail storms and thunderstorms (Trapp et al. 2007). In addition, researchers identified a recent study for Northeastern Spain that estimates the costs of hail nets for apple crops relative to crop insurance (Iglesias and Alegre 2006), which found slight benefits of hail nets relative to crop insurance. However, that study implicitly assumed that crop insurance is already a wise investment and did not evaluate the baseline risk of hail damage each year relative to insurance premiums.

Hail nets have both capital costs and yield implications—they reduce sunlight infiltration, which reduces yield, but they also moderate extreme low and high temperatures to some extent, which can increase yield. The study team used capital costs from Iglesias and Alegre (2006) and their estimates of net yield decrements from their field studies of gala apples and applied them to multiple crops. The results for the central AEZ are shown in figure 3.5 in net present value terms. Note that, for all crops and scenarios, net present values are negative, reflecting costs in excess of benefits. The benefit cost ratios for this measure never exceed 0.25 for any combination in any AEZ. The Iglesias and Alegre (2006) analysis provides some justification for the measure that some Moldovan farmers believe would be beneficial for their orchards,

Figure 3.5 Net Present Value Analysis for Hail Nets to Protect Selected Crops in Central AEZ



Note: The 16 scenarios for which benefit-cost (B-C) ratios are shown include combinations of four climate scenarios (base, low, medium, and high impact); two carbon fertilization assumptions (with and without); and two price projections (low and high).

but our analysis reflecting local conditions suggests this measure would not be cost-effective.

The result of the benefit-cost and other evaluations yielded a ranking of measures. The results of this ranking are presented for national policy measures and for each AEZ in tabular form in table 3.8 with the example of data for the central AEZ. Summary results for adaptation measures at both the national and AEZ level are summarized in table 3.9. The results for Moldova suggest a somewhat greater emphasis on crop insurance and market support for farmers to financially strengthen the sector in order to provide greater resilience to climate change.

FYR Macedonia Climate Risk

FYR Macedonia's climate is highly influenced by the great variance in elevation across this small landlocked country. At one extreme, the nearly Mediterranean

Table 3.8 Moldova: Evaluation of Central AEZ Adaptation Options

		Ranking criterion				
Adaptation measure	*Crop and livestock focus*	*Net economic benefit: ranking in quantitative analysis*	*Net economic benefit: expert assessment*	*Potential to aid farmers with or without climate change*	*Ranking by local farmers*	*Potential to yield mitigation benefits*
Improve crop varieties	Wheat, maize	1	High	Medium to High	Not mentioned	Low
Improve irrigation water efficiency	Maize	2	High	High	3	Low
Rehabilitate irrigation capacity	Apples, maize, vegetables	3	High	High	1	Low
Build new small-scale water storage	All crops, but especially in the Reut basin	Moderate for the Reut basin	Medium—difficult to site, requires integrated water management	High	3	Unknown
Research and improve livestock management, nutrition, and health	Beef cattle, chickens	Unknown	Medium	Low to Medium	Not mentioned	Low
Optimize agronomic practices	Wheat, maize	7	Not mentioned	High	5	Medium

Table 3.9 Moldova: Key Climate Hazards, Impacts, and Adaptation Measures at National and AEZ Levels

		Adaptation measure to address impact									
		National level				*AEZ level*					
Climate change impact	*Cause of impact (exposure)*	*Improve farmer access to technologies and information*	*Improve dissemination of hydrometeorological information to farmers*	*Investigate options for crop insurance*	*Encourage private sector involvement in adaptation*	*Improve crop varieties*	*Improve farm-level irrigation efficiency*	*Improve irrigation infrastructure and increase basin-wide irrigation efficiency*	*Build new small-scale water storage*	*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)	✓		✓	✓	✓		✓	✓	✓	✓

table continues next page

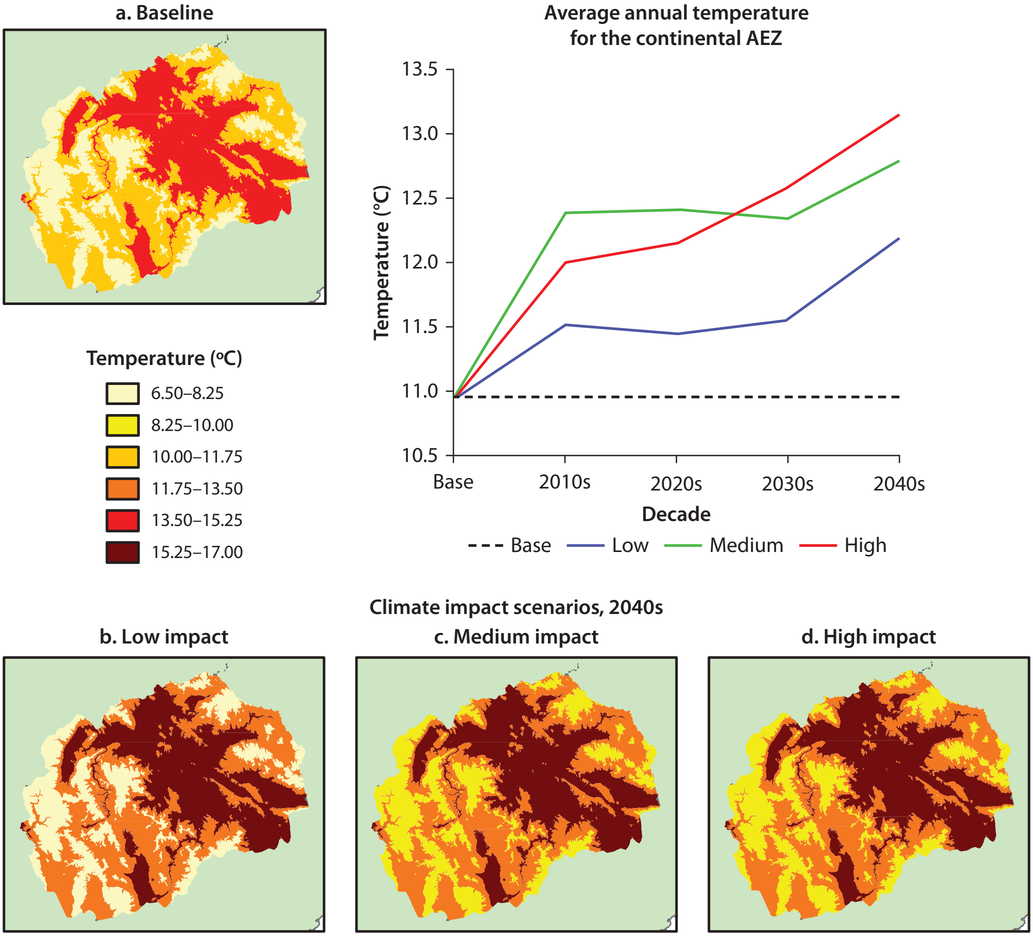
Table 3.9 Moldova: Key Climate Hazards, Impacts, and Adaptation Measures at National and AEZ Levels *(continued)*

		Adaptation measure to address impact									
		National level				*AEZ level*					
Climate change impact	*Cause of impact (exposure)*	*Improve farmer access to technologies and information*	*Improve dissemination of hydrometeorological information to farmers*	*Investigate options for crop insurance*	*Encourage private sector involvement in adaptation*	*Improve crop varieties*	*Improve farm-level irrigation efficiency*	*Improve irrigation infrastructure and increase basin-wide irrigation efficiency*	*Build new small-scale water storage*	*Optimize agronomic practices: fertilizer application and soil moisture conservation*	*Improve livestock management, nutrition, and health*
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	✓	✓	✓		✓		✓	✓		

climate characterizes areas in the south, particularly in the river valleys, reflects generally long and dry summers and mild but rainy winters. At the other extreme, the alpine region in the high mountains is characterized by long, snowy winters and short, cool summers. Most of the country, however, experiences a continental climate, with warm, dry summers and cold but wet winters.

Analysis of recent climate data and information gathered from farmer workshops supports a trend of increasing temperature in FYR Macedonia, and farmers also report a growing trend in extreme heat events. Analysis indicates these trends will accelerate in FYR Macedonia in the near future, as indicated in map 3.5. Although the degree of warming that will occur in FYR Macedonia is uncertain, the overall warming trend is evident in all three AEZs, with average warming over

Map 3.5 FYR Macedonia: Effect of Climate Change on Temperature through 2050 for the Three Climate Impact Scenarios



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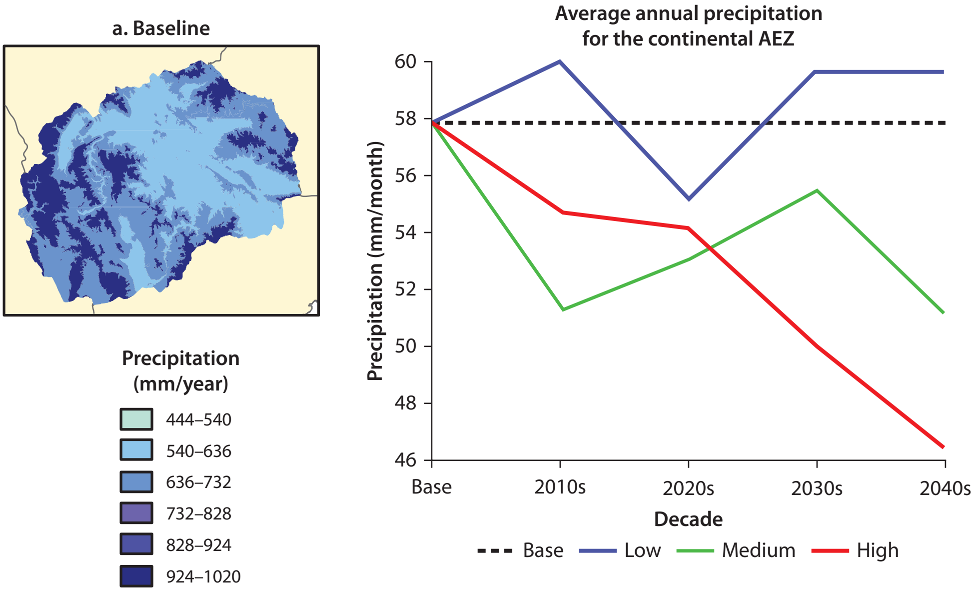
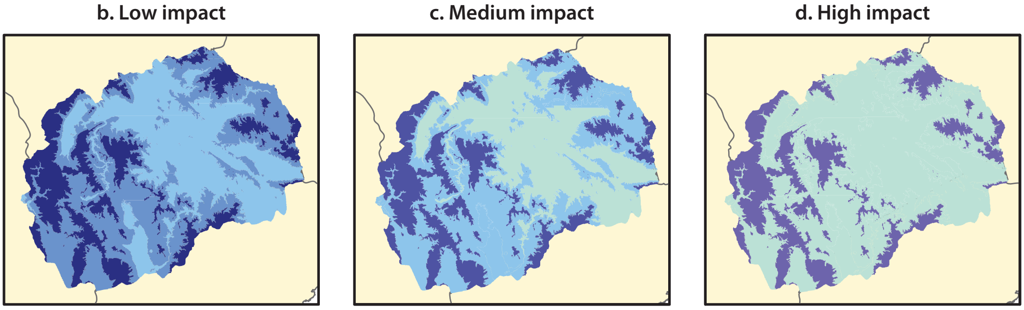
the next 50 years of about 1.8°C, much greater than the increase of less than 0.2°C observed over the last 50 years.

As with Albania and Moldova, precipitation changes are much more uncertain than are temperature changes, as indicated in map 3.6. The medium impact forecast indicates a decline in average annual precipitation for FYR Macedonia of about 96 mm by 2050, mostly in the alpine AEZ. There is a large range of outcomes across the low and high impact alternative scenarios, however, swinging from a modest increase under the low impact scenario to an almost 20 percent decline under the high impact scenario. Uncertainty at the regional level is even higher; annual precipitation declines in the alpine AEZ could be as large as 16mm per month. While the medium and high impact scenarios show significant

Map 3.6 FYR Macedonia: Effect of Climate Change on Precipitation through 2050 for the Three Climate Impact Scenarios



Climate impact scenarios, 2040s



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declines in precipitation across AEZs, the low impact scenario reveals only moderate increases.

Once again, the seasonal distribution of temperature and precipitation holds greater importance than the national averages for this country. Temperature increases are higher and precipitation declines greater in July and August relative to current conditions; the summer temperature increase can be as much as 4–5°C in the continental AEZ of FYR Macedonia, more than twice as great as the annual average temperature change. In addition, forecast precipitation declines are greatest in the key growing period, May–September, when current precipitation is already lowest.

Impact Assessment Results for FYR Macedonia

FYR Macedonian farmers already employ some adaptation measures—increases in use of groundwater-based irrigation and changes in crop variety, for example—but the forecast seasonal changes in climate have clear implications for crop production. If no additional adaptation measures are taken beyond simply changing planting dates in response to temperature change, and reduced water availability is taken into account, climate change is likely to have significant impacts on agriculture in FYR Macedonia. For river basins where large irrigation water shortfalls are expected, yield reductions of 20–60 percent are projected for nearly all crops by 2050, whereas for areas where shortages of irrigation water are not expected, production of cereals in particular could benefit from the warmer climate. First, estimations of impacts on crops if no additional adaptation measures are implemented, but before reductions in irrigation water availability are taken into account, are summarized in table 3.10. The results show that wheat and maize yields, key cereal crops in FYR Macedonia's agricultural sector, will both increase and decrease, depending on elevation, across AEZs and climate scenarios, due to rising temperatures and water stress.

Yields of rainfed apples, grapes, maize, and vegetables are expected to decrease in the Mediterranean and continental AEZs, while yields of all irrigated crops except grapes are expected to increase or remain constant. However, yields at this stage of the analysis assume that there is no constraint on irrigation water; once the effects of projected water shortages are factored in, the results can dramatically change. Wheat yields, both irrigated and rainfed, are expected to increase across all AEZs, with expected yields doubling in the alpine AEZ. Rainfed alfalfa and pasture yields are expected to decrease in the Mediterranean AEZ and increase in the continental and alpine AEZs. All crops grown in the alpine AEZ are expected to see increasing yields by the 2040s under the medium impact climate scenario.

The water resource management implications of the forecast change in climate could be severe, particularly under the high impact scenario, because climate change both increases irrigation water demand overall and, in the high impact scenario, decreases overall water supply. For example, irrigation water demand during the summer months increases up to 50 percent in 2050 relative to historical conditions, while overall water availability declines over the same period by an average of 30–40 percent by the 2040s, especially in the hot summer

Table 3.10 FYR Macedonia: 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*	*Mediterranean*	*Continental*	*Alpine*
Irrigated	Alfalfa	5	28	71
	Apples	9	13	15
	Grapes	−14	−23	N/A
	Maize	0	27	N/A
	Vegetables	11	10	N/A
	Wheat	16	30	100
Rainfed	Alfalfa	−10	2	42
	Apples	−45	−41	6
	Grapes	−25	−32	N/A
	Maize	−62	−54	N/A
	Pasture	−3	8	22
	Vegetables	−11	−9	N/A
	Wheat	6	25	99

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. N/A = the crop is not grown in the AEZ specified.

months, as illustrated in figure 3.6. The net effect of rising demands and falling supply is a significant reduction in water available for irrigation. This shortfall is further exacerbated by overall economic growth that will increase the water demand from the municipal and industrial sectors.

Climate change and economic growth could result in water shortages within the next decade, and severe water shortages in the 2040s under all climate scenarios, but especially under the high impact scenario. Water shortfalls for the irrigation sector are outlined in table 3.11—the estimates presented are the amounts and percentage shortfalls relative to total water amounts demanded in the basin for irrigation purposes. No irrigation water shortages are forecast for the Radika, Vardar, or Bregalnica basins, but by the 2040s, severe irrigation water shortages are forecast to occur in the Crna basin. Shortages are also forecast for the Pcinja basin, though not as severe as in the Crna basin.

As with Moldova, this analysis reveals three climate change stressors that will have negative impacts on crop yields throughout FYR Macedonia:

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

Once again, these effects are worst during the summer growing season. The net effect of these three factors on irrigated agriculture is illustrated in table 3.12,

Figure 3.6 FYR Macedonia: Estimated Effect of Climate Change on Mean Monthly Runoff, 2040–50

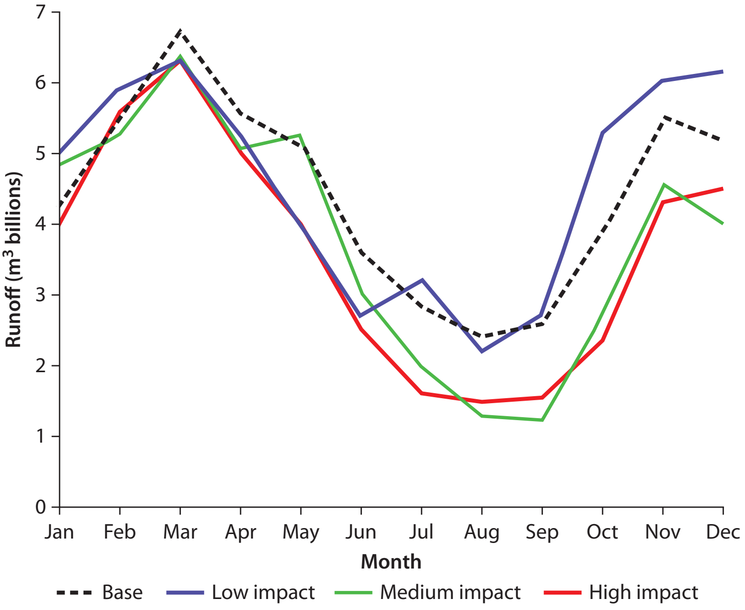


Table 3.11 FYR Macedonia: Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario

	Climate scenario (shortfall in irrigation water relative to total irrigation water demand)					
	Low impact 2040s		*Medium impact 2040s*		*High impact 2040s*	
Basin	*m^3, thousands*	*% shortfall*	*m^3, thousands*	*% shortfall*	*m^3, thousands*	*% shortfall*
Radika	0	0	0	0	0	0
Pcinja	2.3	3.7	5.5	7.9	8.0	10.9
Vardar	0	0	0	0	0	0
Bregalnica	0	0	0	0	0	0
Crna	99.3	36.3	178	55.7	193	57.5
Total	102	13.2	184	20.9	201	22.2

which shows that all crops in the Crna basin in all three AEZs in the medium and high impact scenarios are negatively affected by climate change once irrigation water supply limitations are taken into account. An exception is the alpine AEZ for the low impact scenario. Also, yield effects in the Pcinja basin, where water shortages are estimated to be more moderate, are very similar to those for the unconstrained irrigation water case.

Table 3.12 FYR Macedonia: Effect of Climate Change on Irrigated Crop Yield 2040–50 Period under Three Impact Scenarios, Including Effects of Reduced Water Availability

% change

		AEZ/river basin					
		Mediterranean		*Continental*		*Alpine*	
Scenario	*Crop*	*Pcinja*	*Crna*	*Pcinja*	*Crna*	*Pcinja*	*Crna*
Low impact	Alfalfa	29	−15	37	−10	62	7
	Apples	6	−30	11	−27	11	37
	Grapes	−6	−33	9	−22	N/A	N/A
	Maize	−12	−42	15	−24	N/A	N/A
	Vegetables	15	−24	4	−31	N/A	N/A
	Wheat	9	−28	21	−20	70	12
Medium impact	Alfalfa	−3	−53	18	−43	58	−24
	Apples	0	−52	4	−50	6	−49
	Grapes	−20	−55	−28	−59	N/A	N/A
	Maize	−8	−56	17	−44	N/A	N/A
	Vegetables	2	−51	1	−51	N/A	N/A
	Wheat	7	−49	20	−42	84	−11
High impact	Alfalfa	−8	−56	8	−49	71	−18
	Apples	−3	−54	−1	−53	2	−9
	Grapes	−41	−67	−45	−69	N/A	N/A
	Maize	−21	−62	11	−47	N/A	N/A
	Vegetables	−8	−56	−8	−56	N/A	N/A
	Wheat	2	−51	14	−46	90	−10

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. N/A = the crop is not grown in that AEZ, according to local stakeholders.

Adaptation Options Menu for FYR Macedonia

The study team's review of adaptation options, including economic analyses, expert review, and farmer consultation, coupled with the results of the National Dissemination and Consensus Building Conference held in Skopje in May 2011, suggests a number of high priority measures, presented in table 3.13, with the Mediterranean AEZ as an example. Analyses were also conducted at the national level and for each of the other two AEZs.

