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

IMPACT ASSESSMENT AND ADAPTATION OPTIONS

Nicolas Ahouissoussi, James E. Neumann, Jitendra P. Srivastava, Cuneyt Okan, and Peter Droogers

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Foreword

The changing and increasingly variable climate is a major challenge to ensuring food, nutrition and livelihood security the world over. A country such as Georgia, with a relatively large share of its population dependent on agriculture, is especially prone to the adverse effects of climate change. As the country is already experiencing warmer days and nights, more variable precipitation, and more frequent and intense climate events, there is a clear message: it is imperative to reduce the risks to Georgian agriculture and make the sector more resilient. This book identifies key priorities for policies, programs and investments to reduce the vulnerability of Georgia's agricultural systems to climate change. It reflects the outcomes of a broad and inclusive process of stakeholder engagement and consultation, critical for the success of future actions. In order to develop and target appropriate adaptation measures, it also identifies sub-regions within Georgia that are more vulnerable to impacts of climate change now and in the future.

Climate-smart agriculture contributes to the potential "triple win" of increasing productivity, building resilience, and reducing emissions. Implementing this agenda requires understanding the strengths and weaknesses of the current systems of farming, assessing the potential impacts of climate change on these systems, and identifying practical and effective measures to improve the resiliency of these systems while minimizing greenhouse gas emissions. The findings and recommendations laid out here have great potential to help Georgia and its development partners in shaping a climate-smart approach to agricultural development through policy, upcoming agriculture investments, and capacity building efforts..

Strengthening the climate resilience of the agricultural sector in Georgia is essential. The work underscores the importance and urgency of putting in place the essential for. The World Bank is partnering with the Government through ongoing projects to put essential climate-smart building blocks in place, and we look forward to continuing this engagement and support going forward.

Henry G.R. Kerali
Country Director, South Caucasus
Europe and Central Asia Region

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Sector Director, Agriculture and
Environmental Services

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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. Adaptation measures now in use in Georgia, largely piecemeal efforts, will be insufficient to prevent impacts on agricultural production over the coming decades. There is growing interest at the 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, and building on the findings and recommendations of the landmark report *Adapting to Climate Change in Europe and Central Asia* (World Bank 2009), the World Bank embarked on a program for selected Eastern Europe and Central Asian (ECA) client countries to enhance their ability to mainstream climate change adaptation into agricultural policies, programs, and investments. This multi-stage effort 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, *Reducing the Vulnerability of Georgia's Agricultural Systems to Climate Change*, is the culmination of efforts by the Georgian institutions and researchers, the World Bank, and a team of international experts led by the consulting firm Industrial Economics, Incorporated, to jointly undertake an analytical study to address the potential impacts climate change may have on Georgia's agricultural sector, but, more importantly, to develop a list of prioritized measures to adapt to those impacts.

Specifically, this report provides a menu of options for climate change adaptation in the agricultural and water resources sectors, along with specific recommended actions that are tailored to distinct agricultural regions within Georgia. These recommendations reflect the results of three inter-related activities, conducted jointly by the expert team and local partners: (1) quantitative economic modeling of baseline conditions and the effects of certain adaptation options; (2) qualitative analysis conducted by the expert team of agronomists, crop modelers, and water resource experts; and (3) input from a series of participatory workshops for farmers in each of the agricultural regions. This report provides a summary of the methods, data, results, and recommendations for each of these

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activities, which were reviewed by local counterparts at the October 8, 2012, National Dissemination and Consensus Building Conference.

This study is part of the World Bank's Europe and Central Asia (ECA) Regional Analytical and Advisory Activities (AAA) Program on Reducing Vulnerability to Climate Change in ECA Agricultural Systems. Georgia is one of three countries participating in the program, with the other country participants being Armenia and Azerbaijan.

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Acknowledgments

The report was prepared by a team led by Nicolas Ahouissoussi of the Sustainable Development Department of the World Bank, Europe and Central Asia Region, together with Nedret Durutan Okan, Cüneyt Okan, Jitendra Srivastava, Ana Elisa Bucher, and Darejan Kapanadze, and in collaboration with a team from Industrial Economics, Incorporated. We are grateful for the valuable support and guidance from Dina Umali-Deininger, Sector Manager, Agriculture and Rural Development, Sustainable Development Department, Europe and Central Asia Region, and to Henry Kerali, Country Director, South Caucasus Country Unit based in Georgia, for his support in furthering the agenda on climate change in agriculture. We also gratefully acknowledge Larysa Hrebianchuk for providing administrative support.

Members of the Industrial Economics team include James Neumann, the overall project manager, Kenneth M. Strzepek, Peter Droogers, Stephen Sharrow, and Brent Boehlert. Dr. Droogers led the capacity-building efforts in the area of crop modeling, focusing on extension of crop modeling capacities for the Georgian counterparts. Dr. Droogers and field agronomist Dr. Sharrow also provided technical and on-the-ground expertise for the in-country team. Dr. Strzepek directed the hydrologic and water resources analyses, assisted by Mr. Boehlert. Mr. Boehlert also conducted the economic analyses of adaptation and the farmer and stakeholder consultation aspects of the work plan, providing a link between the technical analyses and the stakeholder outreach components. Other contributors to the report include Ellen Fitzgerald and Miriam Fuchs. Margaret Black provided writing and editing support.

From the government of Georgia, we are grateful for policy guidance and support provided by the Ministry of Agriculture, the Ministry of Environment, and the project steering committee, chaired by Medea Inashvili from the Ministry of Environment, and Konstantine Kobakhidze, Deputy Minister of Agriculture, without whom this study would not have been possible. Outreach and workshops were coordinated by Industrial Economics' local partner, Regional Environmental Center (REC) Caucasus. The study greatly benefited from valuable inputs, comments, advice, and support provided by academia, civil society and nongovernmental organizations (NGOs), farmers, the donor community, and development partners in Georgia throughout this work.

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

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

Cüneyt Okan is a former Senior Operations Officer at the World Bank Turkey Country Office. He has extensive project management experience ranging from various aspects of rural development and integrated participatory watershed planning and implementation to institutional strengthening. He has been working in or with the World Bank since 1975 as a client, supplier, employee, and consultant. A physicist by education, his work experience is with of large-scale, multinational private sector investments across a multitude of sectors including

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

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Abbreviations

AAA	Analytical and Advisory Activities
B-C	benefit-cost
BNPP	Bank-Netherlands Partnership Program
CMI	Climate Moisture Index
ECA	Europe and Central Asia
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDP	gross domestic product
GIS	Geographic Information Systems
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
NFBI	Non-bank Financial Institutions
NGO	nongovernmental organization
NPV	net present value
O&M	operations and maintenance
SEI	Stockholm Environment Institute
UNFCCC	United Nations Framework Convention on Climate Change
WEAP	Water Evaluation and Planning System

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Executive Summary

Introduction

Agricultural production is inextricably tied to climate, making agriculture the most climate-sensitive of all economic sectors. In countries such as Georgia, 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 the countries 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 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 adaptation. This includes steps for aligning agricultural policies with climate change, for developing key agricultural institution capabilities, and for making needed infrastructure and on-farm investments. Developing such a plan ideally involves a combination of high-quality quantitative analysis and consultation of key stakeholders, particularly farmers, as well as in-country agricultural experts.

In response to these challenges, the World Bank and the government of Georgia embarked on a joint study to identify and prioritize options for climate change adaptation of the agricultural sector. The first phase of this work involved raising awareness of the threats and opportunities presented by climate change, beginning with an Awareness Raising Workshop and a consultation with Georgian farmers in April 2012. The second phase of the Study involved

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quantitative and qualitative analysis of climate change impacts and adaptation options. Additionally, a second consultation with Georgian farmers and experts was completed in October 2012 and a capacity-building workshop was held in December 2012. The analysis focused on assessing impacts on key crops in four agricultural regions of Georgia under a range of future climate change scenarios.

Figure ES.1 summarizes the Study's findings regarding priority actions for adaptation at the national level. Figure ES.2 summarizes the recommended measures for the Eastern Lowlands agricultural region within Georgia, as an example of the Study's regional-level findings. These findings reflect extensive discussion at the National Dissemination and Consensus Building Conference as well as consultations with farmers.

Key Climate Change Challenges for Georgia's Agricultural Sector

The Study revealed a number of challenges and opportunities for Georgia's agricultural sector under predicted climate changes:

Temperature will increase in all four agricultural regions, accelerating the historical trend. The Study indicates this trend will accelerate in Georgia in the near future,

Figure ES.1 Climate Change Risks and Recommended Adaptation Measures at the National Level

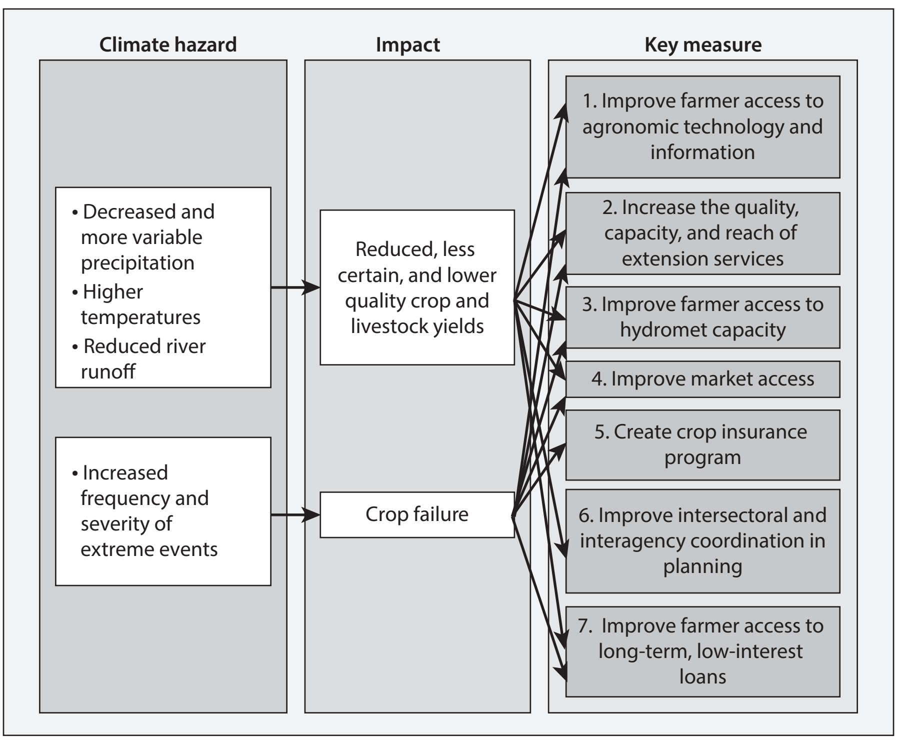

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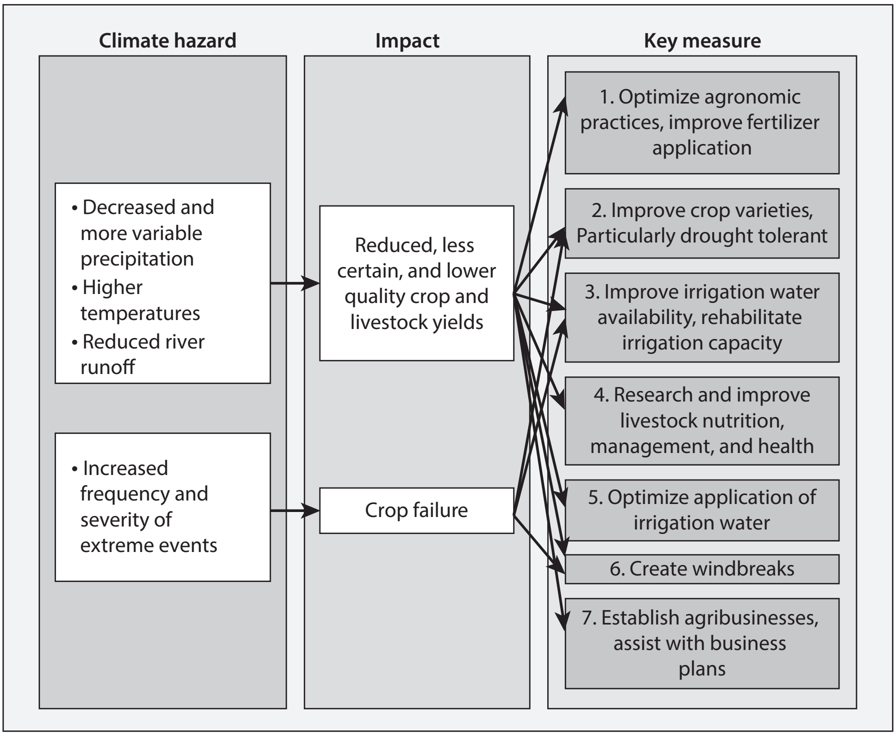
Figure ES.2 Climate Change Risks and Recommended Adaptation Measures for the Eastern Lowlands Agricultural Region



as shown in map ES.1 below. Although uncertainty remains regarding the degree of warming that will occur in Georgia, the overall warming trend is clear and is evident in all four agricultural regions. Over the next 50 years, the average increase in temperature will be about 2.3°C. This can be compared with the 0.2°C to 0.4°C increase in temperature observed over the last 50 years in the western portion of Georgia, and the 0.6°C increase observed in the eastern portion of the country.

