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A WORLD BANK STUDY

Reducing the Vulnerability of the Former Yugoslav Republic of Macedonia's Agricultural Systems to Climate Change

IMPACT ASSESSMENT AND ADAPTATION OPTIONS

William R. Sutton, Jitendra P. Srivastava,
James E. Neumann, Kenneth M. Strzępek,
and Brent B. Boehlert

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Preface

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

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

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

Specifically, this report provides a menu of climate change adaptation options for the agriculture and water resources sectors, along with specific recommendations for adaptation actions that are tailored to distinct agro-ecological zones (AEZs) within FYR Macedonia. Recommendations reflect the results of three inter-related activities, conducted jointly by the team and local partners: (1) quantitative economic modeling of baseline conditions and the effects of climate change and an array of adaptation options; (2) qualitative analysis conducted by

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

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

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The report was prepared by a team led by William R. Sutton when he was in the Sustainable Development Department in the Europe and Central Asia Region of the World Bank, together with Jitendra P. Srivastava, and James E. Neumann, Kenneth M. Strzępek, and Brent B. Boehlert of the consulting firm Industrial Economics, Inc. (IEc). We are grateful to Dina Umali-Deininger, Sector Manager, Agriculture and Rural Development, Sustainable Development Department, Europe and Central Asia Region, for the valuable support and guidance. We would like to thank the Country Director, South East Europe Country Unit, and the Country Manager for FYR Macedonia, for their support in furthering the agenda on climate change and agriculture.

Members of the IEc team also include Richard Adams, Samuel Fankhauser, Johannes Hunink, Sonia Quiroga, Andrew Schwarz, Richard Swanson, and Ordan Kukaliev. The World Bank team also comprised Ana Bucher, Åsa Giertz, Gretel Gambarelli, John Mackedon, Brendan Lynch, Bekim Ymeri, Sunanda Kishore, and Luan Aliu.

From the government of FYR Macedonia, we are grateful for policy guidance and support provided by the Ministry of Agriculture, Forestry and Water Economy, and the Ministry of Environment and Physical Planning, to the steering committee, chaired by Lidija Cadikovska, Head of the Department for International Cooperation, MAFWE, and Nadica Dzerkovska, without which this study would not have been possible. Other members of the steering committee included representatives from the Ministry of Environment and Physical Planning, the Hydrometeorological Institute, Ss. Cyril and Methodius University, Federation of Farmers of the Republic of Macedonia, and the National Extension Agency. The study greatly benefitted from the important contributions made through valuable inputs, comments, advice, and support provided by academia, civil society and NGOs, farmers, the donor community, and development partners in Macedonia throughout this program.

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Abbreviations

AAA	Analytical and Advisory Activities Program
AEZ	agro-ecological zone
B-C ratio	benefit-cost ratio
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
FFRM	Federation of Farmers of the Republic of Macedonia
GCM	global circulation model
GDP	gross domestic product
GIS	Global Information Systems
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
MAFWE	Ministry of Agriculture, Forestry and Water Economy
MEPP	Ministry of Environment and Physical Planning
NPV	net present value
O&M	operations and maintenance
SEI	Stockholm Environment Institute
SPAM	Spatial Production Allocation Model
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WEAP	Water Evaluation and Planning System

Executive Summary

Introduction

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

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

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

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

In order to be effective, a plan for adapting the sector to climate change must strengthen both human capital and physical capital in their capacity. Many of these investments would also yield instant returns under current

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climate conditions, in terms of increased agricultural productivity and improved competitiveness of the agricultural sector. However, the capacity to adapt to climatic changes, both in mitigating risks and in taking advantage of the opportunities that climate change can create, is in part dependent on financial resources, and adaptive capacity is therefore particularly low among smallholder farmers in emerging economies, who have limited access to financial resources. As a result, development partners will continue to have an important role in enhancing the adaptive capacity of the Macedonian agricultural sector.

Another key factor for FYR Macedonia's development of an adaptation plan for agriculture is furthering FYR Macedonia's work toward European Union (EU) accession, for which FYR Macedonia has been a candidate since 2005. The Macedonian government has already begun to focus on required EU reforms, including work on the Agriculture Strengthening and Accession Project with the World Bank. Along with these needed reforms, the EU encourages action toward climate change preparedness and adaptation. As outlined 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. The White Paper also stresses the need to integrate cost-effective adaptation to climate change in the EU Rural Development Policy, sometimes referred to as the "second pillar" of the Common Agricultural Policy.

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

The approach for this study was centered on four objectives:

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

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

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

Challenges and Opportunities for FYR Macedonia's Agricultural Sector

The study revealed a number of challenges and opportunities for FYR Macedonia's agricultural sector under predicted climate changes:

- *Temperature will increase and precipitation will become more variable in FYR Macedonia as a result of climate change.* These findings are consistent with recent changes in climate in FYR Macedonia, that will persist and grow more severe over the next few decades.
- *Farmers in FYR Macedonia are not suitably adapted to current climate.* This effect is sometimes called the "adaptation deficit," which in FYR Macedonia is considerable. As a result, many of the climate adaptation measures recommended in this report can have immediate benefits in improving yields, as well as improving resiliency to future, more severe climate change.
- *The direct temperature and precipitation effects of future climate change on crops are mixed.* Preliminary results suggest that the direct effects of climate change on irrigated crops may be positive in areas where sufficient water will be available. For example, climate change is forecast to have the potential to improve yields of several irrigated crops in the Mediterranean and Continental AEZs. Meanwhile, yields of most rainfed crops in these AEZs are expected to decline. Climate change will seemingly increase yields of crops grown under rainfed as well as under irrigation in the Alpine AEZ. Wheat yields could significantly increase across all AEZs, whereas rainfed maize yields are predicted to decline in the Mediterranean and Continental AEZs. Yields of high-value rainfed fruit crops, such as apples and grapes, as well as vegetables are expected to decrease in the Mediterranean and Continental AEZs. Irrigated vegetable yields are expected to increase in the Mediterranean and Continental AEZs, in those areas where sufficient irrigation water is available.
- *The effect of climate change on crop yields in areas where irrigation water shortages are forecast will be substantially negative*. Water resources are currently abundant in some regions. However, based on modeling of future water supply and demand under climate change, water shortages are forecast for the Crna and Pcinja basins under most climate change scenarios. In other words, there will be insufficient water available to irrigate crops even where functioning

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irrigation infrastructure is available. Increased demand for water during the May through September period, coupled with decreases in runoff in the June through October period, will likely lead to crop losses of up to 50 percent for all irrigated agriculture in the Crna basin.

- *Direct effects of climate change on the livestock sector could be negative over time.* While methods to reliably quantify the effects from climate change on the livestock sector are currently not applicable to FYR Macedonia, it can be expected that the temperature stress effect on livestock is gradual over time, rather than immediate. Farmers also confirm that they have not seen an immediate effect of climate on their livestock production.
- *National-level adaptation and capacity building is a high priority.* While decreasing the adaptation deficit of the sector is a long-term process, there are several measures that could be undertaken immediately to strengthen the sector's adaptive capacity. These include expanding extension service capacity, improving provision of on-time meteorological forecasts to farmers, encouraging consolidation of farmland into larger holdings to facilitate more substantial investments in on-farm technology, and encouraging private sector efforts to adapt to climate change. Also offering high benefit-cost ratios are: national-level studies that specifically map and assess the functionality of existing irrigation and drainage capacity (particularly in flood-prone areas), research and development activities to identify improved varieties and breeds of animals, information dissemination and farmer training, short-term weather forecast information, and the efficient use of water. These activities were also identified by farmers during consultation meetings.
- *At the agro-ecological zone (AEZ) and farm levels, high-priority adaptation measures include: improving and/or augmenting irrigation infrastructure, particularly in the Continental AEZ, optimizing water use efficiency at the farm level (all AEZs), and providing more climate resilient seed varieties and the know-how to cultivate them effectively for high yields (all AEZs).* Irrigation water shortages in the Southwest regions appear likely and can be addressed through a range of adaptive measures. Such measures include farmer training to ensure more efficient on-farm use of water during dry seasons; additional investment in the current irrigation and drainage infrastructure to make better use of available water resources in the agricultural sector; and new water storage. At the same time, climate change could exacerbate existing flooding issues in some areas, requiring rehabilitation of drainage capacity. All of these measures also have high benefit-cost ratios and are favored by Macedonian farmers.

Table ES.1 provides a summary of the key findings including the climate change impacts (incorporating assessments of sensitivity, adaptive capacity, and vulnerability), climate hazards that cause those impacts, and the adaptation options to address the impacts at both national and AEZ-levels. A check mark indicates that the corresponding adaptation option will either reduce the climate change impact directly or will do so indirectly by closing the adaptation deficit.

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Table ES.1 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 dissemination of hydro- meteorological information to farmers*	*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	✓	✓	✓	✓	✓	✓				
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	✓	✓	✓		✓		✓	✓		

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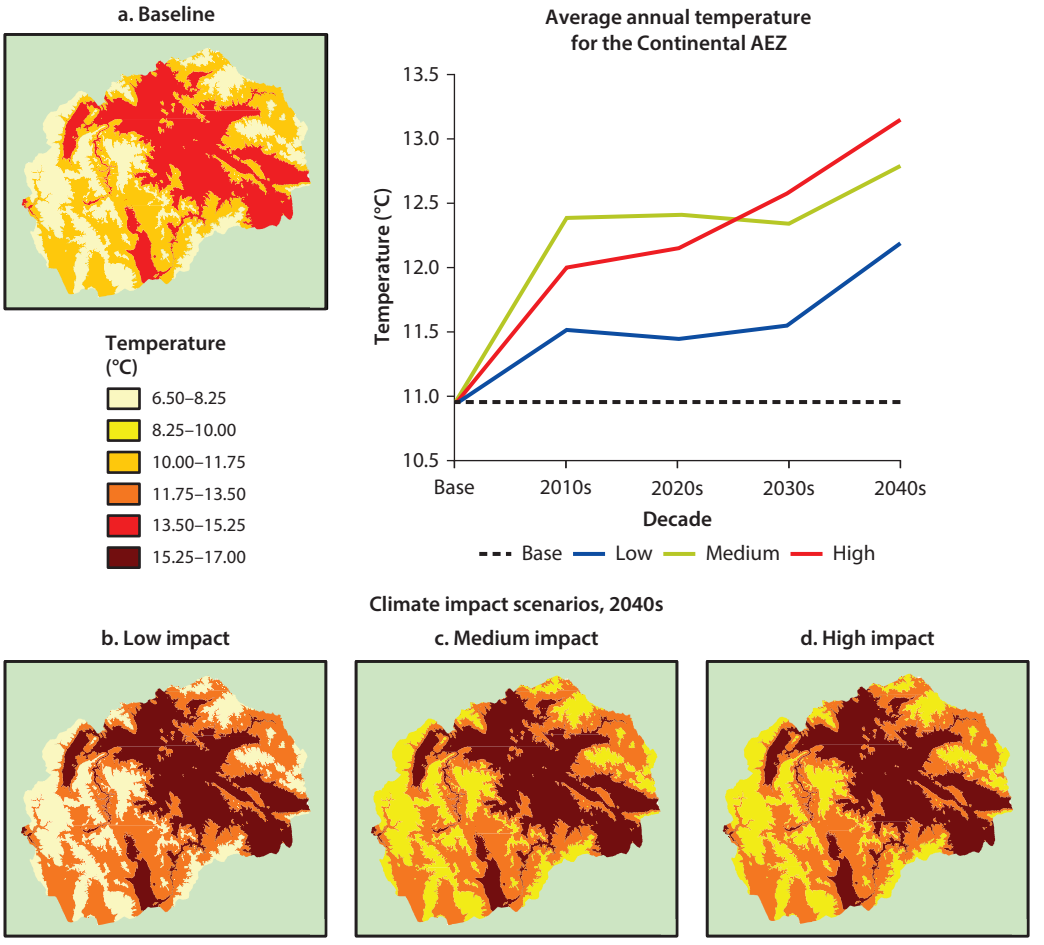
Vulnerability of FYR Macedonia's Agriculture to Climate Change

Analysis of recent climate data and information gathered from farmer workshops both support an increasing trend in temperature in FYR Macedonia. Farmers have also observed an increasing trend in extreme heat events. The analysis indicates that this trend will accelerate in FYR Macedonia in the near future, as shown in map ES.1. Although uncertainty remains regarding the degree of warming that will occur in FYR Macedonia, the overall warming trend is clear and is evident in all three AEZs. Over the next four decades, the average increase in temperature will be about 1.8°C, much greater than the increase of less than 0.2°C observed over the last 50 years.

Precipitation changes are more uncertain than temperature changes, as indicated in map ES.2. The medium-impact forecast indicates that national

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



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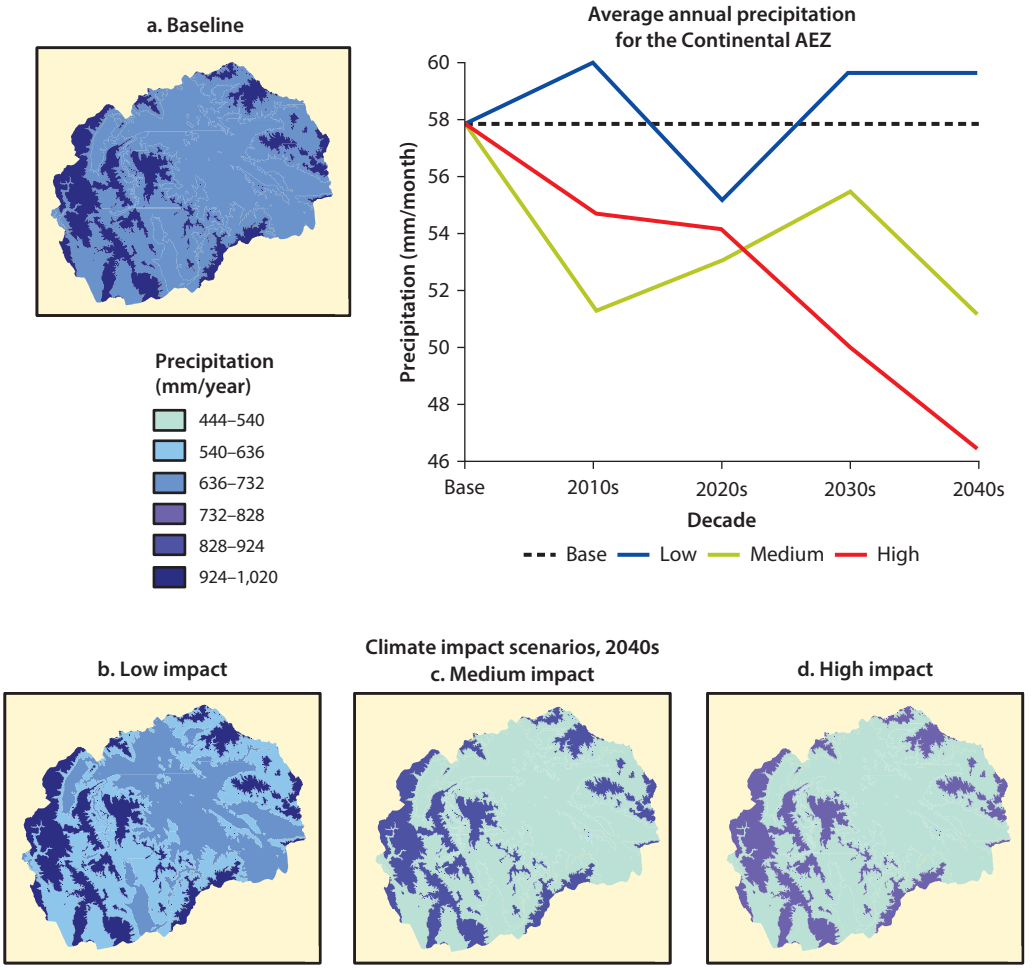
Map ES.2 Effect of Climate Change on Precipitation through 2040s for the Three Climate Impact Scenarios



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precipitation may decline by 8 millimeters in a given month by the 2040s. Most of this decline will occur in the Alpine AEZ, where annual precipitation could decline by up to 16 mm in a given month by the 2040s. The range of outcomes across the low- and high-impact alternative scenarios, however, is large, ranging 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. While the medium and high scenarios show significant declines in precipitation across AEZs, the low scenario reveals moderate increases.

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

current conditions. Over the next 50 years, the summer temperature increase can be as much as 4–5°C in the Continental AEZ of FYR Macedonia, which is more than twice as large as the annual average temperature change. In addition, forecast precipitation declines are greatest in the key May-to-September period, when current precipitation is already at its lowest.

These seasonal changes in climate have clear implications for crop production under current production methods.[1] Climate change impacts on crops production if no adaptation is implemented are summarized in table ES.2. The results show that yields of the key cereal crops from FYR Macedonia's agricultural sector, wheat and maize, will both increase and decrease across AEZs and climate scenarios, due to rising temperatures and water stress. Wheat yields significantly increase in all three AEZs, particularly in currently coolest Alpine AEZ. Yields for irrigated maize are also expected to increase under the medium-climate scenario, while rainfed maize yields are expected to decrease.

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. 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 experience increased yields by the 2040s under the medium-climate scenario.

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

% change

Irrigated/rainfed	*Crop*	*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.

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Climate change is likely to have significant implications for water resource management, particularly under the high-impact scenario, as climate change both increases irrigation water demand and, in the high-impact scenario, decreases overall water supply. For example, demand for irrigation water during the summer months is expected to increase by as much as 50 percent (relative to historic demand) by 2050, when overall water availability will have declined by an average of 30–40 percent (that is, during the 2040s) (figure ES.1). The net effect of the predicted rising demand and falling supply is a significant reduction in water available for irrigation.

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 ES.3—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.

Three climate change stressors therefore combine to yield an overall negative impact on crop yields in FYR Macedonia: (1) direct effect of temperature and precipitation changes on crops; (2) increased irrigation demand required to maintain yields; and (3) decline in water supply associated with higher evaporation

Figure ES.1 Estimated Effect of Climate Change on Mean Monthly Runoff, 2040–50

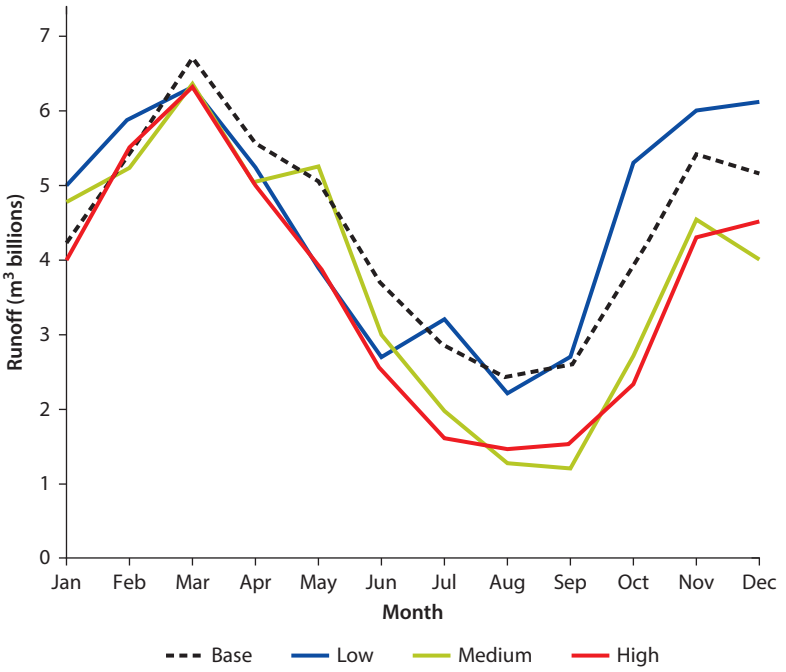

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Table ES.3 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario

	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

Table ES.4 Effect of Climate Change on Irrigated Crop Yield 2040–50 under the 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.

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and lower rainfall. All of these effects will have more impact during the summer growing season. The net effect of these three factors on irrigated agriculture is illustrated in table ES.4.

The direct effects of climate change on livestock also could be severe, but the methods available for quantitatively assessing effects on livestock are relatively untested. There is a robust literature establishing that temperature increases decrease livestock productivity, but suitable modeling tools for quantifying the effect in the Macedonian context are not available. The indirect effect of climate change on livestock feedstocks, including grasslands and alfalfa, would according to the analysis in this study be positive, and provides a counter-balance to the negative direct heat stress effects.

Stakeholder Consultations

Extensive stakeholder consultations with local government officials, farmers and local experts within the scope of this study conveyed several messages. These included:

- *Augmenting water supply.* Although groundwater wells are expensive options for farmers and many do not feel it is worth the cost, many have made this investment. Farmers also use water harvesting on smaller farms when irrigation water is not available. For example, some farmers have been placing rain capturing cans next to fruit trees with a small hole bored in the bottom.
- *Irrigation*. Applying water savings techniques such as drip irrigation, and irrigating crops not previously irrigated.
- *Hail and UV nets.* Orchard growers use hail and ultraviolet (UV) nets.
- *Plastic tunnels and green houses.* To moderate temperatures and improve yields, some farmers have been constructing plastic tunnels and houses for vegetables.
- *Mulching and polyethylene sheets.* These have been used as a water conservation technique.
- *Improve hydrometeorological information for farmers.* Currently there is no agriculture specific information available. Farmers are told when to apply pesticides over public radio, but given no information about timing of irrigation or crop phenology.
- *Improve quality of and access to extension and improved seed*. Improving access to and quality of extension services would improve farming practices. Although large state-owned farms are doing seed selection and these seed varieties are adopted by roughly half the farmers, the remaining half produce their own seeds and thus have yields that are about two-thirds of what they would be with improved varieties.
- *Land consolidation*. Small farm sizes were seen as a disincentive for proper investment.
- *Switch to appropriate crops/livestock varieties for a changing climate.* Farmers in all three AEZs ranked this as one of the most important adaptation responses,

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with a focus on gaining greater access to drought and heat tolerant varieties of both crops and livestock.

- *Rehabilitate irrigation and drainage infrastructure.* Generally, these recommendations focused on rehabilitating existing irrigation and drainage canals and installing more water conserving technologies such as drip irrigation. Because of the high water fees in FYR Macedonia, more efficient irrigation technologies can significantly reduce per hectare costs to farmers.
- *Build additional storage.* Both in the Crna River basin in southwestern FYR Macedonia and elsewhere, farmers recommend constructing either large- or small-scale reservoirs to store runoff from the spring months for irrigation during the summer. This measure is in part a response to declining snowpack, which had effectively stored water in higher altitude areas.

Menu of Adaptation Options

The proposed menus of adaptation options to improve the resilience of FYR Macedonia's agricultural sector to climate change are derived from the results of the quantitative modeling, qualitative analysis, and from the farmer consultations. The results reflect four criteria for prioritizing options from among a larger menu of 29 farm-level adaptation options, 14 infrastructure options, 13 programmatic options, and four indirect adaptation options. The four criteria are:

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

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

Options for National Policy and Institutional Capacity Building

Four measures for adoption at the national level were identified based on the qualitative analysis of potential net benefits by the team, together with recommendations from farmer stakeholder and expert groups.

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1. *Increase the access of farmers to technology and information through farmer education, both generally and for adapting to climate change.* The capacity of the National Extension Agency (NEA) should be improved in two areas: (1) to support better agronomic practices at the farm level, including implementation of more widespread demonstration plots and access to better information on the availability and best management practices of high-yield crop varieties, with a particular focus on drought- and pest-resistant varieties; and (2) to support the same measures but with a focus on maintaining yields during water stress periods that are likely be more frequent with climate change. The first part would be a short-term measure to close the adaptation deficit, and the second part a long-term measure to ensure yield gains are not undermined by future climate change. Investing in extension has a high benefit-cost ratio in the quantitative analysis.
2. *Improve capacity of hydrometeorological institutions.* There is a need for better local capabilities for hydrometeorological data, particularly for short-term temperature and precipitation forecasts. Those capabilities are acutely needed in the short term to support better farm-level decision-making. Economic analysis of the costs and benefits of a relatively modest hydrometeorological investment, which includes training, annual operating costs, land, and certain equipment, suggests that benefits of such investment are very likely to exceed costs.
3. *Consider policy measures to further consolidate farm holdings.* On-farm adaptive capacity is limited by the generally small size of many Macedonian farms. The consequence of small farms is an inability to provide sufficient economies of scale to invest in adaptive measures, such as tertiary irrigation systems and equipment that might both increase yields and reduce soil erosion.
4. *Encourage private sector measures to most efficiently adapt to climate change.* There may be a tendency to assume that adaptation to climate change is necessarily a public sector function, but as the economic analysis in chapter 1 demonstrates, there is strong private sector incentive—with economic benefits greatly exceeding costs—for measures that will improve the resiliency of Macedonian agriculture to climate change. The national government should focus on putting in place policies that enable the private sector to effectively assist in adaptation. An example would be to encourage the provision of inputs such as improved seed varieties and livestock breeds.

An overall set of adaptation measures at the national level were identified as indicated in figure ES.2, which links the climate change hazards to impacts, and then these impacts to the national-level adaptation options. Measures shaded in darker green represent options that were recommended by both the Bank team's assessment and the National Conference group. Adaptation options for each of the three AEZs are provided in figures ES.3, ES.4, and ES.5.