The study team also conducted sensitivity tests of several measures as part of the economic analysis, as shown in figure 3.7. They examined the sensitivity of the B-C ratio and the present value of benefits across 12 (3×2×2) scenarios, 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

Table 3.13 FYR Macedonia: Evaluation of Adaptation Options for Mediterranean AEZ

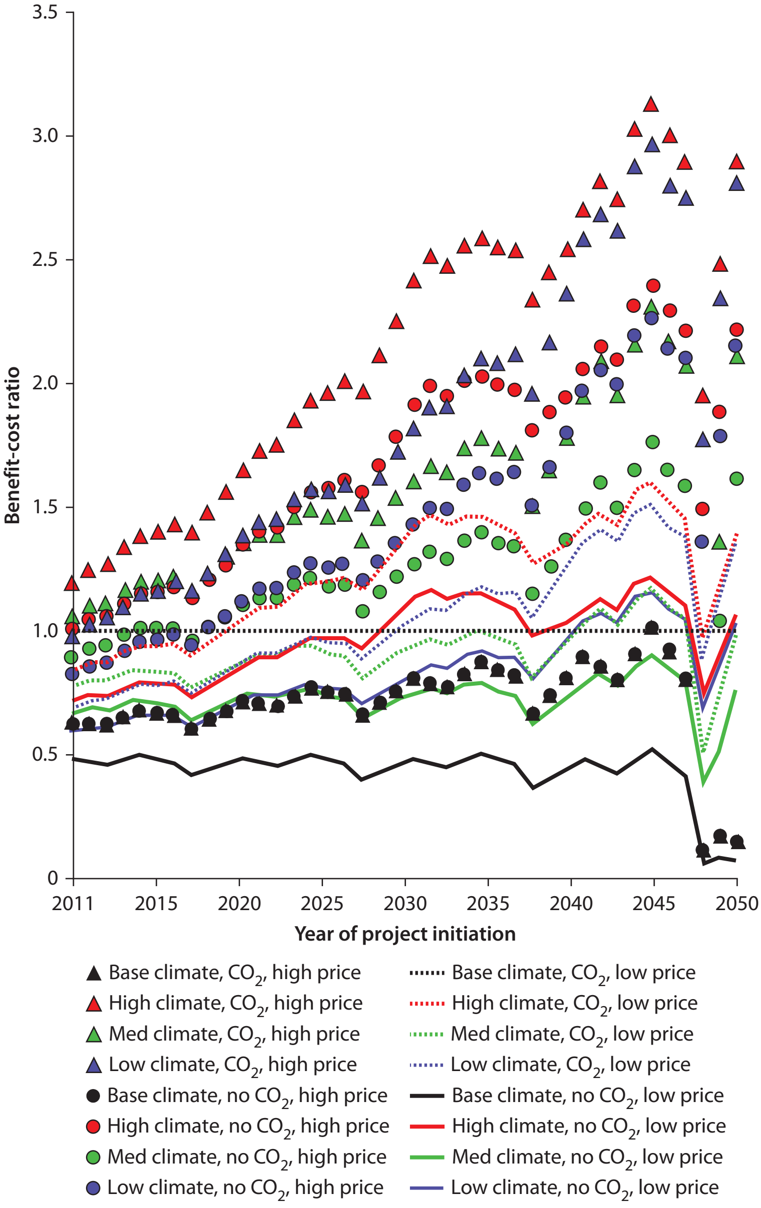
		Ranking criterion				
Adaptation measure	*Crop and livestock focus*	*Net economic benefit: ranking in quantitative analysis*	*Net economic benefit: expert assessment*	*Potential to aid farmers with or without climate change*	*Ranking by local farmers*	*Potential for GHG mitigation benefits*
Improve crop varieties	Wheat, maize	1	High	Medium	2	Low
Improve irrigation water availability, rehabilitate irrigation capacity	Apples, grapes, maize, vegetables, wheat	2	Medium	High	1	Low
Improve drainage infrastructure	All crops	3 for rehabilitation, lower for new	Medium	High	1	Unknown
Research and improve livestock nutrition, management, and health	Beef cattle, chickens	Unknown	Medium	Low to medium	Not mentioned	Low
Optimize agronomic practices	Maize, wheat	6	Not mentioned	High	Not mentioned	Medium

forecast, which holds prices constant, and high forecast, which incorporates a gradual upward trend in prices based on published projections). The results in general are most sensitive to the price projections, which yield relatively larger changes in revenues in later years of our period of analysis, near 2050, although some of those differences are tempered by application of a 5 percent discount rate.

The effect on the study's results of using a 10 percent rather than 5 percent discount and cost-of-capital rate is also considered. Overall, use of a higher discount rate decreases the NPV benefits of the adaptation options by about a factor of two (across crops, AEZs, and climate/crop price scenarios). The effect on NPVs varies and depends on relative magnitudes of the costs and benefits. In a very few instances, the use of a 10 percent discount rate causes NPVs of the adaptation options to change from positive to negative, occurring under adaptation scenarios where the NPVs are already near-zero. Because options are not recommended unless B-C ratios are much greater than 1 or NPVs are much greater than 0, the higher discount rate does not alter the study team's recommendations or 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 figure 3.7.[2] The figure shows that when rehabilitating irrigation in areas that are currently rainfed wheat in the Continental AEZ is taken into account, only some of the climate scenarios and start dates yield B-C ratios greater than 1. As climate

Figure 3.7 Sensitivity Analyses of B-C Ratio: Rehabilitated Irrigation for Currently Rainfed Wheat in the Continental AEZ



change unfolds over time, however, B-C ratios tend to increase. It may then be concluded that, rather than ruling out implementation of this measure, it would be prudent to wait to implement this option and to monitor how climate scenarios and crop prices unfold over time.

Results for adaptation measures at both the national and AEZ level are summarized in table 3.14.

Table 3.14 FYR Macedonia: Key Climate Hazards, Impacts, and Adaptation Measures at 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 dissemination of hydro-meteorological information to farmer*	*Provide incentives to consolidate farm holdings*	*Encourage private sector involvement in adaptation*	*Improve crop varieties*	*Improve drainage infrastructure*	*Improve irrigation water availability, rehabilitate irrigation systems*	*Build new small-scale water storage*	*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, increased crop water demands	✓	✓	✓		✓	✓	✓	✓	✓	
Crop quality reductions	Change in growing season	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Increased pests and diseases	✓	✓	✓	✓	✓	✓				

table continues next page

Table 3.14 FYR Macedonia: Key Climate Hazards, Impacts, and Adaptation Measures at National and AEZ Levels *(continued)*

		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 dissemination of hydro-meteorological information to farmer*	*Provide incentives to consolidate farm holdings*	*Encourage private sector involvement in adaptation*	*Improve crop varieties*	*Improve drainage infrastructure*	*Improve irrigation water availability, rehabilitate irrigation systems*	*Build new small-scale water storage*	*Optimize agronomic practices: fertilizer application and soil moisture conservation*	*Improve livestock management, nutrition, and health*
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	✓	✓	✓		✓		✓	✓		
	More frequent and severe floods	✓	✓	✓			✓				
	More frequent and severe high summer temperature periods	✓	✓	✓		✓		✓	✓		

Uzbekistan Climate Risk

Uzbekistan's climate is continental, with long, hot summers and mild winters, with modest rainfall not more than 100–200 mm per year in most places. The west in particular is flat with desert and near-desert conditions, while the easternmost Fergana Valley region is somewhat higher in elevation and surrounded by mountains. While the Fergana Valley and some other portions of the east have fertile soils, they also experience limited rainfall. As a result, most water for agriculture comes from surface water sources fed by transboundary flows derived from rainfall and glaciers in the surrounding mountains.

Analysis of recent climate data and information gathered from farmer workshops both support an increasing trend in temperature in Uzbekistan; as with the other countries, farmers have also observed an increasing trend in extreme heat events. The study team's analysis indicates this trend will accelerate in Uzbekistan in the near future, as shown in map 3.7. Although the degree of warming that will occur is uncertain, the overall warming trend is evident across all AEZs, with average warming over the next 50 years of about 2–3°C, much higher than the increase of about 1.5°C observed over the last 50 years.

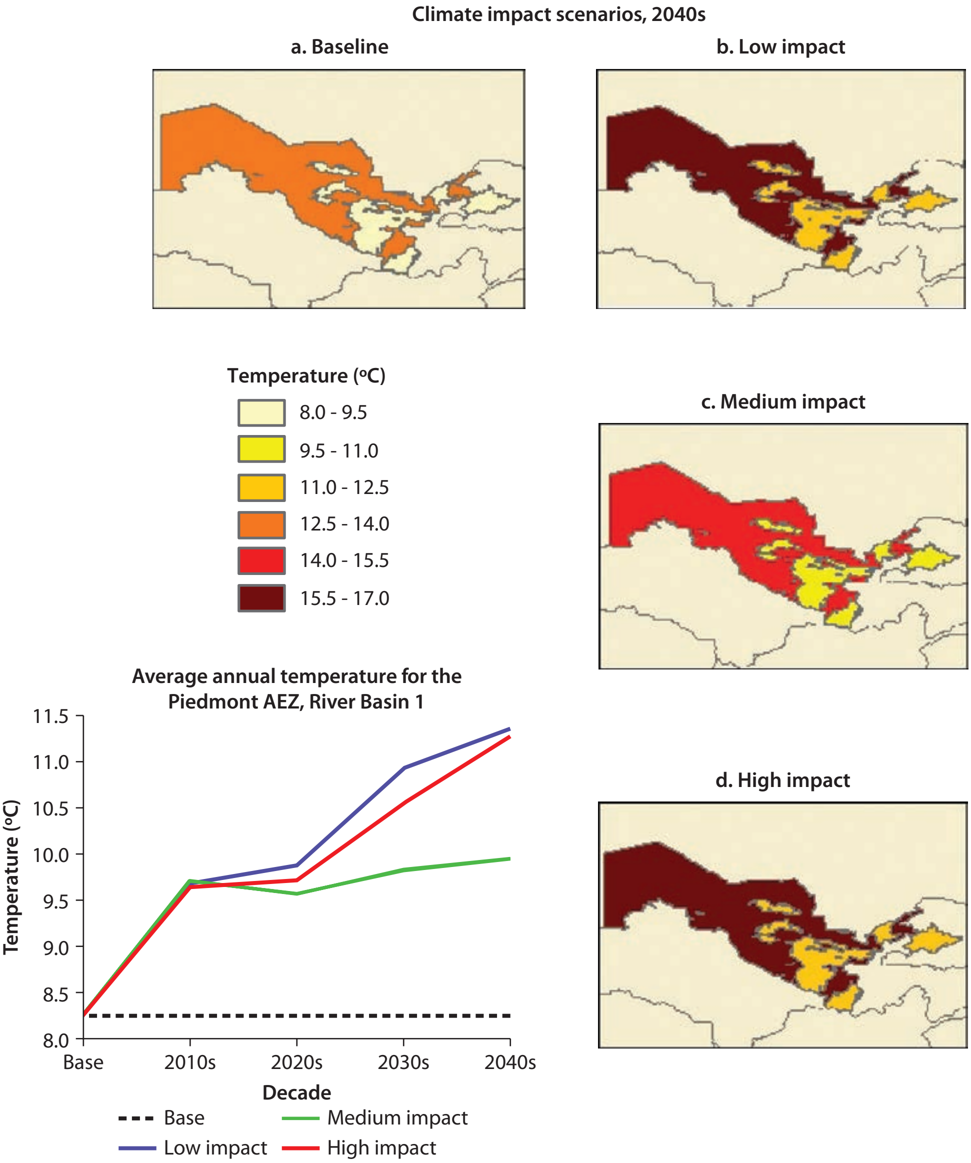
Precipitation changes are much more uncertain than temperature changes, as shown in map 3.8. The medium impact scenario forecast indicates an increase in average annual precipitation for Uzbekistan of 40-50 mm by 2050 in the desert, steppe, and Piedmont zones, and a decrease of 10 mm in the highland zone. However, there is a significant variance in outcomes across the low and high impact scenarios. For example, in the Piedmont AEZ, annual rainfall could decrease by 50 mm by 2050, or it could increase by 150 mm. In Uzbekistan, as with the other study countries, changes in the seasonal pattern of rainfall have important implications for agriculture.

The forecast temperature increases are higher and precipitation declines greater in July and August relative to current conditions; the June–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–August period in the desert and steppe AEZs, when precipitation is already lowest, even though the annual results suggest an overall increase in precipitation. One implication of this change in seasonal rainfall is that irrigation water use efficiency and water storage capacity will become increasingly important.

Impact Assessment Results for Uzbekistan

If no adaptation measures are taken beyond simply changing planting dates in response to temperature change, and reduced water availability is taken into account, climate change is likely to have significant impacts on agriculture in Uzbekistan, with potential yield reductions of 20–50 percent by 2050 for nearly all crops. First, estimations of impacts on crops if no adaptation is implemented, but before reductions in irrigation water availability are taken into account, are

Map 3.7 Uzbekistan: Effect of Climate Change on Average Annual Temperature through 2050 for the Three Climate Impact Scenarios



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summarized in table 3.15. These projections show that yields of the key commodity crops that currently dominate Uzbekistan's agricultural sector, namely 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 stresses. Wheat yields might increase in the eastern portion of the Piedmont AEZ.

Map 3.8 Uzbekistan: Effect of Climate Change on Average Annual Precipitation through 2050 for the Three Climate Impact Scenarios

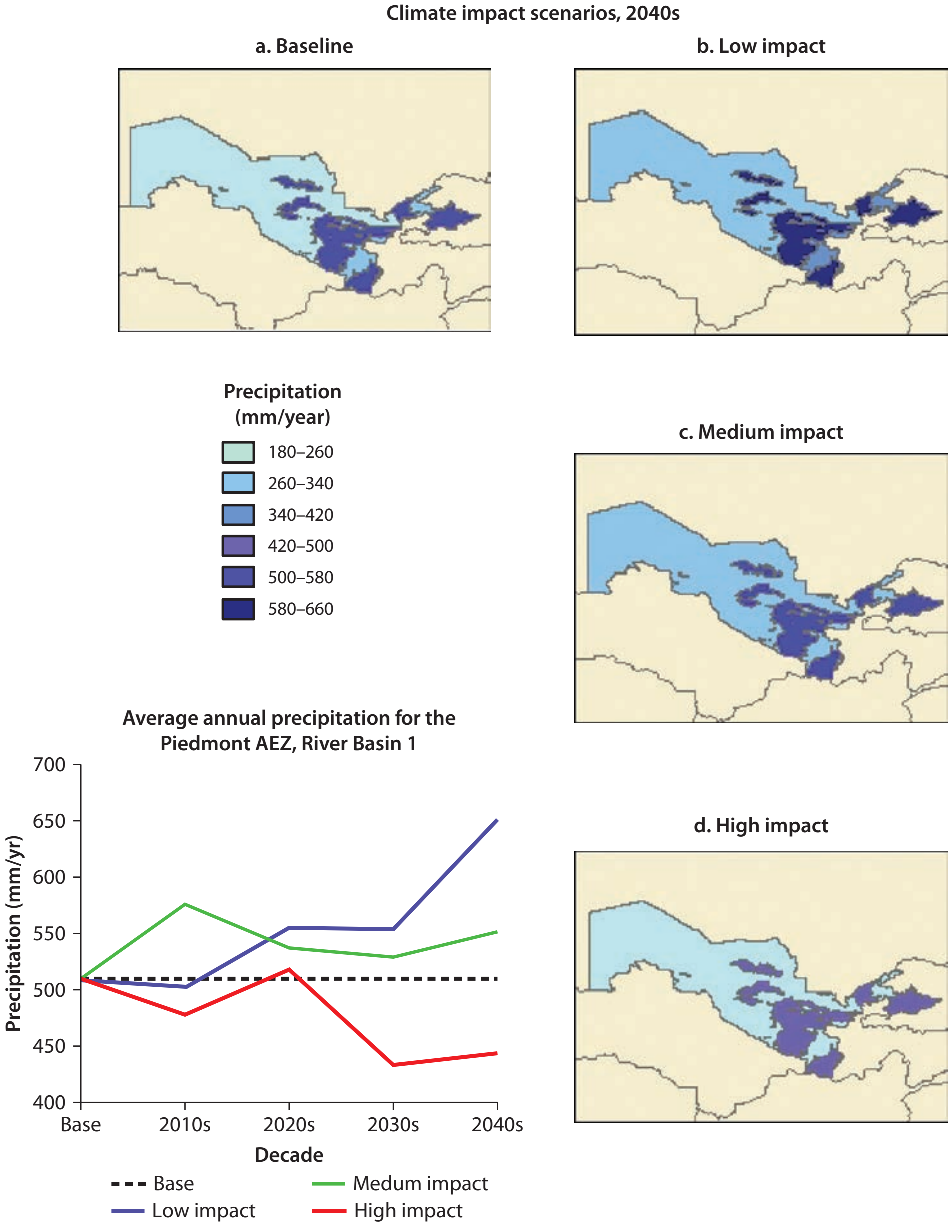

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Table 3.15 Uzbekistan: Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium Impact Scenario, No Irrigation Water Constraints

% change

Irrigated/Rainfed	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont zone East*	*Piedmont zone SW*
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.

Yields of apples, potatoes, and tomatoes are forecast to decline about 1–9 percent under the medium impact scenario. Grassland and alfalfa yields, on the other hand, are expected to show increased yields throughout Uzbekistan, grassland yields jumping by up to 43 percent, and alfalfa yields increasing 1–22 percent.

Some adaptation issues might arise with regard to the relative viability of winter wheat, which may see lower yields in some areas where a winter freeze is less frequent, and also for spring wheat, which has a wider growing area but requires more irrigation and provides a different quality yield. Aggregate yield data for Uzbekistan are only available as an average for the two types; however, in general, yields for winter wheat are about 10 percent higher 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 3.16 provides a summary of yield results for the high-impact scenario if no adaptation measures are taken, and illustrates that wheat (especially spring wheat) and apples in particular could suffer large yield losses in all three AEZs.

As with the three other countries, water resource management implications of the high impact scenario are similarly severe because climate change both increases irrigation water demand and, in the high impact scenario, decreases overall water supply. For example, by 2040 forecast irrigation water demand during the summer months increases 25 percent in 2050 relative to historical conditions, while overall water availability declines by an average 30–40 percent, as illustrated in figure 3.8. This is especially critical in Uzbekistan because nearly all crops are irrigated and irrigation demand accounts for more than 90 percent of water withdrawals. The net effect of rising demands and falling supply is a

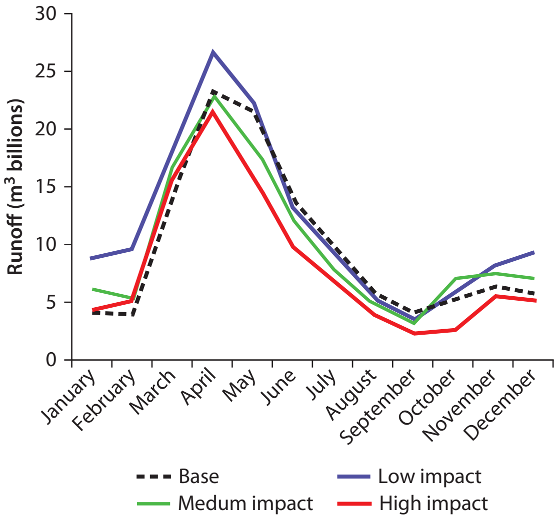
Table 3.16 Uzbekistan: Effect of Climate Change on Crop Yield 2040–2050 Relative to Current Yields under High Impact Scenario

% change

Irrigated/Rainfed	*Crop*	*Desert and Steppe East*	*Desert and Steppe West*	*Highlands South*	*Piedmont zone East*	*Piedmont zone 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 3.8 Uzbekistan: Estimated Climate Change Effect on Mean Monthly Runoff in Uzbekistan, 2040s



significant reduction in water available for irrigation, with severe water shortages in 20–40 percent of 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. Water shortfalls for the irrigation sector are outlined in table 3.17—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.

The same three climate change stressors that affect Moldova and FYR Macedonia also combine to yield an overall negative impact on irrigated crop yields throughout Uzbekistan:

- The direct effect of temperature and precipitation changes on crops;
- The increased irrigation demand required to maintain even reduced yields; and
- 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 3.18, which shows that nearly all crops in all AEZs and basins and across all scenarios are negatively affected by climate change.

The direct effects of climate change on livestock also could be severe, but the methods available for quantitatively assessing these impacts are relatively untested. A robust literature establishes that temperature 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

Table 3.17 Uzbekistan: 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

Table 3.18 Uzbekistan: 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 zone East*	*Piedmont zone SW*
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.

climate change on livestock feed supplies, including grasslands, would be positive, and provides a potential counter-balance to the negative direct heat stress effects.