Precipitation will become more variable in Georgia as a result of climate change. Precipitation changes are more uncertain than temperature changes, as indicated in map ES.2. Under the Medium Impact climate change scenario, average annual precipitation may increase in all but the Eastern Mountainous agricultural region, with a national average increase of about 1 millimeter per year by the 2040s. Most of this increase will occur in the Western Lowlands agricultural region. 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 a 24 percent decline under the High Impact scenario.

Climate impacts will be greatest from July to September—a key period for agricultural production. For temperature, climate change is expected to result in the greatest increase in temperature (relative to current conditions) in the month

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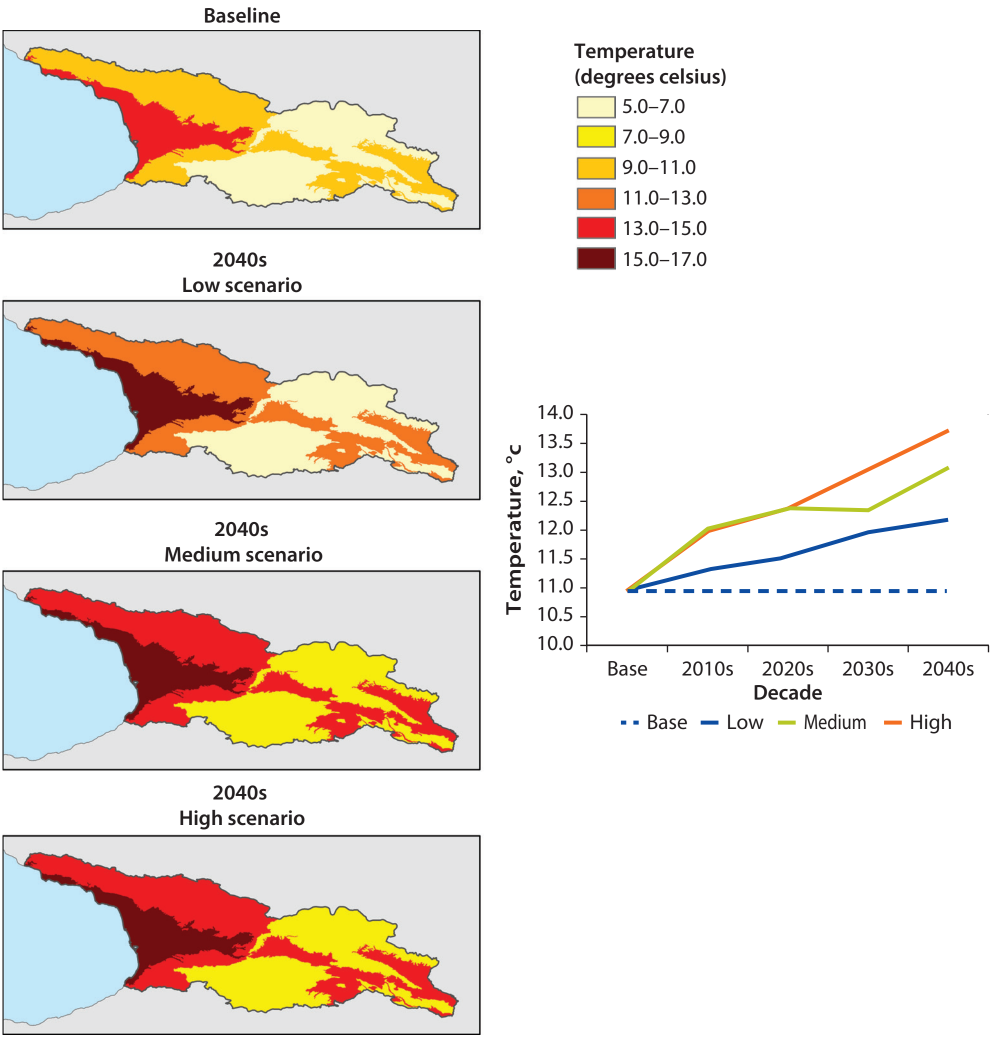
Map ES.1 Effect of Climate Change on Average Annual Temperature in the 2040s under the Low, Medium, and High Impact Climate Scenarios



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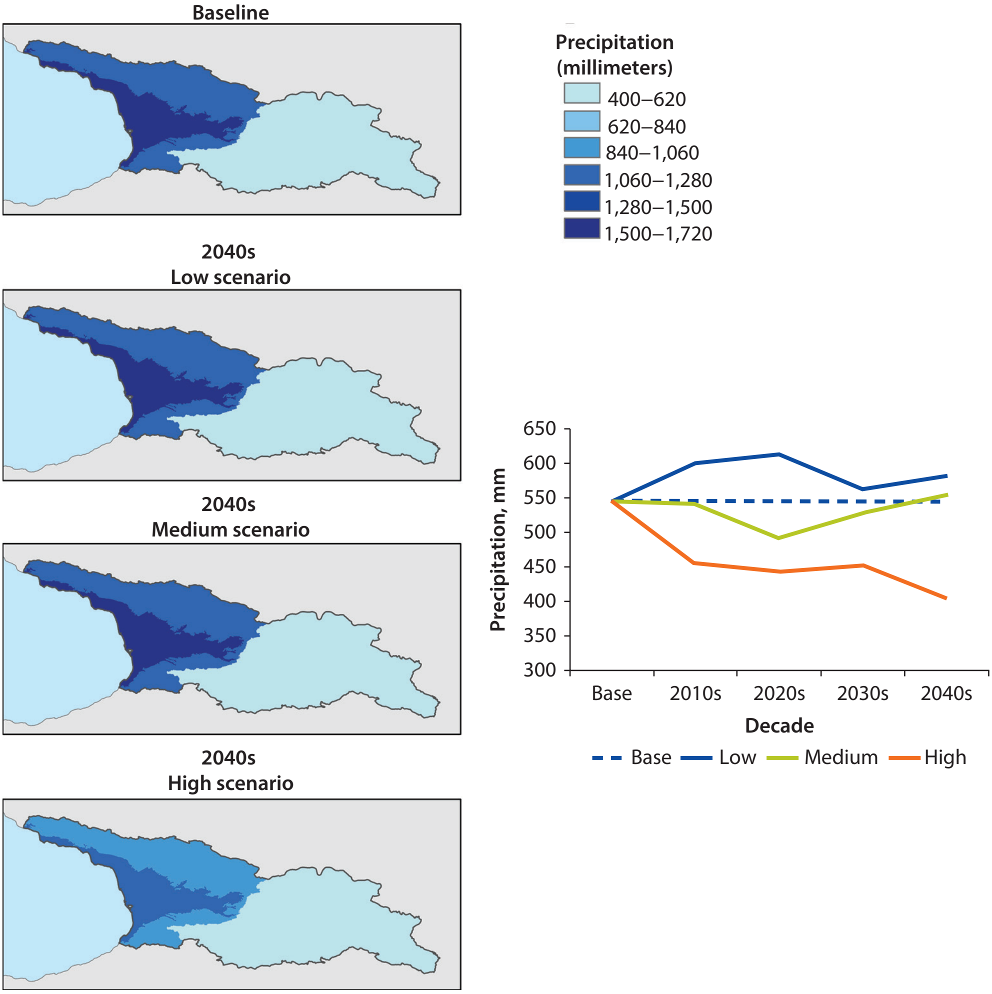
of September, with increases of as much as 5°C in the Eastern Lowlands agricultural region. In addition, forecast precipitation declines are greatest in the May to October period under the High Impact scenario, causing late summer to be the driest time of year.

Farmers are not suitably adapted to current climate. The "adaptation deficit" is large in Georgia. A key finding of the Study is that many of the climate adaptation measures recommended in this report can have immediate benefits in improving yields, as well as improving resiliency to future climate change.

Map ES.2 Effect of Climate Change on Average Annual Precipitation in the 2040s under the Low, Medium, and High Impact Climate Scenarios



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The direct temperature and precipitation effect of future climate change on crops is mixed. Climate change is forecast to reduce yields of most rainfed crops, except for natural pasture and crops in the Eastern Mountainous agricultural region. Yields of high-value fruit crops such as grapes, mandarin, and tomatoes are expected to decline in the Eastern Lowlands, Western Lowlands, and Western Mountainous agricultural regions, mainly due to temperature stress.

Water resources are currently abundant in the western part of Georgia; however, water shortages current exist and are forecasted under all climate change scenarios.

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Further, these shortages are expected to reduce crop yields in the Alazani basin. Increased demand for water during the July through October period, coupled with decreases in runoff in the May through November period, will likely lead to crop losses of up to 55 percent for irrigated agriculture in the Eastern Lowlands agricultural region of the Alazani basin.

Direct effects of climate change on the livestock sector could be negative. Due to lack of location-specific information, the Study is unable to quantify the effects of climate change on the livestock sector in Georgia. However, it can be expected that increased temperatures will negatively affect the health of livestock.

Analysis of the Vulnerability of Georgia's Agricultural Sector to Climate Change

Seasonal changes in climate have clear implications for crop production in both irrigated and rainfed agricultural systems in Georgia. Table ES.1 summarizes the likely effects of climate change on crop production if no adaptation is implemented, and if irrigation water is not constrained by reduced supplies or competing demands. The results show that under the Medium Impact scenario, wheat, corn, and tomato yields are expected to increase in the Eastern Mountainous region, while crop yields in other regions (for corn, grapes, mandarin, potato, tomato, and wheat) are expected to decrease.

Although table ES.1 reflects the assumption that irrigation water will not be constrained, changes in temperature and precipitation resulting from climate

Table ES.1 Effect of Climate Change on Crop Yields in the 2040s under the Medium Impact Climate Scenario (No Adaptation and No Irrigation Water Constraints)

Irrigated/rainfed	*Crop*	*Eastern Lowlands (%)*	*Eastern Mountainous (%)*	*Western Lowlands (%)*	*Western Mountainous (%)*
Irrigated	Corn	−4	48	−4	−3
	Grapes	−5	−5	−5	−5
	Mandarin	−5	N/A	−5	N/A
	Potato	−5	−5	−5	−5
	Tomato	−6	76	−5	−5
	Wheat	−5	69	−5	−5
Rainfed	Corn	−4	48	−4	−3
	Grapes	−6	−5	−5	−5
	Mandarin	−5	N/A	−5	N/A
	Pasture	26	87	20	44
	Potato	−10	−14	−6	−7
	Tomato	−11	55	−9	−11
	Wheat	−5	69	−5	−5

Source: World Bank data.
Notes: Results are average changes in crop yield, assuming no effect of carbon dioxide fertilization, under medium-impact scenario (no adaptation and no irrigation water constraints). Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases. "N/A" indicates that the crop is not grown in the agricultural region specified.

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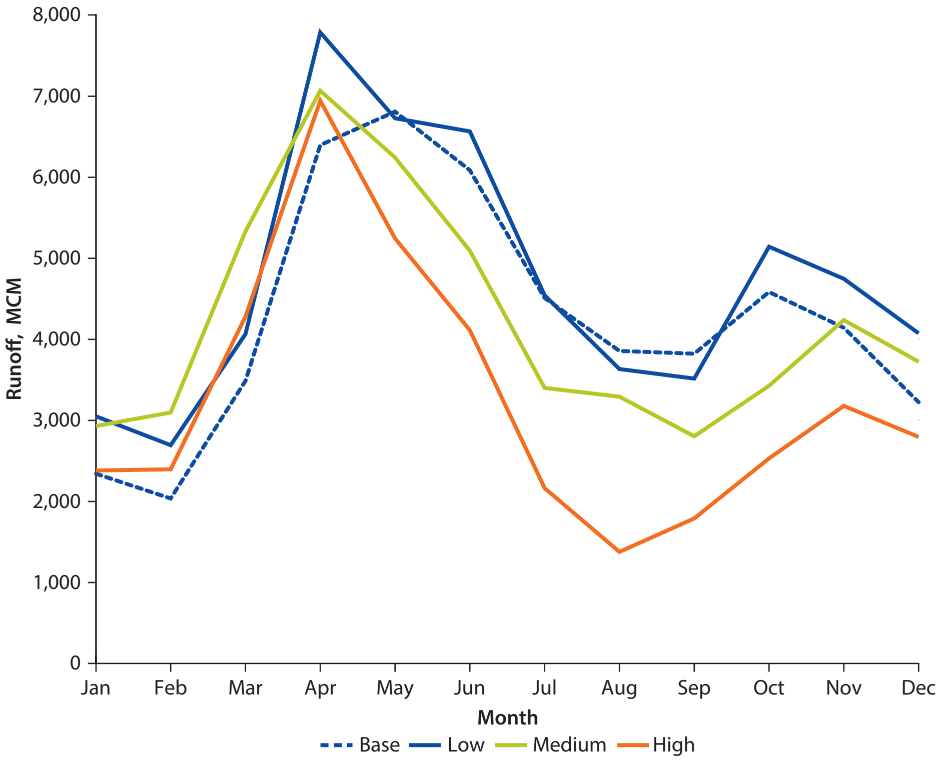
Figure ES.3 Estimated Effect of Climate Change on Mean Monthly Runoff Average in the 2040s



Source: World Bank data.

change are expected to impact water resources in Georgia. As a result, a more detailed water resource analysis is also needed to determine the extent of climate change impacts. This analysis provides projections for localized changes in water availability in the 2040s, relative to current conditions. Specifically, this analysis considers climate change impacts on mean monthly runoff under the Low, Medium, and High Impact climate scenarios (figure ES.3), as well as changes in water demand from the agriculture and nonagriculture sectors. The runoff indicator is directly relevant to agricultural systems and provides insight into the risk of climate change for agricultural water availability, as well as the implications of climate change for water resource management. As shown in figure ES.3, overall water supply is expected to decline by an average of 30 to 40 percent by the 2040s. At the same time, irrigation water demand during the summer months is expected to increase by up to 20 percent by 2050 relative to historic demands. The net effect of the predicted rising demands and falling supply is a significant reduction in water available for irrigation.