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Figure ES.2 Adaptation Measures at the National Level

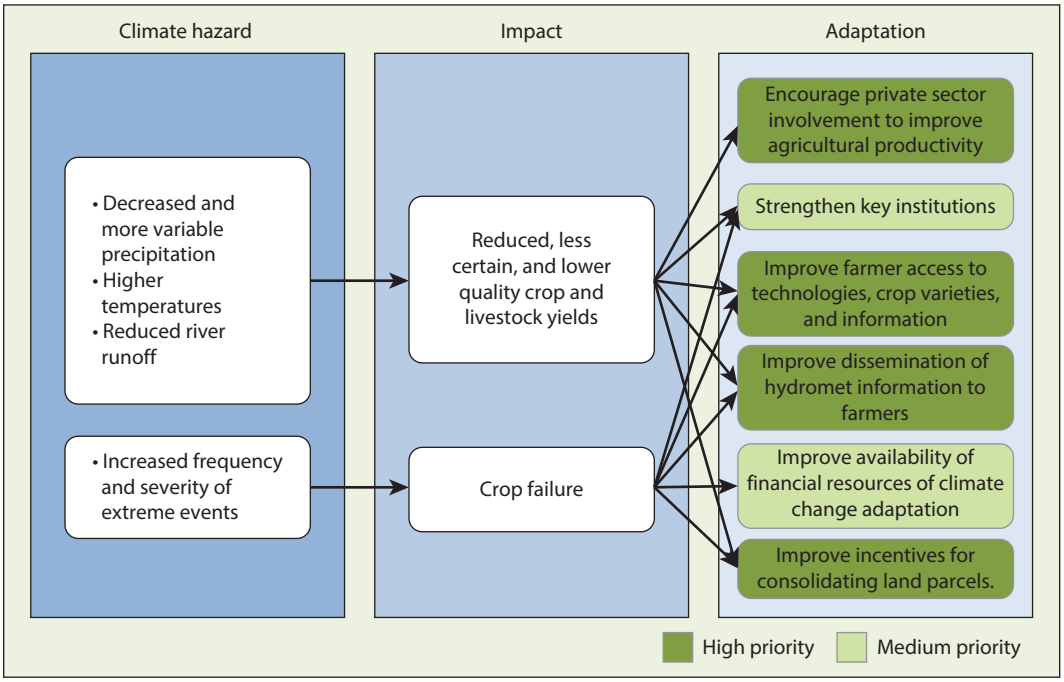

Figure ES.3 Adaptation Measures for the Mediterranean AEZ

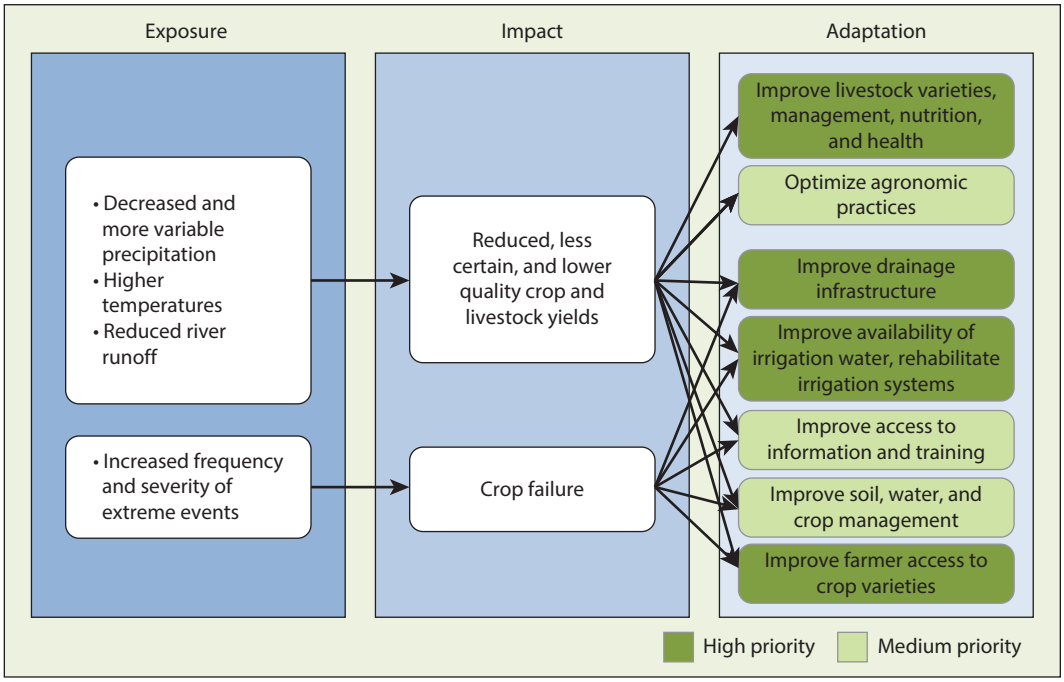

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Figure ES.4 Adaptation Measures for the Continental AEZ

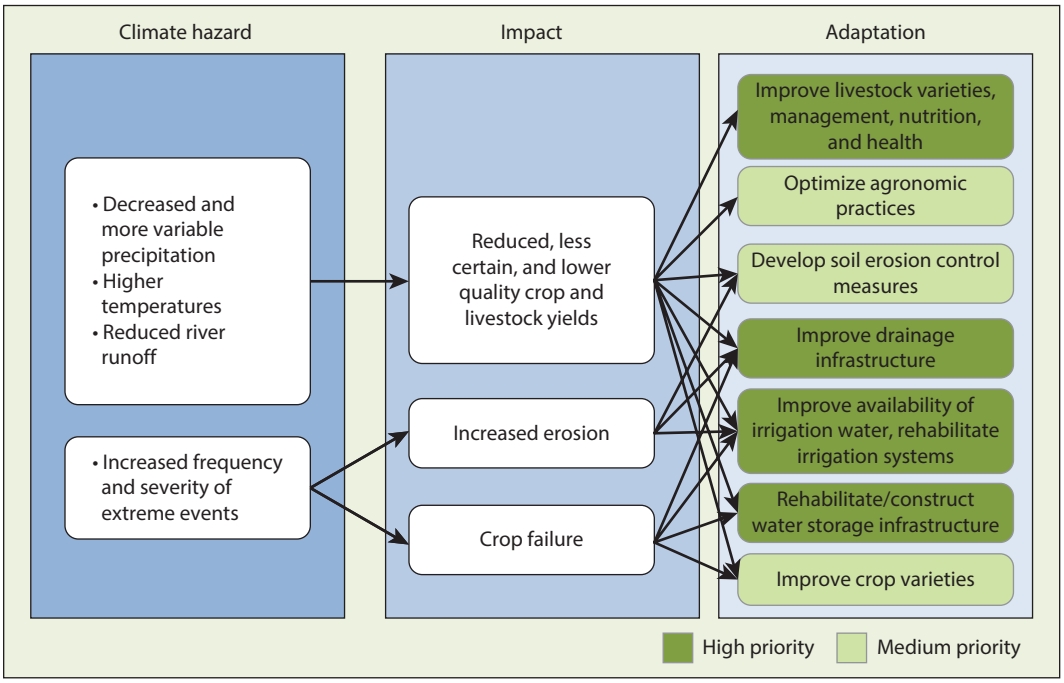
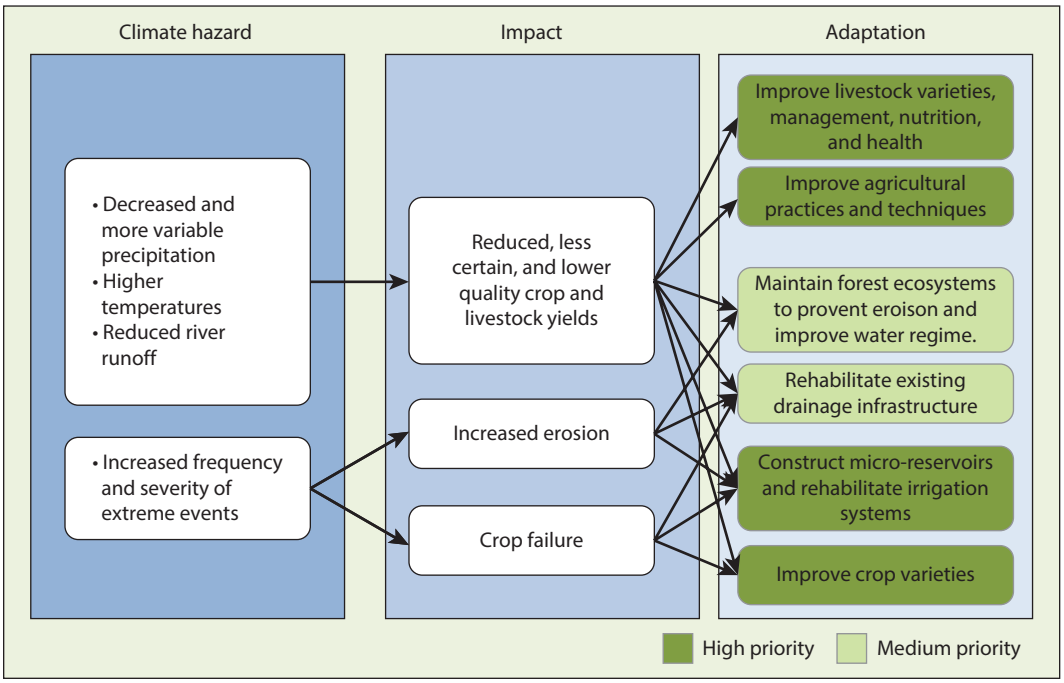


Figure ES.5 Adaptation Measures for the Alpine AEZ



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Options for Specific AEZs

As summarized in figures ES.3 through ES.5, a number of options emerge from the quantitative, qualitative, farmer, and National Conference evaluations of measures as most advantageous for adapting to climate change in each Macedonian AEZ.

Note

1. This assumes that no adaptation measures are adopted beyond those that farmers already employ, including some increases in the use of irrigation and changes in crop variety.

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CHAPTER 1

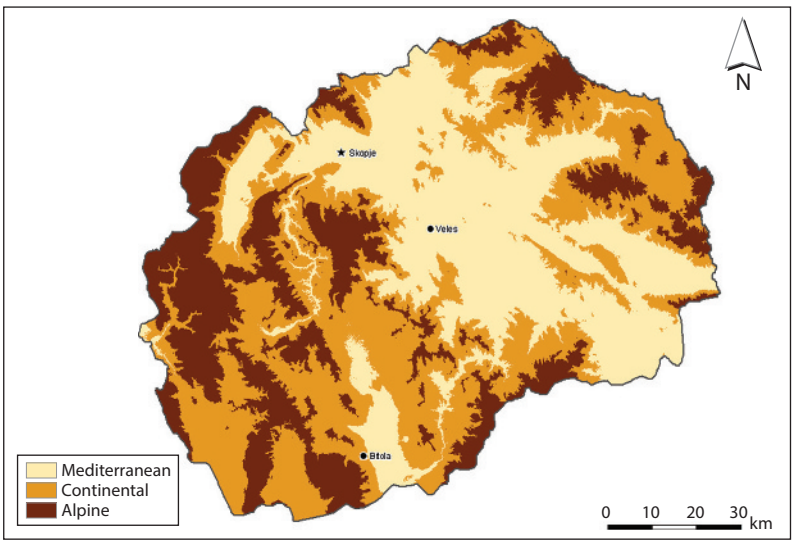
Current Conditions for Macedonian Agriculture and Climate

The Agricultural Sector in FYR Macedonia

The former Yugoslav Republic of Macedonia is located in south-eastern 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 (MEPP 2008). Administratively, FYR Macedonia is divided into 84 local municipalities and eight major regions (CIA 2011).

For the purposes of this study, FYR Macedonia was grouped into three agro-ecological zones, or AEZs, as shown in map 1.1. The area within each of these

Map 1.1 Agro-Ecological Zones in FYR Macedonia



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.

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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 will be similar within each AEZ, with differences between AEZs that are important for developing a specific adaptation plan.

The terrain of FYR Macedonia is primarily mountainous, with 79 percent of the country's territory comprised of hilly or mountainous land, while plains, the richest agricultural area, contribute 19.1 percent and water surfaces contribute 1.9 percent of land area (MEPP 2008). Approximately 20 percent of the country is cultivated land, approximately 19 percent is pasture (State Statistical Office 2010b), and about 37 percent is covered by forests (European Commission 2007). In map 1.1, the light color represents the Mediterranean zone at 50–600 meters above sea level, the middle color represents the Continental zone at 600–1,000 meters above sea level, and the darkest color represents the Alpine zone at 1,000 to greater than 2,250 meters above sea level. The Mediterranean zone is characterized by floodplains to undulating hills, with generally productive conditions and a high benefit of irrigation; the Continental zone is composed of highland plains to undulating hills and mountain slopes and is also relatively productive; and the Alpine zone is characterized by a mountainous terrain and harsh climate, with a lack of productivity and high poverty rates.[1] The terrain and change in relief from the mountains can result in some locations in high rates of soil erosion.

Recent Trends in Macedonian Agriculture

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 2009b). Agricultural contribution to gross domestic product (GDP) has slightly declined, from 13.26 percent in 1994 to 11.32 percent in 2009, as other sectors have grown faster than the agricultural sector (World Bank 2010). Although slightly declining in economic importance, FYR Macedonia is still an agrarian society with the agriculture sector providing 18.2 percent of total employment in 2007 (World Bank 2009b); some local sources indicate the figure is much higher.[2] However, with 34 percent of the population living in rural areas (World Bank 2009b), and with 36.3 percent of the rural population earning less than US$5 per day, much of FYR Macedonia's population is poor and highly vulnerable to any event that affects the agricultural sector (World Bank 2009a).

In 2008, the total output of agricultural production was more than US$1.8 billion and the net value added of agricultural production was US$839 million for the agricultural "industry" (State Statistical Office 2010b). As shown in table 1.1, about 30 percent of the value of production is accounted for in the livestock sector. Crops account for about two-thirds of the value of production, and services, non-agricultural secondary activities and subsidies account for the remainder.

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Table 1.1 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.
Note: Values do not add to total due to exclusion of services, non-agricultural secondary activities, and subsidies.
a. Used an exchange rate for 2008 of 41.94 MDen/US dollar.

Although cereal field crops such as wheat and maize are grown extensively and occupy 24 percent of cultivated land (see figure 1.1),[3] their contribution by value is only 11 percent of total crop output (State Statistical Office 2010b). It should be noted 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-elevation areas are unsuitable for high-value vegetable production and hence the reliance on more resilient, 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 in the area planted in wheat from the beginning of the current decade (see figure 1.1). Total crop area declined by about 13 percent from 2000 to 2008, while fruit crop areas increased by 8 percent (FAOSTAT 2009).

Figure 1.1 Area Planted by Crop in FYR Macedonia, 2000–09

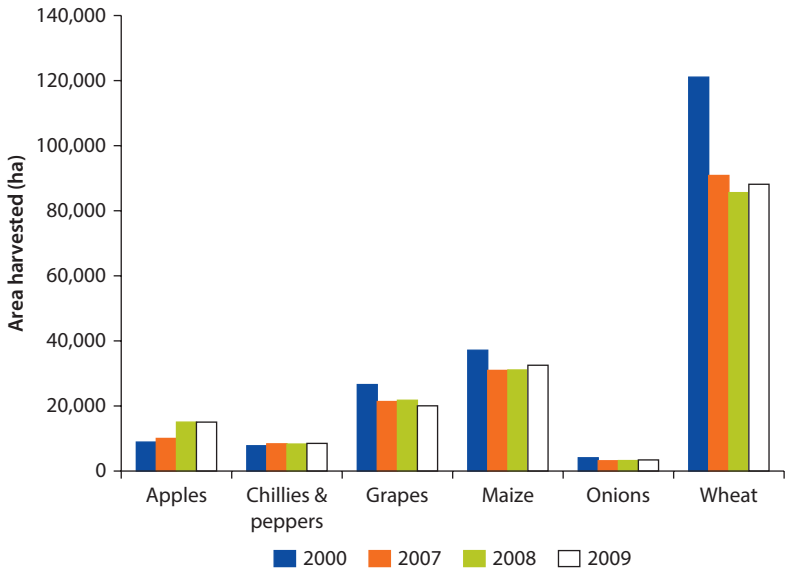

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Table 1.2 Livestock Count by Agro-Ecological Zone

	Mediterranean	*Continental*	*Alpine*
Cattle	91,800	115,000	46,000
Goats	15,900	1,110	77,000
Sheep	197,000	133,000	126,000
Chickens	743,000	861,000	568,000

Sources: Livestock counts from FAOSTAT 2009 country totals. Data broken down to AEZ level using FAOSTAT gridded livestock data of the world (2005).

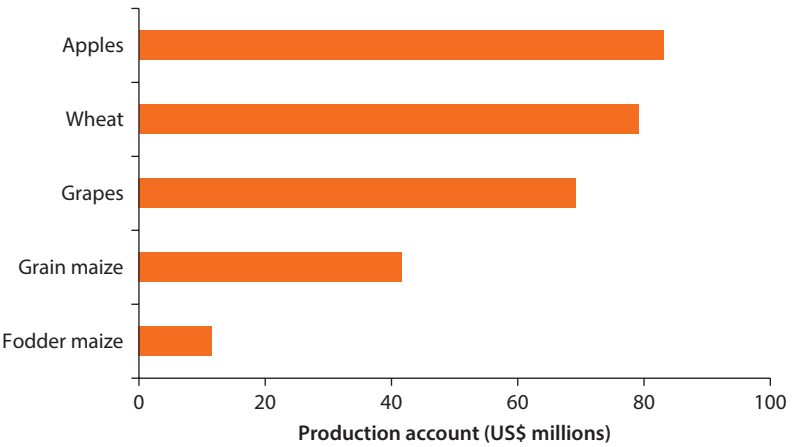
As noted, livestock has long been an important component of the Macedonian agricultural economy, although between 2000 and 2009 it mostly declined. The most significant changes are the declines in stocks of chicken and sheep, by 35 percent and 65 percent respectively, and the increase in goats by 46 percent.

Table 1.2 indicates there is significant variation in livestock counts among the AEZs. When livestock is broken down further by count per unit area, the density of chickens and cattle is relatively similar across AEZs, but goats are much more prevalent per unit area in the Alpine AEZ, and sheep are less prevalent in the Continental AEZ.

Crop Focus for This Study

In consultation with the Macedonian steering committee and in particular the MAFWE, seven crops, including four field crops (wheat, maize, onion, and chilies and peppers), two fruits (grapes and apples), and one crop used for livestock production (grassland pasture) were selected for this study. Figure 1.2 provides estimates of the agricultural production value of four of these focus crops for this

Figure 1.2 Estimated Value of Agricultural Production in 2008 at Producer Prices for Some of FYR Macedonia's Key Crops



Source: Production account from State Statistical Office 2009 and authors' analysis.

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study (production estimates were not available for hay). With a total crop value in 2008 of US$1.25 billion, wheat, maize, apples, and grapes make up 23 percent of total crop value in FYR Macedonia (State Statistical Office 2010b).

Exposure of FYR Macedonia's Agricultural Systems to Climate Change

Potential impacts of climate change on world food supply have been estimated in several studies (for example, Parry et al. 2004). Results show that some regions and crops may improve production, while others suffer yield losses. In FYR Macedonia, the implications of climate change for Macedonian agriculture could be substantial. Increased temperature "speeds-up" crop phenology, which typically means there is less time for crops to develop the harvestable portions of the plant. High temperature and drought stress during critical growth periods can also reduce yields. Excess water from floods can also be damaging.

For some crops (for example, winter wheat), increased temperatures can enhance yields, provided sufficient water is available and certain temperature thresholds are not reached during critical phenological stages. In the lower elevation areas of FYR Macedonia, for example, winter wheat appears to be cultivated at temperatures below the optimal temperature, and so climate change can enhance yields and extend the growing season.

Increased temperatures generally decrease livestock production potential, and decrease water availability by decreasing soil moisture, increasing evapotranspiration, and reducing the yield of water storage reservoirs through increased evaporation. The effect of precipitation on crops and water resources is generally more uniform than for temperature, at least for rainfed crops, with greater precipitation leading to higher yields and less precipitation reducing yields. The seasonal pattern of precipitation is critically important for rainfed crops. However, for example, in FYR Macedonia, relatively low summer precipitation means rainfed maize cannot be profitably cultivated in many areas, and so maize in FYR Macedonia almost always needs to be irrigated.

Forecast Climate Changes for FYR Macedonia

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

Maps 1.2 and 1.3 summarize by decade the resulting forecast of changes in climate at AEZ level from the current period baseline through 2050. Map 1.2 presents changes in temperature by AEZ from the baseline to the 2040s. Temperatures under all scenarios increase gradually from the current base through 2050, with the highest increase under the high-impact scenario and the lowest increase under the low-impact scenario. This increasing trend in

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Box 1.1 Developing a Range of Scenarios of Forecasted Climate for FYR Macedonia

Climate change analyses require some forecast of how temperature, precipitation, and other climate variables of interest might change over time. Because there is great uncertainty in climate forecasts, it is best in a study such as this one to attempt 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 chosen 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, it is assumed to be well correlated with potential agricultural production.

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

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

This study's scenario	*Global general circulation model basis for the scenario*	*Relevant IPCC SRES scenario*
High impact	Geophysical Fluid Dynamics Laboratory, Climate Model 2.1 (US)	A1B
Medium impact	Goddard Institute for Space Studies, Model ER (US)	A2
Low impact	Commonwealth Scientific and Industrial Research Organization, Mk 3.0 (AUSTRALIA)	B1

temperatures is consistent with the observed historical trend, and information gathered from farmer workshops conducted in FYR Macedonia. In addition to increases in average temperature, farmers also have observed an increasing trend in extreme heat events.

The data analysis supports the conclusion that the historical trend in temperature will accelerate in FYR Macedonia in the near future. Although there remains uncertainty in the degree of warming that will occur in FYR Macedonia, the overall warming trend is clear and is evident in all three AEZs, with average warming over the next 50 years for the medium scenario of about 1.8°C, much

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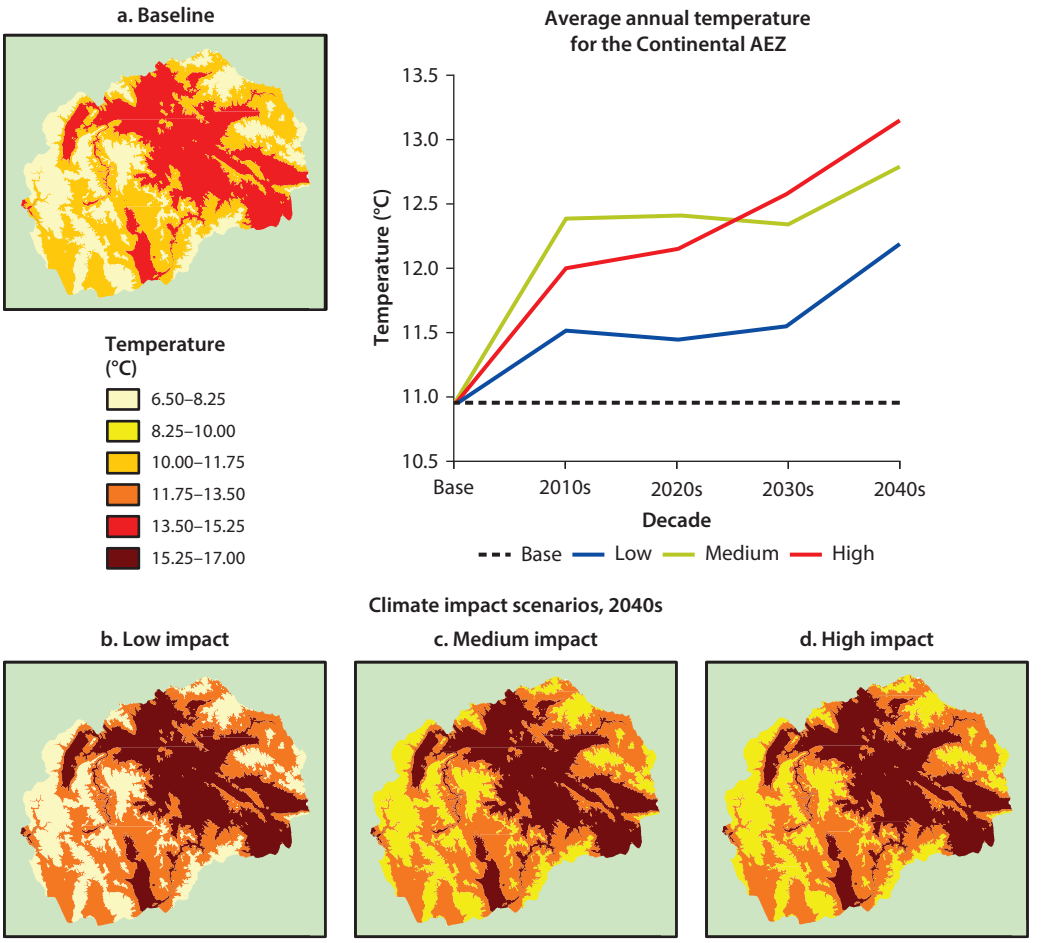
Map 1.2 Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios



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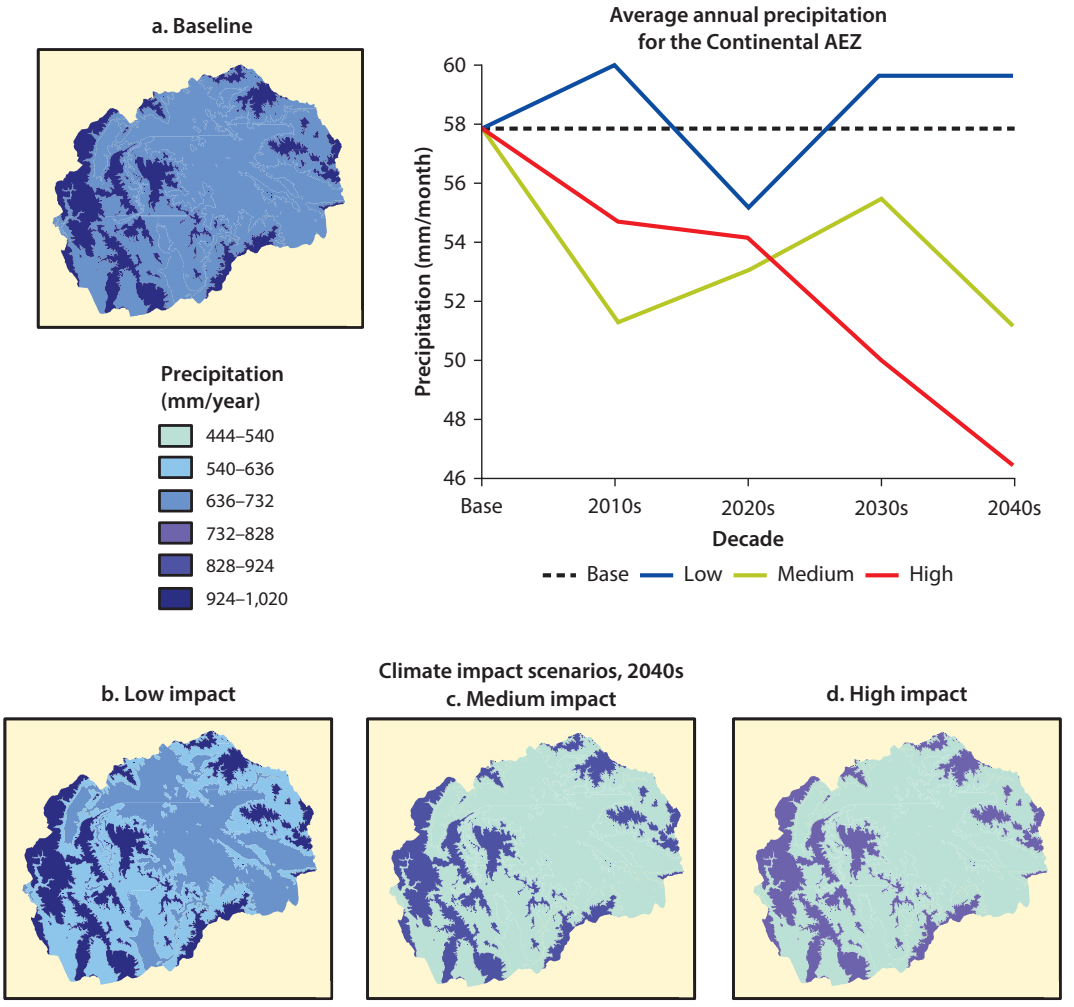
greater than the increase of less than 0.2°C observed over the last 50 years (ClimateWizard 2007). Warming could be more modest, but average temperature changes for the low-impact scenario nonetheless represent an increase of about 1.3°C compared to current conditions. In all scenarios, the warming trend relative to current conditions is about the same magnitude across the three AEZs, but the range of current temperatures across AEZs is quite large, with average temperatures in the Mediterranean AEZ being as much as 8°C higher than those in the Continental AEZ, and 4°C higher than in the Alpine AEZ.

Map 1.3 presents changes in precipitation by AEZ from the baseline to the 2040s. For precipitation, by 2050 the low, medium, and high scenarios indicate uncertainty in the direction of effect as well as its magnitude, with the low scenario forecasting an increase in precipitation, and the medium and high scenarios

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



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forecasting decreases. The use of GCMs also means that the decadal trend in precipitation is not smooth over time. This is consistent with current climate science which suggests that short-term and long-term trends in precipitation can vary substantially, with some scenarios showing increases in precipitation in the short term and decreases in the long term, and vice versa.

Precipitation changes are much more uncertain than temperature changes, as indicated when comparing map 1.2 with map 1.3. The medium-impact forecast indicates a decline in precipitation nationally of about 8 millimeters per month, with most of this decline occurring in the Alpine AEZ. The range of precipitation outcomes across the low- and high-impact alternative scenarios, however, is large, ranging from a modest increase under the low-impact scenario to an almost 20 percent decline under the high-impact scenario. Uncertainty at the regional

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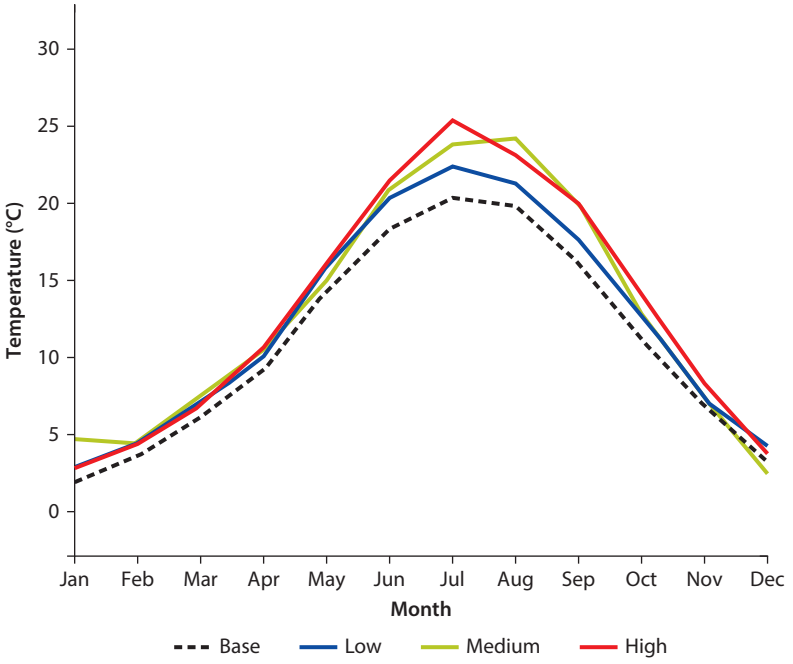
Figure 1.3 Effect of Climate Change on Average Monthly Temperature for the Continental AEZ, 2040s



level is even higher, and annual precipitation declines in the Alpine AEZ could be as large as 16 millimeters per month.