Adaptation Options Menu for Uzbekistan

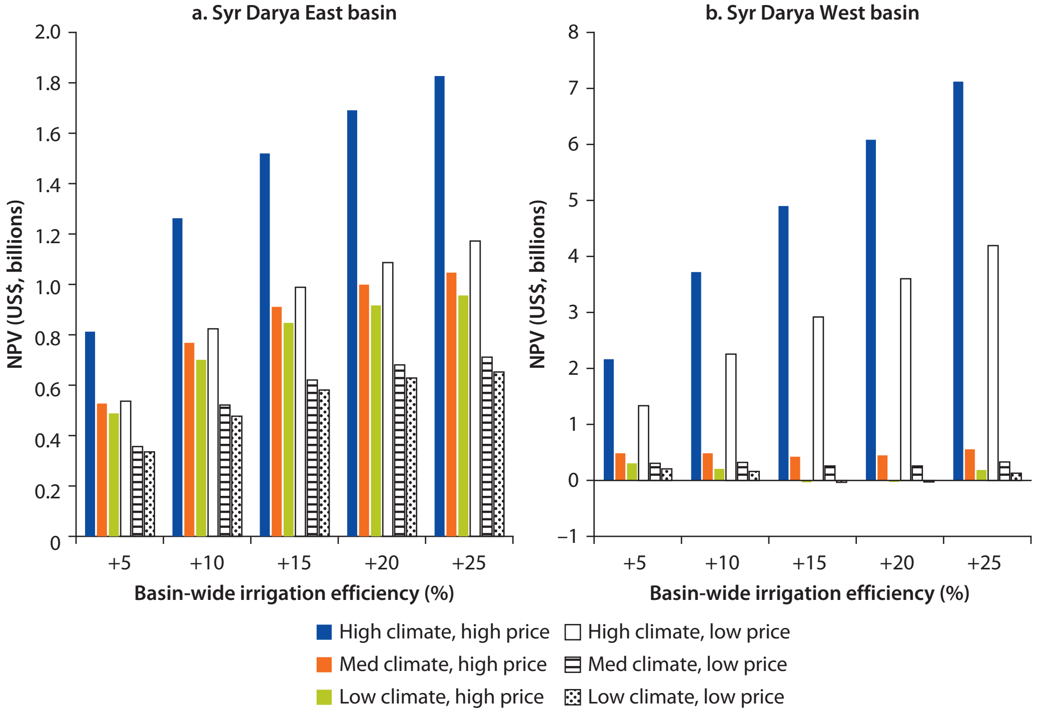
Researchers combined elements of this study—adaptive capacity, identification of the risk of climate change to agricultural yields, the results of the farmer and expert evaluation of adaptation options, and the team's quantitative benefit-cost evaluation of adaptation measures, coupled with the results of the National Dissemination and Consensus Building Conference held in Tashkent in March 2011—to arrive at an overall set of high-priority measures recommended for Uzbekistan. As in the other three countries, the economic evaluation assessed a wide range of measures, including some for which cost data were sparse and where only the present value of potential benefits could be assessed. Because irrigation water use is such an important issue for Uzbekistan, the study team made an extra effort to examine adaptation options in the water sector. An example is shown in figure 3.9, for improvements in water-use efficiency in two parts of the Syr Darya basin.

In the three basins where water shortages are likely— Amu Darya, Syr Darya East, and Syr Darya West—researchers examined improving irrigation efficiency from a baseline of 33.4 percent in 5 percent increments, up to a high of 58.4 percent. The benefit is increased net revenue (not simply gross revenue in this case) from additional irrigation water to bring back to cultivation additional acreage—for example, under the high impact 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 3.9 for two of the three basins examined (the Amu Darya results are similar to those for the Syr Darya East basin).

The Syr Darya West basin generally benefits less from these improvements, partly because the Syr Darya West is downstream of Syr Darya East which means more irrigated hectares in the east basin result in less water actually delivered to the west basin. But overall, the total cumulative benefits of improving efficiency in the 2015–50 period are large—the scale on the vertical axis is billions of U.S. dollars.

There are no cost estimates for these water efficiency improvements, though they might be accomplished by repairing leaking conveyance channels or

Figure 3.9 Net Present Value of Economic Benefits of Improving Basinwide Irrigation Efficiency



performing other leak repair. In a World Bank project in Armenia, analysts found that 150 million m^3 of water was saved by reducing leakage and mechanical losses in main, secondary, and tertiary canals (World Bank 2007, 2009). In total, 261 km were repaired at a cost of $21.9 million, or US$83,900 per kilometer. Additionally, 2,145 water measurement devices were installed for a total cost of $3.54 million or $1,650 per unit. Overall, the anticipated cost of this Armenian project was $0.17 per cubic meter of water, but ultimately the cost was evaluated to be $0.22 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. The Armenian experience nonetheless suggests that the potential benefits of improving water use efficiency in the Syr Darya East basin, while deserving of further study, are likely to exceed costs.

The results of the economic assessment indicate that some of the measures have higher estimated net economic benefits than others. The five measures with the highest net benefits in Uzbekistan's Desert-Steppe AEZ are shown in table 3.19.

Finally, the results of economic and other prioritizing analyses were arrayed for national policy measures and for each AEZ in a tabular form—an example for the Desert-Steppe AEZ adaptation measures is shown in table 3.20. Summary results for adaptation measures at both the national and AEZ level are summarized in table 3.21.

Table 3.19 Uzbekistan: Five Adaptation Measures with High Net Benefits for the Desert-Steppe AEZ

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

Table 3.20 Uzbekistan: Adaptation Options 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*	*Potential for GHG mitigation benefits*
Improve crop varieties	Tomatoes, potatoes, apples, wheat, cotton	1st	High	High	3rd	Low
Improve irrigation efficiency	On-farm systems for tomatoes, potatoes	2nd	High	High	1st	Low
Improve irrigation infrastructure	Tomatoes, potatoes, wheat	3rd	Medium, dependent on water availability	High	1st	Low
Improve drainage infrastructure	Potatoes, tomatoes	4th	Not mentioned	High	2nd	Unknown
Optimize agronomic inputs: fertilizer and soil moisture conservation	Potatoes, tomatoes	5th	Medium	High	Not mentioned	Medium

Common Adaptation Options across Countries

Each country in this assessment can consider a comprehensive list of adaption options, with some shown to be more suitable for each individual country than others. For example, improving crop insurance was seen to be a priority in Moldova, less so in Uzbekistan, and not at all in the other two countries. Small-capacity water storage was also regarded as an important option in FYR Macedonia and Moldova, but not in Albania and Uzbekistan. Improving drainage capacity was viewed as critical to address water-logging issues in Albania. However, several adaptation options were seen as important priorities across all four countries, despite their varying climates, geography, and crop focus.

In particular, there was a universal need to improve farmers' access to agricultural technologies and information, to broaden and improve crop varieties to take advantage of the expected changes in climate and water availability, and to significantly improve water infrastructure and systems in all countries. Other priorities emphasized in at least three out of the four countries include better dissemination of hydrometeorological information to farmers (Albania, Moldova, and FYR Macedonia), encouragement of greater private sector participation in adaptation processes (Albania, FYR Macedonia, and Uzbekistan), and improved drainage (Albania, FYR Macedonia, and Uzbekistan). Additional options regarded as particular priorities in at least half the surveyed countries included national policy

Table 3.21 Uzbekistan: Summary of Key Climate Hazards, Impacts, and 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	✓	✓		✓		✓			

measures to consolidate farm holdings (Albania and FYR Macedonia) and optimized agronomic practices (Albania and Moldova), such as more widespread fertilizer use and better soil moisture conservation.

Overall, farmers appear to recognize the impacts of climate change at the farm level, and some are already trying to respond to it. However, they need better information about new technologies and more dependable forecasts for rainfall and weather patterns so that they can better shape their responses. All four countries found they need to give greater consideration to the mix of crops likely to take advantage of the forecast changes in weather and water availability. And in all four, irrigation infrastructure and drainage were also seen as vital regardless of individual forecast climate change impacts.

On the other hand, increasing irrigation capacity is not a panacea. The results of the modeling of future water supply and demand under climate change demonstrate that in many instances, there will be shortfalls in irrigation water availability, and this will have a major impact on agricultural production.

Figures 3.10 and 3.11 provide results and adaptation options for all four countries in aggregate, similar to table 4.4 in the next chapter, but without the explicit links between impacts and adaptation measures included in the individual country

Figure 3.10 Summary of National-Level Adaptation Measures Identified as Priorities in the Study Countries

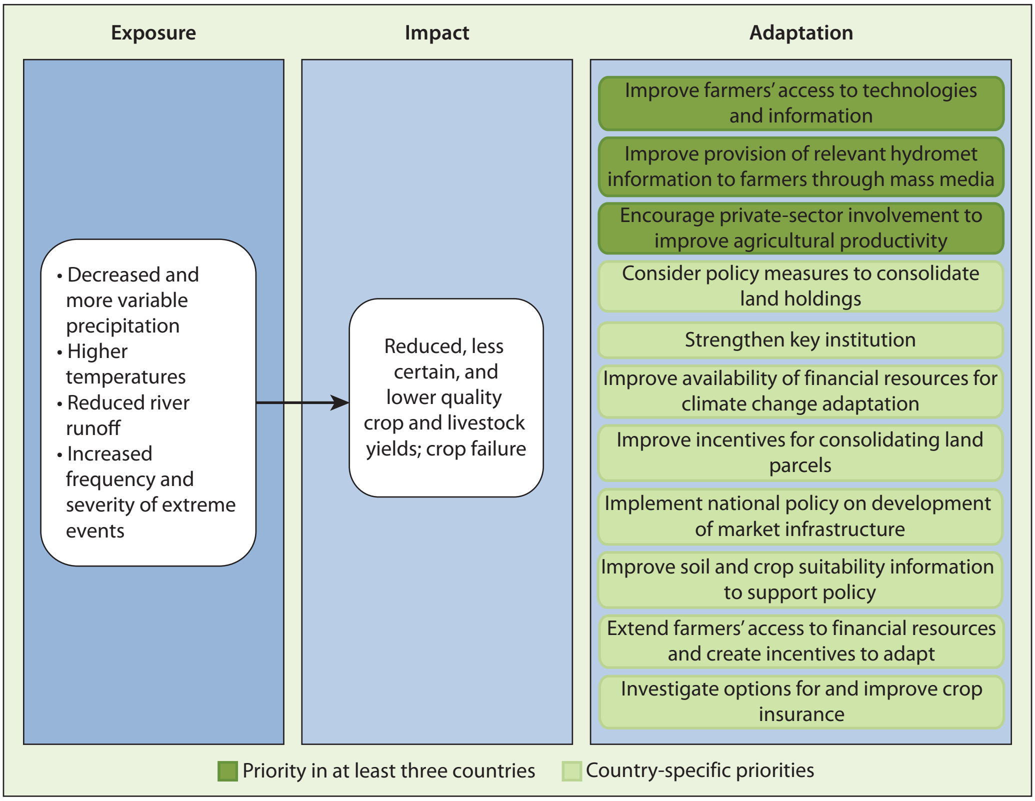
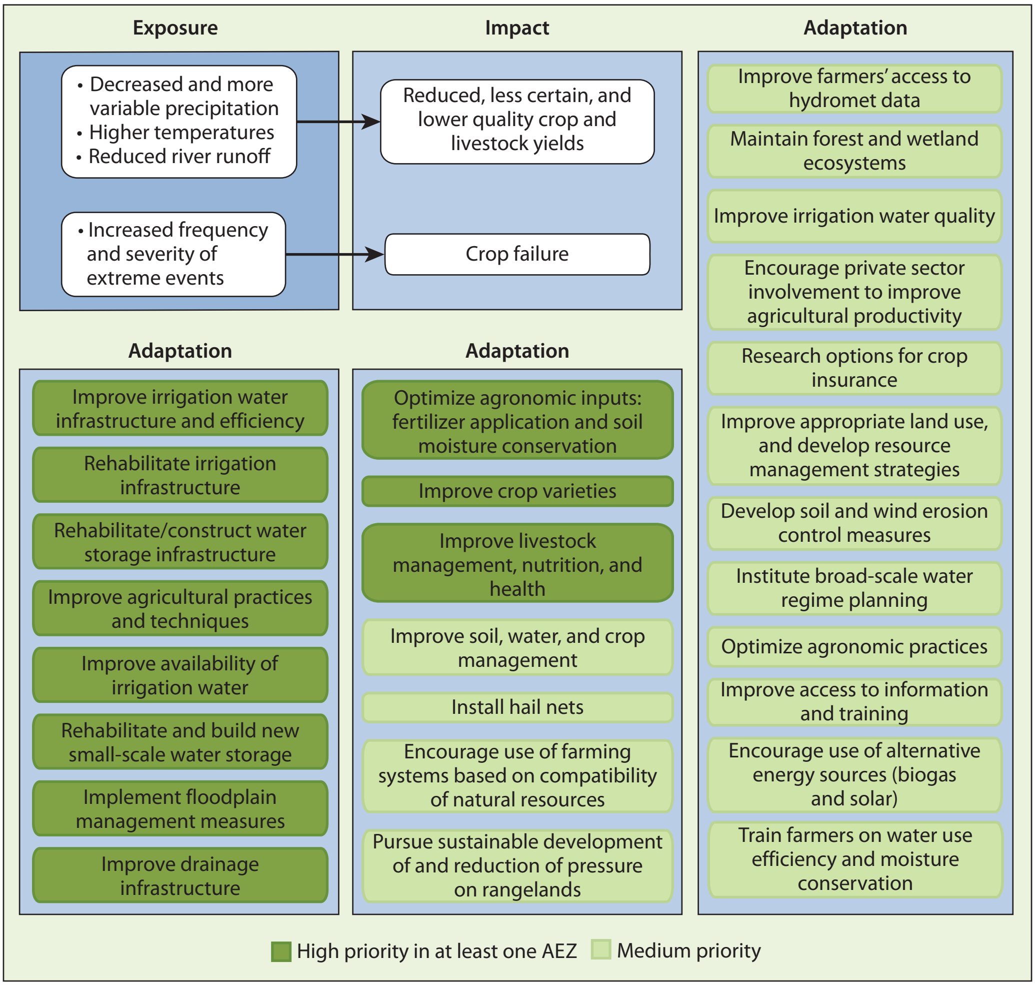


Figure 3.11 Summary of AEZ-Level Adaptation Measures Identified as Priorities in the Study Countries



reports (World Bank 2012a, 2012b, 2012c, 2012d). As noted, many of the high-priority options, highlighted in darker green, represent robust responses in most if not all of the countries studied, but there are also many measures that respond to specific country needs, such as reforming crop insurance, or installing hail nets.

Notes

1. See chapter 2, box 2.1, for definitions of the low, medium, and high climate change impact scenarios.
2. Benefit-cost ratios over time, however, are influenced by an inability to estimate benefits after 2050—in many cases, this may underestimate benefits of options that have a continued useful life after 2050 and may have higher benefits as climate changes accelerate after 2050.

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CHAPTER 4

Key Findings and Cross-Country Insights

The analysis of the four selected Europe and Central Asia countries (ECA) reveals that climate change is already under way and that the adaptation measures now in use—largely piecemeal efforts at the farm level—will be insufficient to prevent impacts on agricultural yields over the next four decades. In addition, while these countries do have the expertise to assess risks and identify responses, as reflected by development of adaptation analyses in National Communications to the United Nations Framework Convention on Climate Change they do not have the advanced expertise to conduct integrated analyses across the domains of agronomy, water resource management, and economics. Furthermore, the predominantly small-scale nature of farming and the stresses on existing infrastructure are hampering implementation of more effective adaptation efforts.

This chapter summarizes the study's key findings for each country and compares the results across the countries. The results show a clear pattern of temperature change and rainfall variation that—unless mitigated by a concerted effort to adapt—could both hasten the already declining importance of agriculture in each of these economies and exacerbate rural poverty. However, this outcome need not be the case. By considering the climate change forecasts across agro-ecological zones (AEZs) and by defining, prioritizing, and adopting a menu of adaptation options, each country can ameliorate some of the impacts and take advantage of the opportunities that are likely to arise with the shift in climate patterns.

Categories of Findings

The results of the analysis of the four selected ECA countries fall into four general categories:

1. The exposure of agricultural systems to forecast climatic changes, particularly changes in temperature and precipitation, at timescales that are relevant for agricultural production;
2. The varying adaptive capacities of agricultural systems, given the national socio-economic, technical, and institutional context;

3. The vulnerabilities of and impacts on agricultural activity, reflecting no or very little adaptation; and
4. The possible "menu" of suitable adaptation measures and rankings for each country and AEZ.

This study also provides a summary of the implications of adaptation options for reducing agricultural emissions of greenhouse gases (GHGs).

Exposure Analysis Shows Temperatures Rising, Differing Rainfall Changes by Country

First, the study analyzed the exposure of each country by selected AEZs to climate change stressors according the forecast changes in temperature and precipitation for each of the three climate impact scenarios. The results of this analysis are shown here for the medium impact scenario (outlined on map 4.1). Similar analysis for each country was made of the results for the high and low impact scenarios, but these are not covered here.

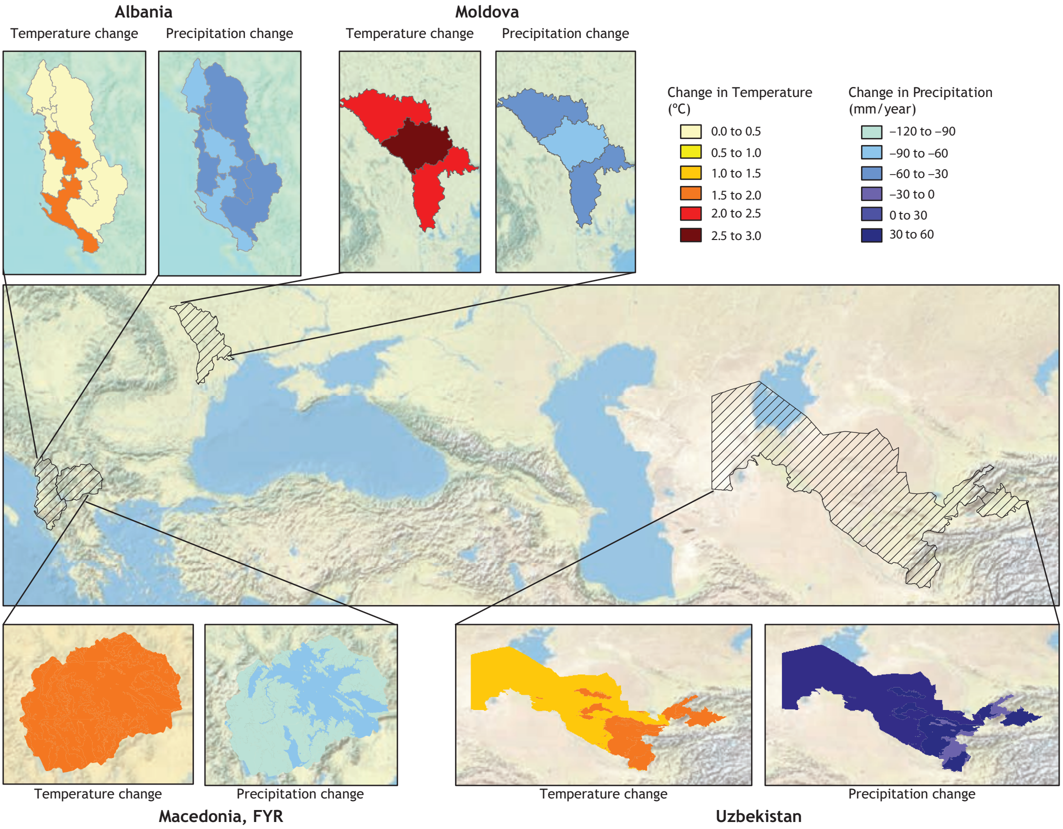
Trends across all three scenarios are similar, with generally warmer temperatures and less rainfall in the high impact scenario, and more modest increases in temperature and more rainfall in the low impact scenario, as would be expected. The map shows that exposure varies among the four countries, particularly with regard to forecast precipitation patterns. In all four countries, temperature is forecast to increase, with comparable increases of about 1.5–2.0°C by 2050 throughout each country. The exceptions are Moldova, where the forecast

Box 4.1 Framework for Analysis

The study framework incorporates three major components: exposure assessment, impact assessment, and adaptation assessment, which are described as follows:

- *Exposure* is typically defined as the climate change and variation to which a system is exposed, and vulnerability is a function of exposure, sensitivity to climate, and adaptive capacity. Impacts can be defined as potential impacts, which are those that occur without considering adaptation, and residual impacts, which would occur after adaptation.
- This study's *estimates of impacts* incorporate two aspects of autonomous adaptation by farmers: the adjustment of planting dates in response to climate change and the optimizing of deficit irrigation or scaling-back of the cropped area to maximize yield in response to deficits in irrigation water. The study found that both of those measures are already being adopted by farmers in the four countries. In general, however, the impact assessment findings are for potential impacts, which lays a baseline for the adaptation assessment.
- Finally, the *adaptation assessment* is focused on reviewing the costs and benefits, either qualitatively or quantitatively, of planned adaptation measures.