Three climate change stressors therefore combine to yield an overall negative impact on crop yields in Georgia: (i) direct effect of temperature and precipitation changes on crops; (ii) increased irrigation demand required to maintain yields; and (iii) decline in water supply associated with higher evaporation and lower rainfall. All of these effects will have more impact during the summer growing season.

The Study's analysis reveals that in Georgia the main effect of climate change on availability of agricultural water (which results from the combined effect of items ii and iii in the preceding paragraph) will be in the Alazani basin. The net effect of these three factors on irrigated agriculture in the Alazani basin is illustrated in figure ES.4 below. The left panel of the figure shows the effect of temperature and precipitation changes alone on irrigated agriculture (item i in the above paragraph) if there are no irrigation water constraints. The right panel shows the combined effect of all three factors mentioned above, including the forecast irrigation water shortages for the Alazani basin. The net effect of these factors on crop yields is dramatic, and provides an important focus for adaptation efforts to mitigate potential losses.

The direct effects of climate change on livestock also could be severe, but due to lack of location-specific data, this analysis does not quantify these impacts. There is, however, a robust literature establishing that higher temperature decreases livestock productivity. The indirect effect of climate change on livestock feed stocks, including pasture, would according to the analysis in this study be positive, and provides a counter-balance to the negative direct heat stress effects.

Identifying a Menu of Adaptation Options

Options for improving the resilience of Georgia's agricultural sector to climate change are evaluated based on the results of quantitative modeling, qualitative analysis, farmer consultation, and expert input from international and local teams. Five criteria were used to select priority options from a larger menu of 29

Figure ES.4 Effect of Climate Change on Irrigated Crop Yields Adjusted for Estimated Irrigation Water Deficits in the 2040s

Crop	Eastern Lowlands (%)	Eastern Mountainous (%)
Corn	−4	48
Grapes	−5	−5
Mandarin	−5	N/A
Potatoes	−5	−5
Tomatoes	−6	76
Wheat	−5	69

→

Crop	Eastern Lowlands (%)	Eastern Mountainous (%)
Corn	−33	3
Grapes	−30	−30
Mandarin	−34	N/A
Potatoes	−34	−34
Tomatoes	−35	23
Wheat	−34	17

Source: World Bank data.
Note: Results are average changes in crop yield, assuming no effect of carbon dioxide fertilization, under medium-impact scenario (no adaptation and no irrigation water constraints). Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases. "N/A" indicates that the crop is not grown in the agricultural region specified.

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farm-level adaptation options, 14 infrastructure options, 13 programmatic options, and five indirect adaptation options.

Some options, if adopted, may also yield benefits due to greenhouse gas mitigation. For example, measures such as soil conservation can enhance the retention of carbon in the soil and optimization of agronomic practices can reduce energy and fertilizer use. Therefore, adaptation options with greenhouse gas mitigation potential may also yield "co-benefits."

Stakeholder Consultations

Stakeholder consultations with local government officials, farmers, and local experts within the scope of this study conveyed several key messages:

Irrigation: (i) improving existing irrigation and drainage schemes; (ii) improving water use efficiency by investing in drip and sprinkler irrigation; (iii) rehabilitating water reservoirs; and (iv) increasing national water storage capacity.

Crop production: (i) making high-yielding, drought-tolerant crops and crop species available to the farmers; (ii) improving farmers' access to new agronomic information, technology and practices; (iii) improving pest management techniques; (iv) improving precision of fertilizer applications; and (v) introducing hail rockets.

Livestock production: (i) improving livestock health and husbandry, including shelter; and (ii) reducing pressure on pastures by introducing rotational grazing and expanding forage crop production.

Crop insurance: introduction and/or expanding affordable crop insurance programs.

Hydrometeorological information: improving access to good-quality hydrometeorological information (general and specific).

Farmer training and extension: improving access to an effective and efficient extension system.

Market access: facilitating better market access for small-scale farms.

Rural finance: making well-targeted, affordable credits to farmers that enable them to acquire technologies.

Options for National Policy and Institutional Capacity Building

Seven measures for adaptation at the national level were identified based on quantitative and qualitative analysis of potential net benefits, which include evaluations and recommendations from farmer stakeholder and expert groups and reflect discussions at the Georgian National Conference.

Improve farmer access to agronomic technology and information. Through improved extension services, farmers could access technologies to improve crop yields—for example, obtaining new seed varieties or investing in drip irrigation. More targeted and practical trainings, such as demonstration plots, could lead to the use of better technologies and agronomic practices.

Improve the quality, capacity, and reach of the extension service, both generally and for adapting to climate change. There was broad agreement that the capacity of the existing extension and research agencies be improved to support agronomic practices at the farm level, including implementation of more widespread

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demonstration plots and increased access to better information on the availability and best management practices of high-yield crop varieties. 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. Farmers 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.

Improve access to local markets. In Georgia, a large portion of farmers are involved in subsistence and semi-subsistence farming and are frequently exposed to marketing problems. More must be done to improve markets if the agricultural sector potential would be realized. However, it is also clear that without improvements on the producer side, issues related to marketing can be solved only partially. Efforts should be made to stabilize semi-subsistent farmers' erratic marketing links by providing support to developing their knowledge and skills to produce surplus and in good quality, to support local cooperatives where feasible, and to provide better access to cold storage to facilitate better timing of produce delivery to market.

Investigate options for crop insurance, particularly for drought. Crop insurance is not viable for the vast majority of agricultural producers due to its high cost, but farmers remain eager to explore insurance options. One possible way to expand coverage could be via the piloting of a privately run weather index-based insurance program. This approach has many potential advantages over traditional multiple-peril crop insurance, including simplification of the product, standardized claim payments to farmers in a district based on the index, avoidance of individual farmer field assessment, lower administrative costs, timelier claim payments after loss, and easier accommodation of small farmers within the program. The drawback of an index-based approach may be the inability to readily insure coverage of damage from pests. In addition, pilot insurance schemes based on weather indices have encountered low demand in many locations, partly because poor farmers are cash and credit constrained and, therefore, cannot afford premiums to buy insurance that pays out only after the harvest (Binswanger-Mkhize 2012). Poorly designed insurance schemes may also slow autonomous adaptation by insulating farmers from climate-induced risks. In general, countries may need to first consider improving market access and credit constraints, in order to better create enabling conditions suitable for crop insurance to be effective.

Improve intersectoral and interagency coordination and planning. At the National Conference, national institutional stakeholders themselves noted that multiple sectors and agencies are not coordinated in their approach to the agricultural sector. Ideally, government expertise in agronomy, irrigation, hydrometeorology, environmental concerns, subsidy policy, marketing, and rural finance and development can be coordinated to enhance the climate resilience of the agricultural sector to improve the current situation and prepare for future challenges of climate change.

Improve farmers' access to rural finance to enable them to access new technologies. Farmers could acquire technologies through well-targeted and affordable credits to improve crop and livestock yields. However, the current rural finance system, with its relatively high interest rate combined with stringent collateral requirements and limited outreach, prohibits access to credit for many rural households despite the demand. The commercial banks and Non-bank Financial Institutions (NBFI) need to tailor their loan products to the specificities of rural investments (periodicity of cash-flow, longer maturity needed to match the specific crop and livestock production cycles, and nonmonthly payment). This is a pressing need for tailoring techniques to shifting climatic conditions without harming ecosystems of the country.

Options for Specific Agricultural Regions

Based on the qualitative and quantitative analyses performed in the Study, and on feedback received at the farmer workshops and National Conference, a number of options emerge as particularly advantageous for adapting to climate change in each Georgian agricultural region. Decreasing the adaptation deficit of the sector is a long-term process, but there are several measures that could be undertaken immediately to strengthen the sector's adaptive capacity. At the agricultural region and farm level, high-priority adaptation measures include optimizing fertilizer application; improving irrigation systems; and providing more climate resilient seed varieties and the training to cultivate them effectively for high yield (all agricultural regions). These measures have high benefit-cost (B-C) ratios (depending on the region and scenario) and are favored by Georgian farmers.

Table ES.2 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 agricultural region 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.

Lastly, due to its broad scope, this study necessarily involves significant limitations. These include the need to make simplifying assumptions about many important aspects of agricultural and livestock production in Georgia, and the limitations of simulation modeling techniques for forecasting crop yields and water resources. As a result, certain recommendations may require a more detailed examination and analysis than could be accomplished here in order to ensure that specific adaptation measures are implemented in a manner that maximizes their value to Georgian agriculture. It is hoped, however, that the awareness of climate risks and the analytic capacities built over the course of this study provide not only a greater understanding among ensure agricultural institutions of the basis of the recommendations presented here, but also an enhanced

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Table ES.2. Summary of Key Climate Hazards, Impacts, and Adaptation Measures at the National and Agricultural Region Levels

		Adaption measure to address impact									
		National-level			*Agricultural region-level*						
Climate change impact	*Cause of impact (climate hazard)*	*Increase access to and extent of extension services*	*Improve dissemination of hydrometeorological information to farmers*	*Increase research on locally relevant crop varieties and farming practices*	*Improve market access*	*Improve crop varieties*	*Improve drainage infrastructure*	*Improve irrigation water availability, rehabilitate irrigation systems*	*Optimize irrigation water application*	*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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capability to conduct the required more detailed assessment that will be needed to further pursue the recommended actions.

Table ES.2 below can serve as a starting point for pursuing a strategic plan for national-level and agricultural region-level adaptation measures in Georgia. In addition, it is desirable that the countries of the South Caucasus address climate change through collaboration on issues such as climate-related data sharing and crisis response. There are many challenges to achieving these objectives, but fortunately there are a wide range of existing models of regional-scale institutional arrangements throughout the world, encompassing the scope of regional cooperation for water resources planning, agricultural research and extension, and enhanced hydrometeorological service development and data provision.

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CHAPTER 1

The Study: Design, Methodology, and Limitations

Overview of Approach

Background

In countries such as Georgia, 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 by climate change 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. Further, the need to adapt to climate change in all sectors is now on the agenda of the countries 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 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 for some crops, higher carbon dioxide concentrations may 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 with key stakeholders, particularly farmers, as well as local agricultural experts. The most effective plans for adapting the sector to climate change will involve both human capital and physical capital enhancements; however, many of these investments can also enhance agricultural productivity right now, 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.

In response to these challenges, the World Bank and the Government of Georgia embarked on a joint study ("the Study") to identify and prioritize options for climate change adaptation of the agricultural sector, with explicit consideration of greenhouse gas emission reduction (or mitigation) potential of these options.

Objectives of the Study

The objectives of the Study are to:

(i) Increase stakeholders' awareness of the threat of climate change on the agricultural sector
(ii) Analyze the vulnerability and potential impacts of climate change on agricultural systems at the national and agricultural region level in Georgia
(iii) Develop a menu of potential adaptation and mitigation options for each sub-national agricultural region and at the national level
(iv) Analyze national policy responses to address the potential changes resulting from climate change impacts
(v) Create mechanisms for fostering regional cooperation on addressing the potential impacts of climate change on agriculture.

Stages of the Study

The Study was conducted in three stages: Awareness Raising; Quantitative and Qualitative Analysis; and Finalization of the Analysis and Menu of Adaptation Options (figure 1.1).

Awareness Raising: The first phase involved raising awareness of the threats and opportunities presented by climate change, beginning with an Awareness Raising and Consultation Workshop and a Stakeholder Consultation with Georgian farmers in April 2012. The culmination of the first phase was the finalization of a Country Report, which summarized existing information on the agricultural sector, forecast climate changes, risks of climate change to agriculture, adaptive capacity, suggestions for adaptation and mitigation measures, and gaps that could be filled in the existing information base by the Study.