The yearly averages, however, are less important for agricultural production than the seasonal distribution of temperature and precipitation. For both temperature and precipitation, temperature increases are higher in July and August relative to current conditions. This summer temperature increase can be as much as 5°C in the Continental AEZ of FYR Macedonia, when temperatures are already highest. In addition, forecast precipitation declines are greatest in the key May to October period, when precipitation is already at its lowest. Figures 1.3 and 1.4 presents the monthly baseline and forecast temperatures and precipitation for the Continental AEZ.

FYR Macedonia has a history of relatively frequent flooding, especially in the last two decades. Floods made up 44 percent of natural and technological disasters in FYR Macedonia from 1989 through 2006. FYR Macedonia is highly vulnerable to natural disasters, as the frequency and intensity of flooding has been increasing over time, and climate change is expected to increase the drought risk (World Bank 2011a). For the recent large flood in December of 2010, the Vardar river overflowed and flooded households and agricultural land, and drowned livestock. After this event, residents noted that there is not enough support in place to protect them from flooding, and that they had no proper defence for continuing rains. Flooding is also noted as being problematic throughout the country (Balkan Insight 2010).

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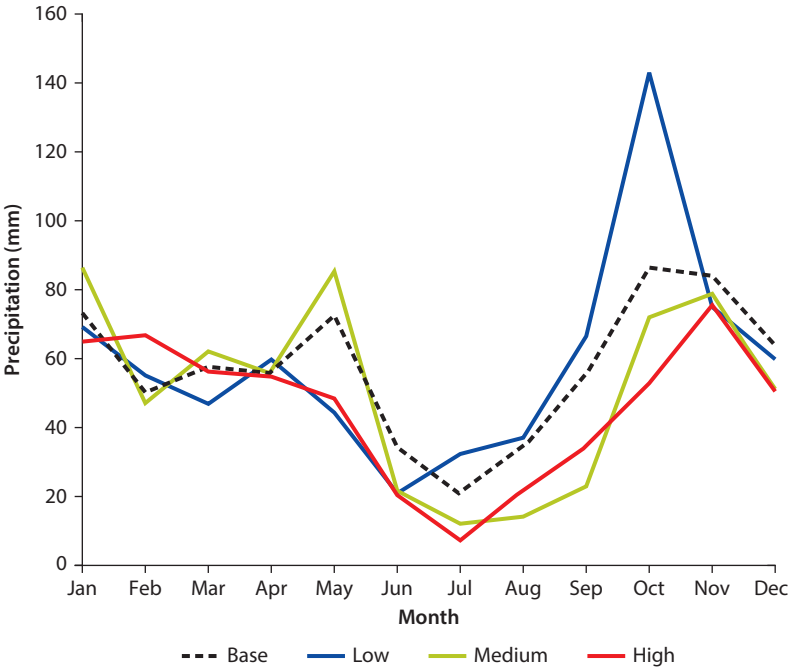
Figure 1.4 Effect of Climate Change on Average Monthly Precipitation for the Continental AEZ, 2040s



Climate change could potentially increase the frequency and magnitude of flooding. While precipitation is only expected to increase in the low scenario by the 2040s (see map 1.3), rainfall events are expected to be more variable, with a high probability of daily to multi-day events being larger and less frequent. For the agriculture sector in FYR Macedonia, floods are particularly problematic in the spring period 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.

FYR Macedonia also has a problem of soil erosion across much of the country, mainly due to poor land management. About 44 percent of the country has very severe erosion, 44 percent has severe erosion, and 12 percent has moderate erosion (FAO 2005). Natural causes of erosion include steep slopes, climate, land cover patterns and soil properties, and anthropogenic factors include cultivation practices, overgrazing and deforestation. Humans have increased the rate of erosion and contributed to land degradation in FYR Macedonia. Farm-level practices leading to erosion and soil degradation include irregular crop rotations, burning crop residues, and poor fertility management. Erosion can lead to pollution of waterways and reduced functioning of reservoirs and irrigation infrastructure (Sutton et al. 2008).

Within the contexts of this study, detailed modeling of the effects of climate change on the key crops in FYR Macedonia was undertaken.[4] As described in

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greater detail in chapter 3, the study concludes that the forecast changes in climate summarized in maps 1.2 and 1.3 will increase the vulnerability of these crops in FYR Macedonia according to the following:

- Rainfed apples and maize, and both rainfed and irrigated grapes have a high potential for yield declines.
- Virtually all crops in the Alpine AEZ have a high potential for yield increases, probably owing to the benefits of higher temperatures during key stages of crop growth and a longer growing season.
- Outside of the Alpine AEZ, both rainfed and irrigated wheat, as well as irrigated alfalfa, apples, maize, and vegetables have a high potential for yield increases, due to beneficial effects of higher temperatures and a longer growing season and the compensating effects of irrigation on soil drying and increased evapotranspiration. Without irrigation, however, many of these crops fare poorly, particularly in the Mediterranean AEZ.
- Livestock are vulnerable to declines in productivity associated with higher temperatures.

FYR Macedonia's Current Adaptive Capacity

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

This section reviews three aspects of adaptive capacity: (1) current agricultural policies and institutional capacities at the national level; (2) evidence of adaptive capacity at the farm level based on consultations with Macedonian farmers (box 1.2 provides a summary of adaptive capacity in each AEZ based on consultations with farmer groups); and (3) a brief review of evidence that Macedonian agricultural systems for the selected crops may be poorly adapted to current climate, reflecting a high current "adaptation deficit."

National Policies and Institutional Capacity

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

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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, systems exist to ensure that collective water infrastructure is well maintained and meets the needs of the farming community, along with systems to resolve conflicts between farmers and other users over water provision. In FYR Macedonia, some of these conditions exist, but most are currently inadequate, as outlined below.

- *The ability to collect, generate, and provide meteorological data to farmers can be improved*. Farmers have noted that they have limited meteorological information available to support their decision-making. In addition, this study relied on monthly historical data that proved difficult to work with; daily data appear to be available but was not provided in time for this analysis. Local counterparts have noted that they are not familiar 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*. While many farmers were aware of the extension service, it was estimated that only a small portion make use of their services. The current extension service also 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 regional study, and is also not uncommon in many other countries.
- *Agricultural research capabilities are expanding but have few connections to extension*. The main agricultural research centers in FYR Macedonia appear to be located in Skopje. 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. 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 adaptation investments*. Both local data and interactions with farmers support this finding. 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 therefore cannot be mechanized due to financial constraints.
- *Agricultural markets are limited*. Many farms in FYR Macedonia 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 very limited. A few entrepreneurial land-owners are developing businesses aimed at wholesale markets, and the number of such producers is gradually increasing.

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- *Agricultural policy appears to be focused on EU accession demands, but climate change adaptation is not considered as part of the EU accession strategy.* The Ministry of Agriculture, Forestry and Water Economy (MAFWE) oversees the agricultural sector. Farmland management and irrigation and drainage fall under the responsibility of the MAFWE. The Ministry is currently modifying the existing National Agricultural and Rural Development Strategies and plans to include 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, and climate change adaptation as a result is not yet emphasized (MAFWE 2009).[5]

Box 1.2 Adaptive Capacity Assessment from Farmer Consultations

As described more fully in chapter 4, consultations with farmers at the AEZ level were carried out within the context of this study. (For more details, see chapter 4.) Some common themes emerged across all of the AEZ meetings, and other results were specific to AEZs.

Mediterranean AEZ. Flooding is the primary climate issue in this region. Farmers have noticed an increase in the frequency of torrential rainfalls. High rainfalls are cited to cause bank overflow and clogged drainage channels, and therefore reduce water quality. Droughts are the next most significant issue. Farmers specifically mention having a year of flood followed by a year of drought, which is harmful to crops. 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, which they would like to have in the form of social capital by working together.

Continental AEZ. In this region, farmers confirmed that climate change impacts have a present effect on agriculture. Declining water availability is the most significant impact currently posing the greatest risk, as evidenced from low reservoir levels and drought. Hail, heat stress, and wind also represent a primary concern; farmers do not feel equipped to respond to these events effectively. Although there are 28,000 hectares of potentially irrigable land in the area, only 15,000 ha are currently irrigated. Floods, acid rain, snowfall declines, and increased winter and spring precipitation were mentioned, but these were not emphasized as a primary concern.

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 come with 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, these are not as much of a concern. Farmers indicate that they need better water storage infrastructure and more widespread information on nets to protect grapes from hail and sunshine, and on crop suitability.

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Crop Yields and Practices for Selected Crops

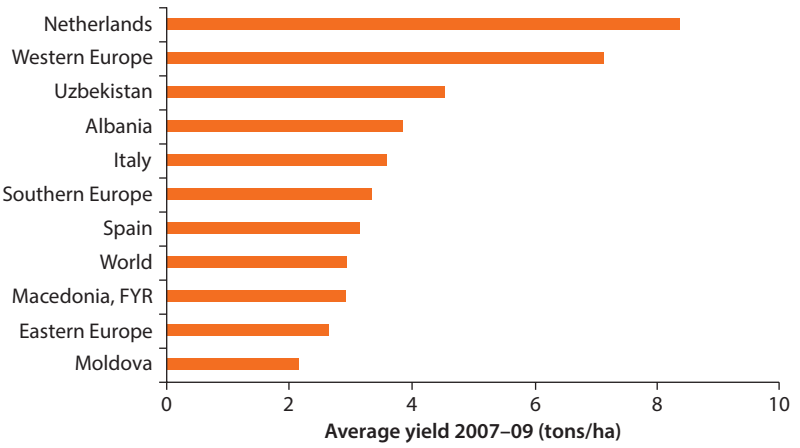
One observable indicator of adaptive capacity is the degree to which current agricultural crop yields and practices keep pace with those in other countries and international averages for key crops. The result of such an assessment gives a sense of what is sometimes termed "the adaptation deficit," or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

Relative yields for two important Macedonian crops—wheat and grapes—were reviewed through analysis of FAO data. For wheat, FAO statistics suggest that production overall is close to 3 tons per hectare, reflecting a mix of rainfed and irrigated wheat. This is less, on average, than yields for other parts of Europe, but about the same as the world average (figure 1.5). One reason is that FYR Macedonia has a relatively low portion of irrigated crops (less than 10 percent), making its overall average wheat yield relatively low as well (World Bank 2009b). Lampietti et al. (2009) and Sutton et al. (2008) also attribute low yields to: distortions and imperfections in markets; inadequate public services for agricultural education, extension, and access to finance; unsustainable management of soils; insufficient irrigation; and high vulnerability to natural hazards. Under irrigation, a good commercial wheat grain yield by international standards is 6–9 tons per hectare.

Grapes in FYR Macedonia have relatively high overall yields compared to other parts of Europe (figure 1.6). In FYR Macedonia, average yields are about 11 tons per hectare, which is significantly higher than most European countries and the world average of 9 tons per hectare. In FYR Macedonia, where it is believed that most grapes are rainfed, yields have even more potential.

The overall conclusion is that current grape production enjoys a significant comparative advantage. For wheat, however, there is significant room for

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



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

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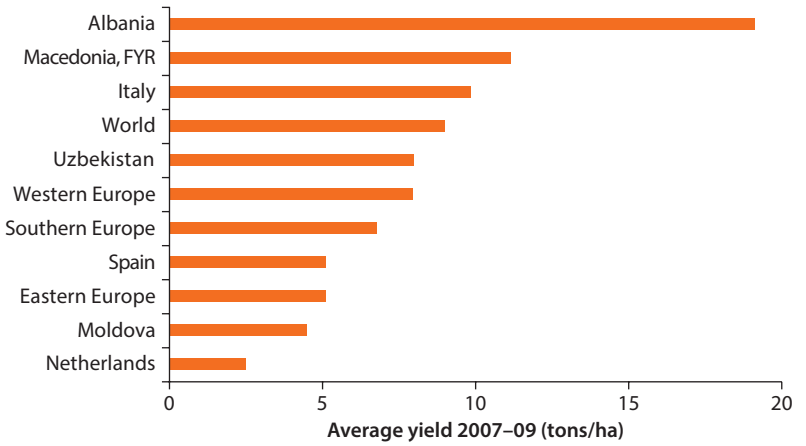
Figure 1.6 Grape Fresh Yield in Selected Relevant Countries, Average 2007–09



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

enhancing adaptive capacity to current climate in FYR Macedonia. As indicated later in this report, many recommendations for adapting Macedonian agriculture to climate change have very high benefit-cost ratios for adaptation options that focus on improving wheat yield.

A Framework for Evaluating Alternatives for Investments in Adaptation

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

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

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

Another key motivating factor for FYR Macedonia's development of an adaptation plan for agriculture is furthering FYR Macedonia's work toward European Union (EU) accession, for which FYR Macedonia has been a candidate since 2005. The Macedonian government has already begun to focus on required EU

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reforms, including work on the Agriculture Strengthening and Accession Project with the World Bank. Along with these needed reforms, the EU encourages 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. The White Paper also stresses the need to integrate cost-effective adaptation to climate change in the EU Rural Development Policy, sometimes referred to as the "second pillar" of the Common Agricultural Policy.

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

The first component consists of rigorous quantitative assessments, supplemented by the judgments of a World Bank team, that consider not only current climate but a range of scenarios of future climate change. The quantitative analyses rely on local data to the extent possible to assess the risks of climate change to specific crops and areas of the country, but also to assess whether the cost of investments justify the benefits in terms of enhancing crop yield now and in the future. In addition, the study considers the specific water resource availability conditions at the basin level, now and in the future.

The second component includes structured discussion with local experts and farmers to evaluate both the potential for specific adaptation strategies to yield economic benefits as well as the feasibility and acceptability of these options. The input of Macedonian farmers to this process proved critical to ensure that the quantitative analyses were reasonable and that the Bank team did not overlook important adaptation actions.

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

1. *Specific infrastructure improvement actions, such as rehabilitating irrigation and drainage capacity, should be high priorities for Macedonian and international donor community investments.* It is important to remember, however, that this study maintained a broad focus, so the results do not represent project-level feasibility evaluations, but rather broad-scale scoping studies. As a result, pursuit of specific investments may require additional, and more detailed feasibility studies.
2. *Creating conditions for farmers to make wise investments themselves to enhance their own adaptive capacity is important.* A number of the farm-level adaptive actions identified are focused on changes in practices, such as better optimizing inputs and use of heat- or drought-tolerant seed varieties, that farmers can readily implement themselves. FYR Macedonia has already adopted water

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pricing, providing an incentive for farm-level water use efficiencies. Policymakers should be aware, however, that many Macedonian farmers currently lack the training or the information (for example, weather forecasts) to implement these practices wisely and effectively. Accordingly, national policymakers should consider making these recommendations focal points for expanding and improving extension services to farmers that explicitly consider adaptation to current climate and forecast changes in climate in the future.

The most effective plans for adapting the sector to climate change will involve both human capital and physical capital enhancements. Many of these investments can also immediately enhance agricultural productivity under current climate conditions. Recommendations, such as improving the accessibility to farmers of agriculturally relevant weather forecasts, will yield benefits as soon as they are implemented and provide a means for farmers to autonomously adapt their practices as climate changes.

Structure of the Report

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

Notes

1. Adapted from: Iglesias, A., A. Keesje, M. Benzie, P. Fisher, M. Harley, N. Hodgson, L. Horrocks, M. Moneo, and J. Webb. 2007. "Adaptation to Climate Change in the Agricultural Sector." AEA Energy & Environment, Didcot. http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/esb_rr/n09_soilresources_of_europe/macedonia.pdf; Macedonian Academy of Science: Gj. Filipovski, R. Rizovski, P. Ristevski, The characteristics of the climate-vegetation-soil zones (regions) in the Republic of Macedonia,1996; and World Bank team analysis of climate change implications.
2. For example, the State Statistical Office (2010b) notes that 629,901 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.
3. Calculated from FAOSTAT 2009 and State Statistical Office 2010 (Macedonia in Figures).
4. A further factor in evaluating vulnerabilities is the fertilizing effect, for some crops, of increases in ambient CO_2 concentrations. Those results are reviewed in chapter 3.
5. See Republic of Macedonia, Ministry of Agriculture, Forestry and Water Economy, Macedonian Agricultural Advisory Support Programme (MAASP), Programme for Mainstreaming Climate Change Adaptation in the Agricultural Management Systems, July 2009. Implemented by consultants GRM International AB And Växa Halland.

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CHAPTER 2

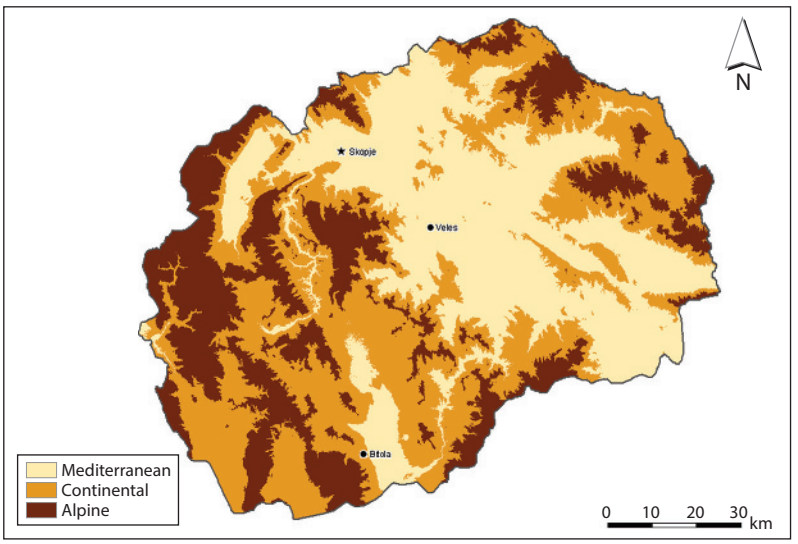
Design and Methodology

Overview of Approach

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

1. *Geographic scope*: The analysis is conducted at the agro-ecologic zone (AEZ) level, as indicated in map 2.1 using representative farms in each of the zones.
2. *Crops*: Based on the availability of existing crop models, consultation with Macedonian counterparts, and the availability of appropriate data to support modeling, the following crops were evaluated quantitatively: wheat; maize; grapes; apples; onions; chillies and peppers; and rainfed pasture (grasslands).

Map 2.1 Agro-Ecological Zones in FYR Macedonia



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.

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3. *Future climate*: Three future climate scenarios were developed based on projections of temperature and precipitation at the country level in 2050. The three scenarios are designed to reflect a range of global circulation model (GCM) outcomes for agriculture that include a low-, medium-, and high-impact outcome. The climate scenarios were selected based on a country-level analysis, and are applied consistently across all three AEZ regions.
4. *Time period*: Results were generated using decadal averages from 2010 to 2050 (that is, 2010s, 2020s, 2030s, and 2040s).
5. *Economic assumptions*: The results are based on two economic projections: (1) continuation of current conditions, prices, and markets; and (2) an alternative crop price projection through 2050 as developed and recently published by the International Food Policy Research Institute (IFPRI).
6. *Baseline for evaluation*: The benefits and costs are estimated for each of the options that are relative to the "current conditions" baseline. As a result, in some cases the benefits and costs of adaptation options may reflect benefits of both adapting to climate change and improving the current agricultural system. In those cases, the options are identified as "win-win" in nature.

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

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

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

The remainder of this chapter describes three key steps in the quantitative analysis. The next section describes how future climate scenarios were developed and applied to conduct an agricultural sector climate impact assessment, modeling a baseline of effects of changed climate on the current agricultural system, before adaptation. The section titled "Development of Adaptation Menu" provides details on the assessment of the effect of specific adaptation options on

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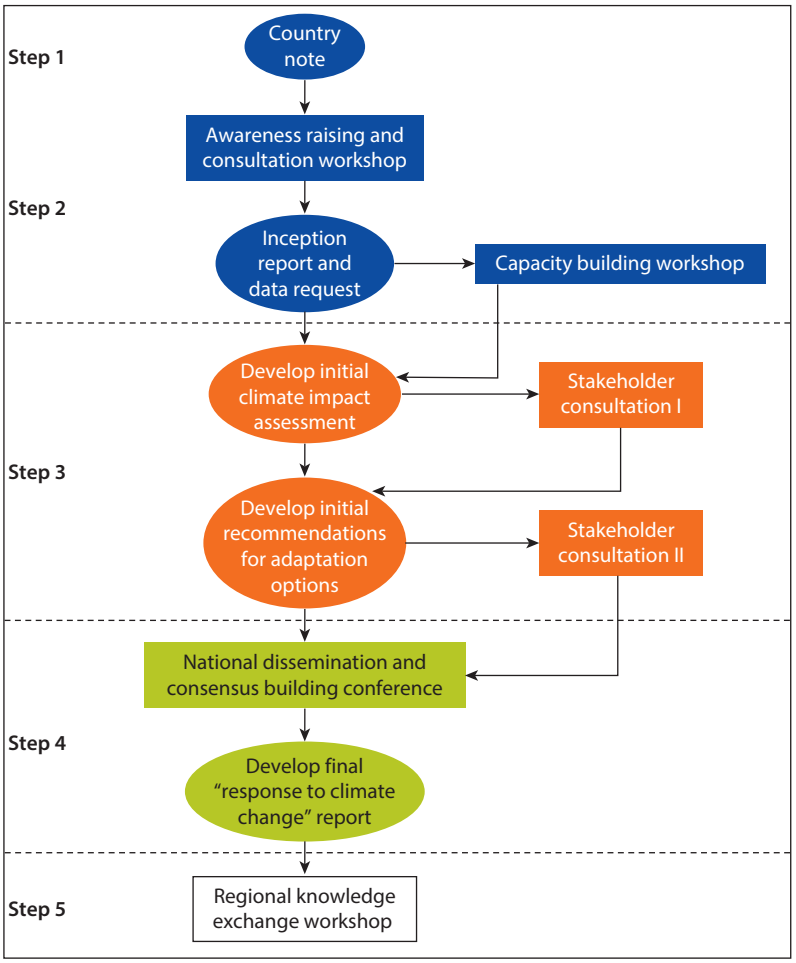
Figure 2.1 Flow of Major Study Action Steps



crop yields and farm revenues. The section titled "Assessing Risks to Livestock" provides an overview of assessment of risks to livestock.

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

Climate Scenarios and Impact Assessment

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

Step 1: Identify Agricultural Growing Regions of FYR Macedonia

Results were generated for "representative farms" in each of the major agricultural production regions of FYR Macedonia, at least one of which must be in each of the three AEZs. Presenting the results at this spatial scale allows using baseline data from meteorological stations that are co-located with agricultural regions, and avoids needing to either interpolate data between stations or rely upon global sources of gridded data (which have already used interpolation). Note that this approach focuses the analysis on regions that are currently 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 across FYR Macedonia was collected based on remote sensing data from several international sources (for example, MIRCA dataset for 26 irrigated and rainfed crops at ~5 minute resolution, McGill dataset for 175 crops at ~5 minute resolution, Spatial Production Allocation Model, SPAM, dataset of detailed global crop maps from IFPRI). Unfortunately, local meteorological data were not available.

Step 2: Gather Baseline Data

Baseline data on meteorology, soil, and water resources were derived from in-country and global sources. Station-level meteorology was provided on a monthly basis, and was merged with global-scale daily data to characterize key crop model inputs. A combination of local and global data for the soils data inputs was used. In-country data were obtained for the water resources requirements. These requirements include:

- *Meteorological*. Because AquaCrop is a daily model, the crop modeling methodology requires at least 10 years of daily historical data in the major agricultural regions of FYR Macedonia.[1]
- *Soil characteristics*. Crop modeling requires data on soil type, suitability, erosion potential, and hydrology characteristics.
- *Water resources*. Water resources modeling requires at least 10 years of average daily (preferred) or monthly historical river flow data for gauging stations along the mainstem rivers of each major drainage basin in FYR Macedonia. These were provided by in-country sources. In addition, locations and active storage volumes of each major reservoir were obtained from in-country sources.

Where global sources of data are used, available at a grid-cell level, gridded meteorological data are translated to the agricultural production regions, and spatially average daily data for grid cells covering that region.

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 box 1.1 in chapter 1,

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three climate scenarios were developed for FYR Macedonia. The scenarios are defined by the Climate Moisture Index (CMI), which is an indicator of the aridity of a region.[2] Based on the average of CMI values across FYR Macedonia, the driest, the wettest, and a "medium" scenario were selected from among the 56 available GCM combinations deployed by IPCC for 2050. The following two subtasks were then conducted:

- *Generate decadal monthly changes in precipitation and temperature.* Monthly changes in climate were generated based on differences between future projections of temperature and precipitation and twentieth century baseline outputs for each GCM. Based on available literature, absolute changes in temperature and relative changes in precipitation are presented.
- *Translate these monthly decadal changes to daily changes.* Crop modeling under future climate change also requires daily data for the 2010–50 period, but the GCMs only produce 12 monthly outputs for each decade between 2010 and 2050 (that is, four sets of 12 monthly values). Therefore, decadal monthly changes were used, combined with the earliest decade of available in-country daily station data, to scale the future projections.[3]

Step 4: Conduct Impact Assessment

The impact assessment uses the process-based crop models AquaCrop and CropWat to analyze changes in crop yields and crop water demand across FYR Macedonia, and the CLIRUN model to analyze changes in water runoff. The Water Evaluation and Planning System (WEAP) model is then applied, using the inputs from CLIRUN to analyze potential basin-level shortages in water available to agriculture. CropWat was used to determine crop water and irrigation requirements from soil, climate, and crop data. AquaCrop was used to model yields for wheat, maize, pasture, tomatoes, alfalfa, grapes, and apples. The CropWat program is less detailed than AquaCrop, and was designed for poor farmers in arid and semi-arid regions, and creates different irrigation schedules by management conditions and calculates water supply of each scheme for varying crop patterns.

Any estimated water shortage from the WEAP model is fed back to the biophysical step to estimate the net effect of the shortage on irrigated crop yields. As outlined in the next chapter, there are two basins in Macedonia for which future water shortages for agriculture are forecast, but in other basins sufficient irrigation water is forecast to be available under climate change.

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

Development of Adaptation Menu

Building on the four steps of the impact assessment, there are three additional steps necessary to develop the adaptation menu: (5) select and categorize a set

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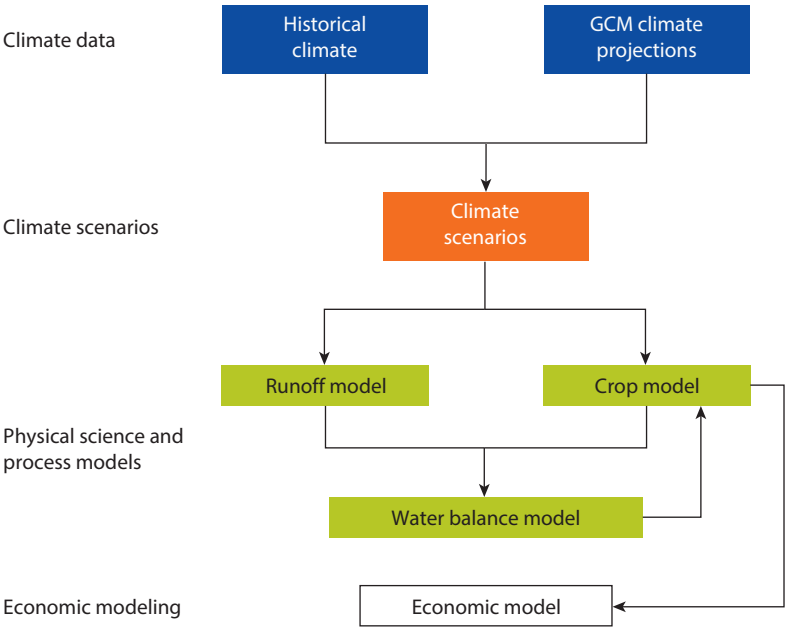
Figure 2.2 Analytic Steps in Action Step 3: Quantitative Modeling of Adaptation Options



Note: GCM = global circulation model.