Map 4.1 Forecast Changes in Temperature and Precipitation for the Medium-Impact Scenario by 2040s for All Countries



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increase is more significant—up to 3.0°C—and parts of coastal Albania, where the forecast increase is somewhat smaller.

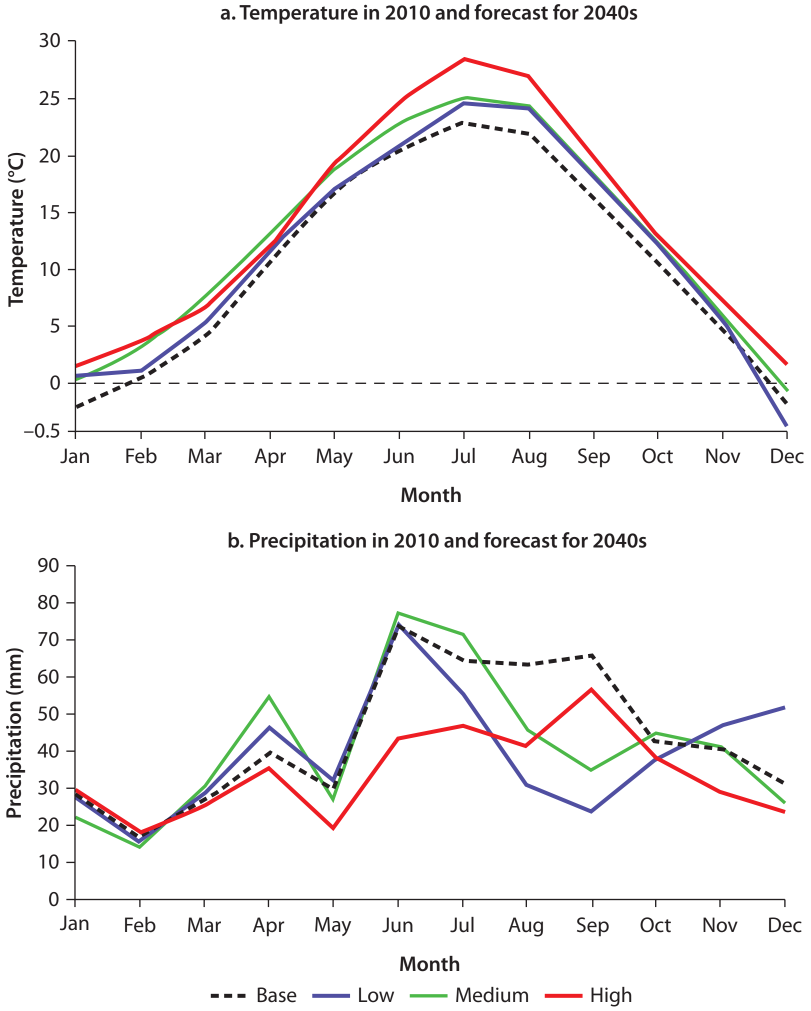
Precipitation patterns, on the other hand, are different in each country. In the Eastern European countries (Albania, the former Yugoslav Republic of Macedonia, and Moldova) precipitation is expected to decrease, while in Uzbekistan, precipitation is forecast to increase, although only by a small amount, and not by enough to substantially alter water availability in this largely arid country. The increases do present some opportunities, however, particularly for rainfed pasture activities and, therefore, for extensive livestock production.

The national average climate changes for the medium scenario are not unusual for smaller countries. Overall, the higher temperatures associated with climate change are expected to accelerate the water cycle, leading to more evaporation and therefore more precipitation. The spatial and temporal patterns of precipitation, however, will also be altered, and for some countries, such as those in Eastern Europe, changes in circulation can lead to lower annual precipitation, while for others these changes imply increased precipitation.

Changes in Seasonal Rainfall Will Matter Most to Farmers

The national averages, however, are less important for agricultural production than are the seasonal distributions of temperature and precipitation. Temperature increases are likely to be higher and precipitation declines greater in July and August relative to current conditions. For example, in one AEZ in Moldova, the summer temperature could increase as much as 7°C. In addition, forecast precipitation declines in all countries are greatest in June–September.[1] Figure 4.1 presents the monthly baseline and forecast temperatures and precipitation for the Southern AEZ of Moldova, as an example of the pattern that was found for

Figure 4.1 Monthly Temperature and Precipitation Patterns for the Southern AEZ of Moldova



Note: AEZ = agro-ecological zone.

virtually all AEZs. These seasonal changes in climate have clear implications for crop production if no adaptation measures are adopted beyond those farmers already employ, which are risks to crop production that result from heat and water stress.

Vulnerability and Adaptive Capacity Varies across Countries

Agriculture in countries with large numbers of rural smallholders can be particularly vulnerable to climate change, primarily owing to their low adaptive capacity. Adaptive capacity is defined as the ability of a system to adjust to climate change and variability, to reduce the potential damage, or to take advantage of opportunities. This study reviewed adaptive capacity in both the public and private sectors.

At the national level, a high level of adaptive capacity in the agricultural sector is characterized by a high level of functionality in the provision of hydrometeorological and relevant geospatial 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, and in-country research oriented toward innovations in agronomic practices in response to forecast climate changes. In addition, in well-adapted countries, systems exist to ensure that collective water infrastructure is well maintained and meets the needs of the farming community; systems also exist to resolve conflicts between farmers and other users over water provision. In all of the countries addressed in this study, some of these conditions exist, but most are currently inadequate. A few of the most common issues in adaptive capacity are as follows:

- *Agricultural research capabilities and technological assistance must be adapted toward climate change.* Agricultural research capabilities have a long history in most former Soviet republics, but are not oriented toward climate change adaptation and may have a poor connection to farmer extension. There is a wide range of technical expertise within the agricultural research communities of these countries. Even the most capable agricultural research institutes, however, have not yet focused on climate change as a major risk to agricultural production and are not as effectively coordinated with the extension service as they could be. In all four countries, research could be better focused on leveraging advances in seed varieties and farming practices shown to be effective in other countries and on coordinating with the extension service to demonstrate these results locally, particularly for small-scale farmers.

- *Many farms are small and have limited resources for adaption investments.* Due to constraints, such as lack of access to finance, land fragmentation, and limited know-how, most small farmers cannot invest in mechanization, irrigation, or new plantations, which limits adaptive capacity.

- *Agricultural markets are limited*. Many farms are subsistence farms that produce for family consumption and have no market links. Many farmers operate as individuals, and organized activities in marketing and other areas are limited. A few entrepreneurial landowners are developing businesses (vegetable and fruit production, especially grapes) aimed at wholesale markets, and the number of such producers is gradually increasing. During consultations, however, farmers stressed that they have a shortage of information on agricultural market conditions that hamper their decision-making.

- *Crop insurance is available to farmers, but has been poorly subscribed*. The agricultural insurance markets in these countries are very small, and thin markets mean the premiums remain very high. The World Bank has recommended insurance as an option to mitigate extreme weather events such as hail, frost, and droughts, including piloting new approaches such as weather index insurance.

- *Current agricultural subsidies are inefficiently implemented*. Most agricultural subsidies in the countries studied are recurrent subsidies, rather than investment subsidies, and are provided to large rather than small farmers. These subsidies are generally inefficient and fail in helping the poor (World Bank 2006a). There has been no evidence that subsidizing agricultural inputs, such as fertilizer, irrigation operations, energy, and pesticides, promotes long-term growth (World Bank 2006b). In addition, large farms are generally less efficient than individual family farms, so directing subsidies at large-scale corporate farms is a less cost-effective use of limited subsidy budgets (World Bank 2006b). Recently, the World Bank suggested to Moldova and the former Yugoslav Republic of Macedonia in particular that they redirect agricultural subsidies towards more efficient investment grants and reduce agricultural subsidies, especially for larger farms, as part of budget consolidation and tighter fiscal policy. Furthermore, subsidies could be redirected to promote adaptive practices rather than crop inputs. By changing the types and recipients, subsidies may be able to promote agricultural growth.

- *Agricultural policy is well-planned, but resources for implementing these plans are limited*. In each country, the Ministry of Agriculture oversees the agricultural sector, and is administratively linked to the major research institutions. However, strategies and legislation do not always translate into programs and projects, largely reflecting state budget constraints on investments. Implementation is also hindered by the limited professional capacities of some relevant institutions. As such, continuous international donor support is a crucial element for ensuring and expanding implementation.

Farmers More Open to Adaptation, but Limited by Capacity Constraints

The first set of farmer consultations, conducted at the AEZ level, provided opportunities for farmers to share their concerns about the risks climate change poses for their crops and livestock and to identify where their current adaptive capacity was low. Greater education has given farmers in the region more flexibility in their responses to climate events, but a number of factors are hampering their efforts to boost their adaptive capacity. Key among these constraints are poorly maintained irrigation and drainage systems, limited financial resources, and inadequate access to technology and relevant know-how. The farmers could also benefit significantly from improved weather forecasts and seasonal climate projections, as well as more comprehensive extension services.

Based on conversations with stakeholders and in-country experts, it emerged that farmers are already undertaking several adaptive responses to climate change and severe climate events, which include the following:

- Expanding water supply for irrigation by building small-scale storage reservoirs, harvesting rainwater, and making greater use of local water sources for irrigation;
- Applying protective measures such as moving vegetable production to greenhouses using mulch or other plant protection on soil, installing plant protection belts, or using hail nets; and
- Changing agronomic practices, such as planting patterns, rotating crops and inter-cropping, using chemical soil augmentation, and using drought-resistant varieties.

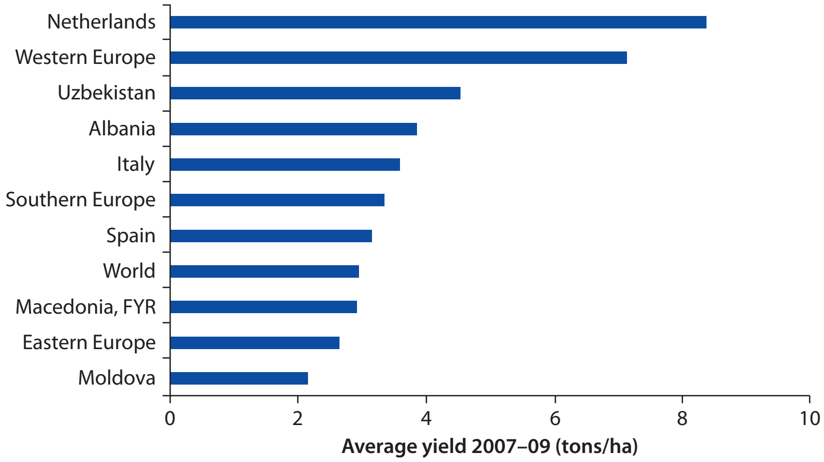
Farmers also noted at least three key impediments to effective adaptation to the effects of climate change:

- The lack of timely meteorological information to respond effectively, especially to extreme events such as droughts;
- A lack of access to alternative crop varieties (particularly seeds) and know-how to make best use of these varieties, through enhanced extension; and
- Poor or limited access to irrigation water and to technologies to make the most efficient use of irrigation infrastructure.

The adaptive capacity of farmers in these countries is clearly stressed by changes in overall climate and by more frequent extreme weather events. The combination of heat waves, droughts, and intense storms is especially disruptive. On-farm adaptation responses have been numerous and partially successful, but farmers believe that larger investments in infrastructure are needed. This includes improved water storage, drainage, and irrigation systems.

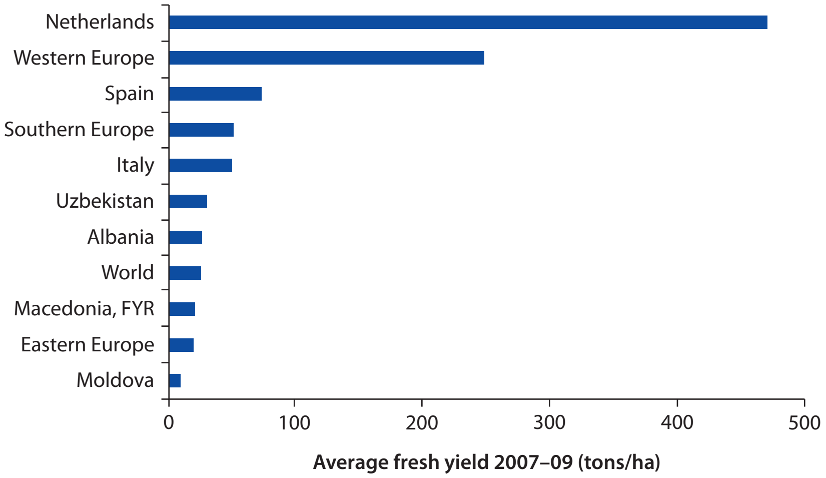
In addition, a key finding was that, for most crops in most countries, farms are poorly adapted even to the current climate. This "adaptation deficit" is clear when comparing yields for key crops across countries and regions. Figures 4.2 and 4.3 compare crop yields for wheat and tomatoes for the four countries studied, as well as for several top-producing countries in Western and Eastern Europe. Uzbekistan and Albania have somewhat higher average yields than FYR Macedonia and Moldova for these crops, but all four countries lag behind

Figure 4.2 Wheat Yield in Selected Countries, Average 2007–09



Source: FAOSTAT.
Note: ha = hectare.

Figure 4.3 Tomato Fresh Yield in Selected Countries, Average 2007–09



Source: FAOSTAT.
Note: ha = hectare.

Western European yields, and Moldova in particular lags behind the Eastern European region average. One of the key findings of this work is that many of the high-priority measures for adapting to future climate can also provide benefits in the short term in closing the adaptation deficit relative to current climate, resulting in "win-win" solutions.

Impact Assessment Predicts Lower Crop Yields and Some Opportunities

The impact assessment results—which consider exposure, vulnerability, and local soil quality, crop yield, and water availability—varied substantially by country, particularly in the water sector. These results, which incorporate only very limited adaptation to climate change, essentially provide a baseline to permit the measurement of the costs and benefits of planned adaptation measures.[2]

Table 4.1 shows results of the crop yield impact assessment for a representative AEZ in each of the four countries for selected crops. The yield changes presented here incorporate only the direct effects of climate on crop yields through changes in temperature and precipitation, showing the net effect over the full 40-year period 2010–50. In Albania and Uzbekistan, the modeling focused on capturing the most prevalent management practice with respect to water use—rainfed or irrigated—with a few crops evaluated for both irrigated and rainfed yields. In Moldova and FYR Macedonia, the assessment evaluated all crops under both rainfed and irrigated management, regardless of prevalence.

The table shows that most crops are expected to experience declines in yield (darker shading shows higher declines). Typically, rainfed crops grown in the traditional summer season, such as maize, tomatoes/vegetables, apples, and grapes, experience the most severe impacts. Some crops, however, will benefit from the direct effect of climate change (see darkest green shading). Typically, benefits are seen for crops grown in winter (winter wheat), alfalfa or pasture, which is grown year-round; both could be expected to benefit on a net basis from a longer, warmer growing season. The latter could lead to positive indirect

Table 4.1 Estimated "No Adaptation" Crop Yield Impacts of Climate Change before Considering Potential Water Shortages

% change 2010–40s

Irrigated or rainfed	*Crop*	*Albania: Lowlands*	*FYR Macedonia: Continental*	*Moldova: Southern*	*Uzbekistan: Piedmont East*
Irrigated					
	Alfalfa	4	28	–18	22
	Maize	–4	27	–9	Not analyzed
	Wheat	Predominately rainfed	30	–34	5
	Apples	Not analyzed	13	–3	–1
	Grapes	Predominately rainfed	–23	–5	Not analyzed
	Vegetables/tomatoes[a]	–11	10	–13	–1
Rainfed					
	Pasture	–3	8	–19	43
	Alfalfa	–3	2	–12	Predominately irrigated
	Maize	Predominately irrigated	–54	–10	Predominately irrigated
	Wheat	7	25	–45	Predominately irrigated
	Apples	Not analyzed	–41	3	Predominately irrigated
	Grapes	–20	–32	–2	Predominately irrigated
	Vegetables/tomatoes[a]	Predominately irrigated	–9	–9	Predominately irrigated

Note: Units are percent change in 2040s yields relative to current yield. Results shown are for the medium impact climate scenario and assume no CO$_2$ fertilization effect. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases.

a. Tomatoes analyzed in Uzbekistan and Albania; vegetables analyzed in Moldova and FYR Macedonia.

impacts on livestock production. Positive impacts are expected for some irrigated crops, as higher temperatures can benefit many crops if sufficient water is available. However, it should be noted that the results in table 4.2 assume that irrigation water will be available to supply existing systems; the indirect effect of climate change on water availability is incorporated in a later step (see table 4.3).

Table 4.2 Annual Water Shortages and Shortages as Percentage of Total Water Demand, in Each Basin and Climate Scenario in Uzbekistan, by Sector, 2040s

	Climate scenario							
River basin	*Base*		*Low*		*Medium*		*High*	
Irrigation								
	m^3 thousands	% shortfall	m^3 thousands	% shortfall	m^3 thousands	% shortfall	m^3 thousands	% shortfall
Syr Darya East	1,087,906	19.2	615,927	11.6	940,601	17.5	3,627,991	51.6
Syr Darya West	0	0.0	122,023	1.9	325,942	4.7	2,817,031	34.4
Amu Darya	424,655	1.8	2,174,069	8.7	4,807,848	17.8	8,405,243	28.9
Aral Sea East	0	0.0	0	0.0	0	0.0	0	0.0
Aral Sea West	0	0.0	0	0.0	0	0.0	0	0.0
Subtotal	1,512,560	4.2	2,912,019	8.0	6,074,391	15.4	14,850,265	33.5
Municipal and industrial								
Syr Darya East	321,996	10.7	30,761	1.0	155,004	5.2	588,769	19.6
Syr Darya West	0	0.0	0	0.0	0	0.0	103,579	3.2
Amu Darya	0	0.0	0	0.0	0	0.0	0	0.0
Aral Sea East	0	0.0	0	0.0	0	0.0	0	0.0
Aral Sea West	587	1.6	289	0.8	443	1.2	5,385	15.1
Subtotal	322,584	2.8	31,050	0.3	155,447	1.4	697,733	6.1
Total	1,835,144	3.9	2,943,069	6.1	6,229,838	12.3	15,547,998	27.9

Note: m^3 = cubic meter.

Table 4.3 Combined Direct and Indirect "No Adaptation" Irrigated Crop Yield Effect in Basins Where Water Shortages Are Forecast

% change 2010–40s

Crop	*FYR Macedonia: Continental, Pcinja*	*FYR Macedonia: Continental, Crna*	*Moldova: Southern, Lower Nistru*	*Uzbekistan: Piedmont, East*	*Uzbekistan: Piedmont, Southwest*
Alfalfa	18	–43	–19	1	–17
Maize	17	–44	–9	N/A	N/A
Wheat	20	–42	–34	–13	–28
Apples	4	–50	–3	–18	–25
Grapes	–28	–59	–5	N/A	N/A
Vegetables/ tomatoes[a]	1	–51	–13	–18	–24

Note: Units are percent change in 2040s yields relative to current yield. Includes only irrigated crops, for the medium climate scenario, and assuming no CO_2 fertilization effect. Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases. N/A = not analyzed.

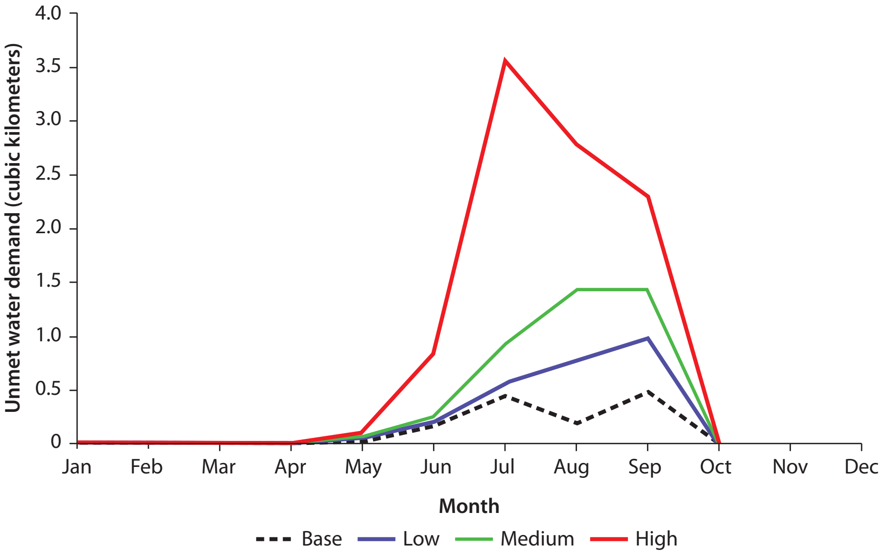
a. Tomatoes analyzed in Uzbekistan and Albania; vegetables analyzed in Moldova and FYR Macedonia.