Quantitative and Qualitative Analysis: The analysis was conducted to provide results that are specific to four agricultural regions of Georgia, to key crops important to the Georgian agricultural economy, and across a range of future climate change scenarios. The culmination of the second phase was the development of a draft menu of adaptation options for consideration at the National Dissemination and Consensus Building Conference that was conducted in October 2012, just after the second Stakeholder Consultation with Georgian farmers was completed. A Capacity Building Workshop was completed in December 2012.

Finalization of the Analysis and Menu of Adaptation Options: The menu of adaptation options was finalized through a structured, consensus-building process that allowed for stakeholder input. Specifically, the Study relied on input received during the stakeholder consultations and National Conference, as well as on quantitative analysis of the options.

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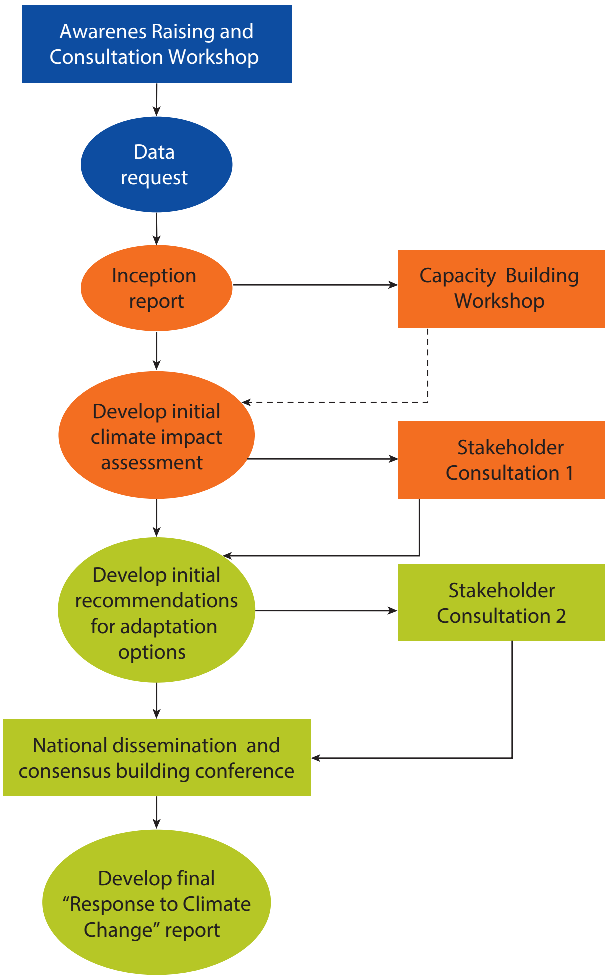
Figure 1.1 Flow Chart of Phases of the Study



Geographic Scope

Georgia is located in the Southern Caucasus region. It is bordered by the Russian Federation to the north and east, Azerbaijan to the southeast, Armenia and Turkey to the south, and the Black Sea to the west. It is divided into nine regions, two autonomous republics, and Tbilisi, the capital city.

For the purposes of the Study, Georgia was grouped into four agricultural regions according to elevation, temperature, and precipitation (map 1.1): Western Lowlands, Western Mountainous, Eastern Lowlands, and Eastern Mountainous. The Likhi Mountain Range divides the country into eastern and western halves, with the west receiving much more rainfall than the east. Irrigation is concentrated mainly in the two Lowlands regions.

Areas within each of these regions share similar characteristics in terms of terrain, climate, soil type, and water availability. As a result, baseline agricultural conditions,

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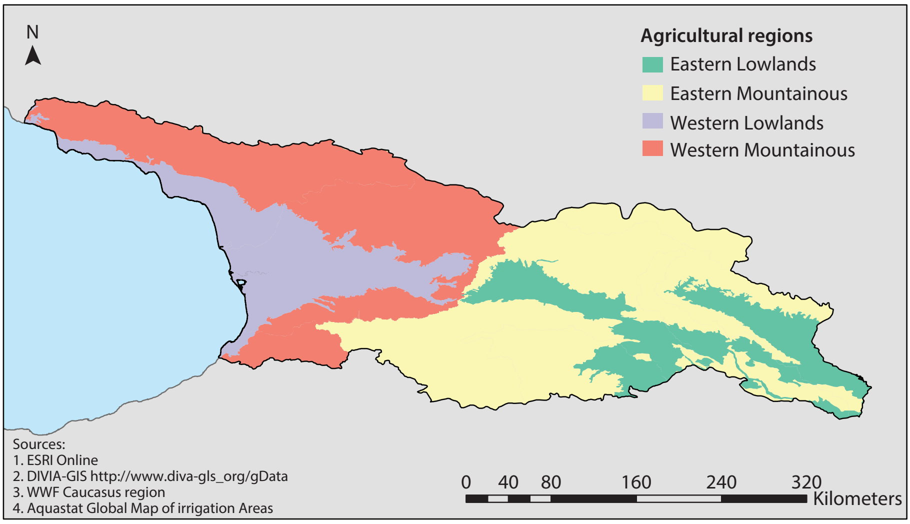
Map 1.1 Agricultural regions of Georgia



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climate change impacts, and adaptive options are similar within each region, with some differences that are important for developing a specific adaptation plan.

Selection of Crops for Modeling

In order to assess the impacts of climate change on Georgia's agricultural systems, it was necessary to first identify key crops for inclusion in the Study. The Ministry of Agriculture, in consultation with the Study Steering Committee, selected seven key crops based on the following criteria: (i) widely grown; (ii) economically important to Georgia; (iii) potentially sensitive (either positively or negatively) to temperature or water stress aspects of climate change; (iv) well supported by in-country yield, cropping pattern, and phenology data; and (v) in total, reflecting a mix of primarily irrigated and primarily rainfed crops. Furthermore, to ensure a wide variety, the list included representatives from the following groups: (i) cereals; (ii) tree crops; (iii) vegetables; and (iv) forage crops.

The selected crops include: wheat, corn, potato, tomato, grape, mandarin, and natural pasture.

Developing Future Climate Scenarios

The first step in understanding the exposure of Georgia's agricultural systems to climate change is to understand the potential for changes in climate from the current baseline. In order to capture a broad range of climate model forecasts, the Study employed Low Impact, Medium Impact, and High Impact climate change scenarios, which were defined based on analysis of the Climate Moisture Index (CMI) at the country level and applied consistently across all three agricultural regions through the year 2050. Detailed information on this topic is provided below and in box 1.1.

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Box 1.1 Developing a Range of Future Climate Change Scenarios for Georgia

Climate change analyses involve estimating how temperature, precipitation, and other climate variables of interest might change over time. Because there is great uncertainty in forecasting these changes, it is best to consider a range of alternatives. For temperature and precipitation projections, three climate scenarios were developed for Georgia: a Low, a Medium, and a High Impact Scenario.

Climate Moisture Index (CMI). The Study's climate scenarios are defined by changes in CMI, which is an indicator of the aridity of a region, in order to reflect the impact of climate change on agriculture. Specifically, the scenarios were developed based on the average change in CMI values across the country from the baseline to 2050.

General Circulation Model (GCM). Each scenario in the Study corresponds to a specific GCM result from among those used by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment of the science of climate change. The Study relies on 56 scenarios that reflect results of 22 IPCC GCM for three emissions scenarios (B1, A1B, and B2). As CMI is an indicator of aridity, the High Impact Scenario is defined by the largest increase in aridity, while the Low Impact Scenario is defined by the largest decrease in aridity. The Medium Impact Scenario reflects a central estimate of change in aridity.

Scenario	*GCM model basis for the scenario*	*Relevant IPCC SRES scenario*
Low Impact	National Center for Atmospheric Research, Parallel Climate Model (US)	A2
High Impact	Goddard Institute for Space Studies, ModelER (US)	A1B
Medium Impact	Center for Climate Modeling and Analysis, Coupled GCM 3.1 (Canada)	A1B

Time Period and Other Parameters

In order to assess the impact of future climate scenarios on Georgia's agricultural sector, the crop modeling performed for the Study employed daily climate data so as to capture the change in weather and its importance for agriculture. However, the projected climate outcomes from the Study are presented in terms of decadal averages for the 2020s and 2040s, which reflect overall changes in climate rather than weather. The economic analysis results are based on two economic projections: (i) continuation of current conditions, prices, and markets; and (ii) an alternative crop price projection through 2050 developed by the International Food Policy Research Institute (IFPRI). Benefits and costs of specific adaptation measures were then estimated for each of the options in relation to the "current conditions" (baseline). As a result, in some cases the benefits and costs of adaptation options may reflect benefits of both adapting to climate change and improving the current agricultural system; these options were identified as "win-win" in nature.

Reducing the Vulnerability of Georgia's Agricultural Systems to Climate Change
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Methodology

The Framework for Evaluating Investment in Adaptation

The Study provides a framework for evaluating alternatives for investment in adaptation for the Georgian government, potentially assisted by the donor community, and for the private agricultural sector. The framework has two critical components: (i) rigorous quantitative assessments, and (ii) structured discussion with local experts and farmers.

(i) *Rigorous quantitative assessments.* The quantitative assessments are supplemented by the judgments of the Expert Consultant 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 costs of investments justify the benefits in terms of enhancing crop yield now and in the future. In addition, the Study considers the current and the future specific water resource availability conditions at the basin level.

(ii) *Structured discussion with local experts and farmers.* Discussions were carried out 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 Georgian farmers to this process proved critical to ensure that the quantitative analyses were reasonable and that the project team did not overlook important adaptation actions.

Further, the Study recommends specific actions for policy makers ranked according to the results of the quantitative and qualitative analyses described above. The ranking can be used to establish priorities for policy makers in enhancing the resilience of the Georgian agricultural sector to climate change. Two types of results from the Study should therefore be most critical for Georgian policy makers for actions regarding: (i) specific infrastructure improvement, and (ii) creating conditions for farmers to make wise investments for adaptive capacity enhancement.

(i) *Specific infrastructure improvement*. Actions such as rehabilitating irrigation and drainage capacity should be high priorities for Georgian and international donor community investments. The Study maintained a broad focus, so the results do not represent project-level feasibility evaluations, but rather broad-scale scoping studies. Therefore, pursuit of specific investments requires additional, more detailed feasibility studies.

(ii) *Creating conditions for farmers to make wise investments for own adaptive capacity enhancement*. A number of the farm-level adaptive actions that were identified by the Study are focused on changes in practices that can be readily implemented by the farmers, such as optimizing agricultural input use and use of heat- or drought-tolerant crop varieties. Policy makers should be aware that many Georgian farmers currently lack the training

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or the information (for example, weather forecasts) to implement these practices wisely and effectively.

Modeling Tools

Modeling tools used in the Study include: (i) climate modeling and (ii) crop, water runoff, and water basin modeling.

(i) *Climate modeling.* The climate projections combine information on current climate, obtained from local sources and the World Meteorological Organization, with projections of changes in climate obtained from General Circulation Model (GCM) results. These GCMs were prepared for the United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. For Georgia, three climate scenarios are defined based on the average Climate Moisture Index (CMI)[1] across the country (box 1.1.), (i) the low impact, (ii) high impact, and (iii) medium impact. These scenarios were selected from among the 56 available GCM combinations deployed by IPCC for 2050.

(ii) *Crop, water runoff and water basin modeling.* Based on the assessment of the country-specific analytical requirements, three modeling tools were used in the Study: (i) AquaCrop for crop modeling (for the selected crops), (ii) CLIRUN for water runoff projections, and (iii) WEAP water basin modeling using the inputs from CLIRUN (box 1.2). All of these models are in the public domain, have been applied world-wide frequently, and have a user-friendly interface.

Analysis and Assessments

A series of analyses and assessments were conducted to assess various agronomic measures (both farm and basin level), including decentralized options for improving water use productivity. In order to identify and analyze the adaptation options two types of assessments were made: (i) quantitative, and (ii) qualitative. Then the options were evaluated and prioritized by using a set of criteria. However, quantitative evaluation of all options was not possible due to data limitations.

Quantitative Impact and Adaptation Assessments

A quantitative impact and adaptation assessment was conducted for each agricultural region and selected crop (winter wheat, potato, tomato, apricot, grapes, alfalfa, and watermelon). The assessment involved three steps: (i) estimating the effect of climate change on crop yields without adaptation, incorporating the effect of estimated irrigation water shortages on yields as well as the direct effects of changes in temperature and precipitation; (ii) identifying a range of appropriate farm level and sectoral adaptation options based on the impact assessment and initial stakeholder meetings; and (iii) analyzing the net benefits of adaptation options. The interaction between modeling tools is presented in figure 1.2.