Box 2.1 Brief Description of Modeling Tools

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

- *AquaCrop*: The strengths of this process model are in its simplicity to evaluate the impact of climate change and evaluation of adaptation strategies on crops, and also in its ability to evaluate the effects of water stress and estimate crop water demand, both key issues in Macedonia currently and with climate change. The model was developed and is maintained and supported by the Food and Agriculture Organization (FAO) and is the successor of the well-known CropWat package. Other advantages of the model are its widespread use and straightforward analysis. The model is mainly parametric-oriented and therefore less data demanding. The diagram included in this box illustrates some of the main crop growth processes reflected in AquaCrop.
- *CLIRUN*: Monthly runoff in each catchment can be estimated using this hydrologic model that is widely used in climate change hydrologic assessments. CLIRUN models runoff as a lumped watershed with climate inputs and soil characteristics averaged over the watershed simulating runoff at a gauged location at the mouth of the catchment. CLIRUN can run on a daily or monthly time step. Soil water is modeled as a two-layer system: a soil layer, and a

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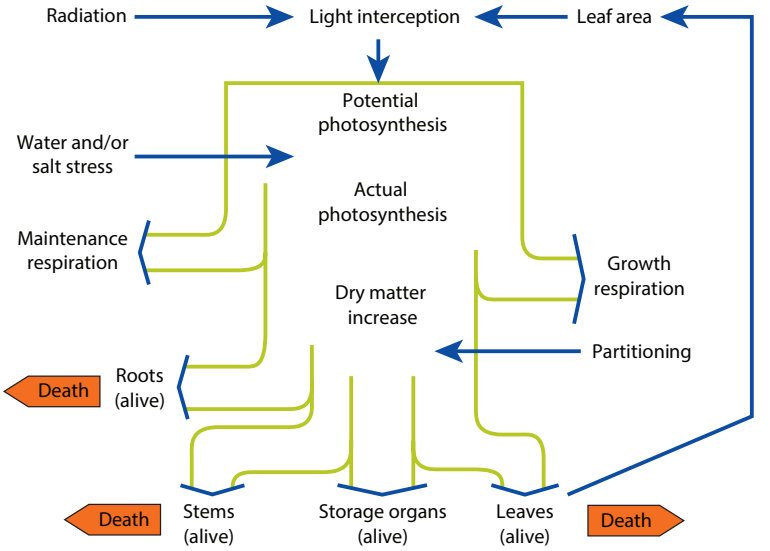
Box 2.1 Brief Description of Modeling Tools *(continued)*



Main processes included in AquaCrop

groundwater layer. These two components correspond to a quick and a slow runoff response to effective precipitation. A suite of potential evapotranspiration models is available for use in CLIRUN. Actual evapotranspiration is a function of potential and actual soil moisture state following the FAO method. CLIRUN can be parameterized using globally available data, but any local databases can also be used to enhance the data for the models. CLIRUN produces monthly runoff for each watershed.

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

of adaptation options to be considered for FYR Macedonia; (6) conduct qualitative and quantitative assessments of those options; and (7) develop a ranked order menu of adaptation options.

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Step 5: Select and Categorize Adaptation Options

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

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

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

Step 6: Conduct Adaptation Assessment

The adaptation options are evaluated based primarily on four criteria: (1) net economic benefits (quantified where possible, based on expert assessment otherwise); (2) robustness to different climate conditions; (3) potential to aid farmers with or without climate change, otherwise referred to as "win-win" potential; and (4) favorable evaluation by stakeholders. 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

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

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

- *Crop yields* with and without the adaptation option in place. These are derived from AquaCrop modeling and input from the Decision Support System for Agrotechnology Transfer (DSSAT) process model.[4]
- *Management multiplier* to convert from experimental to field yields. These estimates were developed in consultation with local experts as part of the team's capacity building work.
- *Crop prices through 2050*. National crop price data from FAO for current conditions were used, price projections under two scenarios were developed—one with constant prices and one based on an IFPRI global price change forecast.
- *Exchange rate* between global and local crop prices
- *Discount rate* to estimate the present value of future revenues and costs. All analyses employ a 5 percent discount rate, consistent with recent World Bank Economics of Adaptation to Climate Change analyses.
- *Capital and operations and maintenance (O&M) costs of each adaptation input* (for example, irrigation infrastructure). Local data were requested to characterize costs of adaptation options, and in some cases they were provided. Overall, these can be difficult to obtain or generalize, and as a result, in many cases estimates were derived from prior work.

The general approach for estimating the net benefits of two of the farm management options assessed (optimizing fertilizer application, and changing crop varieties) is outlined in table 2.1. More details of these analyses are provided in

Table 2.1 Approach for Two Quantifiable Farm-Level Adaptation Options

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

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chapter 5 of this report. Not all options were amenable to such quantitative analysis. In addition to optimizing fertilizer application and changing crop varieties, a quantitative assessment of the following options was undertaken:

- Expanding extension services
- Expanding agricultural research and development activities
- Improving drainage capacity
- Developing new irrigation capacity
- Rehabilitating irrigation capacity
- Improving irrigation water application efficiency.

Finally, farmers in the Bilola and Kavardici regions noted that hail damage was a significant problem. Research indicates that hail events could be more frequent and/or damaging with climate change. An existing study was therefore used to evaluate the cost-effectiveness of hail nets for apple crops and was applied for some relevant Macedonian crops.

Criterion 2: Robustness to Different Future Climate Conditions

All options are assessed relative to climate conditions in three alternative climate scenarios. Benefit-cost ratios and net present value calculations are developed for each of the three scenarios, both with and without the effect of carbon fertilization, providing a mean for assessing robustness to future climate conditions.[5]

Criterion 3: "Win-Win" Potential

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

Criterion 4: Stakeholder Recommendations

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

Step 7: Develop Menu of Adaptation Options

The menu of adaptation options presented in chapter 6 synthesizes the results of the three components of the adaptation assessment: quantitative analysis (described in chapter 5); qualitative assessment of potential net benefits to farmers (also summarized in chapter 5); and farmer recommendations (summarized

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in chapter 4). Tables in chapter 6 provide a prioritized list of national and AEZ-level recommendations with a justification for the recommendation based on these three components of the assessment. In addition, the tables identify whether the option has win-win potential.

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

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

Assessing Risks to Livestock

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

In an effort to assess the effects of climate change on livestock, a broad literature review was conducted to identify existing models on the effect of climate change, particularly changing temperature, on livestock. Ideally, a "process" model similar to the AquaCrop crop model would be employed. A model of this type could be deployed to simulate effects on livestock for various climate scenarios, and also evaluate the impact of taking adaptive actions. The only extensive analysis of this type was a structural Ricardian model of livestock developed by Seo and Mendelsohn based on studies in ten countries in Africa (2006). This model measures the interaction between temperature and livestock and considers the adaptive responses of farmers by evaluating which species are selected, the number of animals per farm and the net revenue per animal under changes in climate. The study relies on a survey of over 5,000 livestock farmers in 10 African countries. In this dataset, the variation in livestock productivity and expected incomes in different regions demonstrates a clear relationship to regional climate, which provides a mechanism, through spatial analogue, to statistically analyze how climate change may affect livestock incomes. [6]

The general results of the study are that, relative to the baseline, the probability of choosing beef cattle and chickens will decline with rising temperatures, but that the probability of selecting dairy cattle, goats, and sheep will increase.

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Expected income per animal falls across all livestock types, but changes are most dramatic for beef cattle, goats, and chickens, which fall 19 percent, 21 percent, and 29 percent respectively with an increase in temperature of 2.5°C. Rising temperatures, in general, lead to a response to reduce the predicted number of beef cattle and chickens on each farm, but increase the number of the other livestock types.

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

Ultimately, however, the Mendelsohn and Seo model was not applied in the Macedonian analysis. The main reason is that the current climate, and in particular the effect of current climate on existing management practices and current livestock varieties in the 10 African countries they studied, differs markedly from those in FYR Macedonia. The Ricardian approach does not allow for a reliable adjustment for those differences. Instead, a qualitative evaluation of both the risk of climate to livestock, and adaptive measures to consider in responding to those risks is provided.

Uncertainty and Sensitivity Analysis

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

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

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Notes

1. CropWat is also used, which requires monthly data.
2. 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.
3. For example, if a selected GCM projects that the change in January temperatures in the 2030s is two degrees and the earliest available station data are from 1994 to 2003, the January 1–31 temperatures for every year in the 2030s will be the temperatures during Januarys between 1994 and 2003 plus two degrees.
4. Although not employed in the impact assessment, the team relied on the Decision Support System for Agrotechnology Transfer (DSSAT) 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 crops; many of the models were specifically developed for climate change impact studies with finding provided by International agencies (USAID, UNEP, UNDP, among others) and have been calibrated and validated in a few hundred sites in all agroclimatic 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.
5. As noted in chapter 5, in most cases it was observed that quantitative results for adaptation options are less sensitive to uncertainties in climate forecasts than to uncertainties in future prices.
6. Because the raw data from this survey were not available, it was not possible to compare the climatic conditions observed in the Seo and Mendelsohn survey to the conditions in FYR Macedonia.

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CHAPTER 3

Impacts of Climate Change on Agriculture in FYR Macedonia

This section describes the results of the climate impact assessment for the Macedonian agriculture sector. The impact assessment is an important component of developing an adaptation plan. It reflects impacts of forecast changes in temperature and precipitation, outlined in the section titled "Exposure of FYR Macedonia's Agricultural Systems to Climate Change" in chapter 1, from 2010 to 2050 on crop yields and water resources available for agricultural irrigation if no actions were taken to adapt to these changes. As such, it represents a baseline from which the effects of individual adaptation options can be measured. It also provides a clear picture of the risks and opportunities presented by climate change at a detailed level, by crop, AEZ, and river basin.

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

The results suggest the following:

- *Overall, the direct effects of climate change on crops in FYR Macedonia could be positive* for all crops grown in the Alpine AEZ, and for irrigated crops in the Mediterranean and Continental AEZs, but could be negative for most rainfed crops in the Mediterranean and Continental AEZs.
- *The direct effect of temperature on livestock, reducing their productivity and farm revenues, could be considerable,* especially for cattle and chickens. The results, however are qualitative in nature at this time.
- *Climate change will increase irrigation water demand and reduce water supply.* The modeling results indicate that although irrigation water shortages already exist during some years, higher temperatures and lower precipitation under climate change will increase irrigation water demand and reduce river runoff during the growing season. These increases in agricultural water demand and reductions in water supply will cause already existing shortfalls to become more severe in future years, most acutely in the southwestern Mediterranean and Continental AEZs.

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Climate Impacts on Crops and Horticulture

The detailed results of the impact assessment for individual crops, for each AEZ and climate scenario, are summarized in tables 3.1 and 3.2. Table 3.1 shows the results for the medium scenario, and table 3.2 shows the range of results for the low- through high-impact scenarios. As shown in table 3.1, rainfed crops tend to

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

% change

Irrigated/rainfed	*Crop*	*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.

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

% change

Irrigated/rainfed	*Crop*	*Mediterranean*	*Continental*	*Alpine*
Irrigated	Alfalfa	4 to 33	21 to 42	68 to 92
	Apples	9 to 10	11 to 15	14 to 15
	Grapes	–35 to –3	–39 to 12	N/A
	Maize	–11 to –9	19 to 25	N/A
	Vegetables	3 to 19	3 to 8	N/A
	Wheat	13 to 15	25 to 28	76 to 113
Rainfed	Alfalfa	–17 to 45	–10 to 42	43 to 56
	Apples	–60 to –7	–63 to 6	–4 to 13
	Grapes	–47 to –12	–53 to 8	N/A
	Maize	–76 to –52	–77 to 8	N/A
	Pasture	–4 to 19	–4 to 33	20 to 58
	Vegetables	–21 to 10	–28 to –8	N/A
	Wheat	–3 to –1	13 to 15	70 to 105

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

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be more negatively affected by climate change than irrigated crops. The Mediterranean AEZ has the most pronounced negative effects, followed by the Continental AEZ. Generally, the high-impact climate scenario has the strongest impact, with less rainfall and higher evapotranspiration due to the higher temperature projections. For the medium-climate scenario the impact of climate change is somewhat less severe than the high-impact scenario, as this scenario is less pessimistic in terms of rainfall projections.

In general, the results indicate that grapes are the only irrigated crop to experience decreased yields in the Mediterranean and Continental AEZs, whereas all of the irrigated and rainfed crops grown in the Alpine zone rise in yields. The decreases in rainfed yields in the Mediterranean and Continental AEZs are particularly significant for apples, grapes, and maize, reaching upwards of a 60 percent reduction for maize. As expected, irrigation increases yields and reduces yield variability.[1]

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

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

Based on other work in the region, it is expected that some of the crops studied in FYR Macedonia could experience an increase in production due to the assumed CO_2 fertilization effect. This effect compensates part of the negative impact of the increased water stress caused by the higher temperatures and evaporative demand. For other crops (that is, grapes and grassland) the overall impact of climate change would likely remain negative. Overall, for more moderate climate scenarios CO_2 fertilization is likely to be positive and could enhance yields by up to 7 percent.

For the irrigated crops, the climate impact on irrigation water demand was also assessed as a key input to the water resources analyses. In table 3.3, orange indicates an increase in crop irrigation water requirements, and darker shades of orange represent larger irrigation demand. For all of the scenarios, the overall trend is that more water is required to maintain the current yields. In particular, grapes, apples, alfalfa, and wheat will need substantially increased amounts of water.

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

% change

Scenario	*Crop*	*Mediterranean*	*Continental*	*Alpine*
High	Alfalfa	34	39	45
	Apples	48	49	63
	Grapes	51	51	N/A
	Maize	21	22	N/A
	Vegetables	23	25	N/A
	Wheat	36	37	51
Medium	Alfalfa	29	32	39
	Apples	50	49	66
	Grapes	51	46	N/A
	Maize	18	13	N/A
	Vegetables	22	21	N/A
	Wheat	28	21	37
Low	Alfalfa	13	12	21
	Apples	13	10	24
	Grapes	27	19	N/A
	Maize	10	4	N/A
	Vegetables	11	9	N/A
	Wheat	23	18	36

Note: The shading is darker the larger the increase in irrigation water requirements. N/A = the crop is not grown in the AEZ.

Climate Impacts on Livestock

Effects on alfalfa and rainfed pasture crops summarized in the previous section present one type of climate change risk to livestock, an indirect effect. Effects of climate change on maize yields may also be linked to effects on livestock. Rainfed alfalfa and pasture yields are expected to decrease in the Mediterranean where livestock graze. As a result, the indirect effects of climate change in areas where livestock are most important could be large.

The direct effect of climate change on livestock is also important. Higher-than-optimal temperatures for livestock can affect animal productivity and, in the case of extreme events, can lead to elevated mortality rates related to extreme heat stress. As outlined in chapter 2, there is limited information to characterize the direct effects of climate on livestock; currently available methodologies are far less sophisticated than the crop modeling techniques applied in the prior section, or the water resources modeling techniques in the following section, and are generally not appropriate for FYR Macedonia.

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

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Climate Impacts on Water Availability for Agriculture

A water availability analysis was conducted at the river basin level using the Water Evaluation and Planning (WEAP) tool, which compares forecasts of water demand for all sectors, including irrigated agriculture, with water supply results under climate change derived from the CLIRUN model. The five major river basins analyzed are shown in map 3.1. They include, clockwise from the North, Pcinja basin, Bregalnica basin, Vardar basin, Crna basin, and Radika basin. Some of these basins extend beyond FYR Macedonia's border, indicated by the thick line in the figure, but the focus of this study was on changes in water supply and demand within FYR Macedonia's territory.

Map 3.1 River Basins in FYR Macedonia

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

Total annual irrigation water withdrawals across FYR Macedonia are approximately 1.07 km^3, representing 69 percent of water withdrawals in the country.[3] In the WEAP model, irrigation water withdrawals in each river basin were estimated based on the total hectares of irrigated land in each basin, per hectare estimates of crop irrigation requirements (discussed above), and an estimate of basin-level irrigation efficiency. The distribution of irrigated hectares across the river basins was based on FAO's Global Map of Irrigated Areas, presented for FYR Macedonia in map 3.2.[4] In total, there are 87,590 hectares of irrigation across the country, with 31,750 hectares in the Crna Basin, 30,499 hectares in the Vardar Basin, 15,312 hectares in the Radika Basin, 7,585 hectares in the Pcinja Basin, and 2,444 hectares in the Bregalnica Basin.

Crop irrigation requirements are affected by both temperature and precipitation, as water demand is directly linked to both crop yield and to evapotranspiration. These irrigation needs are derived from the CropWat model results described above. Figure 3.1 compares total monthly irrigation demands for FYR Macedonia for the current baseline, and under the three climate scenarios for the 2040s. In the presence of higher spring temperatures, crops begin to demand water in April instead of May, and irrigation water demand peaks in June instead of July. Under the medium and high scenarios, much higher demands are sustained through August than under the baseline scenario.

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, World Bank forecasts for municipal and industrial (M&I) demand for water through 2050 in FYR Macedonia were used.[5] M&I demands represent approximately 30 percent of current water use in FYR Macedonia 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 municipal and industrial 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 to each basin were allocated based on the population of each basin, which was derived from Columbia University's Gridded Population of the World database.[6]

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 five hydrological gaging stations located

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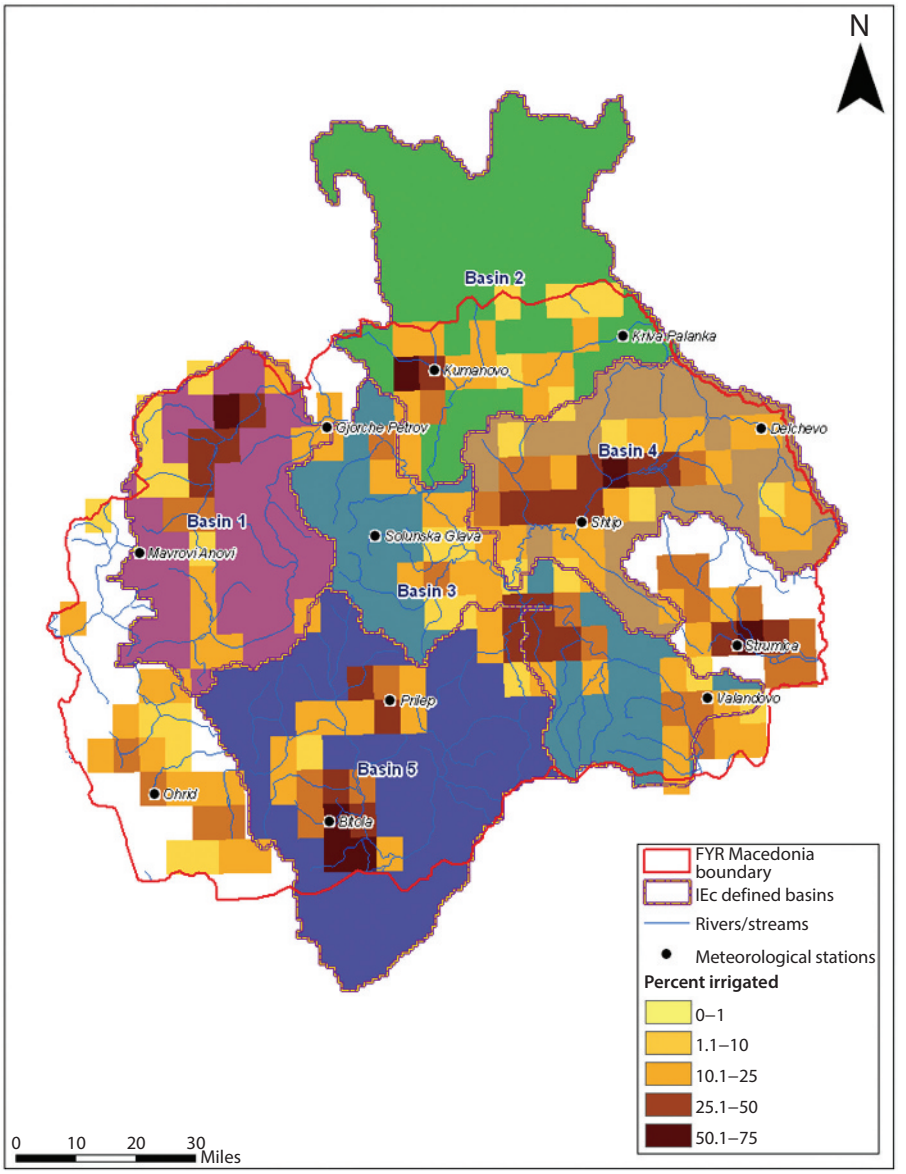
Map 3.2 Irrigated Areas in FYR Macedonia



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within the Vardar river basin, and gaged monthly station data from the Macedonia Hydrometeorological Service.[7] *R*-squared values for the CLIRUN calibration were between 0.71 and 0.84 for the five basins, and deviations between observed and modeled runoff ranged from less than 1 percent to 5 percent, indicating a strong relationship between observed runoff and runoff modeled from precipitation and potential evapotranspiration (PET) inputs. Once calibrated, CLIRUN

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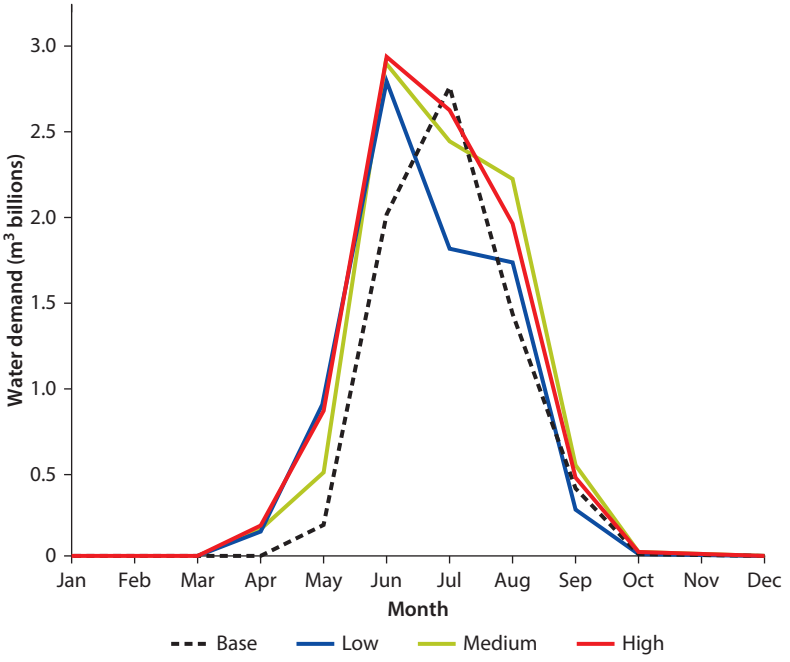
Figure 3.1 Mean Monthly Irrigation Water Demand over All Macedonian Basins, 2040s



uses monthly precipitation and PET projections under the three climate scenarios to project rainfall runoff in each of the five basins.

Figure 3.2 provides the annual runoff across the climate scenarios for all FYR Macedonia basins between 2011 and 2050, and figure 3.3 compares the mean monthly runoff in the 2040s under the baseline and three climate scenarios. As expected, relative to current estimates, runoff declines under the high- and medium-impact scenario, and increases under the low scenario. Variability across the scenarios increases significantly after 2030. In terms of monthly effects, although annual runoff under the low-impact scenario is forecast to increase, runoff during the spring months declines under all three scenarios relative to baseline conditions, in part due to reductions in snowpack, and therefore runoff from snowmelt, during those periods. These reductions occur in months when crop water demand is highest, and when CropWat forecasts the most pronounced increase in crop demand under climate change. It is also important to note that under the high and medium scenarios, a significant decline in river runoff is projected during the late summer months, when reservoir storage is lowest but crop water demand remains high.

Looking at changes in flow across the five basins reveals similar patterns. Map 3.3 provides the mean percentage change in runoff from the historical baseline to the 2040s under the three climate scenarios. The panel of maps on the left show the change when all months of the year are considered, and the panel on the right shows only April to September, which are the months when

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

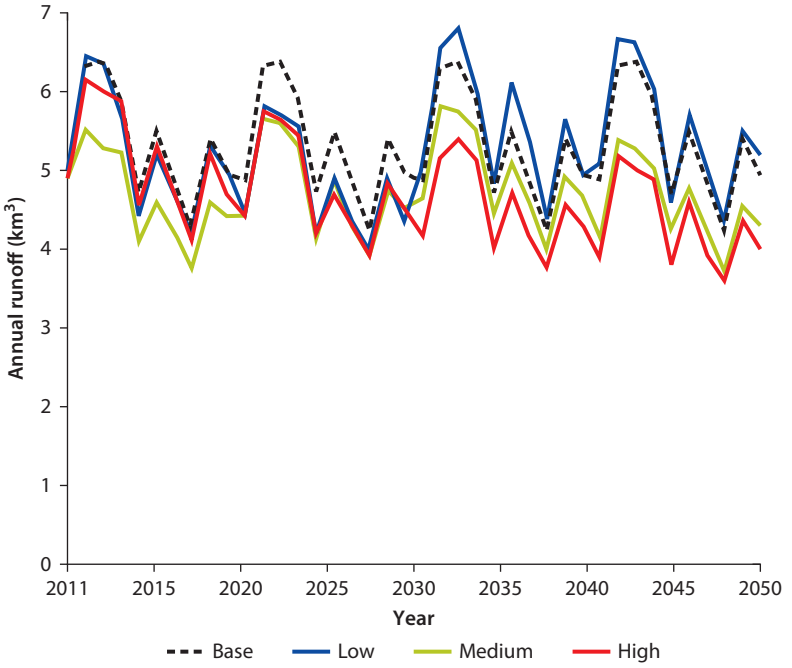
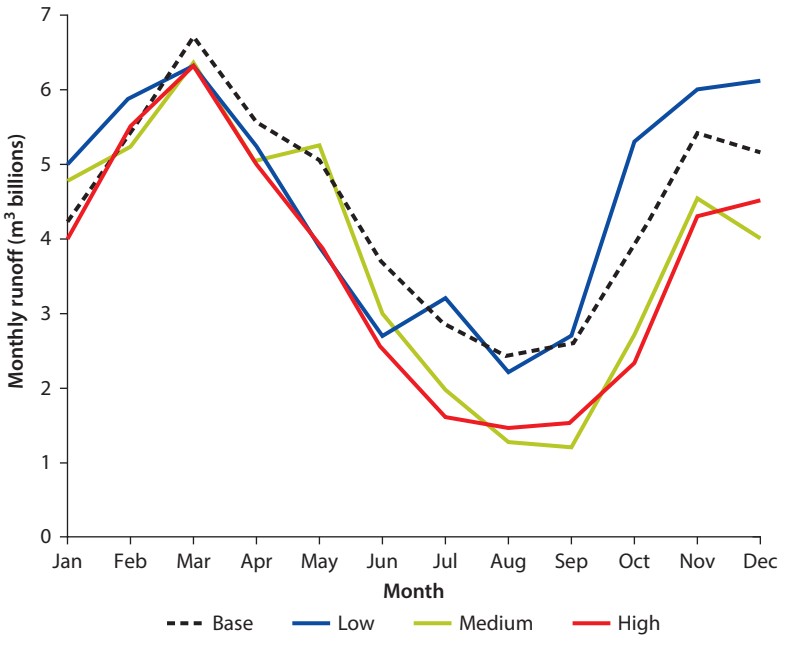
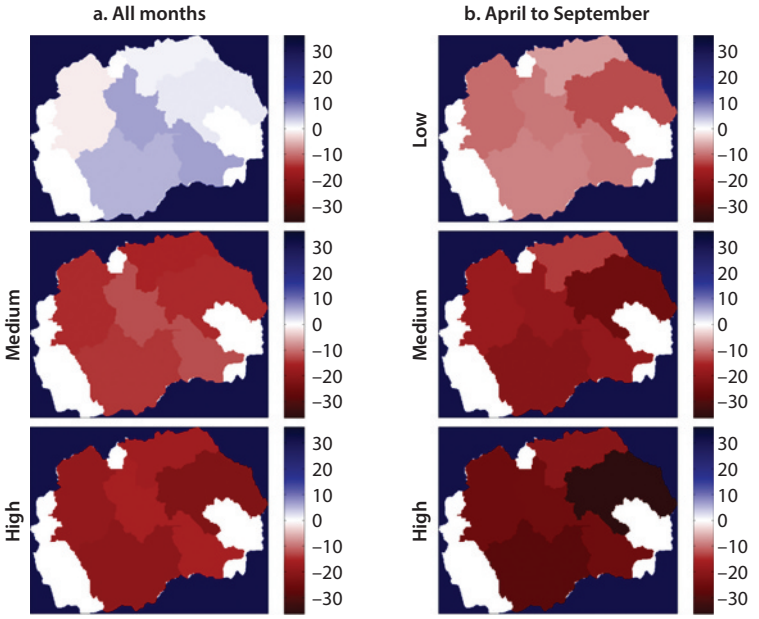


Figure 3.3 Mean Monthly Runoff for All Macedonian Basins, 2040s



Reducing the Vulnerability of FYR Macedonia's Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0043-6

Map 3.3 Mean Percentage Change in Runoff, 2040s Relative to the Historical Baseline



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irrigation demands occur. Although some of the southern basins are projected to have higher mean annual runoff under the low scenario when all months are considered, all of the basins across all of the scenarios show reduced mean runoff during the irrigation season.