Irrigation Water Shortfall Forecast in Three of Four Countries

The water resources analyses conducted in each country on a basin level considered three projections: (1) change in water supply (runoff) from climate change; (2) change in water demand from all non-agricultural sectors (forecast based on projections of population and economic production); and (3) change in water demand from the irrigated agriculture sector for currently irrigated lands (an output of the crop modeling). Irrigation water demand will increase for most crop/AEZ/climate scenario combinations, owing largely to increases in temperature; but for several crops, particularly in Uzbekistan, in areas where precipitation is expected to increase, irrigation demand would decrease. In three of the four countries, however, the three projections (water supply, non-agriculture water demand, and agriculture sector water demand) combine to result in a forecast shortage of irrigation water, or "unmet irrigation demand." The results indicate irrigation water shortages for at least one river basin in Uzbekistan, Moldova, and FYR Macedonia.

Table 4.2 illustrates water shortages, or unmet demand, for both irrigation and municipal and industrial uses in one study country, Uzbekistan, on an annual basis. The monthly results for irrigation in Uzbekistan across all basins are shown in figure 4.4. Irrigation is so prevalent in Uzbekistan that the results show that future shortages are quite likely in multiple basins regardless of the climate scenario, and in most basins the future shortages under climate change scenarios are much worse than in the base, no-climate change case. For example, irrigation water shortages in the Amu Darya basin are 4–20 times larger

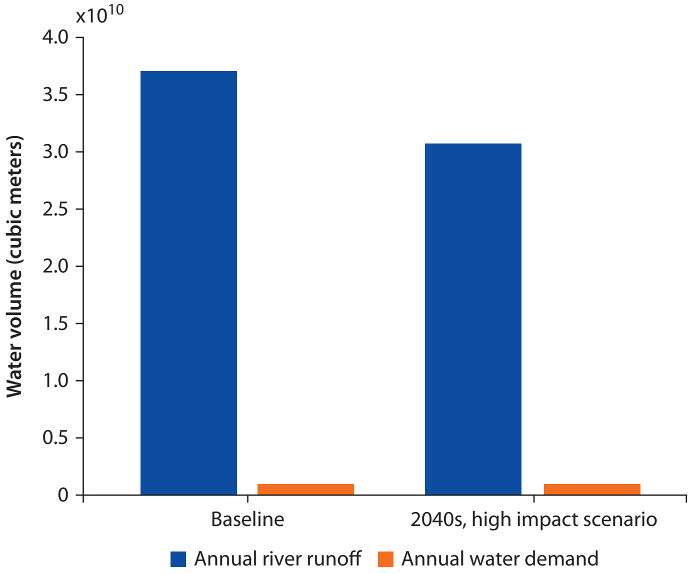
Figure 4.4 Average Monthly Irrigation Water Shortages over All Uzbekistan Basins, 2040s



with climate change than in the base case, as indicated in table 4.2. Uzbekistan is unusual, however, in that precipitation is expected to increase in both the low and medium impact scenarios. The result is that the 2050 irrigation and municipal/industrial water shortages in the Syr Darya East basin are actually higher in the base case (no climate change) than in the low or medium impact scenarios, as the table shows. The important finding is that even with higher precipitation under climate change, significant shortages of water are forecast for irrigation in Uzbekistan due to the much higher crop water demand associated with higher temperatures.

In one country, Albania, water is so abundant that water supply in all basins far exceeds projected demand. Figure 4.5 illustrates this finding at the country level, aggregated across all five basins. In the figure, water supply is represented by the blue bar for annual water runoff, while water demand is represented by the red bar. Even with climate change, Albania appears to have ample water supplies to meet projected irrigation and other non-irrigation water demand. As was made clear in the National Dissemination and Consensus Building Conference in Tirana, however, farmers' access to this water supply is often limited by inadequate and poorly maintained primary and secondary irrigation infrastructure. In addition, Albania often has the opposite problem, with frequent flooding and water-logging of low-lying agricultural land. This situation is likely to worsen under climate change, reinforcing the need for drainage infrastructure that is adapted to tomorrow's climate.

Figure 4.5 Annual Forecast Water Balance for 2040s in Albania



Water-Use Efficiency, Irrigation Infrastructure Need to Improve

Table 4.3 combines the results for the agriculture and water resources analyses for the medium climate scenario, providing the net crop yield effect for both the direct and indirect effects of climate change in selected AEZs in Uzbekistan, Moldova, and FYR Macedonia where future water shortages are forecast for the agriculture sector. The direct effect is based on temperature and precipitation stress, but the indirect effect results in those basins where researchers forecast water shortages: the resulting deficit irrigation reduces yields of currently irrigated crops because of inadequate water to meet the crop demand under climate change (see chapter 2 for more details on the approach).

While only the medium impact scenario is displayed here, the low and high impact scenarios were also analyzed. Crop yields are generally predicted to be relatively higher under the low scenario and lower under the high scenario. The effect of adjusting yields to reflect water shortages is most striking in the Crna basin in FYR Macedonia and in the Piedmont, Southwest region of Uzbekistan, where all the estimates show substantial declines in crop yields over the 2010–50 period. The largest of these deficits is a predicted 59 percent drop in the Crna basin for grapes. In a number of cases, taking into account both the direct and indirect effects, the full impact of climate change on irrigated agriculture was greater than on rainfed farming, because it starts from a higher baseline. In all three of these countries (Uzbekistan, Moldova, and FYR Macedonia) the impact assessment results, which constitute the "no adaptation" baseline, challenged both the analysts and the in-country stakeholders to focus on adaptation measures that could improve water use efficiency at both the farm and the basin levels, to improve the primary and secondary irrigation infrastructure.

Adaptation Options Must Be Identified at Agro-Ecological Zone, National Levels

The key results from the research are a menu of not only high priority adaptation options for each AEZ but also adaptation recommendations at the national level. The results for each AEZ mainly addressed infrastructure or on-farm investments, while the results at the national level focused on policy measures that can facilitate more effective climate change adaptation. These options reflect both quantitative and qualitative analyses, incorporating the results of stakeholder consultations and a consensus-building exercise conducted at each of the four National Dissemination and Consensus-Building Conferences.

Table 4.4 summarizes the menu of high-priority adaptation measures the project team and local stakeholders recommended in response to effects identified in the exposure and impact analyses. These are measures that project participants agreed are not likely to be addressed by existing adaptive capacity or policies. The measures are listed across the column headers, and the first two columns list the key impact and exposure source which the adaptation measure is designed to address. This table provides a summary for all four countries, but

Table 4.4 Key Impacts, Exposures, and Adaptation Measures at the National and AEZ Levels

		Adaptation measure to address impact													
		National level					*AEZ level*								
Climate change impact	*Cause of impact (exposure)*	*Improve farmer access to technologies and information*	*Investigate options for and improve crop insurance programs*[a]	*Improve dissemination of hydro-meteorological information to farmers*[b]	*Provide incentives to consolidate farm holdings*[c]	*Encourage private sector involvement in adaptation*	*Improve crop varieties*	*Improve irrigation efficiency*[d]	*Improve irrigation infrastructure*	*Improve drainage*[e]	*Optimize agronomic practices: fertilizer application and soil moisture conservation*	*Build new small-scale water storage*[f]	*Improve irrigation water quality*[g]	*Implement floodplain land-use management measures*[g]	*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 demand	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	
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)	✓			✓	✓	✓		✓	✓	✓	✓	✓		✓

table continues next page

Table 4.4 Key Impacts, Exposures, and Adaptation Measures at the National and AEZ Levels *(continued)*

		Adaptation measure to address impact													
		National level					*AEZ level*								
Climate change impact	*Cause of impact (exposure)*	*Improve farmer access to technologies and information*	*Investigate options for and improve crop insurance programs*[a]	*Improve dissemination of hydro-meteorological information to farmers*[b]	*Provide incentives to consolidate farm holdings*[c]	*Encourage private sector involvement in adaptation*	*Improve crop varieties*	*Improve irrigation efficiency*[d]	*Improve irrigation infrastructure*	*Improve drainage*[e]	*Optimize agronomic practices: fertilizer application and soil moisture conservation*	*Build new small-scale water storage*[f]	*Improve irrigation water quality*[g]	*Implement floodplain land-use management measures*[g]	*Improve livestock management, nutrition, and health*
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	✓	✓	✓	✓		✓		✓			✓			

Note: AEZ = agro-ecological zone. Adaptation measures apply to all countries, except as follows:
a. For Uzbekistan and Moldova
b. For Albania, FYR Macedonia, and Moldova
c. for Albania and FYR Macedonia
d. for Albania, Moldova, and Uzbekistan
e. for Albania, FYR Macedonia, and Uzbekistan
f. for FYR Macedonia and Moldova
g. for Albania

a similar table was developed in each country report to summarize results (chapter 3, tables 3.4, 3.9, 3.14, and 3.21).

Farmers Looking to New, Cost-Effective Techniques

As indicated in table 4.4, a key finding in all four countries is that enabling policies are urgently needed to provide farmers better access to interregional and global technology in a form that is accessible to them. A traditional method for agronomic knowledge dissemination has been to rely on a large corps of extension agents, but in-country participants in particular strongly favored other, more innovative approaches, such as provision of hydrometeorological data via cell phone. In addition, in countries such as Moldova, extension is provided mainly by private entities under contract to the government or supported by donor assistance. These groups are very effective in using techniques such as demonstration plots and pilot-scale infrastructure deployment to illustrate new and innovative agronomic practices and technologies, such as conservation tillage or mulching to conserve soil moisture.

In other countries, like FYR Macedonia, small local cooperatives are the main providers of on-farm equipment, such as drip irrigation equipment and new seed varieties. Therefore, the recommendations are that additional support is needed for these groups to better understand and respond to the challenges presented by climate change. However, those wishing to provide this support should keep in mind that the most cost-effective and efficient means of achieving extension goals may be through mass media, digital connectivity, and innovative private services, even to reach smallholder farmers.

Other common themes in the results, supported by both quantitative analyses and by farmers in the stakeholder consultations, were to improve access to a broader set of internationally available and locally tested crop varieties; to improve on-farm irrigation efficiency through measures such as drip and sprinkler irrigation (rather than furrow or flood methods); to rehabilitate and in some cases build new irrigation infrastructure; and to conserve soil moisture through conservation tillage, mulching, use of plastic sheeting, and even inter-cropping.

Improved Livestock Management Needed, but Crop Productivity a Higher Priority

In addition, in each of the four countries, livestock was identified as an important component of the overall productivity of the sector, particularly among smallholders. However, unlike for crops, farmers had not yet experienced any effects of climate on their livestock. The study team identified a body of literature that suggested higher temperatures over time could lead to heat stress for animals, lowering productivity. Another possible consequence, a possible increase in disease and pest activity, may also affect livestock productivity. The result of conversations between the expert team and local farmers was a recommendation to continuously research and improve livestock nutrition, management, and health to ensure that adaptive capacity was maintained, but also to place maintenance of crop productivity as a higher adaptation priority. The resulting lower priority was also consistent with the result of the impact assessment, which found that increased temperatures would most likely lead to a net increase in pasture productivity in all four countries, even if some fodder crops used at larger livestock operations (maize and alfalfa) might be negatively affected.

Targeting Agricultural CO_2, Nitrous Oxide, and Methane Emissions

The agricultural sector accounts for 8–15 percent of each of the four countries' total GHG emissions, which are generated by carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH4). As a result, adaptation measures potential could provide a "win-win-win" solution—increasing resilience to climate change, improving productivity in the immediate term, and reducing GHG emissions.

CO_2 emissions are mitigated primarily 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 (crop rotation, strip cropping, intercropping, cover cropping, and so on). Adaptive practices that slow rates of soil decomposition and reduce soil carbon losses include reduced-till and no-till farming.

Adaptive practices also could significantly reduce emissions of the potent GHGs nitrous oxide and methane. Nitrous oxide emissions are largely driven by fertilizer overuse, which increases soil nitrogen content and results in 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 most countries rightly focuses on reducing GHG 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 GHG emissions. In some countries, progress has already been made to mitigate emissions.

For example, in Uzbekistan, projects have been proposed that promote improved methane recovery and combustion for livestock and poultry. And, in Moldova, a recent case study undertaken in the steppe zone assesses the mitigating impact of new agricultural technologies that focus on enhancing carbon accumulation and storage in agriculture soils (that is, conservation tillage, crop rotation, and more efficient fertilizer application). Results show that the improved agricultural technologies successfully reduced GHG emissions and suggest that Moldova could reduce emissions by more than 0.7 million tons of CO_2 if these technologies were applied to 50 percent of arable lands (Ivanov and Manful 2009).

Role of Qualitative Tools in Prioritizing Adaptation Measures, Shaping Results

Qualitative analyses played an important role in this study in discerning priority measures for adaptation, which sometimes led to recommendations to strengthen regional cooperation. For example, discussions with farmers highlighted the need for better provision of hydrometeorological information in terms of timeliness and accessibility. At the national conferences, it became clear that individual countries might not be in the best position to develop the longer term or specialized forecasts necessary to prepare farmers for extreme events like floods and droughts. As a result, work at the national conferences refined this measure to emphasize the need for multi-country, regional cooperation among hydrometeorological institutions to take advantage of country-level comparative advantages in forecast capacity. In other words, not every country in the region needs to develop a full suite of analytic capacities, but they do need to build links to nearby countries and development agreements to share relevant data, particularly concerning monitoring of transboundary water basins. In the crop research areas, the project team consistently urged countries to take advantage of access to the CGIAR (Consultative Group on International Agricultural Research) system, including the ICARDA (International Center for Agricultural Research in the Dry Areas) and CIMMYT (International Maize and Wheat Improvement Center).

Overall, three types of qualitative analysis were used in identifying and evaluating adaptation options, based on the expert judgment of three sets of individuals: (1) in-country agricultural experts who were 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 the study.

The input was gathered to be useful within the same overall framework used to identify high-priority options in the quantitative analyses. In practice, that meant experts attempted to identify options where they believed that economic benefits (to farmers, primarily) would exceed the costs—regardless of who bears them: the country government, donors, cooperatives, farmers themselves, or some combination.

The qualitative analyses worked from lists of adaptation options, which are presented in appendix A. The lists include more than 60 options in four categories:

1. *Infrastructural adaptations*—"hard" adaptation options that involve improvements of agriculture sector infrastructure, including water resources infrastructure improvements;
2. *Programmatic adaptations*—that strengthen existing programs or create new ones;
3. *Farm management adaptations*—farm-level measures, which make up the largest portion of the list; and
4. *Indirect adaptations*—options not directly aimed at the agriculture sector, but that would benefit agriculture.

While the in-country and international expert consultations were conducted informally throughout the course of the study, the farmer consultations followed a structured format. The project team was led by in-country coordinators to recruit farmers and representatives of farmers' associations for two sets of workshops, held in each AEZ. Three representatives from the project team guided and facilitated the discussions: a trained, nontechnical facilitator; a technical person broadly familiar with the climate science, impact assessment, and adaptation analyses; and the in-country coordinator. A translator was also employed, and all presentation materials were provided in the native language of the farmers.

The first set of workshops focused on sharing information on the impact of climate change on agriculture and water resources. Stakeholders were presented with projected yields of crops important to each country and projected future water supply and demand. Attendees were then asked if they had witnessed these impacts and what they had done, or would do, to mitigate their effects. To facilitate discussion, participants were placed into three smaller groups and asked to discuss the following questions and then report back to the larger group:

1. Which, if any, of the impacts discussed in the presentation on climate change impacts have you observed?
2. Of these, which do you think are currently posing the greatest risk to your operations? Which do you think might pose the greatest risks in the future?
3. For those impacts that pose the greatest risk, what measures have you already taken (if any) in response?
4. What other responses do you think might be effective, and should be investigated in more detail?
5. What kind of additional information would be most helpful to you?

The purpose of the second set of workshops was to present local stakeholders with a recommended menu of adaptation options, to gain feedback on those options, and to elicit other climate change adaptation suggestions. The results provided the study with valuable information on challenges facing farmers, their preferences for options that they believed would be most effective, and the feasibility of implementing these measures.

Refined Policies, Capacities, and Investments Needed to Reward Farmers' Flexibility

Overall, the results reinforced conclusions that farmers in all countries are becoming more flexible in their response to climate events through education and knowledge sharing, as well as their own on-the-ground experimentation. Nonetheless, the adaptive capacity of farmers and national governments remains limited because of poorly maintained irrigation and drainage systems; limited financial resources; and inadequate support from and access to technology, relevant know-how, weather forecasts, and extension services. The measures elevated for high-priority action are designed specifically to address these needs in each of the four countries.

Furthermore, this program and the study itself provided capacity building for local governments to enhance their ability to conduct these analyses in the future, including expanding the analysis to new crops. The focus of capacity building in most countries was on developing local skills in crop modeling.

Most countries have already used FAO's CropWat yield modeling tool, but had limited or no familiarity with the more powerful and versatile successor tool from FAO, AquaCrop (see box 2.2 in chapter 2). In particular, the training focused on parameterizing and calibrating this tool for a wide range of crop types, as well as incorporating the effects of adaptive measures in the model to assess the incremental crop yield benefits of adaptation. The tool itself is publicly available and supported through online resources at FAO's website, but the opportunity to discuss and conduct hands-on modeling exercises under the supervision of a highly trained and experienced crop modeler proved valuable to these countries, many of which expect to employ the more refined tool in their next efforts to produce formal National Communications to the United Nations Framework Convention on Climate Change.

In two of the countries, the training was enhanced to meet specific needs. In Albania, the high reliance on hydropower and the presence of multiple use reservoirs in the water system led to an interest in integrated water resource management tools. The training in Tirane therefore incorporated sessions on the application of the WEAP tool, which is also publicly available (to developing countries) and widely supported by the WEAP developers (see box 2.2 in chapter 2). In FYR Macedonia, the Hydromet institution expressed an interest in better understanding issues and uncertainties in the development of climate projections, so the team conducted an additional one-day session on this topic.

Ultimately, the assessment portion of the study was designed to provide a state-of-the-art accounting of adaptation options and priorities for use by each of the supported governments. All four governments expressed their wish to continue these efforts, and capacity building efforts were designed to meet those desires. In the short-term, however, it is clear that effective action will require a coordinated effort to refine policies, enhance farmer and institutional capacity, and make appropriate and well-targeted investments.

Notes

1. Analyses of the relative roles of temperature and precipitation in agricultural yields under climate change are relevant here, and they suggest that temperature changes may be more important in many areas. For example, Lobell and Burke (2008) find that most cereal crops in Asia and Africa are more sensitive to uncertainties in future temperature than to those in precipitation. One exception is West Asia wheat, where uncertainty in precipitation is influential in yield estimates—and wheat is a critical crop in this study's analysis of Uzbekistan in West Asia. While the study did not separately examine the role of temperature and precipitation in its crop modeling (they are jointly considered in each scenario), farmer consultations suggest that the greatest concern at the local level stems from changes in the seasonal precipitation patterns.
2. The impact assessment results incorporate changes to planting dates and loss of crop yield due to an imposed condition of deficit irrigation at the farm level, which the study team considered autonomous adaptations that are already occurring in response to current climate changes.

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CHAPTER 5

A New Approach to Choosing and Prioritizing Adaptation Options

Policy makers, agriculture ministries, and farmers face a daunting task in evaluating current and forecast changes in climate as they affect agriculture and perhaps an even steeper challenge in identifying and agreeing upon adaption options. As the data for the four countries examined in this study reveal, however, there is no time to waste. Opportunities to prepare for climatic changes will be few and limited, ranging from investments in irrigation infrastructure to planting crops that will perform better in higher temperatures or with less water.

This study offers stakeholders in national agricultural sectors a model to understand and approach these challenges. The four countries chosen as the focus of this study exhibit varying climate conditions, and each has a unique set of agricultural sectors and challenges. However, the methodology used in this assessment was able to take into account these characteristics and provide results, projections, and tailored policy options for each of the four study countries.

Model Considers Risks and Defines Adaptation Paths

Quantitative and qualitative analyses played important roles in the processes of identifying and prioritizing adaption options, respectively, in developing the model. Stakeholder outreach was also critical in understanding farmers' experiences with climate change, their current adaptation measures, and their views about necessary steps. The quantitative modeling adds credibility to the results for external parties, including financial institutions and development partners that may potentially fund adaptation measures, and provides an objective basis for prioritization. The qualitative analyses and outreach also add credibility for internal audiences, confirming that results are feasible in the view of farming communities whose acceptance of the measures can be critical to their success. Taken together, this thorough process of information-gathering, analysis, forecasting, consultation, and prioritization yielded menus of tangible, actionable adaptation measures for each country. This approach can be repeated for any other country that seeks to understand the process of climate change, the impacts it promises for their agricultural sector, and the steps that can be taken to adapt and even take advantage of this process.