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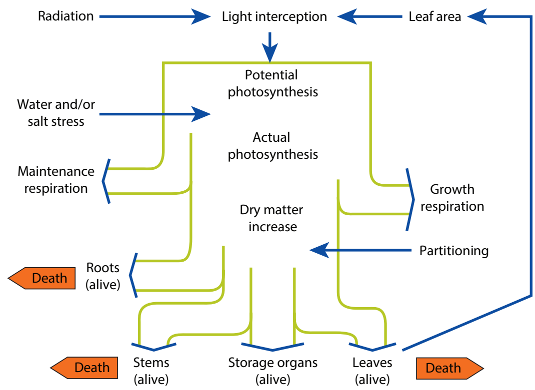
Box 1.2 Description of Modeling Tools

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



- **AquaCrop**: This 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. The model is mainly parametric-oriented and therefore less data demanding and has the following strengths: (i) the simplicity to evaluate the impact of climate change and evaluation of adaptation strategies on crops; (ii) ability to evaluate the effects of water stress and estimate crop water demand, both key issues in Georgia currently and with climate change. The figure illustrates some of the main crop growth processes reflected in AquaCrop.
- **CLIRUN:** This hydrologic model is widely used in climate change hydrologic assessments and can be parameterized using globally available data, but any local databases can also be used to enhance the data for modeling. It can run on a daily or monthly time step. By using CLIRUN, monthly runoff in a catchment can be estimated. It 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. Soil water is modeled as a two layer system: a soil layer and groundwater layer. These two components correspond to a quick and a slow runoff response to effective precipitation. A suite of potential evapotranspiration models are also available for use in CLIRUN. Actual evapotranspiration is a function of potential and actual soil moisture state following the FAO method.
- **Water Evaluation and Planning System (WEAP):** This system was developed by the Stockholm Environment Institute (SEI) and is maintained by SEI-US. It is a software tool for integrated water resources planning that attempts to assist rather than substitute for the skilled planner. Although it is proprietary, SEI makes the model available for developing country users. The software tool provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. WEAP provides 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 used in the Study models water demands and storage, providing a good base for more detailed modelling in the future. For more information, please refer to the WEAP User Guide, available at www.weap21.org (Stockholm Environment Institute 2013).

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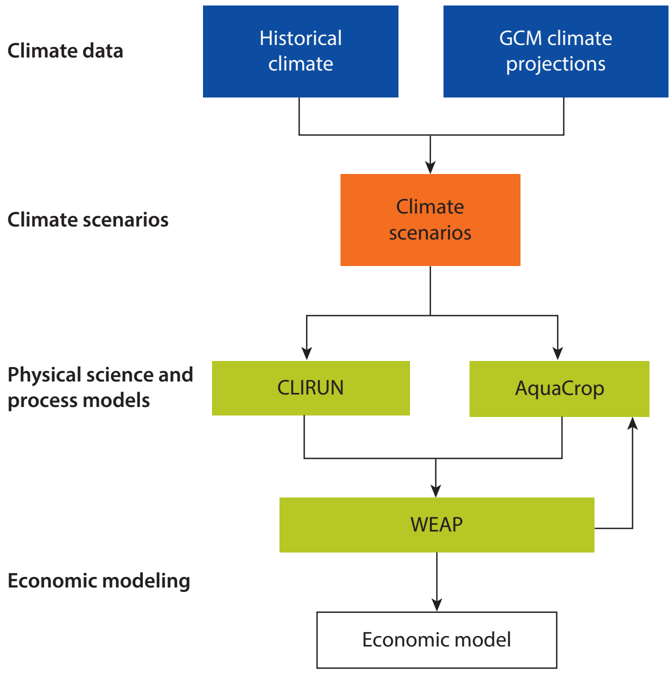
Figure 1.2 Steps in Quantitative Modeling of Adaptation Options



Step 1: Estimating the Effect of Climate Change on Crop Yields without Adaptation. The result of this step is an estimate of the crop yield implications of climate change in terms of percentage gains or losses in yield per hectare. It involves applying the climate scenario development approach, and then applying the physical science and process models indicated in figure 1.2. The step involves the following:

- The **AquaCrop** inputs include baseline and projected climate data (from GCMs), crop phenology data, water application, and other physical parameters. The modeling tool generates ranges of crop yields (which are used to generate agricultural revenues in the economic models) and input requirements (for example, fertilizer, which generate costs) for the crops in each agricultural region, under each climate scenario.
- **CLIRUN** applies baseline climate and runoff data, along with climate projections from GCMs to generate monthly projections of runoff.
- Inputs of **WEAP** include baseline and projected basin-level runoff from CLIRUN, existing and projected non-agricultural water demand (that is, municipal, industrial, if available) (Hughes, Chinowsky, and Strzepek 2010; SEDAC 2011), existing agricultural water demands from AquaCrop, and existing surface water storage (Lehner et al. 2011). For each basin considered, WEAP produced the timing and magnitude of

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agricultural water demand shortfalls within each river basin. These shortfalls may be generated by rising non-agricultural water demands, reductions in water availability caused by climate change, or increases in crop evapotranspiration caused by climate change. 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.

Step 2: Identifying a Range of Adaptation Options. This step involves evaluation of both farm-level and sectoral adaptation responses that were selected from among those identified in the impact assessment and initial stakeholder meetings. Farm-level responses may include individual farmers changing crop mixes, converting to different irrigation systems, or changing the timing of farm operations. These adaptations often require significant capital investments and occur over multiyear periods, but can readily be evaluated using economic models of farm operations. On the other hand, sectoral-level responses include local, state, or national government policy changes, creation of incentive programs, or government investments in infrastructure (for example, irrigation systems or reservoir storage).

Step 3: Analyzing Farm-Level Adaptation Options. To prepare the menu of adaptation options, economic models were developed for each of the agricultural regions and climate scenarios to estimate the agricultural net revenues (that is, revenues minus costs) associated with the adaptation options. Revenue inputs for the economic models are current and projected crop prices (from FAO) coupled with current and modeled crop yields associated with each adaptation option (from AquaCrop). The changes in crop yields associated with a particular adaptation measure reflect the modeled change in yield associated with a change in or optimization of seeds, fertilizer, or water inputs, or improvement of soil drainage through infrastructure. Cost data were estimated from prior World Bank projects and other publicly available sources, and were incorporated for each adaptation option—these include variable and fixed cost information (for example, labor rates, costs of inputs, capital expenses). If some cost data were not available for the representative sites, cost estimates were transferred from other settings based on the knowledge of farming practices in other nearby countries. The economic model then identified adaptation options with the highest net benefits for each agricultural region and climate scenario.

One of the key ranking criteria for the agriculture adaptive measures was mitigation potential. Many of the adaptive measures that were assessed also have the potential to mitigate climate change now and in the future. This potential was assessed by construction of a database of per-hectare CO_2 equivalent measure of mitigation potential for a wide range of measures. The database was then mapped to the much larger list of adaptive measures used in the Study, based on their qualitative descriptions. Measures that have a high mitigation potential, but low or no adaptation potential, were not ranked. This approach reflects the proposition that mitigation by itself is valuable in Georgia (also in similar countries). However, robust and readily available means for carbon finance for mitigation is not accessible to the small-scale farmers. Therefore, in the absence of carbon

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finance, adaptation will remain a higher priority than mitigation. Particular adaptive practices, such as conservation agriculture and manure management, present promising opportunities to lower greenhouse emissions by either reducing the greenhouse gases emitted in agricultural production processes or increasing the carbon stored in agricultural soils.

Evaluation and Prioritization of Adaptation Options: The adaptation modeling and analysis phase yielded a "Menu of Adaptation Options." Then, the options in the menu were evaluated and prioritized based on five criteria:

- Net economic benefits: the estimated cumulative farmer revenue benefits resulting from increased incremental yields for selected measures, minus the cumulative costs of those measures, and incorporating discounting of future returns
- Qualitative expert assessment: the judgments of the expert study team as to the expected benefits and costs of a broader range of measures, in cases where the benefits and costs are difficult or impossible to measure reliably
- Potential to aid farmers with or without climate change, otherwise referred to as "win-win" potential
- Greenhouse gas emissions mitigation potential, as estimated for each measure by application of appropriate literature that quantifies this potential, and then categorized as high, medium, or low potential
- Evaluation by stakeholders, including farmers, research institute representatives, and policy makers.

The fifth criterion was included based on the results of the second stakeholder consultation and the results of National Dissemination and Consensus Building Conference. These rankings were then converted to scores and combined using a multicriteria assessment process based on weights for ranking criteria elicited at the National Conferences.

Qualitative Expert Assessment

The qualitative analyses were based on the expert judgment of the following sources: (i) Georgian in-country agricultural experts who were consulted throughout the study process, in particular at the national conferences; (ii) farmers who shared their insights in consultation workshops; and (iii) international experts engaged by the World Bank to conduct the analytical work for the Study. The same methodology was applied in the qualitative and quantitative analyses for determining the options. In practice, the options were identified based on in-country and international experience with farmers as the primary beneficiaries independent of who bears the cost of the measures: the government, donors, cooperatives, farmers themselves, or combination(s) thereof. To the extent possible, a clear rationale and a time frame for implementing the recommended options were also identified where such recommendations were tailored to the specifics of the agricultural regions of Georgia. Based on the expert assessment, adaptation options were ranked on a scale from one to four.

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Stakeholder Workshops

In the assessment and selection of approaches and tools to adapt to climate change, collecting input from farmers and other stakeholders was considered critical to the success of the World Bank program. For this purpose, two rounds of stakeholder workshops were conducted in Georgia. The end product of these meetings was a set of recommendations for prioritized actions that was presented at the National Conference.

The first workshop was conducted in April 2012 to ensure that those stakeholders who would be responsible for implementing any adaptation responses had the opportunity to identify possible impacts and appropriate adaptation responses for the study team to review during the analytic phase of the Study. During the workshop, input was solicited from stakeholders regarding a list of potential climate impacts and adaptation options. Questions included the following:

- Which, if any, of these climate change impacts have you observed?
- 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?
- For those impacts that pose the greatest risk, what measures have you already taken (if any) in response?
- What policy, technology/research, extension, or infrastructure measures might be taken by the government to enhance the resiliency of your operations?
- Which of the potential responses do you view as the most desirable and feasible?
- What kind of additional information might be helpful about these options?

The second workshop was conducted in October 2012 following the analysis of climate change impacts. It focused on providing stakeholders with the opportunity to share their thoughts and concerns about the proposed adaptation and mitigation responses. It also included a discussion of the relative ranking of the responses. The criteria used to evaluate the different adaptation options included feasibility, political and social acceptance, robustness against possible climate futures, and cost-effectiveness. The workshop was organized around the following set of questions:

- What do you think are the most relevant criteria by which to judge these options?
- Which of these criteria are most important?
- How would you rank the various adaptation options against each of these criteria?
- Once the ranking is done, are there logical ways to group the options, for example, most important to least important?
- Looking over the prioritized lists, do you have any comments or concerns about the rankings?

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Limitations

The Study was carried out with three key limitations: (i) lack of data; (ii) difficulties and limitations regarding projections; and (iii) limitations regarding modeling.

Lack of data: A study of this breadth, conducted under time and data constraints, is necessarily limited. In particular, in order to look broadly across many crops, areas, and adaptation options, particularly options that may be relatively new to Georgia, in many cases general data and characterizations of these options must be relied on. While the Expert Consultant Team has taken care to use the best available data, and applied state-of-the-art modeling and analytic tools, analysis of outcomes 40 years into the future, across a broad and varied landscape of complex agricultural and water resources systems, involves uncertainty.

For Georgia, a wide range of historic meteorological data was available through public sources, including global data from the World Meteorological Organization. These data were supplemented by an exhaustive provision of locally available hydrologic and meteorological data to the Expert Consultant Team. Nonetheless, historic climate data in all countries is subject to missing values in time series and requires interpolation to non-monitored regions. The effect of this limitation on the overall Study results is not clear.

Limitations regarding projections: Such limitations involve: (i) changes in water quality; (ii) future construction schedule for irrigation and storage projects; (iii) future storage capacity of reservoirs; (iv) development of national agricultural system; and (v) farm-scale options. Available information was not sufficient 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. The future construction schedules for irrigation and storage projects were not known with certainty. Therefore, the analysis assumes that no new reservoirs or irrigation projects will be constructed through 2050. If they could be incorporated into the WEAP baseline, this would affect the overall water balance. There was no sufficient data to predict the sedimentation levels in the reservoirs. Therefore, the water balance model assumed that the reservoir capacities remain constant at reported levels and sedimentation does not cause substantial reductions in this capacity. However, this assumption may overestimate the storage availability over the next 40 years.

A potentially larger question that was not addressed in the Study, involves projecting the evolution and development of agricultural systems over the next 40 years, with or without climate change. The future context in which the adaptation measures would 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." It should be noted that the results of the 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

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in the process of evaluating and implementing climate adaptation options for the agricultural sector, using the current best available methods.

Limitations regarding modeling tools: The direct effects of heat stress on livestock have not been studied extensively, but 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). Ideally, a "process" model similar to the AquaCrop crop model would be employed to estimate these effects—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. However, a suitable livestock effects simulation model could not be identified.

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. These studies suggest that our quantitative results, which do not reflect direct effects of climate change on livestock, very likely underestimate the true and complete effect of climate change on livestock resources.