The WEAP model utilizes these forecasts of changing water demand and supply to estimate potential irrigation water shortages under climate change. WEAP (Sieber and Purkey 2007) is a software tool for integrated water resources planning that provides a mathematical representation of the river basins encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, water demands, and reservoir storage. Computations are performed on a monthly time scale between 2011 and 2050 for a base-case scenario (that is, no climate change) and the three climate change scenarios, each of which is characterized by unique inflows and changing water demand. Surface water inflows from CLIRUN were used as inflows to an aggregated river in each basin modeled in WEAP. Water supplies and demands are linked between upstream and downstream basins (all four subbasins flow into the mainstem of the Vardar River), and reservoirs, irrigation, and municipal and industrial demand locations were sequenced consistently with respect to their actual locations.

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

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- *Reservoir locations and volumes* were provided by the International Commission on Large Dams (ICOLD 2010) and Berga (2006) who summarize reservoir volumes by location within FYR Macedonia.[8] In total, they report that FYR Macedonia has 1.73 km^3 of storage, of which 360 million m^3 is in the Radika Basin, 740 million m^3 is in the Vardar mainstem basin, 140 million m^3 is in the Bregalnica basin, and 495 million m^3 is in the Crna basin. These sources list no storage in the Pcinja basin.
- *Transboundary flow agreements* are also a critical determinant of water available in FYR Macedonia, as the Vardar river basin flows into Greece. Although there are no existing transboundary water agreements with Greece, it was assumed that 40 percent of the mean monthly runoff from the entire Vardar system must flow from FYR Macedonia to Greece. In the WEAP model, these sharing arrangements are assumed to 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 a minimum flow requirement of 20 percent of FYR Macedonia's water resources are dedicated to environmental purposes.

WEAP results indicate that unmet irrigation water demands already occur under the baseline, and rise significantly under climate change. Figure 3.4 presents unmet irrigation and municipal and industrial (M&I) demands for the five basins under the baseline and three climate scenarios in the 2040s. Under the historical baseline, the Pcinja and Crna basins experience irrigation shortages totaling approximately 13.1 percent of FYR Macedonia's irrigation demands, driven primarily by a shortage of 34.7 percent in the Crna basin.

Under climate change, overall irrigation water shortfalls are projected to increase to 13.2 percent under the low-impact scenario, 20.9 percent under the medium-impact scenario, and 22.2 percent under the high-impact scenario by the 2040s. Importantly, under the medium- and high-impact scenarios, over 50 percent of irrigation demands are unmet in the Crna basin, and 8–11 percent of demands in the Pcinja basin are not met. Although mean annual runoff increases in the low-impact scenario, unmet demands rise in all scenarios relative to the baseline because, as described above, irrigation demands are higher and available runoff is lower during the summer months. This effect is evident in a graph of mean monthly unmet irrigation water demands in the 2040s, which is provided in figure 3.4.

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

- *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.[9] 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.

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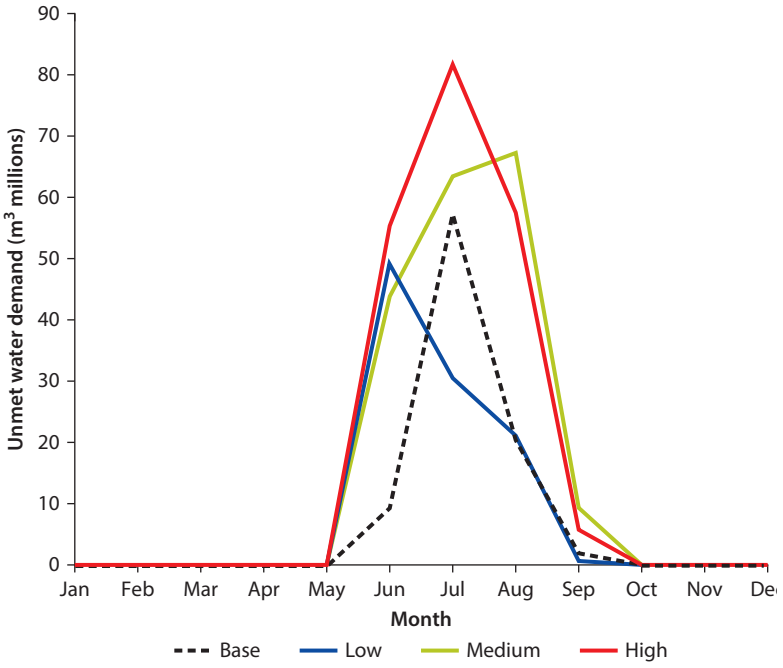
Figure 3.4 Mean Unmet Monthly Irrigation Water Demands over All Macedonian Basins, 2040s



- *Water quality.* Insufficient information was available to assess the implications of deteriorating water quality and increasingly saline soils on water demands in future years. Lessening quality is likely to either further reduce reuse of irrigation water, or cause yields to decline. To the extent that increasing soil salinity causes certain irrigated hectares to fall out of production, irrigation water demand would decline.
- *Future irrigation and storage projects.* The analysis assumes that no new reservoirs or irrigation projects will be constructed through 2050. If the construction schedule for any such projects were known with certainty, they could be incorporated into the WEAP baseline and would affect the overall water balance.
- *Reservoir sedimentation*. Reservoir volumes are assumed to remain constant at reported levels and that sedimentation does not cause substantial reductions in storage capacity. This assumption may overestimate storage availability over the next 40 years.

Effect of Irrigation Water Shortages on Crop Yields

As a final step in evaluating impacts of climate on agriculture, the results of the crop and water impact analyses were combined to evaluate how crop yields may be affected by reductions in basin-level water availability. To adjust mean changes

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Table 3.4 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

in crop yields reported in tables 3.1 and 3.2 for changes in water availability projected by WEAP, information from FAO on crop sensitivity to water availability was combined with basin-level water deficits from WEAP. To do so, it is assumed that each farm will receive the percentage of water that WEAP projects will be available at the basin level (table 3.4). For example, WEAP projects an irrigation water deficit of 7.9 percent in the Pcinja basin under the medium-climate 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 irrigation needs of a fraction of the crops, leaving the remaining fraction unirrigated.

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

The relationship, or elasticity, between relative crop yield and relative water deficit is called the yield response factor (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.[10] FAO has aggregated these seasonal factors into a single coefficient for the entire growing season. For Ky values less than one, 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.

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

Table 3.5 FAO Crop Response Factors

Crop	K_Y	*FAO crop name*
Maize	1.25	Maize
Wheat	1	W. Wheat
Alfalfa	1	Alfalfa 1
Grapes	0.85	Wine grapes
Apples	>1	Assumed; other fruit trees are 1 or greater
Vegetables	1.1	Peppers, tomatoes > 1

Source: FAO 2010.[11]
Note: Ky = yield response factor (the elasticity between relative crop yield and relative water deficit.

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

% change

		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.

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These factors are used to estimate the change in yield resulting from a reduction in water availability for each crop, unique AEZ-basin area, and climate scenario. At the high end of yield impacts, crops have Ky values greater than one and no deficit irrigation will take place. As a result, less area will be irrigated and farm-level crop yield will fall by the water deficit percentage. At the low end, crops have Ky values less than one and crop yields fall by the water deficit percentage multiplied by the Ky value. The resulting mean decadal changes in irrigated crop yields, adjusted for 2040s water availability, are presented in table 3.6.

Notes

1. The results in tables 3.1 and 3.2 provide summary yield changes relative to current yields, expressed as average percent change per decade for the full 40-year study period. In table 3.1, orange indicates a decrease in yield compared to the current situation, while green indicates an increase in yield. The results were calculated by taking the percentage change in yields from the baseline to the 2040s.
2. A full accounting of indirect effects of climate change on crops would also incorporate the effects of higher ambient ozone, which also limits most crop yields.
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CHAPTER 4

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

Options for Consideration

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

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

Table 4.1 provides the overall scope for the adaptation assessments in this chapter and in the quantitative analysis. The table includes four categories of options: (A) infrastructure adaptations—these are "hard" adaptation options which involve improvements of agriculture sector infrastructure, including water resources infrastructure improvements or expansions that are specifically targeted toward water available for irrigation; (B) programmatic adaptations—strengthening existing programs or creating new ones; (C) farm management adaptations—these are farm-level measures, and make up the largest portion of

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Table 4.1 Adaptation Options for Consideration

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

table continues next page

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Table 4.1 Adaptation Options for Consideration *(continued)*

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

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

the list; and (D) indirect adaptations—these are options not directly aimed at the agriculture sector, but which would benefit agriculture. Options that are evaluated quantitatively in chapter 5 are highlighted in bold in the table.

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Recommendations from Farmers

An important component of the study is to inform and consult stakeholders, farmers and farmers' associations, on the impact of climate change on agriculture and water resources. The team met with farmers for structured workshops in three locations in January 2011, for a one-day stakeholder consultation. The first formal consultation was in Bitola, for the Alpine and Continental AEZs. A total of 18 individuals participated including ten farmers, extension agents, FFRM representatives, and representatives from the Ministry of Agriculture. The second day, two formal stakeholder consultations took place. The first was in Skopje for the Mediterranean AEZ with 12 participants, ten of whom were from the branch office of the Ministry, the farmers federation, or the national extension agency and two who were beekeepers. The last meeting was in Kavadarci for the Continental AEZ, with 26 farmers participating.

Stakeholders were presented with projected yields of crops that are important to FYR Macedonia, and projected water supply and demand. Attendees were then asked if they have witnessed these impacts and what they have done, or would do, to mitigate their effects. All confirmed that several of the impacts have been felt on local farms. Although farmers are becoming more flexible in their response to climate events through education, their adaptive capacity is still quite limited because of poorly maintained irrigation and drainage systems, limited financial resources, and inadequate support from and access to extension services.

Summary of Farmer Concerns and Adaptation Option Assessments

Farmers were first asked whether they had experienced the impact of climate change and whether they thought farming will be influenced, now and in the future, by this climate change. A very active discussion resulted in identification of the following topics as most relevant to the farmers in attendance:

- *Large variations in temperature were registered*, with extremely low temperatures in the winter, and summer temperatures over 30°C. Farmers especially noticed these changes in the past eight years.
- *There were changes in the frequency of acid rain and pH values of soil.*
- *Flooding frequency increased* substantially in the past few years with more intense precipitation events because drainage channels cannot be cleared in time. This leads to decreased yields due to moist soil during planting.
- *Snowfall has declined*, which has meant that reservoirs are not replenished.
- *Precipitation overall has also declined*, but precipitation has increased in the winter and spring, which adversely affects fruit trees. Specifically, increased drought frequency was noted.
- *Hail events increased*, which can completely eliminate fruit yields.
- *Fruit are damaged* due to increased temperature and sunshine.
- *Frost at higher elevations disappeared* over the past four to five years.

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Current Adaptive Responses

Based on conversations with stakeholders and with in-country experts, adaptive responses that farmers are taking are summarized below.

- *Augmenting water supply.* Although groundwater wells are expensive options for farmers and many do not feel it is worth the cost, many have made this investment. Farmers also use water harvesting on smaller farms when irrigation water is not available. For example, some farmers have been placing rain capturing cans next to fruit trees with a small hole bored in the bottom.
- *Irrigation*. Applying water savings techniques such as drip irrigation, and irrigating crops not previously irrigated
- *Hail and UV nets.* Orchard growers use hail and UV nets.
- *Plastic tunnels.* To moderate temperatures and improve yields, some farmers have been constructing plastic tunnels for vegetables.
- *Mulching and polyethylene sheets.* These have been used as a water conservation technique.

The adaptive capacity of farmers in FYR Macedonia is clearly stressed by changes in overall climate. The combination of heat waves, droughts, and torrential rains 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, as well as farmer training and information access about weather related farming practices.

Summary of Discussions in Each AEZ

Below is a summary of each of the stakeholder consultations on the consultation participants, adaptive capacity, and ranked stakeholder recommendations. To facilitate discussions, the participants were divided into three smaller groups and were asked to discuss the following questions, and then report back to the whole workshop.

1. Which, if any, of the impacts discussed in the presentation on climate change impacts in FYR Macedonia 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?

In the second set of stakeholder consultations, the purpose of the meetings was threefold: (1) to present local stakeholders with a recommended menu of adaptation options, (2) to gain feedback on those options, and (3) to elicit other climate change adaptation suggestions.

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Alpine and Continental AEZs: Bitola

A total of 16 individuals participated in the Bitola consultation, including farmers, extension agents, FFRM representatives, and representatives from the ministry of agriculture. Farms ranged in size from a minimum of 1 hectare and a maximum of 20 hectares. The primary crops grown included maize, wheat, and alfalfa, although farmers also grew tobacco, chili peppers, apples, peaches, and organic produce. Several of the farmers also had livestock.

The most significant effects in these AEZs are droughts, heat waves, and flooding, although hail and wind are problematic as well. These farmers have been acutely aware of a changing climate due to increased frequency of these extreme events, as well as an increase in winter precipitation falling as rain instead of snow (which effectively reduces storage capacity). In response to these concerns, the following list summarizes the group's ranking and scoring of adaptation options:

1. Improve extension and hydrometeorological forecasting capacity (12).
2. Switch to appropriate crops/livestock varieties/breeds for new climate (11).
3. Increase irrigation/water use efficiency (drip irrigation, covering channels, mulching; 7).
4. Construct additional reservoir storage (4).
5. Build and rehabilitate irrigation infrastructure (3).
6. Provide land consolidation programs/incentives (1).

Mediterranean AEZ: Skopje

Although a total of 12 people participated in the AEZ consultations, ten of these were from the branch office of the ministry, the farmers federation, or the national extension agency. The remaining two participants were beekeepers.

Unlike the Continental and Alpine AEZs near Bitola, participants in the Skopje region indicated that flooding is the most significant climate change impact. Next were droughts, then heat waves, and hail. Although no participant suggested large-scale reservoir construction in the region, several suggested that smaller-scale ponds and reservoirs would be useful for supplying irrigation water to farms through the summer months. Farmers ranked and scored adaptation options as follows:

1. Improve extension service and hydrometeorological forecasting capacity (16).
2. Increase water use efficiencies (10).
3. Build and rehabilitate irrigation and drainage infrastructure (8).
4. Improve market access/commercial development (5).
5. Improve access to appropriate crops/varieties for changing climate (2).

Continental AEZ: Kavadarci

A total of 26 farmers participated in the Kavadarci workshop. Though some participants were from the local ministry branch, and others represented extension services, a large majority of the group was farmers, primarily grape growers.

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These farmers had between 0.3 hectare and 42 hectares of land. All farmers had grapes, and a subset had cereals, peaches, vegetables, or blackberries.

In these consultations, farmers indicated that increased frequency and intensity of heat waves have been the most significant issues in the Continental AEZ. These have been responsible for major crop losses in recent years. In addition, drought, general reductions in water availability due to changing precipitation patterns, and UV damage were stated as significant concerns. Ranks and scores of recommendations to respond to these threats include:

1. Build and rehabilitate irrigation infrastructure (covered, filtered; 19).
2. Improve access to crop varieties for changing climate (livestock; 18).
3. Improve water use efficiency (drip irrigation, lined channels, mulching; 17).
4. Offer land consolidation programs (15).
5. Improve farmer education through extension service (14).
6. Improve water basin management and allocation laws (4).
7. Mulch (rather than burn) the trimmings from pruning (2).

Recommendations of the World Bank Team

The Bank team arrived at the general conclusion that the "adaptation deficit" (the difference between current Macedonian yields and potential yields for the current climate) is larger than the incremental gains that can be made from adapting the Macedonian system to the projected effects of climate change. Closing the adaptation deficit, however, should be accomplished with future climate change explicitly considered, especially for larger capital/infrastructural projects such as construction and/or rehabilitation of irrigation and drainage infrastructure.

Nonetheless, every large investment project should include analyses of climate change in the design phase since it is much less expensive to incorporate adjustments (for example, in the capacity of drainage pipes) in design phase than to retrofit them after the system is built. Options favored by the team include the following.

- *Improve irrigation infrastructure and educate farmers on irrigation practices at the farm level (Options A.13, A.14, and B.2)*. There appears to be a strong potential for benefits from additional investment in irrigation infrastructure, including storage capacity. The team suggests that analyses be performed in the short term to evaluate the benefits and locations of possible new storage capacity for irrigation. These analyses should include explicit consideration of climate change. Irrigation infrastructure is evaluated quantitatively in chapter 5.
- *Improve drainage infrastructure and educate on drainage practices at farm level (Options A.12, B.2, and C.13)*. The team suggests that analyses be performed in the short term to increase the capacity of existing drainage infrastructure to include explicit consideration of potential flooding associated with climate change. Drainage infrastructure is evaluated quantitatively in chapter 5,

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but to realize the full benefits of that infrastructure option better farmer education on the need to keep drainage infrastructure well maintained is needed.

- *Increase general education level of farmers (Options B.1, B.2, and B.3; possibly coupled with B.14)*. More specifically, this option involves improving the existing extension agency capacity overall to support better agronomic practices at the farm level, and strategic implementation of a plan for more widespread demonstration plots. This option could also be coupled with investment in research focused on the testing of varieties that are better suited for future climates.
- *Improve capacity of hydrometeorological institutions (Option B.9)*. Additional capabilities are needed from the hydrometeorological institution in FYR Macedonia to provide additional information most relevant to farmer decision-making, for example to support irrigation timing decisions.
- *Switch to crops and varieties appropriate to future climate regime (Options C.11, C.6, and B.2)*. This option, partially analyzed in chapter 4, requires a combination increased knowledge at the national level and effective extension to advise farmers on those varieties best suited to the emerging temperature and precipitation trends. This option has both medium-term and long-term components.
- *Consider policy and/or private sector options to encourage more cooperative farming (Option B.4, as a step to more widespread adoption of all measures in Category C)*. The Bank team was impressed by the obstacles that face smallholder plot owners in making yield-enhancing investments. For smaller farms, these investments are difficult to justify; in larger cooperatives, there is a much greater likelihood that substantial economies of scale can be realized in implementing farm-level management improvements.
- *Improve fallow and mulching practices to retain moisture and organic matter (Options C.1 and C.2)*. This measure is relatively low cost but could yield a substantial closure of the adaptation deficit and, in the process, improve the resiliency of the agricultural sector to climatic shifts and extremes (such as drought).
- *Consider strip cropping and contour bunding (plowing) (Option C.10)*. This option is designed to improve water management and reduce soil erosion; contour plowing in particular has been identified as an important measure to reduce soil erosion in other Macedonian work on adapting the agriculture sector to climate change (MAFWE 2009).

Greenhouse Gas Mitigation Potential of Adaptation Options

Many of the adaptive measures recommended to improve the climate resilience of FYR Macedonia's agricultural sector also have the potential to mitigate climate change now and in the future. Particular adaptive practices, like manure management, present promising opportunities to lower greenhouse emissions by either reducing the greenhouse gases emitted in agricultural production processes or

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increasing the carbon stored in agricultural soils. This section discusses the potential for greenhouse gas mitigation in FYR Macedonia's agricultural sector and highlights the specific adaptive measures that demonstrate the greatest opportunities for emissions reductions. A summary of the mitigation potential of various adaptive measures is provided in table 4.2.

The relative mitigation potential of the various adaptive measures described in table 4.2 is primarily based on each measure's contribution to climate change as described in table 5.14 of Albania's Second National Communication (SNC)

Table 4.2 Greenhouse Gas Mitigation Potential of Adaptation Options

Adaptation measure	*Adaptation option reference number*	*Mitigation impact*	*Mitigation potential*
Irrigation systems: new, rehabilitated, or modernized (including drip irrigation; irrigation using less power)	A.13	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	C.1	Increases carbon inputs to soil and promotes soil carbon sequestration; Reduces energy used in transportation; Reduces energy consumption for production of agro-chemicals.	✓✓
Conservation tillage	C.3	Minimizes the disturbance of soil and subsequent exposure of soil carbon to the air; Reduces soil decomposition and the release of CO_2 into the atmosphere; Reduces plant residue removed from soil thereby increasing carbon stored in soils; Reduces emissions from use of heavy machinery.	✓✓
Crop rotation	C.5	Rotation species with high residue yields help retain nutrients in soil and reduces emissions of GHG by carbon fixing and reduced soil carbon losses. Also increase carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Strip cropping, contour bunding (or plowing) and farming	C.10	Increases carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Optimize timing of operations (planting, inputs, irrigation, harvest)	C.12	More efficient fertilizer use reduces 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	C.13	Increases soil carbon stocks; especially in highly degraded soils that are at risk erosion.	✓✓
Switch from field to tree crops (agro-forestry)	C.16	Retains nutrients in soil and reduces emissions of GHG by fixation of atmospheric N, reduction in losses of soil N, and increased carbon soil sequestration.	✓✓

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Table 4.2 Greenhouse Gas Mitigation Potential of Adaptation Options *(continued)*

Adaptation measure	*Adaptation option reference number*	*Mitigation impact*	*Mitigation potential*
Livestock management (including animal breed choice, heat tolerant, change shearing patterns, change breeding patterns)	C.17	Reduces CH_4 emissions.	✓
Match stocking densities to forage production	C.18	Reduces CH_4 emissions by speeding digestive processes.	✓
Pasture management (rotational grazing, etc.) and improvement	C.19	Degraded pastureland may be able to sequester additional carbon by boosting plant productivity through fertilization, irrigation, improved grazing, introduction of legumes, and/or use of improved grass species.	✓✓
Rangeland rehabilitation and management	C.20	Degraded rangeland may be able to sequester additional carbon by boosting plant productivity through fertilization, irrigation, improved grazing, introduction of legumes, and/or use of improved grass species.	✓✓
Intercropping to maximize use of moisture	C.27	Increases carbon inputs to soil and fosters soil carbon sequestration.	✓✓✓
Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night)	C.28	Minimizes CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓
Use water-efficient crop varieties	C.29	Minimizes CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	✓

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

to the Conference of Parties under the United Nations Framework Convention on Climate Change (Islami et al. 2009). Albania's SNC was relied on to estimate mitigation potential because FYR Macedonia's SNC (Azievska 2008) lacks a quantitative assessment of mitigation potential across adaptive practices. In particular, Albania's SNC estimates a "score" for each adaptive measure according to its potential to reduce greenhouse gas emissions and mitigate the economic impacts of climate change. The measures were ordered by these scores and assigned a "high" potential (three checks in table 4.2) to the top third, a "medium" potential (two checks) to the middle third, and a "low" potential (one check) to the last third.

The adaptive practices discussed in Albania's SNC were then mapped to those listed in table 4.2 based on similarities across qualitative descriptions. For example, Albania's SNC estimates the mitigation potential of "Perennial crops (including agro-forestry practices), and reduced bare fallow frequency," which is attributed to "Change fallow and mulching practices to retain moisture and organic matter" and "Switch from field to tree crops (agro-forestry)." To supplement the analysis,

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a comprehensive review was also conducted of the economic and scientific literature related to the mitigating impacts of agricultural adaptation in Europe (Medina and Iglesias 2010; Paustian et al. 2006; Smith et al. 2005, 2008; Weiske 2007). The results of this review were used to corroborate the mitigation potentials identified in Albania's SNC and to provide additional mitigation potentials for adaptive measures that were not explicitly quantified in Albania's SNC.

Each year FYR Macedonia's agricultural sector accounts for 8–15 percent of the country's total greenhouse gas emissions, which are generated by CO_2, nitrous oxide, and methane (Azievska 2008). Mitigation of CO_2 emissions is primarily enabled by adaptive crop yield and cropland management practices that increase soil carbon content. Soil carbon content is augmented by either enhancing the uptake of atmospheric carbon in agricultural soils or reducing carbon losses from agricultural soils. Specific adaptive practices that promote carbon soil sequestration include changing fallow season and mulching practices to retain moisture and organic matter and introducing cropping systems that promote high residue yields (that is, crop rotation, strip cropping, intercropping, cover cropping, etc.). Adaptive practices that slow rates of soil decomposition and reduce soil carbon losses include reduced till and no till farming.

Adaptive practices also have the ability to significantly reduce nitrous oxide and methane emissions. Nitrous oxide emissions are largely driven by fertilizer overuse and misuse, which increases soil nitrogen content and 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 enabled 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 and proper use of animal manure (for example, for biogas production) also lead 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.

The potential for adaptive agricultural practices to simultaneously mitigate climate change has already garnered attention in FYR Macedonia. Several new waste management programs have been developed to simultaneously improve agricultural production efficiency and reduce greenhouse gas emissions (Azievska 2008). These programs are currently focused on modernizing technology for biogas collection and combustion at pig farms (including covered lagoons and anaerobic digesters) and are expected to reduce annual greenhouse gas emissions by 17.6 thousand tons CO_2 equivalent by 2012 (roughly 1 percent of annual agricultural emissions). Additionally, FYR Macedonia's SNC also recognizes the need for further research into increasing livestock production, improving animal diets, and improved fertilization techniques (Azievska 2008).

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CHAPTER 5

Cost-Benefit Analysis

Scope and Key Parameters

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

1. Adding new 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 species
7. Optimizing fertilizer use

These options may include costs for extension programs, as appropriate, if enhanced extension is necessary to achieve the full benefits of the adaptation option. This is true for two of these options, improving water use efficiency, and changing crop varieties. In the case of changing crop varieties, it is expected that farmers will incur little or no net cost from this change in farming practice. In the current situation, these good farming practices are assumably not currently pursued because of inadequate research at the national level and lack of knowledge at the farm level. This has been confirmed by at least some of the farmers in the consultations. Therefore, the costs that would be incurred to enable these measures are to improve the capacity of extension services and availability of new varieties/breeds.

In addition, less detailed analyses of five other options was conducted: improving hydrometeorological services; improving extension services; enhancing basin-level water use efficiency; adding water storage capacity; and installing hail nets for selected crops.

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

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estimates are conducted for representative "model" farms, located in each of the three Macedonian AEZs, for farms that cultivate each of the key crops. The yield benefits for adaptation options are analyzed for the seven crops modeled with the AquaCrop system (wheat, maize, pasture, alfalfa, vegetables, apples, and grapes). Yield benefits of adaptation options for wheat, maize, and pasture were evaluated using the DSSAT system. Yield changes for the remaining crops were evaluated by reference to other work conducted in the region with AquaCrop. With seven crops, most of which are evaluated for both irrigated and rainfed yields, and three AEZs, there are a total of over 35 model farms in the analyses.

The results presented here are useful as a first order assessment of actions that are likely to yield positive returns for farmers. No conclusions are however made in this analysis about farmers ability to pay for these measures. For example, 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 the study recommends that farmers attempt to construct and pay for this infrastructure themselves. In fact, few farmers would actually be able to obtain individual farm-level irrigation infrastructure at the price per hectare were used, which reflects construction of a broader irrigation infrastructure project with potentially significant economies of scale. In many cases, national policies and/or funding are needed to enable these adaptations to occur.