Pairing Quantitative Analyses with Stakeholder Consultations to Map Out Options

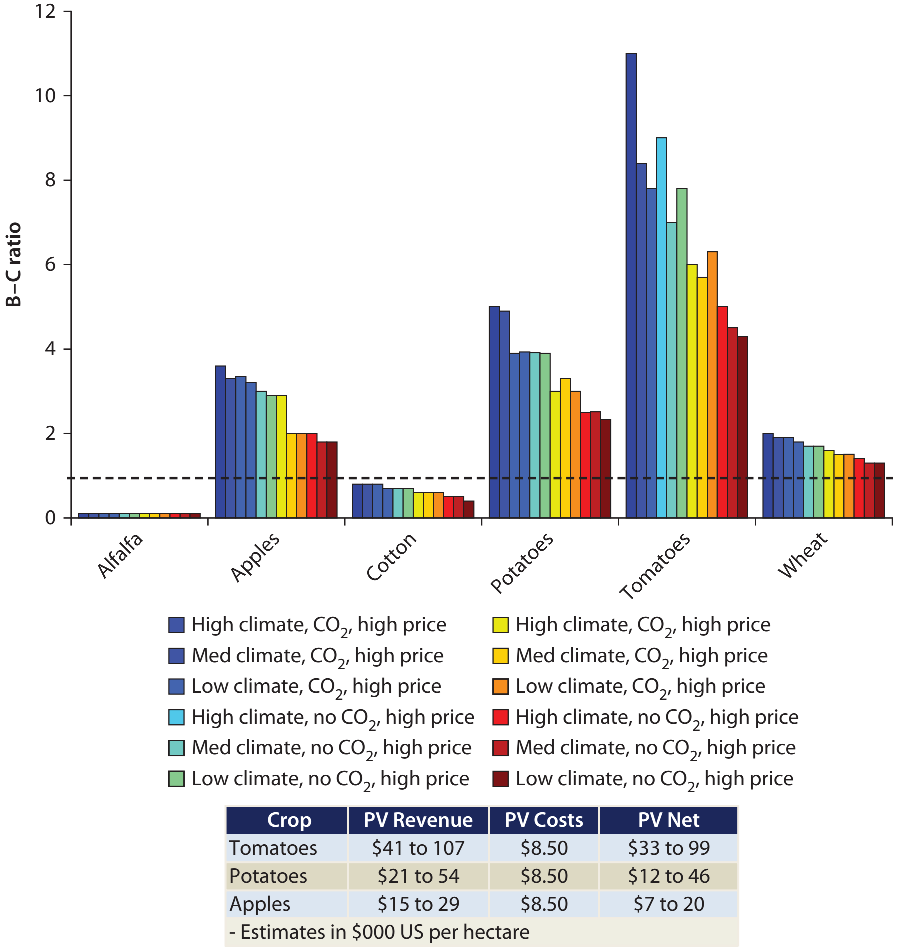
In general, the quantitative benefit-cost (B-C) analyses proved most useful for identifying classes of measures that could provide the best likelihood of a cost-effective investment. This approach was particularly useful for ensuring that the cost-effectiveness result was robust across climate scenarios and future price projections and for identifying a crop-specific focus for adaptation efforts, usually oriented toward the highest value crops. The stakeholder consultations and the consensus-building exercises in the final conference, on the other hand, helped focus the measures on local-scale issues, provided more specific focus and identification of relevant techniques to employ, "ground-truthed" the broader scale quantitative results, and provided an assessment of the feasibility of the measures for adoption by farmers in each location.

Underlying these results were detailed B-C analyses of a specific set of adaptation measures. For every agro-ecological zone (AEZ), these analyses considered for each measure, the crop yield and revenue performance for each focus crop (incorporating local soil types and baseline climate), for all three climate change projections, across two price scenarios, and considering two alternatives for the possible effect of higher carbon dioxide concentrations on crop yields. An example of the richness of these quantitative analyses for the improved on-farm water use efficiency measure in Uzbekistan is provided in figure 5.1.[1] Two economic indicators were developed for each adaptation measure: (1) the present value (PV) (using a 5 percent discount rate) of the incremental stream of future benefits and costs of the measure relative to baseline conditions, shown in table 5.1, and (2) the B-C ratio, shown in figure 5.1.

Present value revenue results are presented as a range reflecting the low and high estimates across the climate, carbon dioxide fertilization, and price scenarios. Present value costs for this measure include capital and operating costs for a representative water use efficiency measure, adopting drip irrigation. Figure 5.1 also includes a horizontal line showing a B-C ratio of 1, where present value benefits just equal costs. As the figure and table indicate, for tomatoes, potatoes, and apples in particular, the economic analysis suggests this will be a cost-effective measure, while for cotton and alfalfa, the costs exceed the benefits. For wheat, benefits exceed costs for some scenarios but are about equal to costs for others. Because there are uncertainties in both benefit and cost estimation that are not captured in these results, measure/crop combinations where benefits did not exceed costs by a factor of about 2 or more did not receive a high priority.

Another example of the B-C results is presented in figure 5.2, this time for a measure to rehabilitate drainage infrastructure in the Lowlands AEZ in Albania. Severe flooding in some agricultural regions of Albania has been a

Figure 5.1 Benefit-Cost Analysis for Improved Water Use Efficiency in Uzbekistan's Desert and Steppe AEZs



Crop	PV Revenue	PV Costs	PV Net
Tomatoes	$41 to 107	$8.50	$33 to 99
Potatoes	$21 to 54	$8.50	$12 to 46
Apples	$15 to 29	$8.50	$7 to 20
- Estimates in $000 US per hectare			

Note: AEZ = agro-ecological zone, PV = present value. The 12 scenarios for which benefit-cost (B-C) ratios are shown include combinations of three climate scenarios (base, low, medium, and high impact); two carbon fertilization assumptions (with and without); and two price projections (low and high).

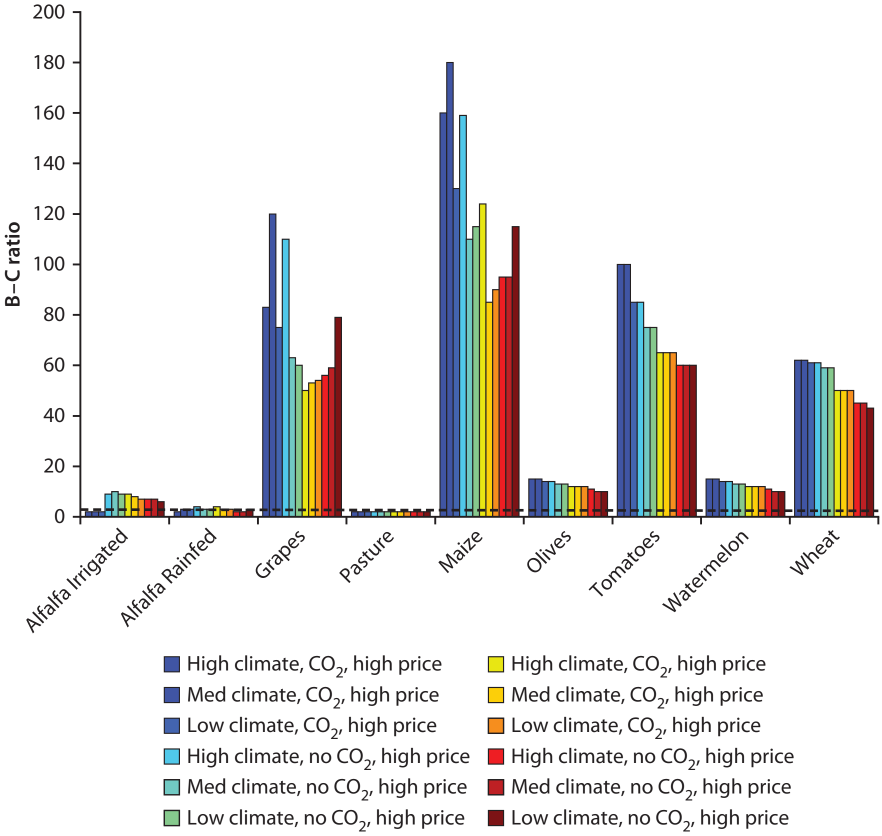
Table 5.1 Estimated Revenue Performance for Select Crops with Improved Water Use Efficiency in Uzbekistan AEZs

US$ thousands/ha

	Present value		
Crop	*Revenue*	*Costs*	*Net*
Tomatoes	41–107	8.5	32–99
Potatoes	21–54	8.5	12–46
Apples	15–29	8.5	7–20

Note: AEZ = agro-ecological zone, ha = hectare.

Figure 5.2 Benefit-Cost Analysis Results for Rehabilitated Drainage Infrastructure in Albania's Lowlands AEZ



Note: The 12 scenarios for which benefit-cost (B-C) ratios are shown include combinations of three climate scenarios (base, low, medium, and high impact); two carbon fertilization assumptions (with and without); and two price projections (low and high).

problem for several years, in part because of poor maintenance of the drainage infrastructure. Although the flooding problem is not unique to Albania among the four study countries, it is a more acute problem there. In figure 5.2 results are presented for a measure to improve drainage by rehabilitating drainage infrastructure. The crop modeling indicated that improving the drainage on agricultural land has the potential to increase yields substantially for most of the crops, particularly maize, grapes, tomatoes, and wheat. As a result, this measure was recommended for future investment. The World Bank has already begun a project to invest in drainage rehabilitation. This study has provided information and insights to that effort concerning the focal regions and crops, as well highlighting the importance of considering the impact of climate change when designing the investment program, particularly to ensure the drainage system is of adequate capacity to handle the expected higher temporal variability in runoff flows.

Lessons Learned and Potential Applications for Model

In retrospect, some of the process and analytic choices made by the project team were critical to the success of the program; others could have been modified and perhaps led to an even better outcome. Three categories of key lessons emerged: process steps, quantitative modeling, and "on-the-ground" work to achieve adaptation outcomes.

Key Lessons Learned Regarding Study Process

- *Key line ministries should be involved at policy level to ensure there is support for the study.* In each of these countries, it was evident that both the ministry of agriculture and the ministry of environment should be involved from the inception of the work. The respective deputy ministers were often the focal points for the work.

- *Research institutes, farmers' federations, and academics are great resources.* In addition to ministry staff, it is important to make early contacts with research institutes for crops, horticulture, and livestock management; the hydrometeorological institute; the farmer's federation; and academic researchers with expertise in this area, provided they are well-known within the ministries and eager to work on policy matters.

- *Preparation of analytical approaches and outreach to contacts help get the ball rolling.* In the initial stages of data collection and work plan development, it is important to develop an initial menu of general adaptation options (see appendix A), a list of needed and desired data, and a list of international and World Bank study team contacts to provide to the local focal point. In addition, a clear work plan in the form of an inception report needs to be presented and agreed to among the key stakeholders early on.

- *Building capacity is a challenge, but local sources can be helpful.* Climate change adaptation analyses involve data management challenges, a complex series of interacting analytic components, and the need for broad multidisciplinary teams. Deciding how best to pursue capacity building to facilitate mainstreaming of climate change in agricultural policy-making is therefore difficult. The approach used in this study was to hire local consultants as coordinators of the in-country work, identify host institutions that might continue the analytic work, and then train members of the host institution in the basic elements of the crop and water modeling needed to conduct assessments. In addition, the hydrometeorological institution in one country had a need for focused training on accessing and interpreting climate forecast data, and the study team followed up with a specialized but informal workshop on this topic. One aspect that could have enhanced in the study is direct farmer education, particularly in the area of agronomic practices that enhance resilience to climate stress (such as small-scale water storage).

- *A national focus is key, but subnational and multi-national links need to be considered*. National governments are the traditional World Bank partners, and in both the initial and concluding phases of this project it proved critical to have national support. Where possible, however, it is useful to identify and cultivate links with subnational institutions as well, to the extent they exist. This worked best in Albania, where the Ministry of Agriculture, Food, and Consumer Protection is organized to include both national and regional institutions. Additionally, regional cooperation among hydrometeorological institutions in multiple countries should take best advantage of country-level comparative advantages in forecasting capacity. In other words, not every country in the region needs to develop a full suite of analytic capacities, but they do need to build links to nearby countries and development agreements to share relevant data, particularly concerning monitoring of transboundary water basins.

Key Lessons Learned in the Quantitative Analyses

- *Geographic and political boundaries are useful guides for defining Agro-Ecological Zones.* In practice, AEZs defined by specific contiguous geographic or political boundaries proved more workable, and AEZs identified by their elevation proved difficult to work within the analytical and, more importantly, the *qualitative* and stakeholder analyses. The AEZ delineations in Albania and Moldova worked best. These delineations were based on agglomerations of contiguous political districts and, in Albania, also coincided well with the locations of Agriculture Technology Transfer Centers (ATTCs), which are regional agricultural research branches of the Ministry of Agriculture, Food, and Consumer Protection.

- *Choosing the best modeling and analytic tools.* Three crop models (DSSAT, AquaCrop, and CropWat) were used across countries and crop types. This experience provided useful insights about what crop modeling tool might work best in future contexts. In the end, AquaCrop proved sufficiently detailed for this application, but also straightforward for in-country participants to learn. AquaCrop was easily adapted to a wide variety of crops and management practices, and it is effective in estimating both yields and water demand. AquaCrop was also best suited to estimating incremental crop yields for more specific individual measures of interest for adaptation planning.[2]

- *Assessments should look at adaptation measures for extreme climatic events.* The approach used, while broad in scope, did not address a key issue that emerged through the course of the study—the impact of changes in extreme events. For example, in Albania and Moldova, shortly after the study team's initial visits, several agricultural areas experienced record flooding, which in some cases delayed planting and, if it had occurred later in the season, could have wiped out crops. The study did identify several adaptation measures that could improve resiliency of agricultural systems to the extreme events linked with climate change (for example, drainage infrastructure and hailnets). However, but more detailed analysis beyond the scope of this project would be necessary to fully explore the benefits of adaptation measures in responding to extreme weather events.

- *Integrate analyses of crop yield, crop water demand, and irrigation water supply.* A key lesson of the overall quantitative analysis was the need to fully integrate the analyses of crop yield and water resource demand and availability, in order to fully understand the multi-dimensional effects of climate change on agriculture. As chapter 3 shows, the irrigated crop yield analyses alone provide an overly optimistic assessment of the impact of climate on crops, because they assume that sufficient irrigation water will be available in the future. Subsequent analyses of the water resource sector incorporated the increased crop water demand that results from higher growing season temperatures, as well as the broader prospect of water shortages in the system as a whole. Water shortages result in part from increased water demand from all sectors (including agriculture) and in part from the combined effect of precipitation and temperature changes on runoff and evaporation rates, which reduces water supply. Combining all of these effects and integrating "loop-back" from the water resource analysis to the crop yield analysis, provided a more complete and, in many cases, much more dire assessment of the net impacts on crop yield. Many existing analyses, including most of the analyses conducted to support National Communications to the United Nations Framework Convention on Climate Change and national policies on climate adaptation, fail to include this important integration of the sectoral analyses, yet this assessment shows it to be a critical step in the analysis.

- *Consider issues around transboundary water resources.* When a nation is riparian to a transboundary river basin, implementing adaptation measures in the water sector can be more complicated. In international river basins, climate change impacts may alter current hydro-political balances and overwhelm the institutional capacity to absorb these impacts. Consequently, regions and basins not governed by treaties or water related institutions may be more vulnerable to tension and conflict. In regions that are already governed by treaties and agreements, climate change and variability could affect the ability of basin states to meet their water treaty commitments and effectively manage transboundary waters, especially if such treaties are not suited to dealing with variability and new hydrological realities (De Stefano et al. 2012). All four countries in this study have a significant portion of their land as part of transboundary river basins. Care must be taken to consider not only the potential constraints transboundary water issues may play on national plans, but also opportunities that regional cooperation centered on transboundary water management may bring to adaptation plans.

Key Lesson Learned in Achieving "On-the-Ground" Results

Identifying "win-win" and "win-win-win" measures and engaging early and often locally. The key objective of all the work conducted for this program was to identify and encourage actions to improve the resiliency of agriculture to future climate change. Both substantive and process characteristics of the work facilitated achievement of that goal. On the substantive side, the focus on identifying "win-win" measures meant that most investments identified by the study can also yield benefits in adapting to current climate challenges. On the process side, it is important to be engaged locally early on, and that engagement must be consistent throughout the project, including frequent check-ins among both World Bank task managers and the analytic experts. A key to maintaining long-term momentum in the planning work completed in the course of this study was the effort of the World Bank staff to fully integrate the results into multiple opportunities for investment financing.

Results

As noted throughout this volume, the ultimate goal of this program has always been to help each beneficiary country identify practical options for mainstreaming climate change adaptation into agricultural policies, programs, and investments, whether implemented by the countries themselves or with the support of development partners like the World Bank. Results have already been encouraging, with all four of the participating countries responding to the information and options the study yielded by taking action across several fronts. Examples of these actions, highlighting the practical value of this approach as well as the urgency of the situation in each setting, are as follows:

- *Albania* has begun incorporating the study's recommendations into a new irrigation and drainage project and is creating a new initiative with the Global Environment Facility to pilot other recommendations.
- *The former Yugoslav Republic of Macedonia* has incorporated several recommendations from this assessment into their new Country Partnership Strategy with the World Bank and in their agricultural development project, as well as in their "Green Growth Strategy" under preparation.
- *Moldova* has already incorporated some of the findings of this study into their disaster risk mitigation and adaptation project, and more recently incorporated them into a new agricultural competitiveness project.
- *Uzbekistan* is also teaming with the Global Environment Facility to pilot some recommendations generated by this program. The nation is also addressing other options raised through this exercise in a new agriculture competitiveness project and in a series of irrigation projects.
- *South Caucasus countries of Armenia, Azerbaijan, and Georgia* are replicating the approach developed for this program, and these countries have already applied many of the lessons learned from the initial four-country work. For example, they have decided to use only AquaCrop, the crop model that worked best in the current study.

An additional lesson learned from this pioneering work is that, while the approach could be simplified by using globally available data and global expert evaluations, those results would not be accepted by local counterparts without active engagement in data identification, identification of appropriate agricultural regions, and on-the-ground interactions with farmers. The local engagement activities add considerable time and resource costs to the approach, but also contribute significantly to the success.

It is very likely that farmers will ultimately benefit from pursuit of the climate change adaptation plans this analytical program developed in conjunction with the countries of Albania, FYR Macedonia, Moldova, and Uzbekistan. Addressing challenges of poor access to credit, low uptake rates for available crop insurance, and poor access to modern technologies like seeds and equipment is important. However, it is clear that farmers do not take advantage of the limited opportunities that do exist because they lack either the knowledge, the resources, or both.

Going forward, while it is likely that many of these adaptation measures may have to be financed on a piecemeal basis, it will be critically important that countries operate on more than one front, simultaneously pushing new policies, better information provision, and enhanced on-farm and regional-scale infrastructure investments. Each of these countries has already experienced a surprising number of success stories: farmers who are well-informed, connected to credit, and connected to markets. It is hoped that through efforts similar to this study, success stories can be made more widespread and in the process that the resiliency of agriculture to both current and future climate will be greatly enhanced.

Notes

1. These figures are provided as illustrations of the benefit-cost results. More detailed graphics are available in the country reports (World Bank 2012a, 2012b, 2012c, 2012d) available at http://www.worldbank.org/eca/climateandagriculture.
2. AquaCrop has also been field validated for several major cereal crops; for example, see Heng et al. (2009) and Hsaio et al. (2009) for maize; and Farahani, Izzi, and Oweis. (2009) for cotton.

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APPENDIX A

Product Design and Methodology

This technical appendix provides additional details on the overall analytic framework and methodology used in the quantitative modeling of climate change impacts and on the benefit-cost analysis of adaptation measures. This appendix supplements the framework provided in chapter 2 and offers additional technical details for Action Step 3 of the framework, specifically Analytic Steps 1 through 6, with particular focus on Analytic Step 4 (Impact Assessment) and Analytic Step 6 (Adaptation Assessment).

Analytic Step 1: Identify Agricultural Growing Regions

Results were generated for "representative farms" in each major agricultural production region of each country, with at least one farm in each agro-ecological zone (AEZ). Note that this approach focuses the analysis on regions that are currently in agriculture and does not evaluate regions that may become newly suitable for agriculture as the climate changes. Information on rainfed and irrigated crop coverage in each country informed the process of identifying AEZs. Crop coverage was provided by local in-country experts where possible. In addition, remote sensing data were collected 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, and Spatial Production Allocation Model [SPAM] dataset of detailed global crop maps from International Food Policy Research Institute). In some countries, these data were supplemented by local meteorological data (Moldova and Uzbekistan), but in other countries these data were not available (Albania and the former Yugoslav Republic of Macedonia).

Analytic Step 2: Gather Baseline Data

This step is discussed extensively in chapter 2 and throughout the volume. No further detail will be provided here.