Another limitation regarding the modeling tools involves the WEAP model that does not incorporate groundwater resources in the overall water balance, based on the assumption that these resources ultimately interact with and influence either the quantity or quality of surface water supplies (Winter et al. 1998). Assuming that these withdrawals are truly separable from surface water resources and that groundwater mining is not occurring, including these resources in the model would increase.

Crop modeling results also 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. It is difficult to accurately estimate the effect 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. Further, climate change can exacerbate other atmospheric environmental conditions, such as tropospheric ozone levels, which limit plant production. Since there is no current reliable method to jointly estimate the direct and indirect effects of CO_2 and ozone on crop yields, the yield estimates are presented excluding these effects.

Despite these limitations, which are important to document and clarify, the results of the Study are still relevant and applicable for policy-making purposes. However, interpretations of the results of the Study's quantified benefit-cost (B-C) analysis should incorporate a "risk factor"—in other words, recommendations based on the B-C analyses should recognize that the estimated benefits

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need to greatly exceed costs to ensure a positive outcome, rather than marginally exceed costs. This "risk factor" is taken into account in the recommendations provided in the Study, and was communicated to local counterparts throughout the stakeholder engagement process.

Note

1. The CMI depends on average annual precipitation and average annual potential evapotranspiration (PET). If PET is greater than precipitation, the climate is considered to be dry whereas if PET is smaller than precipitation, 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.

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CHAPTER 2

Overview of Agricultural Sector and Climate in Georgia

Overview of Georgia's Agricultural Sector

Agriculture and the Economy

Agriculture has traditionally been a significant and stable part of the Georgian economy. Agriculture's contribution to the country's gross domestic product (GDP) has declined from 22 percent in 2000 to 9 percent in 2011 (World Bank 2013a). Although the sector has declined in terms of economic importance, Georgia is still an agrarian society with 47 percent the population living in rural areas in 2010 (World Bank 2013a). As a result, much of the country's population is highly vulnerable to any event that affects the performance of the agricultural sector.

In 2009, the total value of agricultural production was about US$1.2 billion (Table 2.1). Over half of the value of production is accounted for in the livestock sector, while crops account for about 42 percent and agricultural service activities account for the remainder. Cereals such as wheat and corn are grown extensively and occupy 33 percent of arable land and contribute 32 percent of the value of total crop output (GeoStat 2011).

In Georgia, farming systems vary according to climatic zones. In the Western and Eastern Mountainous agricultural regions, for example, agriculture is based on more resilient, less input-intensive crops such as wheat, maize, and natural pastures. Nonirrigated areas are used for livestock and rainfed cereal crops,

Table 2.1 Value of Agricultural Products in Georgia in 2009

Agricultural products	*Value (millions of 2009 US$)*
Cereals	224.0
Fruits, nuts, crops for beverages and spices	171.3
Vegetables	124.5
Livestock production	682.7
Agricultural service activities	38.0
Total output of the sector	**1,240.5**

Source: GeoStat 2011.

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while irrigated areas in the lower elevations are devoted to fruits and vegetables. The subtropical climate in certain areas in western Georgia favor a variety of crops including citrus and tea, while viticulture and fruit production prevail in the east.

Agriculture is based on a dual system of family holdings and commercial operators, with more than 90 percent of the production concentrated within highly fragmented, small-scale family holdings (FAO 2012). The average size of a family holding is 1.22 hectares, and they are often fragmented into two or three land parcels of 0.45 hectares each. The products from small-holdings are often primarily for subsistence or semi-subsistence purposes. Those farmers who are engaged in semi-subsistence farming market their surplus when available, and often do not have sufficient information to effectively market their products. There are several interrelated challenges related to marketing, including: (i) poor quality of the products taken to the market due to poor production and post-harvest practices; (ii) low commodity prices; (iii) inability to market the produce even though the market is not saturated; (iv) distance to the markets and transportation problems; and (v) lack of access to agro-processing.

In general, the contribution of crop production to overall agricultural output has been declining in Georgia, as the contribution of animal husbandry to overall output increases. Prices of local produce have been affected by various factors, including weather, animal and plant disease, pest-induced fluctuations in already low levels of production, diseconomies of scale in local production, volatile energy prices, inflation, limited access to adequate storage infrastructure, the political situation in major importing countries, and developments in international commodity markets.

In 2010, agriculture was designated a priority for the Georgian government, and the Ministry of Agriculture initiated preparation of a sector development strategy. In 2011, the Ministry's budget was increased by 80 percent (GEL 69.15 million) compared to the previous year for investment in the sector (FAO 2011).

Agricultural Resource Base

A complete review of the agricultural resource base that is provided in the Country Note for Georgia is summarized below. The Country Note is publicly available on the World Bank's website (World Bank 2013b).

Climate, Land, and Soils: The climate in Georgia varies substantially with location, from humid subtropical to permafrost. Mountains cover roughly 54 percent of the country while highlands and valleys compose the other 33 percent and 13 percent, respectively. About 70 percent of the country is below 1,700 meters, at an elevation which supports agriculture, while in general only pastures exist at higher altitudes (FAO 2008).

In the western region along the Black Sea, the climate is humid and subtropical, with temperatures ranging from -15°C to 45°C (averages temperature 14°C to 15°C) and annual precipitation between 1,500 millimeters and 2,500 millimeters (UNFCCC 2009). The influence of the Black Sea leads to mild winters, hot summers, and large amounts of precipitation. In the mountainous parts of

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the country, average temperatures range from 2°C to 10°C with minimum temperatures of -35°C, and annual precipitation ranges from 1,200 millimeters to 2,000 millimeters (UNFCCC 2009).

In the eastern part of the country, the lowlands have a dry subtropical climate while the mountainous area has an alpine climate. Average temperatures are around 13°C in the plains and between 2°C and 7°C in the mountains, with minimum temperatures of -25°C and -36°C, respectively. The temperature in the high mountains ranges from -42°C to 42°C. Annual precipitation is 400 to 600 millimeters in the plains, and 800 to 1,200 millimeters in the mountains (UNFCCC 2009).

Georgia's climate is, in general, advantageous for agriculture, and there is great potential for high-value annual and perennial crops such as grapes, fruits, tea, citrus, vegetables, tobacco, and medicinal plants. However, poor soils are prevalent in the eastern portions of the country where overgrazing and reduced precipitation have led to wind erosion. In many cases, lands either lack the necessary irrigation to be productive or are irrigated but suffer from poor irrigation application such as waterlogging and salinization. Salinization is especially problematic, affecting 20 to 40 percent of all land in Georgia—as a result, much of this land is no longer in agricultural production (World Bank 2007). Human-induced land degradation represents a fairly small portion of land degradation compared to other countries, but agriculture accounts for all human-induced land degradation in Georgia, as opposed to accounting for only 23 percent of human-induced degradation across Europe.

Soil erosion, desertification (mainly in east Georgia) and salinization (most common in east Georgia) are growing problems. Water and wind erosion, environmentally degrading agricultural practices and other anthropogenic (for example, uncontrolled logging) and natural processes has led to an almost 35 percent degradation of farmland. Given the scarcity of arable land, soil erosion remains one of the greatest problems. There is no systematic monitoring of industrial pollution of soils. There is however, an increase in the use of chemical substances (fertilizers, pesticides, herbicides, etc.) which may affect the soil quality. Bad waste management practices, including insanitary landfills (official and illegal dumping sites) cause constant pollution of soil, water and air (SIDA 2013). Factors affecting the soil fertility in agricultural land and the ratio of affected land are the following: (i) soil erosion: about 30 percent; (ii) acidity: 11 percent; (iii) waterlogging due to malfunctioning drainage systems: about 8 percent; (iv) excessive potassium and nitrate use: 5 percent; and (v) salinity: 7 percent.

Extreme events, potentially impacted by climate change, are affecting Georgia's economy. From 1995 through 2009, floods and erosion, particularly through landslides and mudflow, led to US$650 million in economic losses.

Water Resources and Irrigation: Georgia's geography is diverse, supporting a wide range of freshwater resources. The geography includes humid subtropical lowlands and wetlands, plains, semi-deserts, highlands, mountains covered by forests and glaciers, lakes and many rivers. The Likhi Mountain Range serves as

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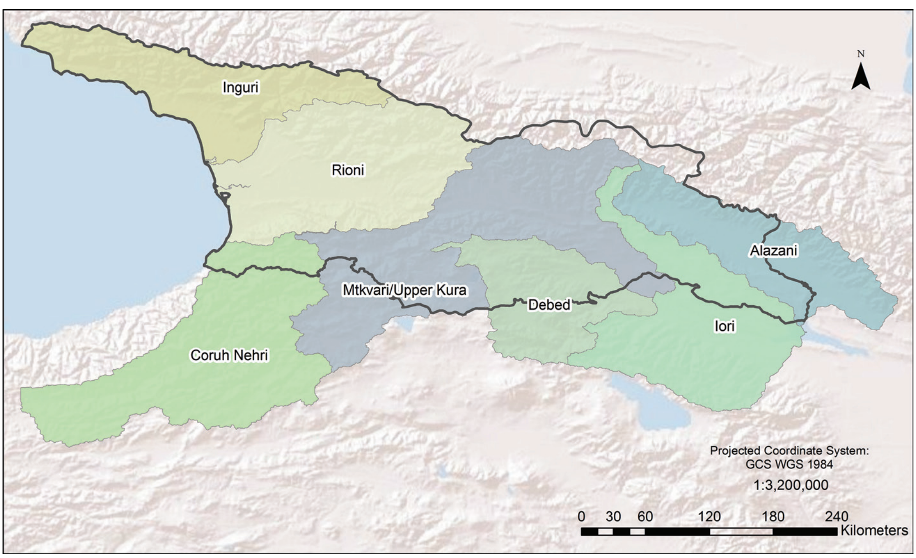
a geographical barrier, dividing the country into eastern and western halves. The lowlands in the western portion of the country consist mostly of wetlands while the lowlands in eastern Georgia are dry. Georgia is generally rich in fresh water with rivers, lakes and springs. Its largest river is the Mtkvari (Kura), which originates in Turkey and flows through Georgia to the Mingechaur Reservoir in Azerbaijan. Many rivers, especially Mtkvari and Rioni, are heavily polluted, affecting water quality nationally as well as in downstream countries.

The major river basins of Georgia (map 2.1) are the following, clockwise from the North: (i) Inguri basin, (ii) Rioni basin, (iii) Mtkvari/Upper Kura basin, (iv) Alazani basin, (v) Iori basin, (vi) Debed basin, and (vii) Coruh Nehri basin. Some of these basins extend beyond Georgia'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 Georgia's territory.

Total annual irrigation water withdrawals across Georgia are approximately 1.06 km^3, representing 65 percent of water withdrawals in the country (FAO 2008). In the Water Evaluation and Planning System (WEAP) model, irrigation water withdrawals in each river basin were estimated based on: (i) the total hectares of irrigated land in each basin; (ii) per hectare estimates of crop irrigation requirements, and (iii) an estimate of basin-level irrigation efficiency. The distribution of irrigated hectares across the river basins was based on a weighted spatial analysis of in-country data by administrative region (map 2.2 and table 2.2; FAO 2013). In total, there are 300,959 hectares of irrigation across the country.