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

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

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

Figure 5.1 presents the revenue per hectare for crops, for rainfed and irrigated conditions, comparing current conditions with those with climate change in

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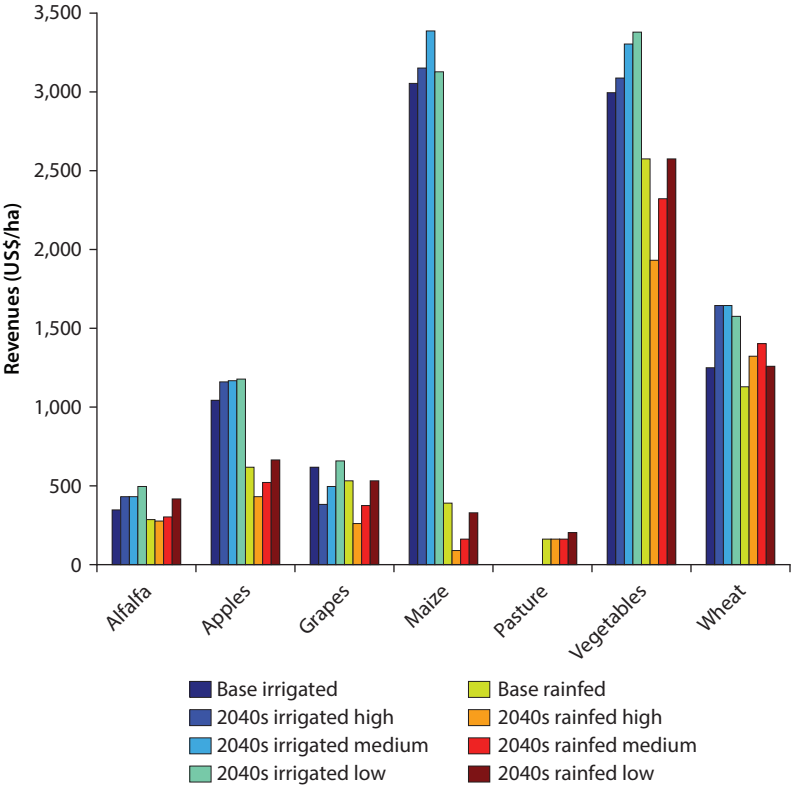
Figure 5.1 Estimated Crop Revenues per Hectare for the 2040–50 Decade Before Adaptation Actions Are Taken



2040s, but before adaptation actions are taken. For comparison purposes across years, the price forecasts incorporated in this figure are current prices rather than the "high" 2040 price forecasts. The figure indicates that the highest value crops now and in the future, are vegetables. Among cereal crops, irrigated maize and irrigated wheat provide comparable revenues per hectare, but as suggested by the low revenues, rainfed maize is not typically profitable and often not viable in FYR Macedonia. As seen in the next section, adopting adaptation options has the potential for further yield and revenue enhancement, because adaptation can both address current yield deficits relative to full yield potential (closing the "adaptation deficit"), and enhance farmers abilities to both minimize risks and exploit opportunities presented by climate change.

Results of Quantitative Analyses—Cost-Benefit Assessments

This section presents sample results for each of the options, focusing on the Continental AEZ. Each adaptation option is illustrated in a graph that shows B-C ratios for each crop assessed, for the baseline and each climate scenario, and under the two price scenarios. The dashed line near the bottom of the graph shows a B-C ratio of one. Bars that extend above this line represent

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crop/scenario/price forecast combinations where benefits exceed costs. Higher bars indicate higher benefit-cost ratios, and therefore those crop/scenario combinations, for the option examined, are more likely to be good investments. This chapter later summarizes and ranks the quantitative results for each AEZ.

Adding New or Rehabilitating Existing Irrigation Infrastructure

Figures 5.2 and 5.3 illustrate, respectively, the results of adding irrigation capacity and of rehabilitating existing irrigation capacity. The option is modeled as a switch from rainfed to irrigated crops for the model farms in each of the AEZs. The graphs present B-C ratios for the Continental AEZ for each of the focus crops. The results in these figures indicate that B-C ratios are relatively high in this AEZ for vegetables, maize, and apples, and lower for wheat, grapes, alfalfa, and pasture. Because rehabilitating irrigation infrastructure is less expensive than new infrastructure (while the benefits are the same), B-C ratios for rehabilitated infrastructure are higher than for new infrastructure. Generally, B-C ratios are

Figure 5.2 Benefit-Cost Analysis Results for Newly Irrigated Crops in the Continental AEZ

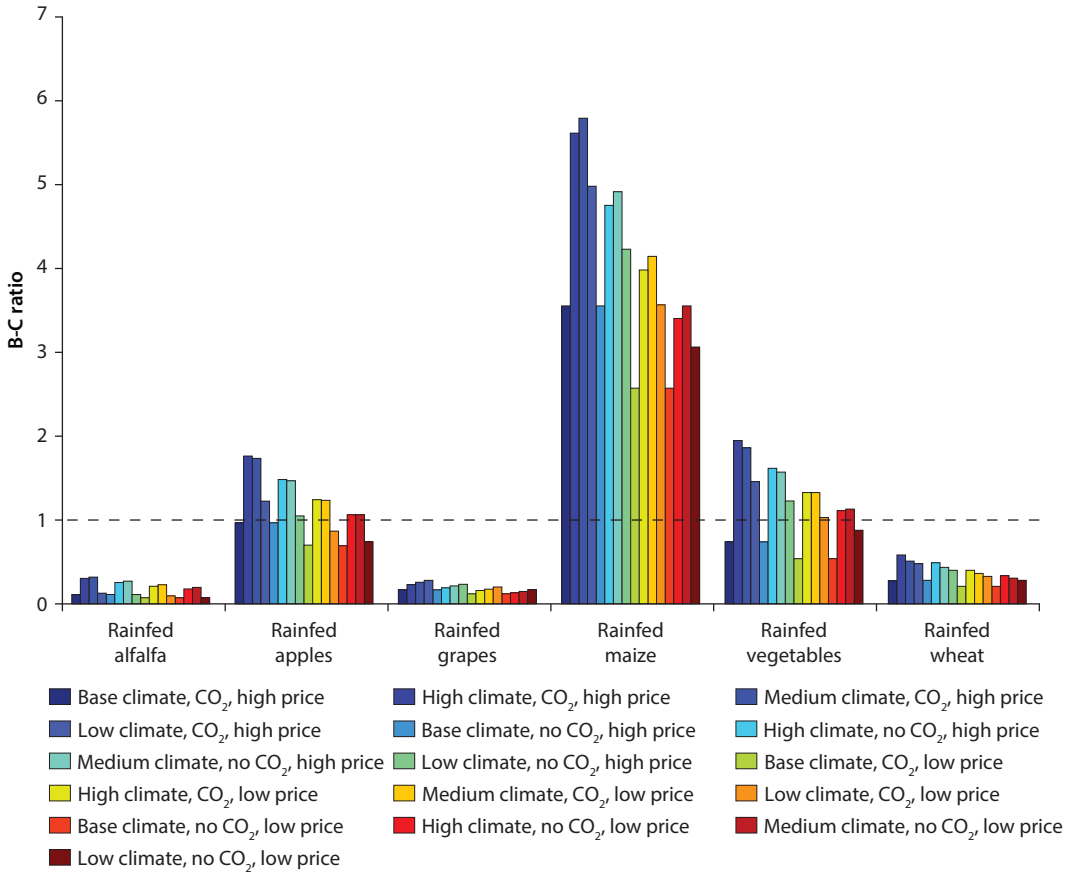

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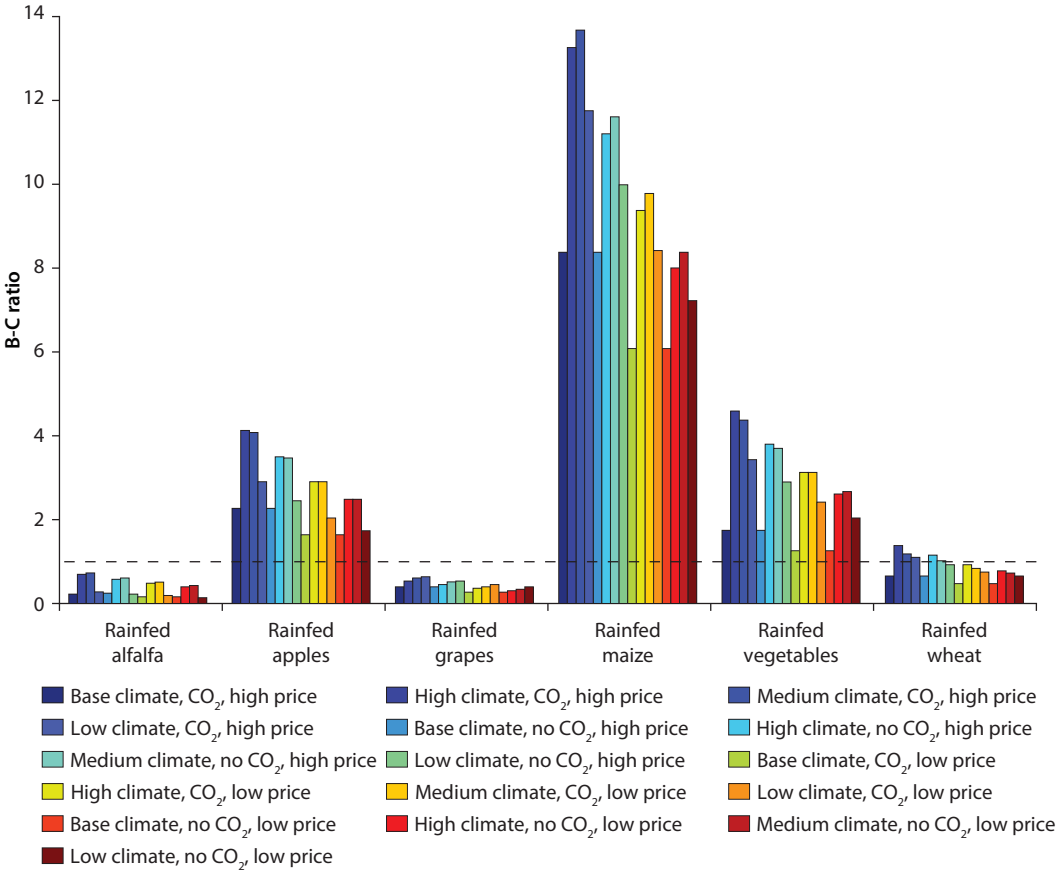
Figure 5.3 Benefit-Cost Analysis Results for Rehabilitated Irrigation Infrastructure for Crops in the Continental AEZ



highest under either the high- or medium-climate scenario, and are significantly higher than if the adaptation options are adopted under base climate conditions.

Similarly, Figure 5.4 illustrates B-C ratios for improved water use efficiency in the Continental AEZ.

Adding New Drainage Capacity and Rehabilitating Existing Drainage Infrastructure

The results of the analysis of improving drainage are presented in figures 5.5 and 5.6 for the Continental AEZ. Figure 5.5 is for new drainage infrastructure, and figure 5.6 is for rehabilitated drainage infrastructure.

This option involves a farm-level improvement of drainage conditions similar to that which would result from the difference between poorly drained and well-drained soils, and entails both capital and ongoing maintenance costs, estimated on a per hectare basis. Costs are higher for new drainage infrastructure than for

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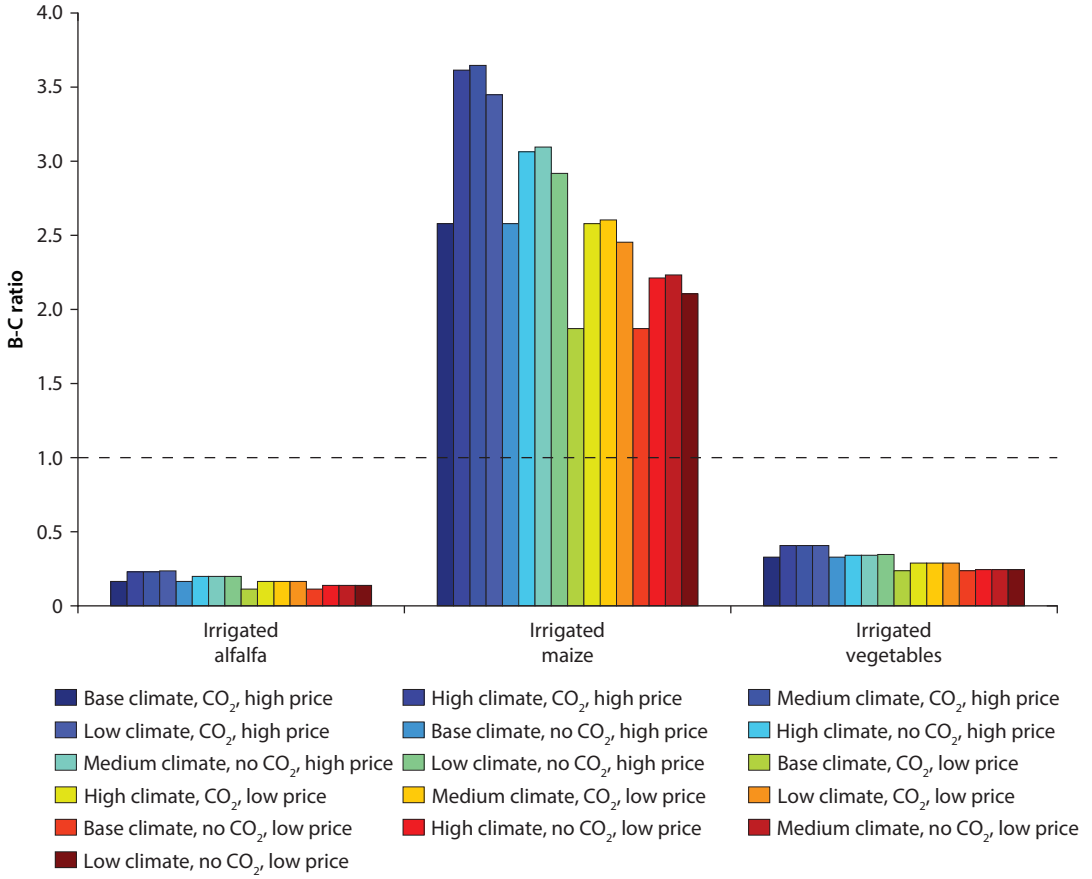
Figure 5.4 Benefit-Cost Analysis Results for Improved Water Use Efficiency in the Continental AEZ



rehabilitated infrastructure, but the estimated yield increase is the same, so benefit-cost ratios are higher where it is possible to rehabilitate existing infrastructure. The yield effect in the calculations likely underestimates benefits, because the modeling reflects only the continuous yield improvements, and does not reflect additional yield changes that might result from improved drainage during extreme flood events.[1]

The results indicate that improved drainage can be most beneficial for improving yields of irrigated maize, but suggest it can also be beneficial for virtually all non-fodder crops (all but alfalfa and pasture). As indicated by farmers, there is a great need for rehabilitation of existing drainage infrastructure, but the high cost of new drainage infrastructure may limit the feasibility of that option.

Changing Crop Varieties

Figure 5.7 shows the results for changing crop varieties for the Continental AEZ. For this option, it is estimated that the main cost is enhanced research and

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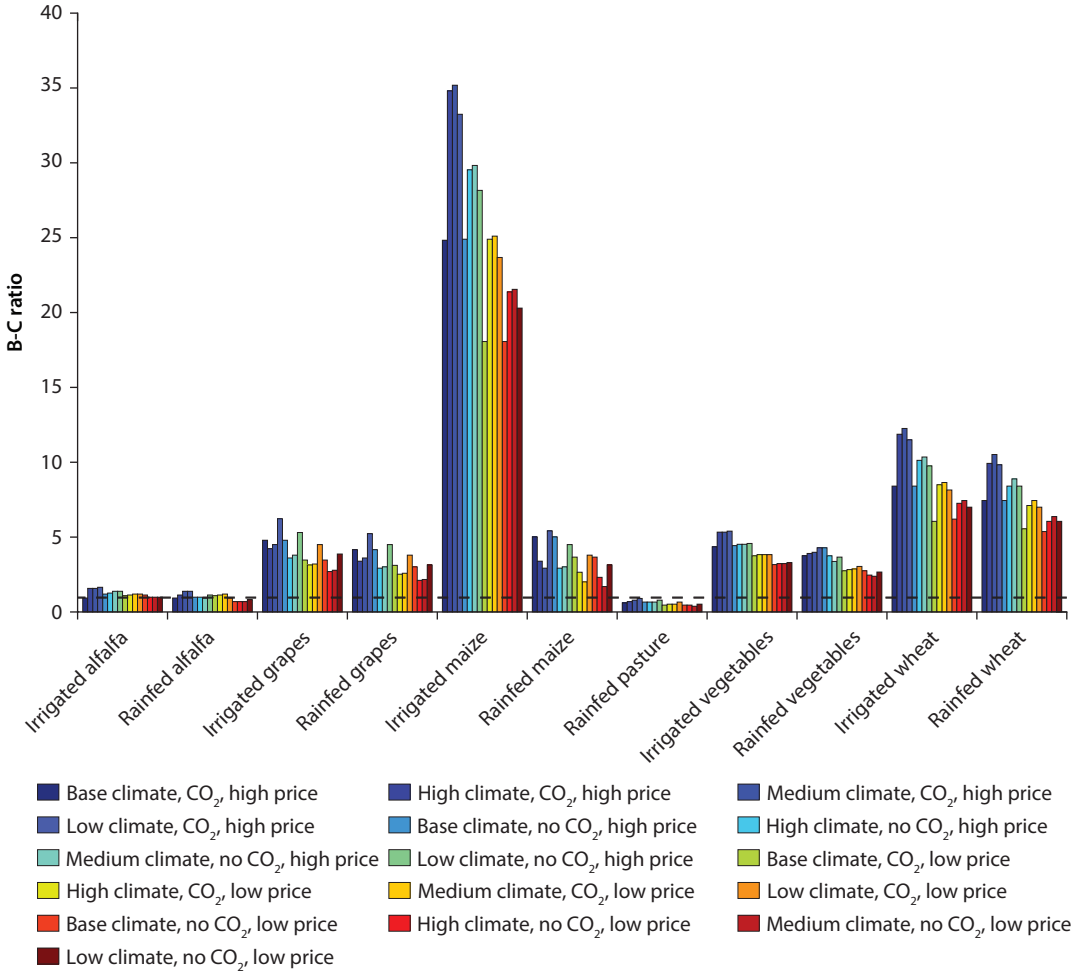
Figure 5.5 Benefit-Cost Analysis Results for Improved Drainage in the Continental AEZ—New Drainage Infrastructure



development at the regional level, likely funded by national expenditures but potentially funded privately by farmer cooperatives or agribusiness concerns. For changes in crop variety, only the results for the Continental AEZ are presented. Results for other AEZs are similar. For this option the value of yield is estimated to benefit from a change from current to optimal crop varieties, as feasible within the options available within the DSSAT model database of crop varieties.[2]

As indicated in the figure, B-C ratios are highest for irrigated maize, with extraordinarily high ratios of up to 200 to 1. B-C ratios for wheat are lower but still significantly greater than one. In most cases, the benefits of optimizing crop varieties reflects the adaptation deficit, in that better varieties could result in substantial yield gains regardless of the change in climate. However, costs for this adaptation option may be underestimated as there may be additional costs to

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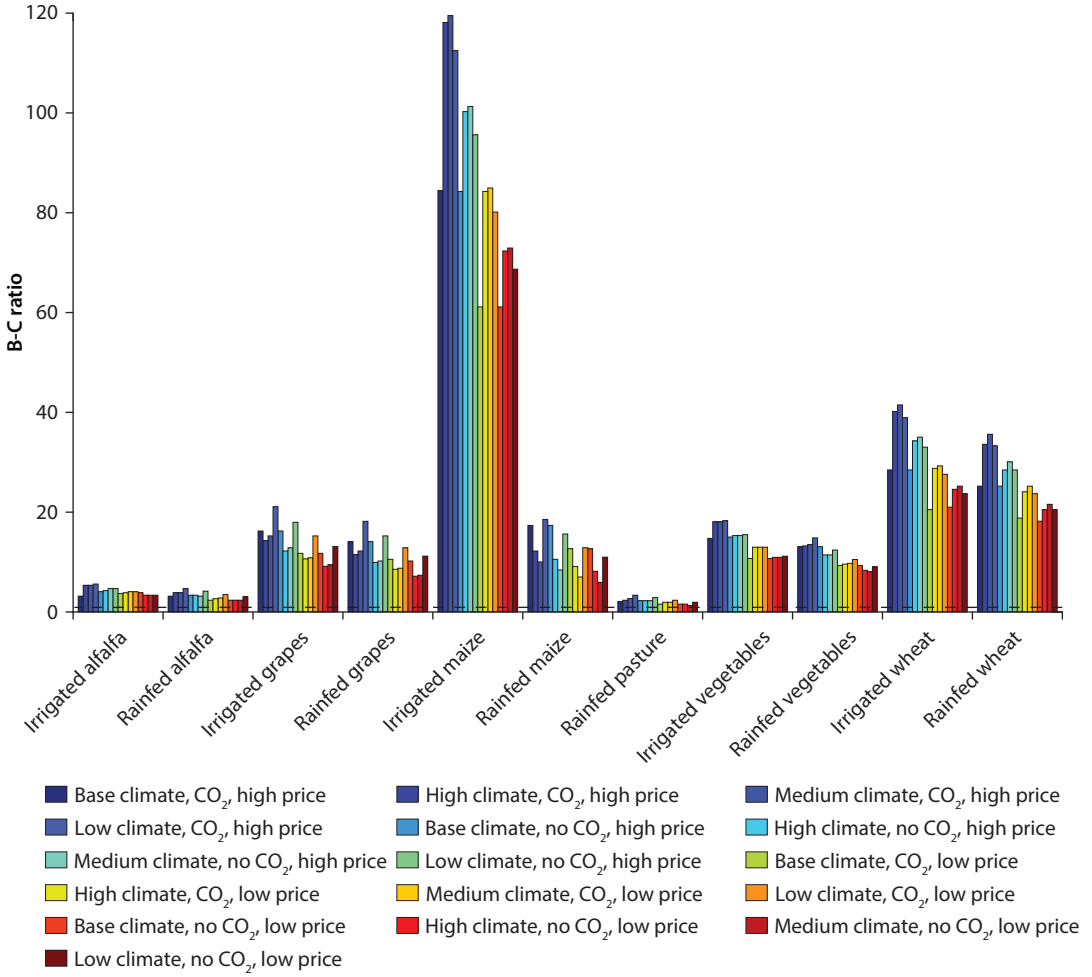
Figure 5.6 Benefit-Cost Analysis Results for Improved Drainage in the Continental AEZ—Rehabilitated Drainage Infrastructure



farmers for more expensive varieties, and possibly other direct costs for nutrient, pesticide, and water inputs to achieve higher yields.

Optimizing Fertilizer Application

Figure 5.8 illustrates results for optimized organic fertilizer application, relative to current use of fertilizer, for the Continental AEZ. The graph shows high B-C ratios for irrigated maize, and much lower ratios for irrigated and rainfed wheat. As noted above, however, the costs for fertilizer in this framework include only the direct expenditures, and do not reflect indirect costs and effects of fertilizer application for the surrounding environment, or the possibility that enhanced fertilizer application could in some cases also increase greenhouse gas emissions that contribute to climate change. As a result, while B-C ratios for this option are

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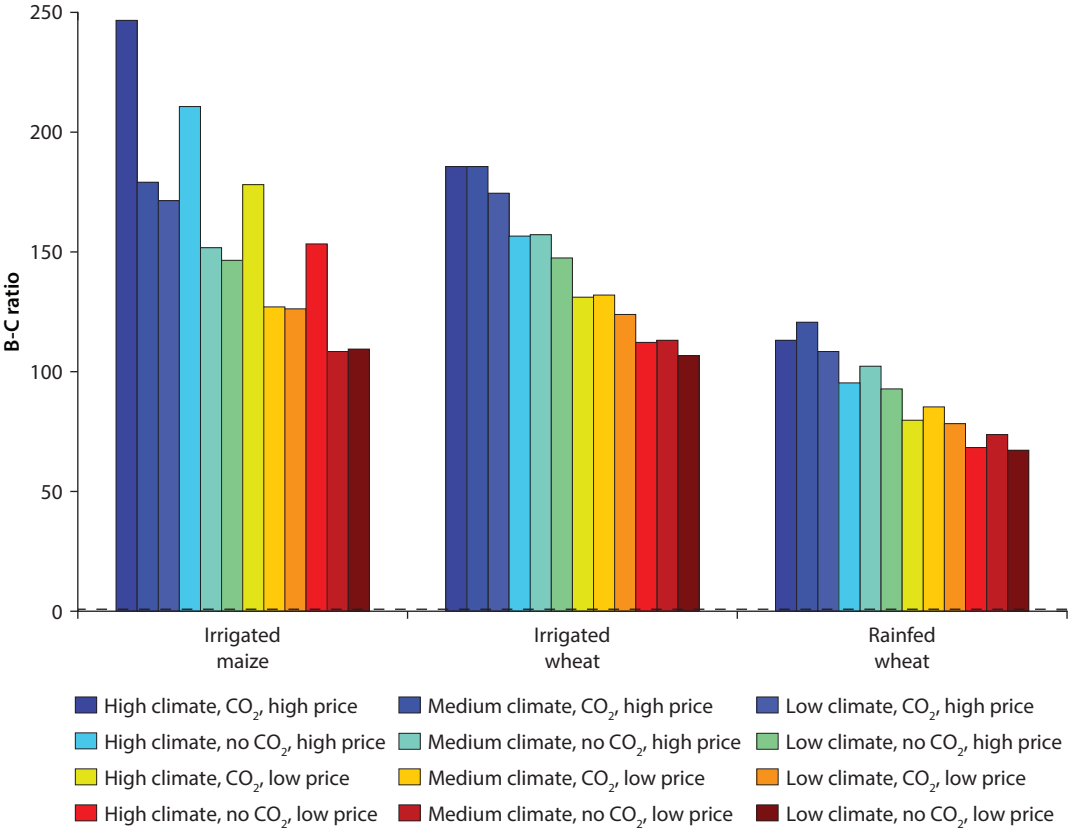
Figure 5.7 Benefit-Cost Analysis Results for Optimizing Crop Varieties in the Continental AEZ



greater than one for maize, when other non-quantified social costs are considered it is possible that the B-C ratio could drop to less than one.

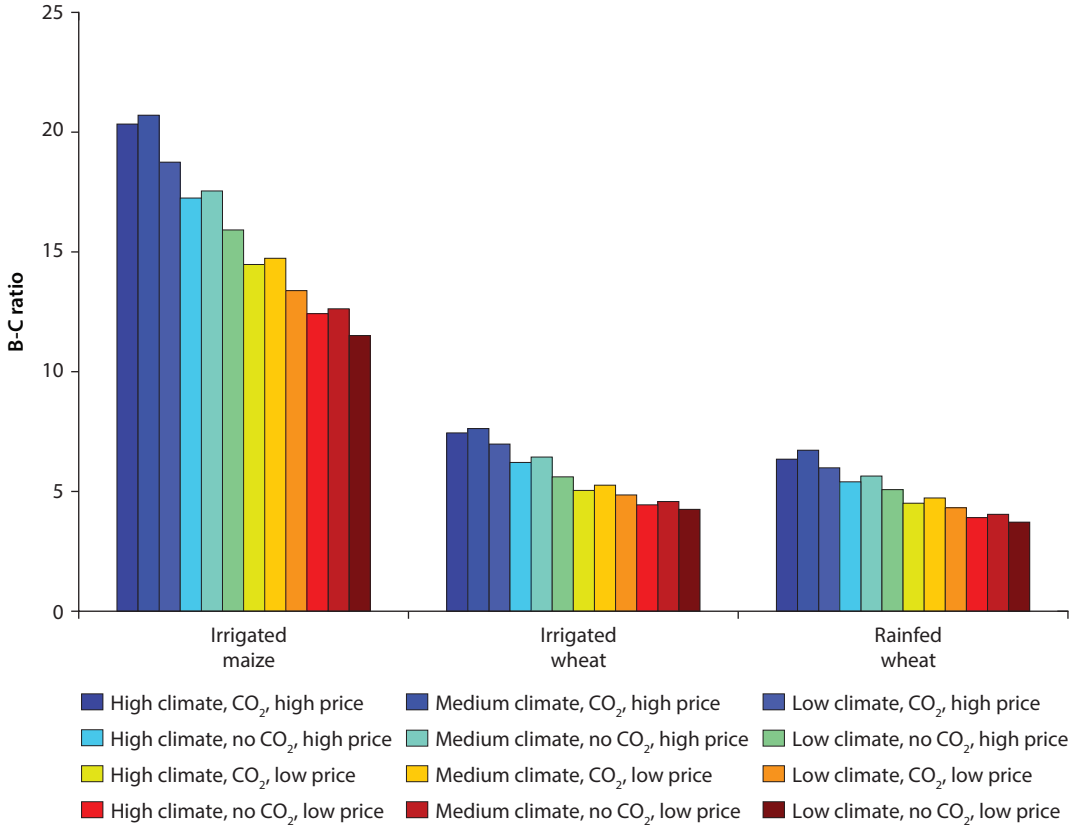
Other Economic Analyses

In addition to the detailed economic analyses described above, analyses were conducted of the potential benefits and costs for six additional options that were of interest to farmers, but for which data were more sparse: improving the hydrometeorological network; expanding extension services; enhancing basin-level water use efficiency; adding water storage capacity; and installing hail nets for selected crops. These other economic analyses are informative for ranking options but provide less certainty than the more detailed analyses in the prior section.