Analytic Step 3: Develop Climate Projections

The climate projections combine information from the baseline datasets with projections of changes in climate obtained from global circulation model (GCM) results prepared for the United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. As noted in chapter 2 (see box 2.1), three climate scenarios were developed in each country. The scenarios were 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 each country, the driest (high impact), the wettest (low impact), and a "medium" impact scenario were selected from among the 56 available GCM combinations deployed by IPCC for 2050. Note that, because CMI reflects both precipitation and temperature, the driest and wettest are not simply a function of the lowest and highest precipitation outcomes, but they also incorporate temperature—both have been shown to be important determinants of forecast crop yields (for example, see Lobell and Burke 2008). The study team then conducted the following two subtasks: (1) Generate decadal monthly changes in precipitation and temperature and (2) Translate these monthly decadal changes to daily changes.

Monthly changes in climate were generated based on differences between future projections of temperature and precipitation and 20th century baseline outputs for each GCM. Based on available literature, absolute changes in temperature and relative changes in precipitation were presented.

Crop modeling under future climate change also requires daily data for the 2010 to 2050 period, but the GCMs only provide 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]

Table A.1 lists the specific GCMs employed for each of the four countries.

Analytic Step 4: Impact Assessment

The impact assessment uses the process-based crop models AquaCrop, DSSAT, and CropWat to analyze changes in crop yields and crop water demand across each country, and the CLIRUN model to analyze changes in water runoff. It then applies the Water Evaluation and Planning System (WEAP) model, using the inputs from CLIRUN to analyze potential basin-level shortages in water available to agriculture. CropWat was used in FYR Macedonia to determine crop water and irrigation requirements from soil, climate and crop data. AquaCrop and DSSAT were used to model crop yields. These models are described in chapter 2 (box 2.1).

Crop Model Selection

In order to evaluate the effect of climate change on crop production and to assess the impact of potential adaptation strategies, models are used frequently (Aerts and Droogers 2004). The purposes of these models are (1) to gain better

Table A.1 Global Circulation Model Basis for Climate Change Scenarios

Country	*Scenario*	*Global general circulation model basis for the scenario*	*Relevant IPCC SRES scenario*
Moldova	High impact	Centre National de Recherches Météorologiques, Coupled Model 3 (France)	A1B
	Medium impact	Center for Climate Modeling and Analysis, Coupled GCM 3.1.t63 (Canada)	A1B
	Low impact	Goddard Institute for Space Studies, ModelER (US)	A2
Albania	High impact	Goddard Institute for Space Studies, Model EH (US)	A1B
	Medium impact	Center for Climate Modeling and Analysis, Coupled GCM 3.1 (Canada)	A1B
	Low impact	Commonwealth Scientific and Industrial Research Organization, Mk 3.0 (Australia)	B1
FYR Macedonia	High impact	Geophysical Fluid Dynamics Laboratory, Climate Model 2.1 (US)	A1B
	Medium impact	Goddard Institute for Space Studies, ModelER (US)	A2
	Low impact	Commonwealth Scientific and Industrial Research Organization, Mk 3.0 (Australia)	B1
Uzbekistan	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

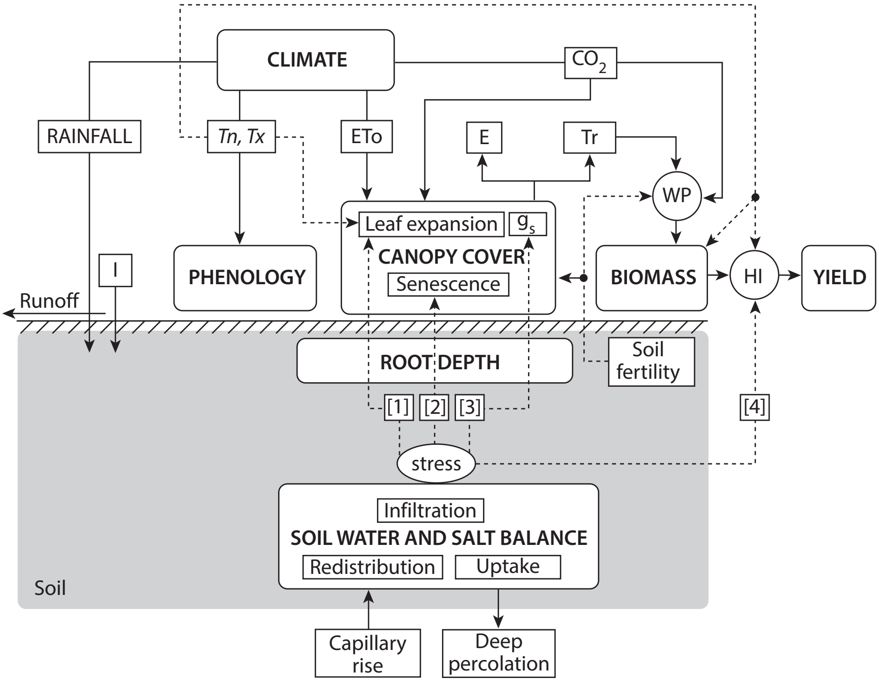
Source: SRES Scenario (IPCC 2000).
Note: IPCC = Intergovernmental Panel on Climate Change, SRES = Special Reports on Emissions Scenarios.

understanding of water-food-climate change interactions, and (2) to explore options to improve agricultural production now and under future climates.

Frequently used agricultural models are: CropWat; AquaCrop; CropSyst; SWAP/WOFOST; CERES; DSSAT; and EPIC (see box 2.2). Each of these models is able to simulate crop growth for a range of crops. The main differences are the representation of physical processes and the main focus of the model. Some of the models are strong in analyzing the impact of fertilizer use, some are able to simulate different crop varieties, farmer practices, and so on. However, this project needed models with a strong emphasis on crop-water-climate interactions. Based on the study team's previous experiences, AquaCrop was selected for Albania, Uzbekistan, and FYR Macedonia, and DSSAT for Moldova. Elsewhere in this document (chapter 4), AquaCrop is recommended for future analyses for the following reasons: it has limited data requirements; it has a user-friendly interface enabling non-specialists to develop scenarios; it focuses on climate change, CO_2, water, and crop yields; it was developed by and is supported by FAO; it has a fast-growing group of users world-wide; and it has flexibility in expanding the level of detail.

AquaCrop includes the following submodel components: soil, with its water balance; the crop, with its development, growth, and yield; atmosphere, with its thermal regime, rainfall, evaporative demand, and CO_2 concentration; and management, with its major agronomic practices such as irrigation and fertilization. The AquaCrop flowchart is shown in figure A.1.

Figure A.1 AquaCrop Flowchart of Procedures



Source: Raes et al. 2009.

Features that distinguish AquaCrop from other crop models are its focus on water, its use of ground canopy cover instead of a leaf area index, and its use of water productivity values normalized for atmospheric evaporative demand and CO_2 concentration. These features give the model the extrapolation capacity to consider diverse locations and seasons, including future climate scenarios. Moreover, although the model is simple, it pays particular attention to the fundamental processes involved in crop productivity and responses to water from a physiological and agronomic perspective.

The main components included in AquaCrop for calculating crop growth are Atmosphere, Crop, Soil, Field Management, and Irrigation Management. Each is discussed below; further details can be found in the AquaCrop documentation (Raes et al. 2009).

Atmosphere

The minimum weather data requirements of AquaCrop include the following five parameters: (1) daily minimum air temperatures, (2) daily maximum air temperatures, (3) daily rainfall, (4) daily evaporative demand of the atmosphere expressed as reference evapotranspiration (ETo), and (5) mean annual carbon dioxide concentration in the bulk atmosphere.

In contrast to CropWat, the reference evapotranspiration (ETo) is not calculated by AquaCrop itself but is a required input parameter. This input enables the user to apply the ETo method most commonly used in a certain region and/or consistent with a certain availability of data. From the various options to calculate ETo, reference is made in the AquaCrop documentation (Raes et al. 2009) to the Penman-Monteith method, as described by FAO (Allen et al. 1998). The same documentation also makes reference to the Hargreaves method, which can be used in cases of data shortage.

A companion software program (ETo calculator) based on the FAO56 publication (Allen et al. 1998) might be used if preference is given to the Penman-Monteith method. A few additional parameters were used for a more reliable estimate of the reference evapotranspiration. Besides the minimum and maximum temperature, measured dewpoint temperature and windspeed were used for the calculation.

AquaCrop calculations were performed at a daily time-step. However, input is not required at a daily time-step, but can also be provided at 10 daily or monthly intervals. The model itself interpolates these data to daily time steps. The only exception is the CO_2 levels, which were provided at annual time-step and were considered to be constant during the year.

Crop

AquaCrop considers five major components and associated dynamic responses used to simulate crop growth and yield development: (1) phenology, (2) aerial canopy, (3) rooting depth, (4) biomass production, and (5) harvestable yield.

As mentioned earlier, AquaCrop's strengths are in the crop responses to water stress. If water is limited it will have an impact on the following three crop growth processes:

- Reduction of the canopy expansion rate (typically during initial growth)
- Acceleration of senescence (typically during completed and late growth)
- Closure of stomata (typically during completed growth)

Finally, the model has two options for crop growth and development processes:

- Calendar based: the user has to specify planting/sowing data
- Thermal based on Growing Degree Days (GDD): the model determines when planting-sowing starts.

Soil

AquaCrop is flexible in terms of description of the soil system. Its special features include:

- Up to five horizons
- Hydraulic characteristics
    - hydraulic conductivity at saturation
    - volumetric water content at saturation

  - field capacity
  - wilting point
- Soil fertility can be defined as additional stress on crop growth influenced by:
  - water productivity parameter
  - the canopy growth development
  - maximum canopy cover
  - rate of decline in green canopy during senescence

AquaCrop separates soil evaporation (E) from crop transpiration (Tr). The simulation of Tr is based on:

- Reference evapotranspiration
- Soil moisture content
- Rooting depth

Simulation of soil evaporation depends on:

- Reference evapotranspiration
- Soil moisture content
- Mulching
- Canopy cover
- Partial wetting by localized irrigation
- Shading of the ground by the canopy

Field Management
Characteristics of general field management can be specified, reflecting two groups of field management aspects: soil fertility levels, and practices that affect the soil water balance. In terms of fertility levels, the user can select from predefined levels (non-limiting, near optimal, moderate, and poor) or can specify parameters obtained from calibration. Field management options influencing the soil water balance that can be specified in AquaCrop are mulching, runoff reduction, and soil bunds.

Irrigation Management
One of the strengths of AquaCrop is simulation of irrigation management, which offers the following options:

- Rainfed-agriculture (no irrigation)
- Sprinkler irrigation
- Drip irrigation
- Surface irrigation by basin
- Surface irrigation by border
- Surface irrigation by furrow
- Scheduling of irrigation can be simulated as fixed timing or depletion of soil water
- Irrigation application amount can be defined as fixed depth or back–field capacity.

Climate Change

The impact of climate change can be incorporated in AquaCrop in three ways: (1) adjusting the precipitation data file, (2) adjusting the temperature data file, and (3) calculating the impact of enhanced CO_2 levels. The first two options are quite straightforward and require the standard procedure of creating climate input files in AquaCrop. AquaCrop itself calculates the impact of enhanced CO_2 levels. In this respect, AquaCrop uses the so-called normalized water productivity (WP*) for the simulation of aboveground biomass. The WP can be normalized for atmospheric CO_2 concentration and for climate, taking into consideration the type of crop (for example, C3 or C4 types of photosynthesis). The C4 crops assimilate carbon at twice the rate of C3 crops.

Parameterization of AquaCrop for AEZs

The following sections address the parameterization of the AquaCrop model for soil and crop inputs.

Soils

The Harmonized World Soil Database is a 30 arc-second raster database that integrates existing regional and national soil databases worldwide. The database was assembled by FAO and partners especially for studies on the scale of AEZs in 2008. This digitized and online-accessible soil information system allows policy makers, planners, and experts to overcome some of the shortfalls of data availability to address today's pressing challenges of food production and food security and plan for new challenges of climate change. These data were used as the main basis for determining the dominant soil types in each AEZ.

Crops

The standard AquaCrop package has some predefined crop files that can be adjusted to local conditions. Some of the crops required for this study are not included in the AquaCrop package, so separate files were developed using expert knowledge, documentation, and local expertise obtained during the capacity building workshops in each country. Two examples of parameterization of crops in Albania—grapes (a non-standard crop) and wheat (a standard crop)—illustrate the type of data used.

Grapes are not yet included as one of the standardized crop files within AquaCrop. Based on various references and local expertise, a specific grape file for Albania was created. Biomass production and yields are calculated by AquaCrop, like almost all other crop growth models, as dry matter. In farm management practice and crop statistics, however, yields are always expressed as fresh yields. On average, grapes have a dry matter content of 20 percent, so about 80 percent moisture is included in the fresh yield. To convert AquaCrop results into fresh yields requires dividing by 0.20.

Average grape yields in Albania, according to FAOSTAT, are 19 ton/ha (fresh yield). Converting into dry matter yields 3,800 kg dry matter. Good commercial yields in the subtropics are in the range of 15–20 kg grapes per vine or 15–30 (or more) tons/ha (80–85 percent moisture). According to FAOSTAT, yields in Albania are very high compared to other countries and regions. Local expertise on yields was obtained during the capacity workshop in Tirana in October 2010 (see table A.2). Overall fresh yields range from about 8 ton/ha up to 13 ton/ha according to these local experts. This is substantially lower compared to the official FAOSTAT statistics. However, it should be taken into account that yields in FAOSTAT are often based on total production in a country divided by the reported area. Especially for grapes, total official area might be an underestimation given the many small farms growing some grapes, and these small areas are not always registered. In summary, it might be concluded that fresh grape yields in Albania are between 8,000 and 13,000 kilograms per hectare (kg/ha). This translates into dry matter yields of 1,600 to 2,600 kg/ha.

The AquaCrop data file for grapes was created by adjusting parameters to the local conditions in each country. Some basic assumptions included:

- Grapes are never irrigated in Albania.
- Grapes are sensitive to water stress, especially at the beginning of the growing season, but can develop deep roots that enable the crop to make use of water stored in deeper soil layers.
- Grapes are medium-sensitive to fertilizer stress. A medium amount of organic fertilizer is provided to grapes in Albania.

The most important AquaCrop (crop) parameters relevant to grapes are the following:

- Planting density is about 2.0 × 4.0 m, so number of plants per ha is 10,000/(2.0 × 4.0) = 1,250.
- Assuming that grapes are grown on about 10 percent of the area at spring, just after initial leaf development, the size of the canopy cover per tree = 10%/1,250 × (10,000 × 10,000) = 8,000 cm^2.
- Growing season is March 15 to September 15.
- Grapes are considered to have moderate stress for fertilizer shortage.
- Soils receive near optimal fertilizer application for grapes in the country.
- Maximum canopy cover in fraction of soil cover (CCx). It was assumed that, on average, 70 percent of the canopy covers the soil.

Table A.2 Grape Yields Reported by Albanian Local Experts

AEZ	*Yield (kg/ha)*
Lowlands	13,000
Intermediate	10,000
North/Central Mountains	10,000
Southern Highlands	8,000

Source: FAOSTAT.
Note: AEZ = agro-ecological zone, kg/ha = kilograms per hectare.

- Reference Harvest Index (HIo). This factor is low for grapes, as only part of the biomass is converted to harvested yield. For grapes in Albania, a universal value for all AEZs is assumed and set at 15 percent.
- Canopy growth coefficient (CGC). Increase in canopy cover (fraction soil cover per day). For grapes, like other tree crops, this parameter is high and set at 0.2.
- Canopy decline coefficient (CDC) is the decrease in ground cover (in percent or fraction per day), which is relatively low and set at 0.08.

The wheat crop file is calibrated for a location in Italy with climate conditions similar to Albania, meaning that only slight changes in parameters were required; these are summarized in table A.3. The existing wheat varieties can be grouped as winter or spring type. Winter wheat requires a cold period or chilling during early growth for normal heading under long days. This is the main wheat variety cultivated in Albania. The minimum daily temperature for growth is about 5°C for both winter and spring wheat. Mean daily temperature for optimum growth is 15–20°C. Mean daily temperatures of less than 10–12°C during the growing season make wheat a risky crop. The length of the total growing period for winter wheat is about 180–250 days.

Under favorable water supply conditions, including irrigation and adequate fertilization, row spacing is 0.12–0.15m (450,000–700,000 plants/ha); however, row spacing increases to 0.25m or more under poor rainfall conditions (less than 200,000 plants/ha). Wheat is also grown as a rainfed crop in the temperate climates in Albania. For high yields, growing season water requirements (ETm) are 450–650mm, depending on climate and length of growing period. The crop coefficient (Kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is as follows: during the initial stage 0.3–0.4 (15–20 days); during the development stage 0.7–0.8 (25–30 days); during the mid-season stage 1.05–1.2 (50–65 days); during the late-season stage 0.65–0.7 (30–40 days); and at harvest 0.2–0.25.

Water uptake and extraction patterns are related to root density. In general, 50–60 percent of the total water uptake occurs from the first 0.3m, 20–25 percent from the second 0.3m, 10–15 percent from the third 0.3m, and less than 10 percent from the fourth 0.3m of soil depth. Normally,

Table A.3 Crop Characteristics of Wheat at Different Development Stages in Albania

	Development stages				
Crop characteristic	*Initial*	*Crop development*	*Mid-season*	*Late*	*Total*
Stage length (days)	30	140	40	30	240
Depletion coefficient (p)	0.6	n.a.	0.6	0.9	0.55
Root depth (m)	0.3	n.a.	n.a.	1.4	n.a.
Crop coefficient (Kc)	0.2	0.65	0.55	n.a.	1.05
Yield response factor (Ky)	0.2	0.6	0.5	n.a.	1.15

Note: n.a. = not applicable.

100 percent of the water uptake occurs over the first 1.0–1.5m (D = 1.0–1.5m). Under conditions in which the maximum evapotranspiration is about 5–6 mm/day, water uptake of the crop is little affected at soil water depletion of less than 50 percent of the total available soil water (p = 0.5). Moderate water stress to the crop occurs at depletion levels of 70–80 percent, and severe stress occurs at levels exceeding 80 percent.

Under irrigation, a good commercial grain yield is 6–9 ton/ha (10–13 percent moisture). In this case a dry matter content of 87 percent was assumed. In Albania, grain yield is about 4 ton/ha (more or less, depending on the AEZ). For good yields, the fertilizer requirements are up to 150 kg/ha N; 35–45 kg/ha P; and 25 to 50 kg/ha K. In Albania, optimal amounts of nitrogen fertilizers are applied, while for phosphorus, minimum to medium amounts are used, according to information from local experts. The sensitivity of the crop to fertility stress was defined as moderate, as defined by the following parameter values:

- Shape factor for the response of canopy expansion for limited soil fertility: 3.92
- Shape factor for the response of maximum canopy cover for limited soil fertility: 1.77
- Shape factor for the response of crop water productivity for limited soil fertility: 6.26
- Shape factor for the response of decline of canopy cover for limited soil fertility: –1.57

CO_2 Fertilization

Potential production of a crop is based on the fixation of solar energy in biomass, or photosynthesis. In this process, CO_2 from the atmosphere is transformed into glucose (CH_2O), resulting in the so-called gross assimilation of the crop. The required energy for this originates from sunlight, or more precisely, from the photosynthetically active radiation (PAR). The amount of PAR in the total radiation reaching the earth's surface is about 50 percent. However, some part of the produced glucose is directly used by the plant through the process of respiration. The difference between gross assimilation and respiration is the so-called biomass production or crop production.

It is important in this process to make a distinction between C3 and C4 plants, which have different carbon fixation properties. C4 plants are more efficient in carbon fixation and lose a negligible amount of carbon during the photorespiration process. C3 plants may lose up to 50 percent of their recently fixed carbon through photorespiration. This difference suggests that C4 plants will not respond positively to rising levels of atmospheric CO_2. However, it has been shown that atmospheric CO_2 enrichment can and does elicit substantial photosynthetic enhancements in C4 species (Wand et al. 1999).

Examples of C3 plants analyzed are potato, wheat, and most tree crops. C4 plants are mainly found in the tropical regions, but one is a major crop produced in the four countries: maize. The maximum gross assimilation rate (A_{max}) is about 40 (20–50) kg CO_2 ha^{-1} h^{-1} for C3 plants and 70 (50–80) kg CO_2 ha^{-1} h^{-1} for C4 plants. This maximum is only reached if no water, nutrient, or light (PAR) limitations occur.

Modeling studies based on detailed descriptions of crop growth processes also indicate that biomass production and yields will increase under elevated CO_2 levels. For example, Rötter and Van Diepen (1994) showed that potential crop yields for several C3 plants in the Rhine basin will increase by 15–30 percent in the next 50 years as a result of increased CO_2 levels. According to their model, the expected increase in yield for maize, a C4 plant, will be only 3 percent, indicating that their model was indeed based on the assumption that C4 species don't benefit from higher CO_2 levels.