Pollution from Agricultural Activities: Fertilizer imports declined from 200,000 tons in 1989 to 60,000 tons in 2005. While a shift to manure application was

Map 2.1 River Basins in Georgia



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Map 2.2 Irrigated Areas in Georgia

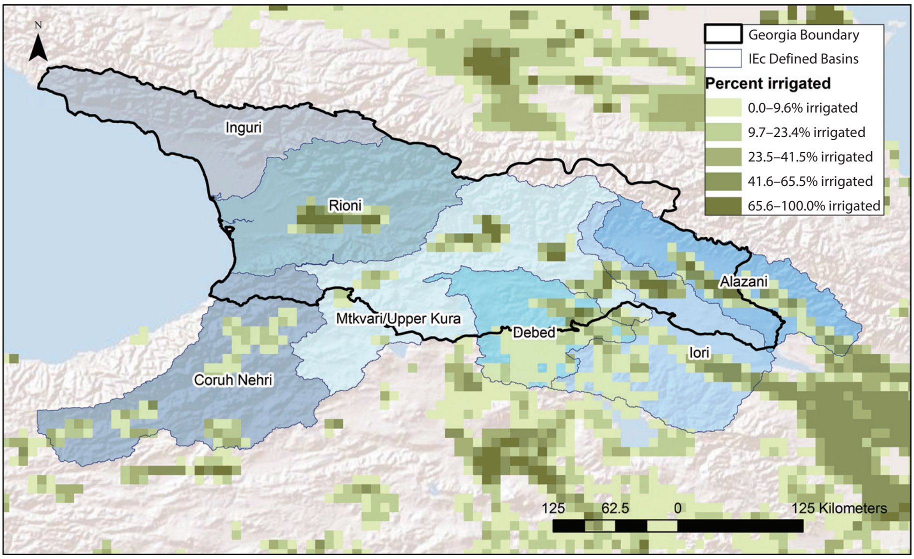

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Table 2.2 Size of Irrigated Areas in Georgia's River Basins

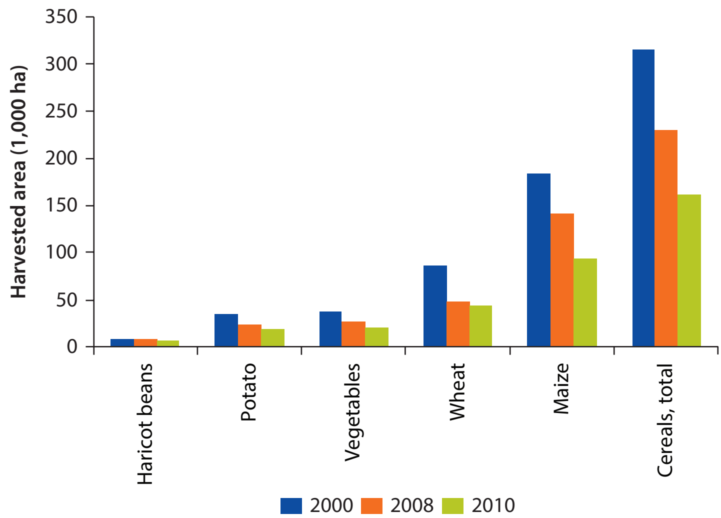
River basin	*Size of irrigated area (ha)*
Inguri	0
Rioni	75,102
Coruh Nehri	0
Mtkvari/Upper Kura	98,530
Debed	25,595
Iori	49,319
Alazani	52,413
Total	**300,959**

Source: World Bank data.

expected, a significant drop has been experienced over the same period of time. This resulted in less pollution in agricultural land. However, reduction in pesticide use did not yield a similar result due to: (i) pesticide applications undertaken by nonlicensed operators; (ii) lack of regular training programs that will update their knowledge and skills; (iii) inadequate and unsafe storage and dumping of chemicals and containers.

Crop and Livestock Production: The prevailing farming system is mixed farming where crops and livestock are equally important and in some regions, either crops or livestock could be dominant. Cereal field crops such as wheat and maize are grown extensively and occupy 33 percent of agricultural land (figure 2.1) and

Figure 2.1 Areas Planted by Crop in Georgia, 2000–10



Source: GeoStat 2011.

contribute 32 percent of total crop outputs (FAOSTAT 2013, World Bank 2013a). In many parts of Georgia except the lowlands, the agro-ecological characteristics, access to water, availability of agricultural infrastructure and inputs are not favorable for the production of high-value horticultural crops. Therefore, the rural communities in highland areas depend on more resilient, less input-intensive crops, for example wheat and alfalfa.

Trends within the field crop sector over the last decade indicate a decline in overall agricultural land (figure 2.1). Areas planted for the crops shown in figure 2.1 declined by about 54 percent from 2001 to 2010 (FAOSTAT 2013).

As noted above, livestock has long been an important component of the Georgian agricultural economy. Between 2002 and 2011, however, livestock counts have decreased, as has the GDP contributed by animal husbandry (31 percent decrease between 2006 and 2011). Between 2006 and 2011, stocks of pigs declined significantly (by 74 percent), stocks of sheep and goats declined by 30 percent, and poultry stocks increased by 17 percent (FAOSTAT 2013).

Table 2.3 indicates there is significant variation in livestock counts among the agricultural regions. The livestock densities vary widely across agricultural regions, with cattle, goats, sheep, and pigs more prevalent in the eastern areas than in the west, and chickens more prevalent in the Lowlands than in the Mountainous regions.

Exposure of Georgia's Agricultural Systems to Climate Change

Historical Climate Trends

Changes in climate in the Southern Caucasus region seen thus far include: increasing temperatures, shrinking glaciers, sea level rise, reduction and redistri-

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Table 2.3 Livestock Count by Agricultural Region

Livestock type	*Eastern Lowlands*	*Eastern Mountainous*	*Western Lowlands*	*Western Mountainous*
Cattle	191,000	477,000	122,000	273,000
Goats and sheep	82,500	377,000	26,600	69,700
Pigs	32,400	31,000	15,400	9,490
Chickens	1,350,000	1,680,000	1,330,000	1,940,000

Source: World Bank data.
Note: Livestock total count derived from GeoStat 2011 totals. Data disaggregated to agricultural regions using FAOSTAT gridded livestock data of the world (2005).

bution of river flows, decreasing snowfall, and an upward shift of the snowline. In the past ten years, the region has also experienced more extreme weather events with flooding, landslides, forest fires, and coastal erosion which resulted in economic losses and human casualties (WWF 2008).

UNFCCC (2009) reports climate trends for Georgia between two periods: 1955 to 1970; and 1990 to 2005. In the western portion of the country, the mean temperature increased 0.2°C to 0.4°C and precipitation increased 8 to 13 percent between these periods. Similarly, in eastern Georgia, temperature increased 0.6°C and precipitation increased by 6 percent. These changes were experienced in both the winter and summer seasons.

Georgia has a history of floods and erosion, especially in the last one to two decades. From 1995 through 2009, floods and erosion, particularly through landslides and mudflow, led to US$650 million in economic losses. Heavy downpours lead to landslides and mudflows in many mountain areas in April and May 2005. This resulted in loss of infrastructure and homes, and created health, sanitation, food, and water problems, with a total cost of millions of U.S. dollars.

Along with increasing temperatures, the glaciers are melting rapidly in the region, as they are globally. The volume of glaciers in the Caucasus has been reduced by 50 percent over the last century, and 94 percent of the glaciers retreated 38 meters per year (Stokes et al. 2006). In Georgia, glaciers are retreating 5 to 10 meters per year, with a maximum of 25 meters per year.

Extreme climatic variables are also noted in extreme temperature trends. An increasing trend in the number of days per annum with maximum temperature over 25°C was noted in over half of the stations monitored. Additionally, an increasing number of days per annum with daily minimum temperatures over 20°C were observed in over a quarter of the stations analyzed (UNDP 2011). Floods are reported as killing more people, but drought affects far more people and causes greater economic damages, for example a large drought in 2000 affected 700,000 people and caused damages of 5.6 percent of GDP due to its effects on agriculture and on hydro-power generation (World Bank 2006).

UNFCCC (2009) includes a case study of the Kvemo Svaneti region, a mountainous area along the central portion of the Georgia's northern border in the

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central agricultural zone, as a region that is most vulnerable to climate change. Disastrous weather events, including floods, landslides, and mud torrents, are becoming more and more common in this area. Increased frequency and intensity of these phenomena causes land erosion which impacts agriculture, forests, roads, and communications. Over the past 50 years, mean air temperature has risen 0.4°C and precipitation has increased 106 millimeters (8 percent). Increased extreme events are apparent in the frequency of floods doubling from the first half of the period between 1967 and 1989 to the second half of the period and, over the same period, floods lasted 25 percent longer. Landslides increased by 43 percent since 1980 and both mud streams and droughts have become much more frequent as well.

Additionally, the duration and recurrence of droughts have increased in Kvemo Svaneti in the last several decades. The occurrences of pests and diseases in forests of the region, which cover 60 percent of land area, have increased over the past 15 to 20 years. The Central Caucasus glaciers of this region have decreased in area by 25 percent and in volume from 1.2 km^3 to 0.8 km^3 (UNFCCC 2009). Increasing temperatures might cause the glaciers of this region to disappear by 2050.

Forecast Climate Changes for Georgia

The effect of climate change on annual average temperature and average annual precipitation in Georgia is presented in maps 2.3 and 2.4. The figures summarize by decade the resulting forecast of changes in climate at agricultural region level from the current period baseline through 2050.

Changes in temperatures: 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 (map 2.3). This increasing trend in temperatures is consistent with the observed historical trend and information gathered from local farmer workshops. In addition to increases in average temperature, farmers also have observed is an increasing trend in extreme heat events.

The data analysis supports the conclusion that the historical trend in temperature will accelerate in Georgia in the near future. Although there remains uncertainty in the degree of warming that will occur in the country, the overall warming trend is clear and is evident in all four agricultural regions. Although there remains uncertainty in the degree of warming that will occur in Georgia, the overall warming trend is clear and is evident in all three agricultural regions, with average warming over the next 50 years under the Medium Impact scenario of about 2.3°C—much greater than the increase of less than 0.2°C to 0.4°C observed in the eastern portion of the country over the last 50 years (UNFCCC 2009). Warming could be more modest, but average temperature changes for the Low Impact scenario nonetheless represent an increase of about 1.2°C compared to current conditions.

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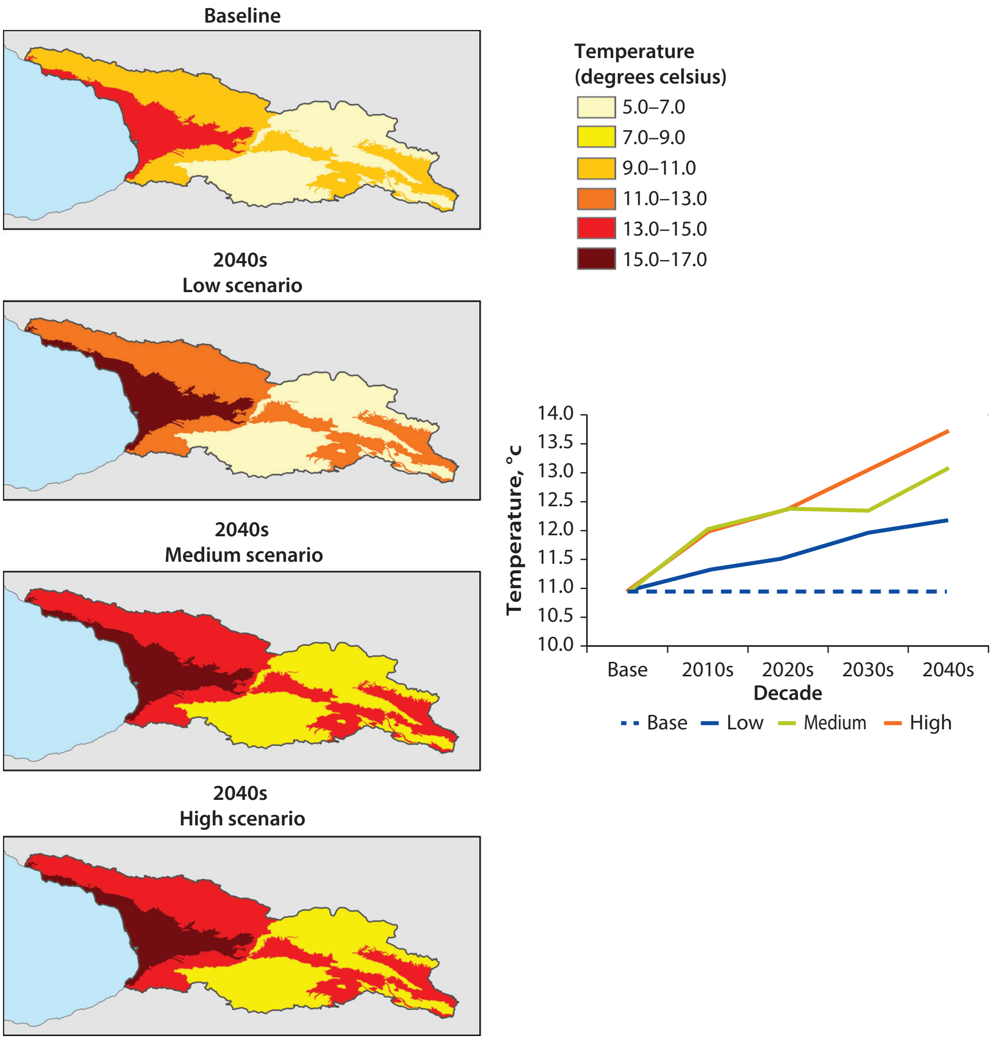
Map 2.3 Effect of Climate Change on Average Annual Temperature in the 2040s under the Low, Medium, and High Impact Climate Scenarios