Improving the Hydrometeorological Network

In other regional work, the costs of improving hydrometeorological data collection and institutions in Albania were estimated and compared to the yield increases that would be necessary to achieve yield benefits equal to the estimated costs. Some of those estimates are here transferred to FYR Macedonia.

Figure 5.8 Benefit-Cost Analysis Results for Optimized Fertilizer Use in the Continental AEZ



Although one of the benefits of this measure is improved timing of irrigation water application (analyzed above), it was not possible to monetize several other benefits of this alternative, some of which include flood forecasting, improved forecasting of crop life stages, and less frequent and more precise fertilizer and pesticide application. Because direct comparison of costs and benefits is not possible, this option was instead evaluated by considering how much crop yields would need to increase in order to justify the costs of improving hydrometeorological capacity; this is sometimes referred to as a "break-even" analysis.

In total, it was estimated that the annualized capital and annual O&M improvements in hydrometeorological capacity could cost 21 US cents per irrigated hectare per year. The cost would be considerably lower if rainfed hectares were included.

For the break-even analysis, the present value (over the 2015–2050 period) per hectare costs of hydrometeorological services is divided by the present value revenues for a typical hectare of each crop in each AEZ across each of the price and climate scenarios. This reveals the percentage increase in per hectare yields (that is, yields are linear with respect to revenues) necessary to cover the per

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hectare costs. Across all crops, AEZs, and scenarios, yields would need to increase an average of about less than 0.1 percent to justify the costs. Based on these results, expanding and tailoring the hydrometeorological network to agricultural needs would very likely yield benefits substantially greater than its costs.

Expanding Extension Capabilities and Services

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

To estimate costs for an enhanced extension service, the Bank team relied on information from its broader regional analyses. It can be assumed that about 70 percent of the total number of farmland hectares in FYR Macedonia could benefit from enhanced extension, that a reasonable program of extension would cost about US$500,000 per year, and that the resulting program would have an annual cost per hectare of US$6.44. The average break-even yield increase required to justify this cost, across all crops, AEZs, and scenarios is about 1 percent.

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

Improving Basin-Wide Water Efficiency

A screening analysis was conducted on the benefits of improving water efficiency in two basins where the WEAP analysis finds that water shortages are likely: the Crna and the Pcinja. Unmet demands in the Crna basin are much larger than in the Pcinja. Improving irrigation efficiency was examined from the baseline of 50 percent (based on FAO data) in 5 percent increments, up to a high of 75 percent, in both basins. The benefit is increased profit (not revenue) from additional irrigation water that brings additional acreage back to cultivation. For example, under the high-impact climate change scenario in the Crna basin, a 5 percent increase in efficiency makes available an additional 25 million cubic meters of water to meet irrigation demand, reducing the unmet demand from 56 percent to 48 percent, and allows an additional 2,500–3,000 hectares to be irrigated each year by the 2040s. The results are presented in figure 5.9, with one panel for each of the two basins. Although the benefit-cost ratios for improved basin-wide water efficiency are comparable across the two basins, the scale of the potential

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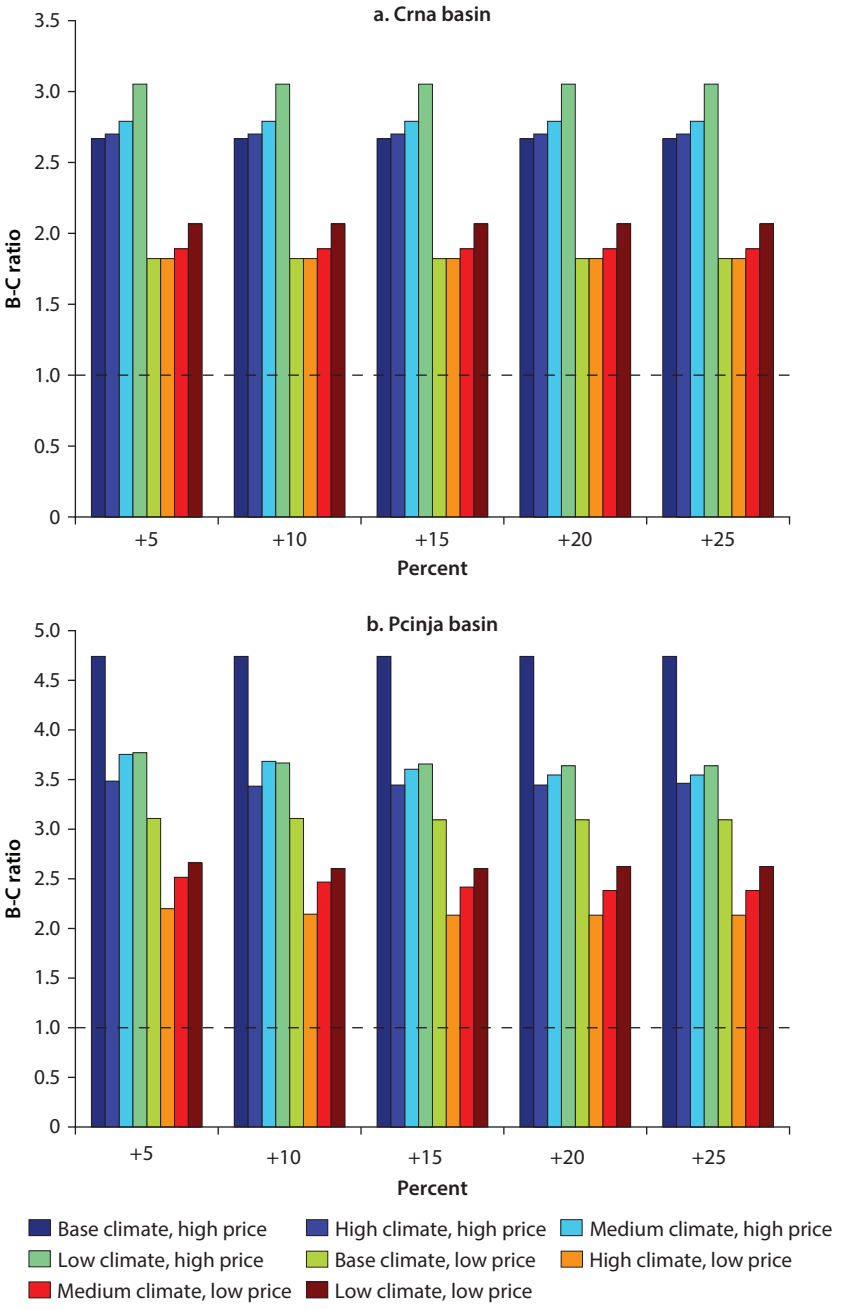
Figure 5.9 Impact of Improving Basin-Wide Irrigation Efficiency



adaptation project for the Crna basin, which has a much larger projected unmet irrigation demand, is much larger. Nonetheless, in both basins it appears that the costs of substantial improvements in basin-wide water efficiency are justified by the yield-enhancing benefits of additional irrigation potential.

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Expanding Water Storage Capacity

A screening analysis was also conducted of the costs and benefits of building new storage capacity to provide additional water during times of low water supply. The limitations of this approach are substantial; the team was unable to conduct detailed studies of basin dynamics, and has not analyzed the implications of storage for transboundary flows and compliance with international water treaties. Estimated costs of constructing storage are from Ward et al. (2010), and are between 12 and 30 US cents per cubic meter, varying based on the size of storage structure and the average slope of the basin.

The benefits of storage are in reducing unmet irrigation water demand, and therefore providing additional net revenues of cultivating crops. The value of additional crop cultivation is net revenue from a mix of crops identical to those currently cultivated in the basin; however, in practice this may overstate benefits because, as water shortages manifest, water might be diverted to higher value crops.

The two panels of figure 5.10 illustrate the range of results for the two basins where continued water shortages are forecast with climate change. Benefit-cost ratios for storage vary substantially by the amount of storage, along the horizontal axis, and the climate scenario, represented by the individual bars, and by basin, with storage generally showing favorable benefit-cost ratios in the Crna basins for almost all scenarios up to very large incremental increases in storage capacity, while for the Pcinja basin only more modest storage increases yield favorable benefit-cost ratios. What underlies these results is a relationship between storage and annual water yield, which translates to an increase in hectares that can be irrigated. For the Crna basin, these relationships imply that about 100 additional hectares can be irrigated for each 1 million cubic meters of storage capacity added, but this value decreases rapidly after a total of about 50 million additional cubic meters of storage is put in place. The marginal additional hectares per unit of storage are lower for the Pcinja basin and drop off much more rapidly as more storage is added, in part because the projected unmet irrigation demand in the Pcinja basin is so much less than in the Crna.

These results should be considered with caution, however, as they reflect only a zero-order analysis of the viability of storage across the basin, at a very coarse resolution, without the benefit of detailed study of the feasibility of constructing additional water storage. Even with those caveats, these results for the Crna basin in particular generally support the conclusion of local farmers that increased storage capacity could be an effective adaptation strategy in light of increased spring precipitation and the need for irrigation water in the mid-summer period.

Installing Hail Nets for Apple Orchards and Other Crops

Hail nets were mentioned by farmers in the Continental and Alpine regions as a measure that they believed could be beneficial. There is some emerging literature that indicates that climate change will lead to more frequent and more severe hail storms and thunderstorms (Trapp et al. 2007). In addition, a recent study for Northeastern Spain estimates the costs of hail nets for apple crops relative to crop insurance (Iglesias and Alegre 2006). This study found that the benefits of

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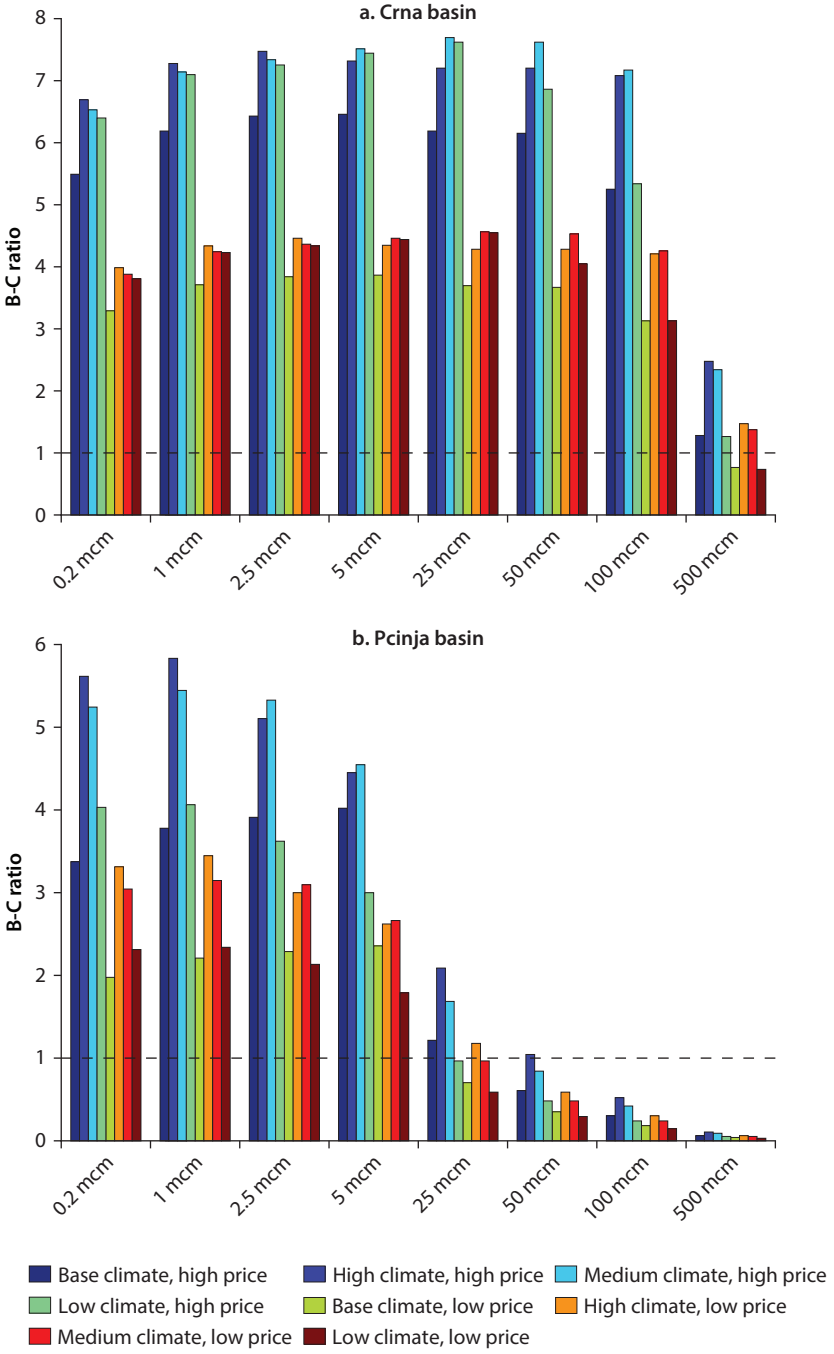
Figure 5.10 Preliminary Analysis of the Benefits and Costs of Water Storage



Note: mcm = million cubic meters.

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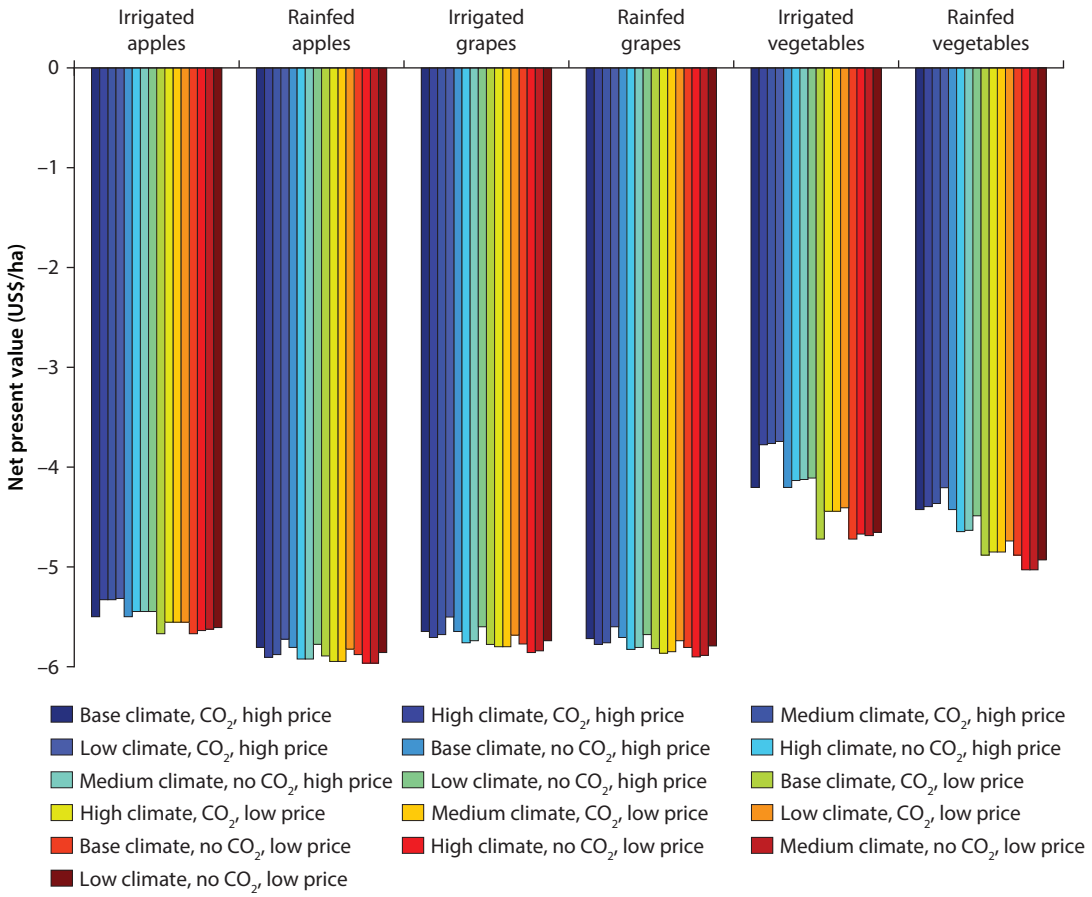
hail nets are slightly better relative to crop insurance. However, it implicitly assumed that crop insurance is a wise investment, and therefore did not evaluate the baseline risk of hail damage each year relative to insurance premiums.

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. In this analysis, capital costs from Iglesias and Alegre and their estimates of net yield decrements from their field studies of gala apples were applied to apples, grapes, and vegetable crops in the Continental and Alpine AEZs. The result is illustrated in figure 5.11, in net present value terms. 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 0.5 for any combination in any AEZ. The Iglesias and Alegre analysis provides some justification for the measure that some Macedonian farmers believe would be beneficial for their orchards, but the

Figure 5.11 Results of Net Present Value Analysis for Hail Nets to Protect Selected Crops in the Mediterranean AEZ



Bank analysis reflecting local conditions suggests this measure would not yield benefits in excess of costs.

Sensitivity Analyses

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

The effect on 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 results in present value benefits of the adaptation options falling by about a factor of two (across crops, AEZs, and climate/crop price scenarios). The effect on present values varies and depends on relative magnitudes of the costs and benefits. In a small number of instances, the use of a 10 percent discount rate causes NPVs of the adaptation options to change signs. The changes are from positive NPVs to negative NPVs, and occur under adaptation scenarios where the NPVs are already near-zero. Because options are not recommended unless B-C ratios are much greater than one, or NPVs are much greater than zero, the higher discount rate does not alter the 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 figures 5.12 and 5.13.[3] Figure 5.12 shows that, under all scenarios and start dates, rehabilitating irrigation in areas that are currently rainfed maize in the Continental AEZ has a B-C ratio greater than one. Figure 5.13, for the same measure in the same AEZ, but for rainfed wheat, shows a different pattern, where only some of the climate scenarios and only one of the start dates yield B-C ratios greater than one. One conclusion from figure 5.13 might be 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.

Analysis of Livestock Sector Adaptation

In the absence of a process model that can simulate the effects of climate change and adaptation measures on livestock productivity, it is difficult to evaluate livestock sector adaptation options. As a result, the livestock sector recommendations are based on a literature review and qualitative analysis. These include options such as providing better protection for livestock during heat waves (ranging from better shade to air-conditioned barn space) and transitioning livestock

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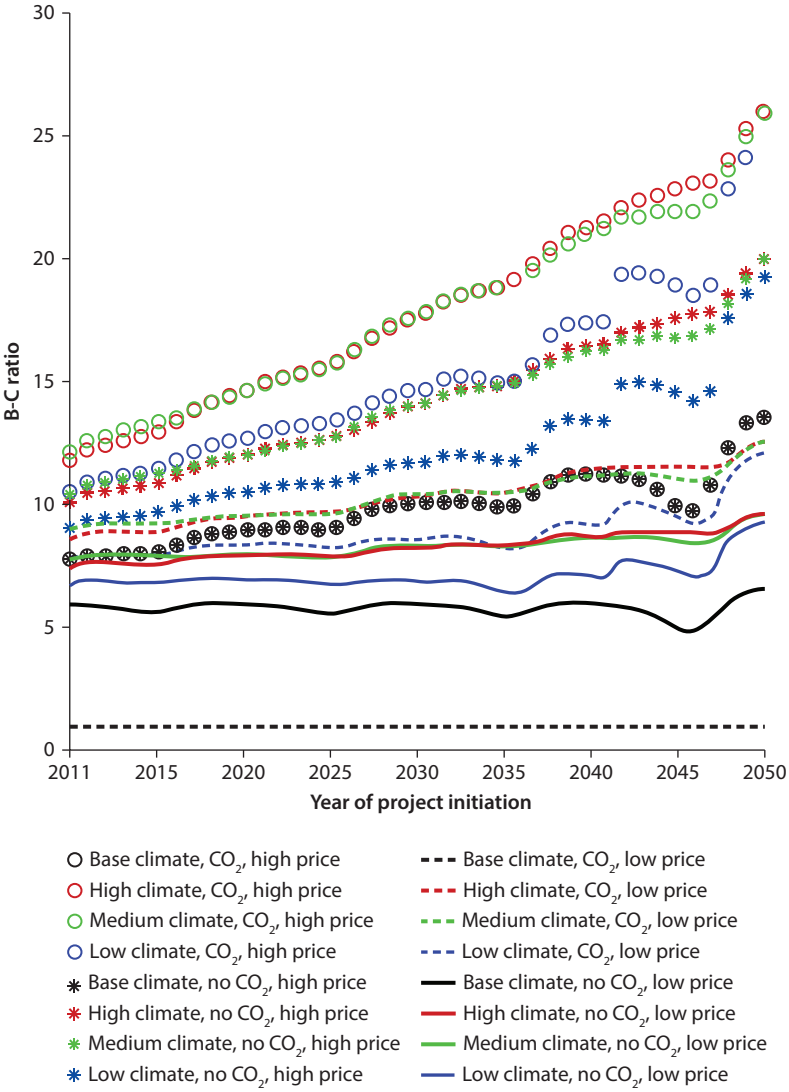
Figure 5.12 Detailed Sensitivity Analyses: Rehabilitated Irrigation for Currently Rainfed Maize in the Continental AEZ

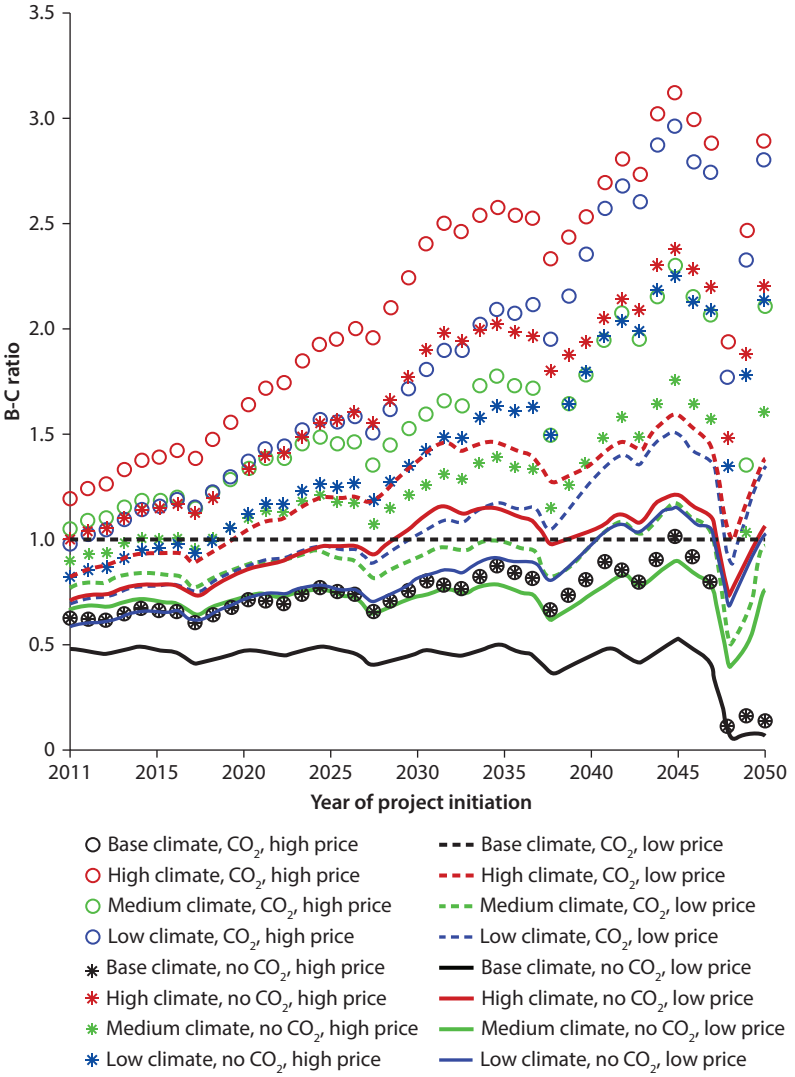


varieties. Chapter 6 recommends a national policy to devote greater attention to evaluating the suitability of gradually introducing heat-tolerant breeds for stocking Macedonian herds.

Summary of Quantitative Results in AEZs

The previous section highlights selected results for benefit-cost ratios with a focus on the Continental AEZ. Benefit-cost ratios are useful, but another useful measure is net present value benefits, which indicates the per hectare benefits

Figure 5.13 Detailed Sensitivity Analyses: Rehabilitated Irrigation for Currently Rainfed Wheat in the Continental AEZ



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

Tables 5.1 through 5.3 summarize the net benefit estimates for the three AEZs. The tables list what are considered to be the five adaptation measures with the highest overall net benefits. Roughly the same five to six measures have the highest overall rankings in the Mediterranean and Continental AEZs while on-farm water use efficiency and new and rehabilitated irrigated systems are too

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Table 5.1 Adaptation Measures with Highest Net Benefits: Mediterranean AEZ

Description of recommended adaptation measure	*Crop focus for Mediterranean AEZ*	*Illustrative present value economic results per hectare (000 2009$)*			
		Estimated revenue gain	*Estimated costs*	*Net revenues*	*Notes*
Improve varieties	Irrigated maize:	$65 to 95	$0.35	$64 to 95	Costs are for R&D.
	Rainfed maize:	$0.8 to 1.8		$0.4 to 1.5	
	Irrigated wheat:	$69 to 103		$68 to 103	
	Rainfed wheat:	$41 to 62		$41 to 61	
Rehabilitate old irrigation systems	Rainfed apples:	$12 to 19	$5.1	$7 to 14	
	Rainfed maize:	$47 to 67		$42 to 62	
	Rainfed vegetables:	$11 to 18		$6 to 13	
	Rainfed wheat:	$5 to 8		$0.3 to 3	
Create new irrigation systems	Rainfed apples:	$12 to 19	$9.6	$3 to 9	
	Rainfed maize:	$47 to 67		$37 to 57	
	Rainfed vegetables:	$11 to 18		$2 to 8	
Rehabilitate existing drainage infrastructure	Irrigated alfalfa:	$1 to 1.6	$0.31	$0.8 to 1	Benefits do not reflect increased risk of floods with climate change.
	Rainfed alfalfa:	$0.7 to 1		$0.4 to 1	
	Irrigated grapes:	$2 to 3		$1 to 3	
	Rainfed grapes:	$1 to 3		$1 to 2	
	Irrigated maize:	$26 to 36		$25 to 36	
	Rainfed maize:	$1 to 2		$0.6 to 2	
	Rainfed pasture:	$0.6 to 1		$0.3 to 0.8	
	Irrigated vegetables:	$3 to 4		$3 to 4	
	Rainfed vegetables:	$2 to 3		$2 to 3	
	Irrigated wheat:	$10 to 14		$10 to 14	
	Rainfed wheat:	$8 to 12		$8 to 12	
Use irrigation water more efficiently	Irrigated maize:	$14 to 20	$8.5	$5 to 11	Costs are for drip irrigation, extension & hydromet.
	Irrigated vegetables:	$11 to 16		$2 to 8	
Optimize fertilizer application	Irrigated maize:	$19 to 27	$1.2	$17 to 26	Costs do not include environ. damages.
	Irrigated wheat:	$9 to 13		$8 to 12	
	Rainfed wheat:	$7 to 10		$6 to 9	

expensive to be viable options in the Alpine AEZ. Net benefits are higher in low-elevation AEZs, in general. Only those crops with a positive net benefit are listed; for all other crops not listed in the table, there is a negative or very near zero net benefit for the measure.