The impact of enhanced CO_2 levels is calculated by AquaCrop itself. AquaCrop uses for this the so-called normalized water productivity (WP*) for the simulation of aboveground biomass. The WP is normalized for the atmospheric CO_2 concentration and for the climate, taking into consideration the type of crop (for example, C3 or C4). AquaCrop considers 369.47 parts per million by volume as the reference. It is the average atmospheric CO_2 concentration for the year 2000 measured at Mauna Loa Observatory in Hawaii. This is the concentration used for the analysis without CO_2 fertilization. Other CO_2 concentrations will alter canopy expansion and crop water productivity.

The effect of CO_2 increase on crop growth is still under debate. Many experiments have been done, most under laboratory conditions. However, crops in field conditions usually are grown in dense populations where they compete for space and light. Under more realistic field conditions, crop plants are likely to respond as a community rather than individual plants wherein light (solar radiation) becomes a limiting factor for growth. Under these conditions, elevated CO_2 cannot promote horizontal expansion and greater light capture (Bazzaz and Sombroek 1996). In general, knowledge is still lacking on the CO_2 responses for many crops. Some experimental data exist on the effects of elevated CO_2 on crops under both optimal and limiting conditions. However, scaling this knowledge to farmers' fields and even further to regions, including predicting the CO_2 levels beyond which saturation may occur, remains a challenge (Tubiello, Soussana, and Howden 2007).

Estimating Effect of Irrigation Water Shortages on Crop Yields

As a key step in evaluating impacts of climate on agricultural yields, the results of the crop and water impact analyses (AquaCrop and WEAP) were combined to evaluate how crop yields may be affected by reductions in basin-level water availability. To adjust mean changes in the irrigated crop yields (developed from the crop modeling without constraints on water availability) for the 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 would receive the percentage of water that WEAP projects will be available at the basin level. For example, WEAP projects an irrigation water deficit of 7.9 percent in FYR Macedonia's Pcinja basin under the medium-impact scenario in the 2040s; from this it was assumed that each farm in the Pcinja basin receives 92.1 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 receives less water (that is, deficit irrigation), or meet all the irrigation needs of a fraction of the crops, leaving the remaining fraction unirrigated. The optimal approach taken at the farm level 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) would 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 would 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 (Ky). 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 (FAO 1998). FAO has aggregated these seasonal factors into a single coefficient for the entire growing season. For Ky values less than 1, deficit irrigation causes crop yields to fall less than the water deficit, whereas Ky values greater than one result in higher yield losses relative to the water deficit. For example, if Ky 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 Ky value for another crop is 1.1, the resulting yield loss will be 11 percent.

Table A.4 presents the growing season Ky values for a sample of crops from FAO's CropWat decision support tool. Note that only grapes have an overall growing season Ky value less than 1, so deficit irrigation will reduce yield losses for only that crop.

These factors were 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 Ky values greater than one and no deficit irrigation will take place. As a result, less area will be irrigated and

Table A.4 Ky Values for Sample Crops, as Derived from CropWat

Crop	*Ky*[a]	*FAO crop name*
Maize	1.25	Maize
Wheat	1	W. Wheat
Alfalfa	1	Alfalfa 1
Grapes	0.85	Wine grapes
Vegetables	1.1	Peppers, tomatoes >1

Source: CropWat (FAO 2010).
a. Yield response factor.

farm-level crop yield will fall by the water deficit percentage. At the low-end, crops have Ky values less than one and crop yields fall by the water deficit percentage multiplied by the Ky value. The result is estimates of mean decadal changes in irrigated crop yields, adjusted for water availability.

CLIRUN Modeling

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 runoff data from gauging stations located within each country. R-squared values for the CLIRUN calibration were generally high, between 0.7 and 0.9 at the basin scale, and deviations between observed and modeled runoff ranged from less than 1–5 percent, indicating a strong relationship between observed runoff and runoff modeled from precipitation and potential evapotranspiration (PET) inputs. Once calibrated, CLIRUN uses monthly precipitation and PET projections under the three climate scenarios to project rainfall runoff in each basin.

WEAP Modeling

A water availability analysis was conducted at the river basin level using the Water Evaluation And Planning tool (WEAP), which compares forecasts of water demand for all sectors, including irrigated agriculture (from AquaCrop or DSSAT), with water supply results under climate change derived from the CLIRUN model. In each country, the team delineated major river basins to be used as the unit of analysis in WEAP (see chapter 1, map 1.1) for each of the four countries. Some of these basins extend beyond the borders of the subject countries, but the focus of the study was on changes in water supply and demand within the territory of each country. 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.

In the WEAP model, irrigation water withdrawals in each river basin were estimated based on the total hectares of irrigated land, per hectare estimates of crop irrigation requirements from the crop modeling step, 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 (FAO 2011).

To account for potential conflicts between irrigation and other water uses, water demand forecasts for other sectors were also incorporated into the WEAP model. Specifically, forecasts for municipal and industrial (M&I) demand for water through 2050 were used from the World Bank (Hughes, Chinowsky, and Strzepek 2010). M&I demands represent approximately 30 percent of current water use in FYR Macedonia, for example, relative to agriculture. The World Bank forecasts these demands will rise from 630 million m^3 in 2010 to peak at 708 million m^3 in 2030, and then fall to 625 million m^3 by 2050. This pattern is primarily attributable to per capita projections of M&I demands that peak in 2030 and then fall as FYR Macedonia becomes more developed, coupled with a relatively level trend in population. In absence of information on the exact location of M&I water uses, these demands for each basin were allocated based on the population of each basin, which was derived from Columbia University's Gridded Population of the World database (SEDAC 2011).

The WEAP model utilizes the 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 were performed on a monthly time scale between 2011 and 2050 for a base-case 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 were linked between upstream and downstream basins, and reservoirs, irrigation, and M&I 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. These data were provided by the International Commission on Large Dams (ICOLD 2010) and, in some cases, local sources that summarize reservoir volumes by location (for example, see Berga 2006).

Transboundary flow agreements. Also a critical determinant of water available in each country, these agreements were researched and paramaterized for each subject country. In the WEAP model, the assumptions were that these sharing arrangements would 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. It is assumed that a minimum flow requirement of 20 percent of water resources is dedicated to environmental purposes.

Several important limitations to the WEAP analysis are as follows:

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 (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. Decreasing 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.

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 were 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.

Analytic Step 5: Select and Categorize Adaptation Options for Each AEZ and Country

Table A.5 lists the overall scope for the adaptation assessments in the following four categories of options:

1. *Infrastructural Adaptations*. These are “hard” adaptation options that involve improvements of agriculture sector infrastructure, including water resources infrastructure improvements or expansions that are specifically targeted toward water available for irrigation.
2. *Programmatic Adaptations*. These adaptations strengthen existing programs or create new ones.
3. *Farm Management Adaptations*. These are farm-level adaptation measures that can be taken up by individuals with or without government or collective support. They make up the largest portion of the list.
4. *Indirect Adaptations*. Options not directly aimed at the agriculture sector, but that would benefit agriculture, are included here.

Options that were evaluated quantitatively are in bold in table A.5.

Analytic Step 6: Conduct Adaptation Assessment

As described in chapter 2, the adaptation options were evaluated based primarily on four criteria: (1) net economic benefits (quantified where possible or based on expert assessment otherwise); (2) robustness to different climate conditions; (3) potential to aid farmers with or without climate change, otherwise referred

Table A.5 Adaptation Options for Consideration

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

Table A.5 Adaptation Options for Consideration *(continued)*

Category	*Adaptation measures and investments*
Land management	More turning over of the soil Strip cropping, contour bunding (or plowing), and conservation farming Switch to crops, varieties appropriate to temperature, precipitation Optimize timing of operations (planting, inputs, irrigation, harvest) Allocate fields prone to flooding from sea level rise as set-asides Mixed farming systems (crops, livestock, and trees) Shift crops from areas that are vulnerable to drought Switch from field to tree crops (agro-forestry)
Livestock management	Livestock management (including animal breed choice, heat tolerant, change shearing patterns, change breeding patterns) Match stocking densities to forage production Pasture management (rotational grazing, etc.) and improvement Rangeland rehabilitation and management Supplemental feed Vaccinate livestock
Pest and fire management	Develop sustainable integrated pesticide strategies Fire management for forest and brush fires Integrated pest management Introduce natural predators
Water management	Intercropping to maximize use of moisture Optimize use of irrigation water (e.g., irrigation at critical stages of crop growth, irrigating at night) Use water-efficient crop varieties
4. Indirect adaptations	
Market development	Physical infrastructure and logistical support for storing, transporting, and distributing farm outputs
Education	Increase general education level of farmers
Water management	Improvements in water allocation laws and regulations Institute water charging or tradable permit schemes

to as “win-win” potential; and (4) favorable evaluation by stakeholders. Because of data limitations, not all options were evaluated quantitatively.

The quantitative assessments of benefits and costs were conducted at the farm level on a per hectare basis; they consider available estimates of the incremental cash costs for implementing the option as well as the revenue implications of increasing crop yields. All of the estimates were generated for representative “model” farms, located in each AEZ, which cultivate each of the key crops identified by each country’s government representatives. The yield benefits for adaptation options were analyzed for most crops using AquaCrop, with the exception of Moldovan wheat, maize, and pasture where the DSSAT system was used.

The results provide a first-order assessment of actions that are likely to yield positive returns for farmers. However, no conclusions were made in this analysis about the farmers' ability to pay for these measures. For example, while 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 farmers should 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. Therefore the results are useful for decision making at the national or regional scale, with the target decision-making audience being government policy makers and donor communities with interest in financing agricultural sector investments.

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, as part of the overall recommendations.

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 infrastructural 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 were derived from AquaCrop modeling and input from the Decision Support System for Agrotechnology Transfer (DSSAT) process model.[3]

Management multiplier to convert from experimental to field yields. These were developed by the study team in consultation with local experts as part of the capacity building work of the study.

Crop prices through 2050. National crop price data from FAO for current conditions were used to develop price projections under two scenarios: one with constant prices and one based on an IFPRI global price change forecast (see Nelson et al. 2010).

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, and sensitivity analyses were conducted using a 10 percent discount rate.

Capital and operations and maintenance (O&M) costs of each adaptation input. Local data (for example, on irrigation infrastructure) were requested to characterize costs of adaptation options, and in some cases they were provided. Overall, these can be difficult to obtain or generalize, and as a result, in many cases the study team used estimates derived from prior work.

Table A.6 provides more detailed documentation of sources for the key parameters for the economic analysis.

Table A.6 Adaptation Analysis Parameter Values

Parameter	*Value*	*Source*	*Comment*
General			
Discount rate	5%	Prior climate studies (e.g., EACC)	Real discount rate
Dollar year	2010 U.S. Dollars	U.S. Bureau of Economic Analysis	All costs updated to 2010 dollars using the GDP Implicit Price Deflator (*source:* U.S. Bureau of Economic Analysis)
Irrigated hectares	Varies by country	Ministry of Agriculture or FAO AquaStat	Used to distribute national adaptation cost estimates (e.g., hydromet, extension) across hectares. Conservatively assumes benefits only apply to irrigated hectares.
Crop revenues			
Crop yields	Vary	Crop yield modeling	Dimensions were 40 years x 8 crops x 2 irr/rainfed x 3 scenarios x 2 CO_2 x 4 AEZs (many elements of which were blank)
Harvested crop prices	Vary	FAO PriceSTAT	Includes price per tonne of fresh yield for grapes, maize, olives, tomatoes, watermelon, and wheat
Net revenues from grazing land	US$558/ha/year (mean across AEZs)	FAO PriceSTAT and in-country sources	Net revenues for each livestock type in each AEZ were coupled with per ha stocking rates from FAO. A linear relationship is assumed between yield and stocking rates, and thus between yield and per ha livestock net revenues for irrigated and rainfed alfalfa, and rainfed pasture. Value at left applies to mean irrigated alfalfa yields.

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Table A.6 Adaptation Analysis Parameter Values *(continued)*

Parameter	*Value*	*Source*	*Comment*
Crop price projections	Low: no increase High: 0.0183% increase per year	Nelson et al. (2010, table 2.2)	High increase based on "pessimistic" maize price increase of 106.3% over 40 years (that is, 2.063^(1/40) = 1.0183)
Fertilizer costs			
Nutrient volumes	35 kg/ha N, 10 kg/ha P, and 15 kg/ha K	FAO	Crop modeling assumed 10–20% less fertility stress. FAO shows about 20–50 kg/ha N, around 10 kg/ha P and 10–20 kg/ha K are needed to address this.
Fertilizer types	Urea (CH_4N_2O), superphosphate (P_2O_5), and potash (K_2O)	Barbarick and Westfall (1982)	Ratios of fertilizer volumes to nutrient volumes: 2.22, 2.29, and 1.21
Total amount of additional fertilizer	118.8 kg/ha	FAOSTAT (www.faostat.fao.org) and Barbarick and Westfall (1982)	Sum product of the nutrient volumes required and the fertilizer volume ratios above.
Fertilizer costs	Varies by country (e.g., Albania = US$73.52 per ha)	In-country sources, including written communication with country focal points	The average farm currently uses 210 kg of fertilizer per ha at a cost of $130 (that is, $0.62 per kg). It is assumed that the costs for the additional fertilizer are at this rate. Alternatively, a Colorado State article and an article from Agrimoney.com indicate that the urea price is US$0.33 per kg, US$0.31 per kg of superphosphate, and US$0.43 per kg of potash. In total, the additional costs would be US$40.56 based on these unit costs. The higher estimate was adopted based on in-country sources.
Irrigation costs			
Capital costs, new system	US$5,977 per ha	Inocencio et al. (2005)	Mean costs of new global irrigation projects, updated from 2000 dollars
Capital costs, rehabilitated system	US$550 per ha in the lowlands, US$1,100 per ha in other AEZs	Written communication with in-country focal points.	Mean cost of rehabilitated irrigation project in Albania. This is a low estimate, however. Inocencio et al. (2005) estimate rehabilitation to cost an average of US$2,460 per ha. A World Bank IRC for Albania from an irrigation and drainage project initiated in 1999 indicates average costs of US$390/ha (2010 dollars).
O&M costs	US$156 per ha	Smathers, King, and Patterson (1995)	Average per ha O&M costs (excluding ownership costs) for five different types of irrigation systems. Updated from 1995 dollars.
System life	20 years	Internal expert team assessment	

Table A.6 Adaptation Analysis Parameter Values *(continued)*

Parameter	*Value*	*Source*	*Comment*
Drainage costs			
Capital costs, new system	US$663 per ha	World Bank (2005b) Shaping the Future of Water for Agriculture.	Full range cited as $200 to $1,000 in 2005, where the low end is for surface drainage systems and the high end is for subsurface piped systems. Authors estimate roughly US$500 per ha for subsurface ditch systems.
Capital costs, rehabilitated system	US$196 per ha	IRC on Albania (World Bank 2005a)	Average per ha costs for 90,000 ha that were rehabilitated in a 1999 World Bank project. The reasonableness of this estimate was confirmed by written communication with Tatjana Dishnica of the Ministry of Agriculture in February 2011.
O&M costs	2.5% of capital costs	World Bank (2005b)	Implies that annual O&M costs are US$16.60. Full range cited in study is 2–3% of capital costs.
System life	20 years	Internal team expert assessment	
Hail net costs and benefits			
Increased yield from hail protection	+8.21 to +27.6%	Hagelschutz Fruit Security (www.fruitsecurity.com)	This range is revenue increases based on two scenarios: (1) 80 percent of crops are damaged in hail events that occur every two years, and (2) 80 percent of crops are damaged in hail events that occur every five years. These damaged crops fall into a lower price category and thus reduce revenues. Revenues are utilized because both changes in yield and quality were considered. With hail nets, 5 percent of crops were assumed to be affected through a "splash" effect.
Capital costs	US$19,285 per ha	Iglesias and Alegre (2006)	The total cost of net installation (nets, poles, poles anchorages, rented machinery, net installation, labor, etc.): €14,358 ha/yr. Apply 2006 exchange rate of US$1.255 per €1.00. (http://www.oanda.com/currency/historical-rates). Note that based on an online search of commercial hail net costs, this value is near the low end of per ha costs.
O&M costs	US$2,165 per ha	Iglesias and Alegre (2006)	€1,612 ha/yr (Apply 2006 exchange rate of US$1.255 per €1.00; http://www.oanda.com/currency/historical-rates)
System life	15 years	Iglesias and Alegre (2006)	

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Table A.6 Adaptation Analysis Parameter Values *(continued)*

Parameter	*Value*	*Source*	*Comment*
Hydrometeorological forecasting stations costs			
Number of hydromet stations	Varies by country	Personal communication with in-country focal points	
Capital costs	US$18,477 per automated station	World Bank (2008)	Includes costs of automated weather stations, new modems, computer platforms and software to access and display precipitation data from radar, a dedicated forecaster workstation system, and training staff at forecast centers. Conversion from 2008 MDL to US$ from http://www.oanda.com/currency/historical-rates.
Annual costs	US$1,339 per automated station	World Bank (2008)	Annual support for the dedicated forecaster workstation.
Extension services costs			
Annual costs	Varies by country (Albania, e.g., was estimated at US$530,965)	Personal communication with in-country focal points	Illustration of calculations for Albania: • Improve infrastructure of agricultural information centers: €2250 per center *100 centers = €225,000. • Training of 221 specialists: €147,815. • Publishing (leaflets, brochures, etc.): €18,000. • Other activities: €10,000. Total: €400,815. Converted using 2010 exchange rate of US$1.325 per €1.00 (http://www.oanda.com/ currency/ historical-rates).
Percentage of farmers reached by extension services	Varies by country (Albania, e.g., value was 70%)	Personal communication with in-country focal points	Range is 60–80%.
Research, development, and selection of new crop varieties			
Capital costs	US$189/ha	World Bank (2001)	Assumes 7,000 ha benefit, according to assumptions in the Project Assessment Document (PAD) (World Bank 2001) (although this is acknowledged to be conservative). Expenditures are assumed for education, research, seed development, and training within a national seed institute, the Agricultural University, and seed research institutions. The World Bank study assumed increases of 5–15% in yields.
Annual costs	US$8.19/ha	World Bank (2001)	Ongoing cultivation and hybrid development expenses and education. Project Assessment Document assumes these programs benefit 7000 ha.

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 to 31 temperatures for every year in the 2030s will be the temperatures during Januarys between 1994 and 2003 plus two degrees.
3. Although not employed in the impact assessment, the Decision Support System for Agrotechnology Transfer (DSSAT) was utilized to generate adaptation multipliers for improved fertilizer application and improved crop varieties. DSSAT is a decision support system used to facilitate simulations of crop responses to climate and management. The DSSAT software includes over 20 models for the main food and fiber corps; many of the models were specifically developed for climate change impact studies with findings provided by international agencies (USAID, UNEP, UNDP, among others) and have been calibrated and validated in a few hundred sites in all agro-climatic regions. The DSSAT models have been used widely for evaluating climate impacts in agriculture at different levels ranging from individual sites to wide geographic areas. This type of model structure is particularly useful in evaluating the adaptation of agricultural management to climate change.

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APPENDIX B

Glossary

Source of definitions is IPCC (2007, Appendix I: Glossary), unless otherwise noted. Italics in glossary definitions 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).

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 mm 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 byproduct 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).

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—i.e., their sensitivity or social vulnerability. Risk can also be considered as the combination of an event, its likelihood and its consequences—i.e., 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 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 mm 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 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.

General 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 hexafluorisde (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.

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 mm 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*, 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 mm 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) (IPCC 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.

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*.

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Agriculture is one of the most climate-sensitive of all economic sectors. In many countries, such as the four examined in *Looking Beyond the Horizon*, the risks of climate change are an immediate and fundamental problem because the majority of the rural population depends either directly or indirectly on agriculture for its livelihood.

The risks of climate change to agriculture cannot be effectively dealt with—and the opportunities cannot be effectively exploited—without a clear plan for aligning agricultural policies with climate change, developing the capabilities of key agricultural institutions, and investing in infrastructure, support services, and on-farm improvements. Developing such a plan ideally involves a combination of high-quality quantitative analysis; consultation with key stakeholders, particularly farmers and local agricultural experts; and investments in both human and physical capital. The diverse experiences of Albania, the former Yugoslav Republic of Macedonia, Moldova, and Uzbekistan, highlighted in this book, show that it is possible to develop a plan to meet these objectives—one that is comprehensive and empirically driven as well as consultative and quick to develop.

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."

Looking Beyond the Horizon draws on the experiences of applying this approach to these four nations in Eastern Europe and Central Asia with the goal of helping each country mainstream climate change adaptation into its agricultural policies, programs, and investments. The book also highlights the projected impacts of climate change on agriculture in these countries through forecast variations in temperature and rainfall patterns, which are crucial to farming, and offers a map for navigating the risks and realizing the opportunities. Finally, a detailed explanation of the approach, as well as lessons learned from its implementation, is provided for those who would like to implement similar programs in other countries of Europe, Central Asia, or anywhere else in the world.

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