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

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Table 5.2 Adaptation Measures with Highest Net Benefits: Continental AEZ

Description of recommended adaptation measure	*Crop focus for Continental AEZ*	*Illustrative present value economic results per hectare (000 2009$)*			
		Estimated revenue gain	*Estimated costs*	*Net revenues*	*Notes*
Improve varieties	Irrigated maize:	$39 to 75	$0.35	$38 to 74	Costs are for R&D.
	Irrigated wheat:	$38 to 56		$38 to 55	
	Rainfed wheat:	$24 to 36		$24 to 36	
Rehabilitate old irrigation systems	Rainfed apples:	$9 to 17	$5.1	$3 to 12	
	Rainfed maize:	$35 to 56		$30 to 51	
	Rainfed vegetables:	$10 to 19		$5 to 14	
Create new irrigation systems	Rainfed maize:	$35 to 56	$9.6	$25 to 47	
	Rainfed vegetables:	$10 to 19		$0.5 to 9	
Rehabilitate existing drainage infrastructure	Irrigated alfalfa:	$1	$0.31	$0.7 to 1	Benefits do not reflect increased risk of floods with climate change.
	Rainfed alfalfa:	$0.7 to 1		$0.4 to 1	
	Irrigated grapes:	$3 to 6		$3 to 5	
	Rainfed grapes:	$2 to 5		$2 to 4	
	Irrigated maize:	$22 to 32		$21 to 31	
	Rainfed pasture:	$0.5 to 0.9		$0.2 to 0.6	
	Irrigated vegetables:	$3 to 5		$3 to 5	
	Rainfed vegetables:	$3 to 4		$3 to 5	
	Irrigated wheat:	$7 to 11		$7 to 11	
	Rainfed wheat:	$6 to 9		$6 to 9	
Use irrigation water more efficiently	Irrigated maize:	$18 to 26	$8.5	$9 to 18	Costs are for drip irrigation, extension & hydromet.
Optimize fertilizer application	Irrigated maize:	$13 to 20	$1.2	$0.7 to 1	Costs do not include environ. damages.
	Irrigated wheat:	$5 to 7		$4 to 6	
	Rainfed wheat:	$4 to 7		$3 to 5	

Table 5.3 Adaptation Measures with Highest Net Benefits: Alpine AEZ

Description of recommended adaptation measure	*Crop focus for Alpine AEZ*	*Illustrative present value economic results per hectare (000 2009$)*			
		Estimated revenue gain	*Estimated costs*	*Net revenues*	*Notes*
Improve varieties	Irrigated wheat:	$23 to 61	$0.35	$23 to 61	Costs are for R&D.
	Rainfed wheat:	$12 to 43		$12 to 43	
Rehabilitate existing drainage infrastructure	Irrigated alfalfa:	$0.5 to 0.8	$0.31	$0.2 to 0.5	Benefits do not reflect increased risk of floods with climate change.
	Rainfed alfalfa:	$0.5 to 0.8		$0.2 to 0.5	
	Irrigated wheat:	$2 to 5		$2 to 5	
	Rainfed wheat:	$2 to 5		$2 to 4	
Optimize fertilizer application	Irrigated wheat:	$4 to 10	$1.2	$3 to 9	Costs do not include environ. damages.
	Rainfed wheat:	$2 to 8		$1 to 7	

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

Notes

1. Note that it was not possible to estimate yield effects of this option with the DSSAT model, so estimates for the AquaCrop model from the Albanian analysis in the report *Reducing the Vulnerability of Albania's Agricultural Systems to Climate Change* are used to illustrate the potential yield benefits for improving drainage.
2. Note that, because this option was not evaluated within the AquaCrop system, results are presented only for DSSAT modeled crops.
3. Benefit-cost ratios over time, however, are influenced by the team's inability to estimate benefits after 2050; in many cases, there might be an underestimation of the benefits of options that have a continued useful life after 2050, and may have higher benefits as climate changes accelerate after 2050.

CHAPTER 6

Options to Improve Climate Resilience of FYR Macedonia's Agricultural Sector

This chapter combines the review of current adaptive capacity (chapter 1), the identification of the risk of climate change to agriculture (chapter 3), the results of the farmer and expert evaluation of adaptation options (chapter 4), the quantitative evaluation of adaptation measures (chapter 5), and the results of the National Dissemination and Consensus Building Conference held in Skopje on April 6, 2011, to arrive at an overall set of high-priority policy, institutional capacity building, and investment measures to improve the resiliency of Macedonian agriculture to climate change.[1]

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

Recommendations at the National Level

Measures for consideration at the national level focus on policy and institutional capacity that have value on their own, or which are essential to ensure that farm-level and private sector actions are applied to their best advantage. Four measures were identified for adoption at the national level. The basis for the ranking of these options in most cases is the qualitative analysis of potential net benefits, combined with suggestions from the farmer consultations. These national-level recommendations include the following:

- *Increase the capacity of the extension and research service, both generally and for adapting to climate change.* The Bank team recommends that the capacity of the existing extension and research agencies be improved in two areas: (1) to support better varieties and agronomic practices at the farm level, including implementation of more widespread demonstration plots and access to better information on the availability and best management practices of

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high-yield crop varieties; and (2) to support the same measures but with a focus on maintaining yields during extreme water stress periods that are likely be more frequent with climate change. The first part of this recommendation is a measure to close the adaptation deficit, and the second part is a long-term measure to ensure yield gains are not undermined by future climate change. As outlined in chapter 5, the economic analysis suggests that expansion of extension services is very likely to yield benefits in excess of estimated costs.

- *Improve capacity of hydrometeorological institutions.* The farmer meetings noted the need for better local capabilities for hydrometeorological data, particularly for short-term temperature and precipitation forecasts. Those capabilities are acutely needed in the short term to support better farm-level decision-making. The economic analysis of the costs and benefits of a relatively modest hydrometeorological investment, which includes training and annual operating costs, suggests that benefits of such a program are very likely to exceed costs.
- *Consider national policy measures to further consolidate farm holdings.* Both the Bank team and farmer groups noted that on-farm adaptive capacity is limited by the generally small size of many Macedonian farms. The consequence of small farms is an inability to provide sufficient economies of scale to invest in adaptive measures, such as tertiary irrigation systems and equipment that might both increase yields and reduce soil erosion.
- *Encourage private sector measures to most efficiently adapt to climate change.* There may be a tendency to assume that adaptation to climate change is necessarily a public sector function, but as the economic analysis in chapter 5 has demonstrated, there is strong private sector incentive—with economic benefits greatly exceeding costs—for measures that will improve the resiliency of Macedonian agriculture to climate change. The national government should focus on putting in place policies that enable the private sector to effectively assist in adaptation, for example, by conducting testing of seed and livestock varieties for their suitability for Macedonian climate, terrain, and soil conditions, and making recommendations through extension of the best varieties, but allowing the private sector to provide those varieties.

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

- *Strengthen institutions,* including: (1) internal reorganization of individual institutions, (2) human resource development, (3) financial resources and their use, and (4) client orientation and performance monitoring.
- *Improve the farmers' access to agronomic technology and information*, including: (1) seed varieties, (2) more efficient use of water, (3) new technologies, and (4) advisory packages.
- *Remove barriers for the private sector.* This option also focused on improving incentives for insurance and reinsurance.
- *Improve incentives for consolidating land parcels.*

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Table 6.1 Adaptation Options at the National Level

		Ranking criterion			
Adaptation measure	*Specific focus areas*	*Net economic benefit: Quantitative analysis*	*Net economic benefit: Expert assessment*	*Potential to aid farmers with or without climate change*	*Favorable evaluation by local farmers*
Improve farmer access to agronomic technology and information	*Seed varieties; more efficient use of water*	*High*	*High*	*High*	*High*
Improve hydrometeorological capacity	*Short-term temperature and precipitation forecasts*	*High (based on "break-even" analyses)*	*High*	*High*	*High*
Provide incentives to consolidate farm holdings	*None identified*	*Not evaluated*	*Not mentioned*	*Potentially High*	*High*
Encourage private sector adaptation	*Seeds, livestock breeds, particularly on international market*	*Not evaluated*	*Potentially High*	*High*	*Not mentioned*

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

- *Improve the capacity of hydrometeorological systems.* The group focused on enhancing regional cooperation and improving weather information through media.
- *Improve availability of financial resources for implementation of climate change adaptation in agriculture.*

The options from this study are summarized in table 6.1. Options in italics indicate overlap between these options and the National Conference recommendations (all four options overlap).

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

Recommendations at the AEZ Level

Tables 6.1 through 6.3 present the results of the adaptation modeling (chapter 5), qualitative analysis, and farmer consultations (chapter 4), which form the basis for overall results in identifying options to improve the resilience of FYR Macedonia's agricultural sector to climate change. The tables reflect four ranking criteria, and assessment of the measure on a five-point scale for net economic benefits, with all measures on that scale representing a favorable economic evaluation, but the scale providing a rank order; and a three-point scale (high, medium, or low) for other criteria:

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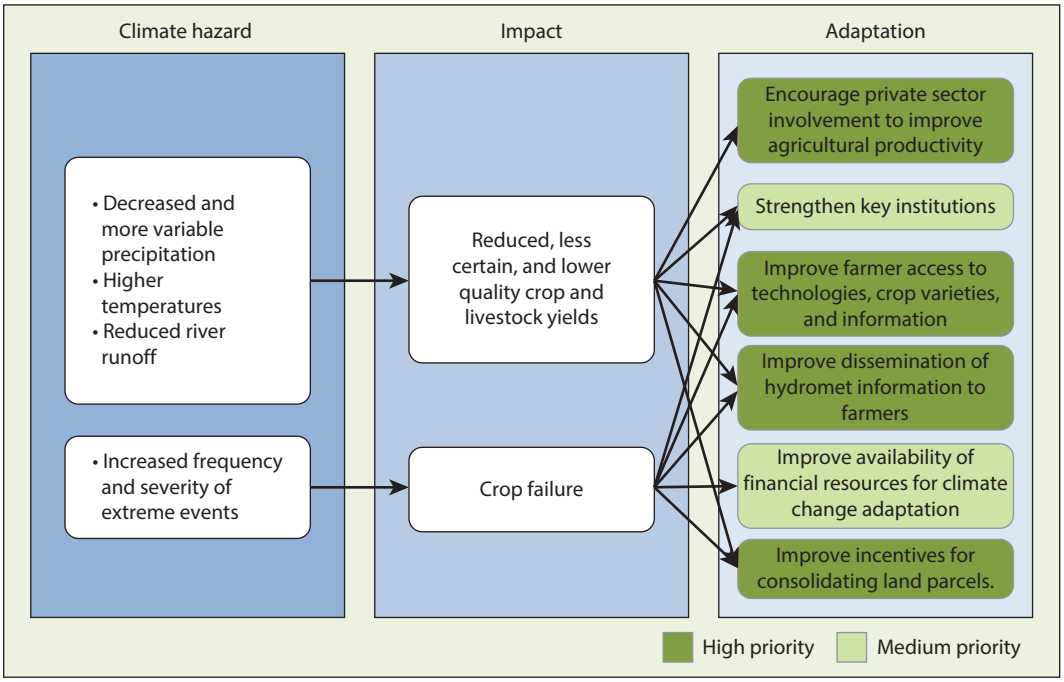
Figure 6.1 Adaptation Measures at the National Level Based on World Bank and National Conference Assessments



- *Net economic benefits* (benefits minus costs)
- *Expert assessment of ranking* for those options that cannot be evaluated in economic terms
- *"Win-win" potential*. A measure with a high potential for increasing the welfare of Macedonian farmers, with or without climate change
- *Favorable evaluation by the local farming community*. In this draft, these results are based on the results of the first stakeholder consultations at the AEZ level, with farmers and local agriculture sector experts.

The following sections summarize the results of the individual, AEZ-specific small groups that met at the National Conference. The purpose of those groups was to rank adaptation options most advantageous for each AEZ. The synthesized menus of high- and medium-priority adaptation options for each AEZ are summarized in figures 6.2 through 6.4.

Mediterranean AEZ

At the National Conference, the Mediterranean AEZ breakout group developed the following ranked list of adaptation options.

1. Improve availability of irrigated water and rehabilitation of irrigation systems.
2. Improve drainage infrastructure.
3. Improve farmer access to crop varieties with drought, heat, and pest tolerance, and adapted livestock breeds.

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Table 6.2 Adaptation Options for the 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 greenhouse gas 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

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

4. Improve soil, water, and crop management and land use.
5. Strengthen technology and information dissemination mechanisms for farmers.
6. Financially support the implementation of adaptation measures.
7. Consolidate land parcels.

Several options emerge from the quantitative, qualitative, and farmer evaluations of measures as most advantageous for adapting to climate change in the Mediterranean AEZ. Where these options overlap with recommendations from the National Conference, they are italicized in table 6.2.

- *Improve access to higher yield and drought-resistant crop and livestock varieties.* In this study possible yield increases by changing varieties to higher yield alternatives were evaluated. To achieve the higher yields, this measure needs to be combined with extension on management practices. (The costs for this are also reflected in the analysis.) These measures represent some of the potentially most cost-effective measures to improve resiliency, they provide benefits both with and without climate change, and they were strongly supported by farmers.

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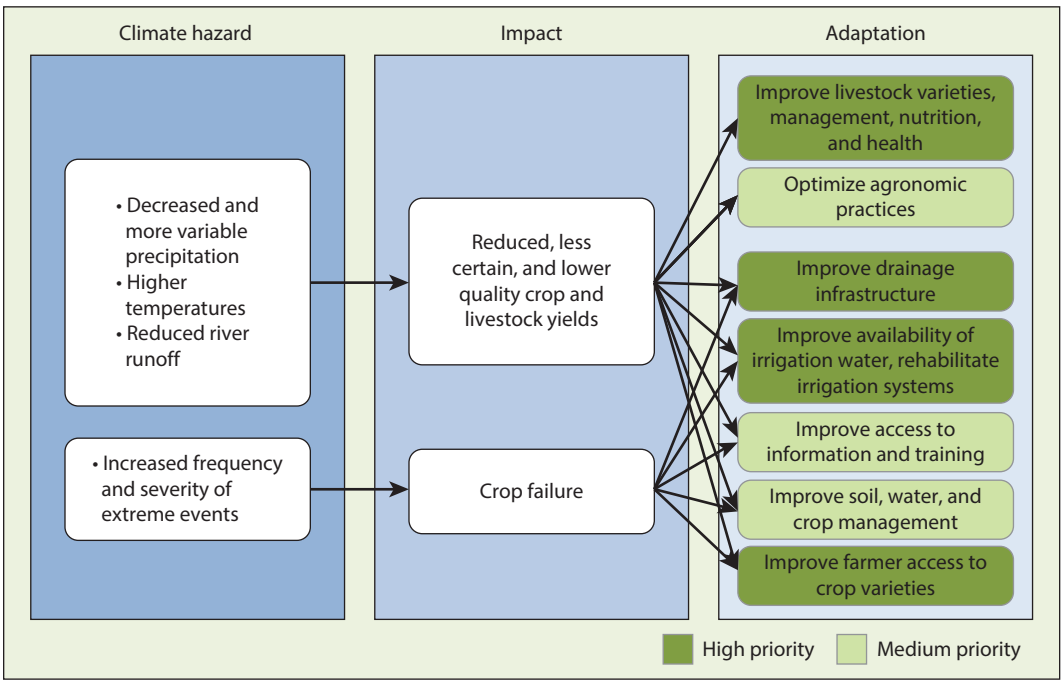
- *Enhance on-farm irrigation efficiency and repair irrigation infrastructure.* This suite of measures to improve the effective irrigation water supply was supported by farmers as well as by the quantitative analysis. For example, analysis of a measure to repair irrigation infrastructure finds a very high benefit-cost ratio.
- *Improve drainage*. The quantitative analysis suggests that economic benefits to farmers of improved drainage are 10–20 times higher than estimated costs, and benefit-cost ratios exceed one by a wide margin across climate scenarios and across alternative future price projections. In addition, improving drainage could improve yields today, and is thus favored by farmers. As for this analysis, it was noted that there is a need to improve drainage infrastructure and to properly size drainage capacity in light of the effect of future climate change on the variability of water flows, since climate change could contribute to higher extreme flow episodes in the future.
- *Optimize agronomic practices*. High to very high benefit-cost ratios were found for optimizing fertilizer application, based on the enhanced yields indicated by crop modeling. When combined with omission of other costs of fertilizer application, however, such as reduced water quality, there is a significant potential that a full cost analysis could yield costs in excess of yield benefits. As a result, this measure is low on the list of ranked results.

Figure 6.2 presents an overall set of prioritized adaptation options based on the National Conference recommendations and the options considered by

Figure 6.2 Adaptation Measures for the Mediterranean AEZ Based on World Bank and National Conference Assessments



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the Bank team. Measures shaded in darker green represent options that were recommended by both the team assessment and the National Conference groups.

Continental AEZ

Many of the recommended measures in the Continental AEZ are similar to those in the Mediterranean AEZ. Switching from existing to higher yield adapted varieties has greatest value where there is already irrigation and that there is less impact from the higher yield varieties when the crop is rainfed, because water application cannot be timed to achieve the best results from these varieties. Farmers in this AEZ also advocated for support to improved drought-resistant varieties, which currently have limited availability and so are difficult to evaluate quantitatively. These varieties would be beneficial for both irrigated and rainfed crops, but have their greatest effect over time, and for the lower precipitation scenarios. As a result, a phased approach to this variant of the "improve varieties" option may be called for.

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

1. Rehabilitate/construct water storage infrastructure.
2. Improve and rehabilitate existing irrigation systems.
3. Improve drainage infrastructure.
4. Develop soil erosion control measures.
5. Improve beef cattle, sheep, and goat livestock breeds.
6. Ensure access to improved crop varieties with drought, heat, and pest tolerance.
7. Improve adoption of agronomic practices both under rainfed and irrigated conditions to increase overall water use efficiency.
8. Improve market access.

Where the top five National Conference recommendations overlap with the original priorities from the analysis are listed in italics in table 6.3.

Merging the above priorities with the options from the National Conference generates an overall menu of adaptation measures for the Continental AEZ. Figure 6.3 summarizes exposures, impacts, and adaptation options, where measures shaded in darker green represent options that were recommended by both the Bank assessment and the National Conference groups.

Alpine AEZ

Table 6.4 summarizes the recommended adaptation measures for the Alpine AEZ. Crop modeling suggests that crops in the Alpine AEZ may face the greatest risks from changes in temperature and precipitation. Development of water storage options may be more important in this region. Risks to livestock may also be most acute in this region, not only because of the direct effects of climate and heat stress, but also because this is the only region where crop modeling suggests

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Table 6.3 Adaptation Options for the Continental 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*
Improve crop varieties	Wheat, Maize	1	High	Medium	2
Improve irrigation water availability, rehabilitate irrigation capacity	*Apples, Grapes, Maize, Vegetables, Wheat*	*2*	*Medium*	*High*	*1*
Improve drainage infrastructure	*All crops*	*3 for rehabilitation, lower for new drainage*	*Medium*	*High*	*Not mentioned*
Build new water storage	*All crops, but especially in the Crna basin*	*High for the Crna basin in particular*	*Not mentioned*	*High*	*3*
Research and improve livestock nutrition, management, and health	*Beef cattle, Chickens*	*Unknown*	*Medium*	*Low to Medium*	*4*
Optimize agronomic practices	Pasture, Wheat	6	Not mentioned	High	5

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

fodder crops and pasture yield may decline as a result of the direct effects of temperature and precipitation changes.

Accordingly, the Alpine AEZ breakout group at the National Conference developed the following ranked list of adaptation options:

1. Improve agricultural practices and techniques. Specifically, focus on: (1) soil, water, crop, pastures, and agro-forestry; and (2) livestock feed, beekeeping, and organic orchards.
2. Improve plant varieties for higher yields and tolerance to dry conditions.
3. Research and improve productivity of commercial livestock, focused on cattle, sheep, and goats for both milk and meat systems.
4. Maintain forest ecosystems by planting suitable tree species in order to prevent erosion and improve the water regime.
5. Construct micro-reservoirs and rehabilitate existing irrigation systems.
6. Improve incentives for adopting new agricultural practices and techniques.
7. Increase government support for agro-ecological policies.

Where these National Conference recommendations overlap with the original Bank team priorities in table 6.4, they are listed in italics.

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Figure 6.3 Adaptation Measures for the Continental AEZ Based on World Bank and National Conference Assessments

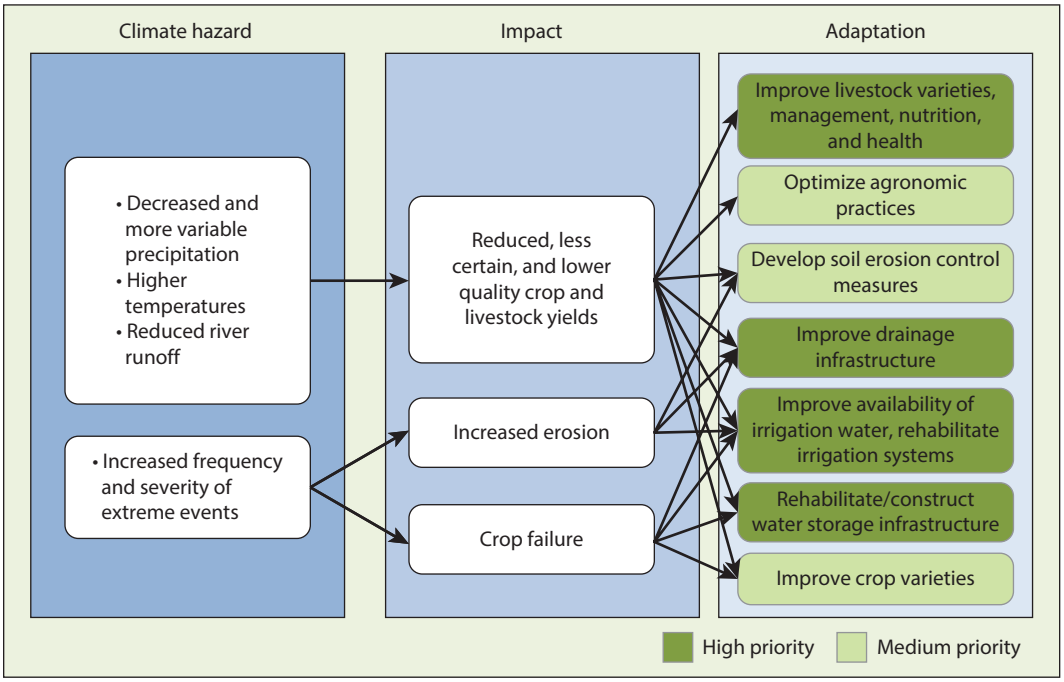

Table 6.4 Adaptation Options for the Alpine AEZ

		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*
Improve varieties for higher yield and drought tolerance	*Wheat, Apples*	*1*	*High*	*High*	*1*
Build new water storage	*All crops, but especially in the Crna basin*	*High for the Crna basin in particular*	*Not mentioned*	*High*	*2*
Rehabilitate existing drainage infrastructure	All crops	2	High	High	3
Research and improve livestock nutrition, management, and health	*Beef cattle, Chickens*	*Unknown*	*High*	*Low*	*1*
Optimize agronomic practices	*Wheat*	*3*	*Not mentioned*	*High*	*Not mentioned*

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

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Figure 6.4 Adaptation Measures for the Alpine AEZ Based on World Bank and National Conference Assessments

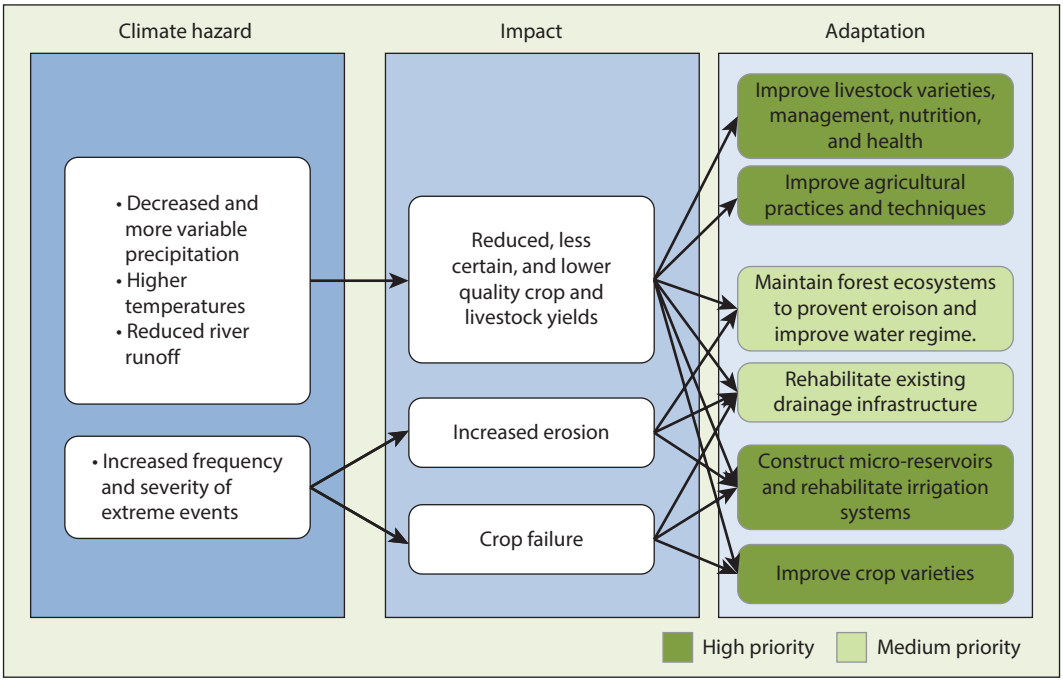

Figure 6.4 summarizes exposures, impacts, and adaptation options for the Alpine AEZ, where measures shaded in darker green represent options that were recommended by both the Bank' assessment and the National Conference groups.

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

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

As a result, categorization of short-, medium-, and long-term options is mainly based on qualitative assessment. Short-term options are those recommended for

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implementation with 1–3 years; medium-term options would be implemented in 4–10 years; and long-term options in 10 years or more.

Short-Term Options

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

- Provide enhanced weather forecasts.
- Improve farmer access to technology and information.
- Evaluate small-scale and large-scale options for increased water storage capacity.
- Increase farm-level water use efficiency.
- Optimize agronomic practices.
- Encourage farmer cooperatives to gain scale advantages of farm consolidation.

Medium-Term Options

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

- Implement small-scale water storage options.
- Improve drainage infrastructure.
- Improve irrigation water infrastructure.

Long-Term Options

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

- Implement larger-scale water storage options, where the evaluation suggests they are beneficial.
- Develop farmer education in the management of drought-resistant varieties.
- Improve livestock breeds, nutrition, management, and health.

In conclusion, a study with this broad scope necessarily involves significant limitations. These include the need to make assumptions about many important aspects of agricultural and livestock production in FYR Macedonia, the limits of simulation modeling techniques for forecasting crop yields and water resources, and time and resource constraints. Some of the recommendations will require

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more detailed examination and analysis than could be accomplished here, to ensure that specific adaptation measures are implemented in a manner that maximizes their value to Macedonian agriculture.

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

Note

1. The National Conference was structured so that participants could first learn more about the work presented in this report, and then work in small groups to develop AEZ-level rankings of options identified here, determine if some of the options were infeasible or not needed, and add new options for consideration. Ultimately, each of the small breakout groups, one for each AEZ, made a specific recommendation to the conference with a ranked list of adaptation options, including in some cases national-level policy and institutional strengthening needed to successfully implement those options.

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Glossary

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

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

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

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

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

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)

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

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

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

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

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

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

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

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

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

Catchment. An area that collects and drains water.

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

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

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

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

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

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

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

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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 millimeters per year.

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

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

Evaporation. The transition process from liquid to gaseous state.

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

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

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

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

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

Forecast. See climate projection.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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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 millimeters precipitation per year. See also *arid region*.

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

Silviculture. Cultivation, development, and care of forests.

Special Report on Emissions Scenarios (SRES). The storylines and associated population, GDP, and emissions scenarios associated with the Special Report on Emissions Scenarios (SRES) (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,

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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 2011b).

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

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

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

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

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

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

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