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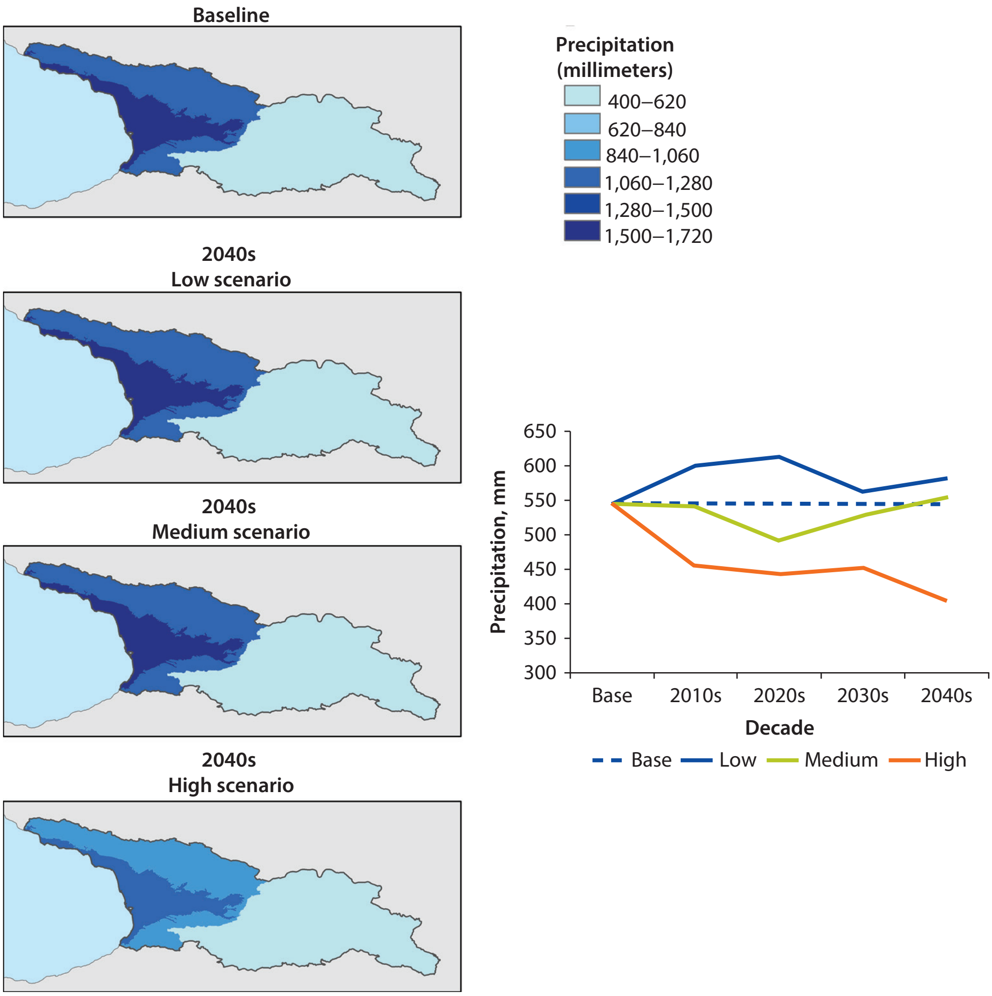
In all scenarios, the warming trend relative to current conditions is about the same magnitude across the four agricultural regions. However, the range of current temperatures across the agricultural regions is quite large. For example, average temperatures in the Western Lowlands agricultural region are as much as 9°C higher than those in the Eastern Mountainous region and 3°C higher than those in the Western Mountainous and Eastern Lowlands regions.

Changes in Precipitation: For precipitation, by 2050 all scenarios indicate uncertainty in the direction of effect as well as its magnitude (map 2.4). The Low

Map 2.4 Effect of Climate Change on Average Annual Precipitation in the 2040s under the Low, Medium, and High Impact Climate Scenarios



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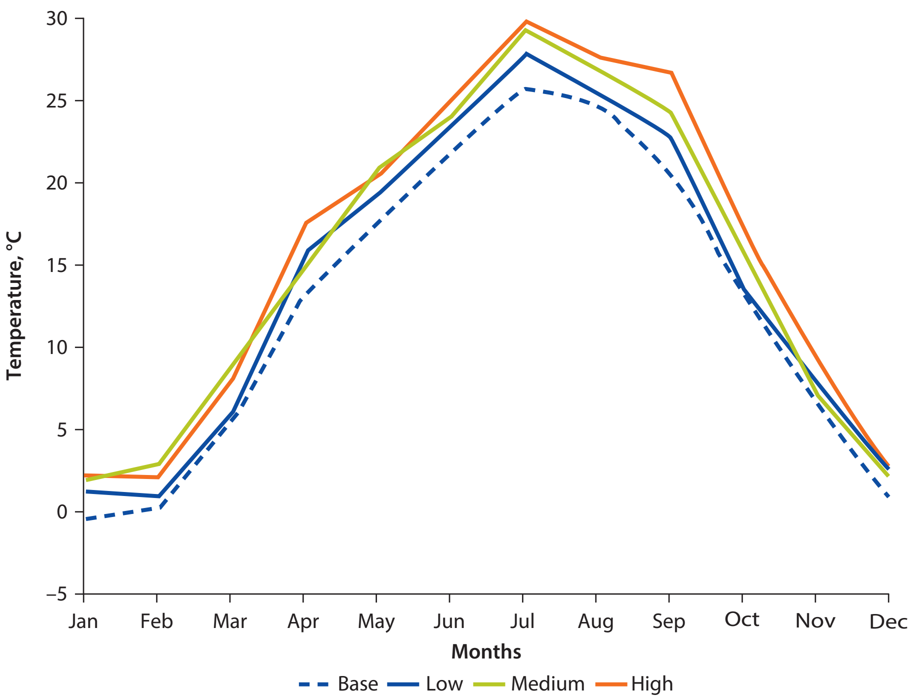
Impact scenario forecasts an increase in precipitation, while the other two scenarios indicate decreases. The use of General Circulation Models (GCMs) also means that the decadal trend in precipitation is not smooth over time. This is consistent with current climate science which suggests that short-term 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.

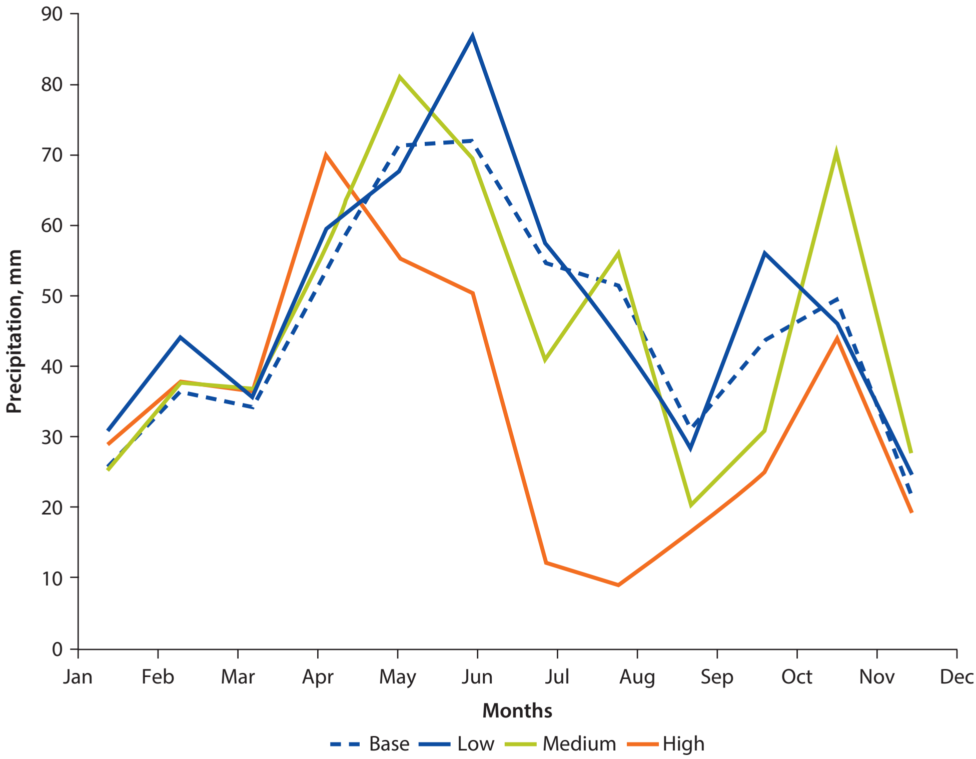
Precipitation changes are much more uncertain than temperature changes, as indicated when comparing map 2.3 with map 2.4. The Medium Impact scenario indicates an increase in precipitation in all but the Eastern Mountainous agricultural region, with a national average increase of about 1 millimeter per year. Most of this increase is forecast to occur in the Western Lowlands agricultural region. The range of precipitation outcomes under the Low and High Impact scenarios is large, however, ranging from a modest increase under the Low Impact scenario to a 24 percent decrease under the High Impact scenario. Uncertainty at the regional level is even higher, with annual precipitation declines in the Western Lowlands agricultural region as much as 323 millimeter.

The yearly averages, however, are less important for agricultural production than the seasonal distribution of temperature and precipitation. For temperature, increases are highest in September, when temperatures are already at their highest, and can be as much as 5°C in the Eastern Lowlands region. For precipitation, the forecast declines are greatest in the key May to October period under the High Impact scenario, causing late summer and early fall to be the driest times of year. Figure 2.2 presents the monthly baseline and forecast temperatures and precipitation for the Eastern Lowlands agricultural region.

Climate change could potentially increase the frequency and magnitude of droughts, frost, and floods. While precipitation is only expected to increase in the Low Scenario by the 2040s (and sometimes the Medium, see map 2.4), rainfall events are expected to be more variable, with a high probability of daily to

Figure 2.2 Effect of Climate Change on Monthly Temperature and Precipitation Patterns for the Eastern Lowlands Agricultural Region (2040s)





Source: World Bank data.

multiday events being larger and less frequent. For the agriculture sector in Georgia, 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 crop productivity. Prolonged water-logging is detrimental to many crops.

CHAPTER 3

Impacts of Climate Change on Georgia's Agricultural Sector

Impacts on Crops and Livestock Systems in Georgia

The impact assessment was undertaken for: (i) each climate scenario; (ii) the crops selected for the Study; and (iii) each agricultural region. The results are summarized in tables 3.1, 3.2, and 3.3.

Climate scenarios: The assessment was conducted for three scenarios that were selected in the beginning of the Study to capture a broad range of climate model forecasts. The results are the given below by impact scenario.

High Impact scenario: Generally, the scenario has the strongest impact, with less rainfall and higher evapotranspiration due to the higher temperature projections.

Medium Impact scenario: This scenario reflects a mid-range forecast of climate change. For Georgia, the impact of climate change in this scenario is somewhat less severe than the High Impact scenario, as this scenario is less pessimistic in terms of rainfall projections. Under this scenario, rainfed crops tend to be more negatively affected by climate change than irrigated crops (table 3.1). The Eastern Mountainous agricultural region may experience significant increases in production, as colder temperatures become more moderate. The effects are similar and broadly negative across the other three agricultural regions.

Low Impact scenario: This scenario shows a net negative impact for most crops in the Eastern Lowlands, Western Lowlands, and Western Mountainous agricultural regions, though to a lesser extent than in the Medium and High Impact scenarios, due to the increased rainfall projections. The higher temperatures also result in a higher evapotranspiration, but only a part of the increased rainfall is lost through nonproductive evaporation. Most of the crops in the Eastern Mountainous region are affected positively.

Crops: In general, the results indicate that of the seven crops selected at the beginning of the Study, only pasture experiences increased yields, whereas the others (wheat, corn, grapes, mandarin, tomato, and potato) experience decreases in yields in all but the Eastern Mountainous region (table 3.2.). The yield decreases are largest for tomatoes, with about 11 percent reduction under the Medium Impact scenario in both the Eastern Lowlands and Western Mountainous regions. As expected, irrigation increases yields and reduces yield variability.

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Table 3.1 Effect of Climate Change on Crop Yields in the 2040s under the Medium Impact Scenario (No Adaptation and No Irrigation Water Constraints)

Irrigated/ rainfed	*Crop*	*Eastern Lowlands (%)*	*Eastern Mountainous (%)*	*Western Lowlands (%)*	*Western Mountainous (%)*
Irrigated	Corn	−4	48	−4	−3
	Grapes	−5	−5	−5	−5
	Mandarin	−5	N/A	−5	N/A
	Potato	−5	−5	−5	−5
	Tomato	−6	76	−5	−5
	Wheat	−5	69	−5	−5
Rainfed	Corn	−4	48	−4	−3
	Grapes	−6	−5	−5	−5
	Mandarin	−5	N/A	−5	N/A
	Pasture	26	87	20	44
	Potato	−10	−14	−6	−7
	Tomato	−11	55	−9	−11
	Wheat	−5	69	−5	−5

Source: World Bank data.
Notes: Results are average changes in crop yield, assuming no effect of carbon dioxide fertilization, under Medium Impact scenario (no adaptation and no irrigation water constraints). Declines in yield are shown in shades of orange, with darkest representing biggest declines; increases are shaded green, with darkest representing the biggest increases. "N/A" indicates that the crop is not grown in the agricultural region specified.

Table 3.2 Range of Yield Changes Relative to the Current Situation (Percent Change to 2040s) Across the Three Climate Scenarios

Irrigated/ rainfed	*Crop*	*Eastern Lowlands*	*Eastern Mountainous*	*Western Lowlands*	*Western Mountainous*
Irrigated	Corn	−7 to −3	24 to 49	−6 to −3	−6 to −3
	Grapes	−6 to −4	−6 to −4	−6 to −4	−6 to −4
	Mandarin	−6 to −4	N/A	−6 to −4	N/A
	Potato	−13 to −4	−6 to −4	−6 to −4	−6 to −4
	Tomato	−15 to −4	50 to 74	−6 to −4	−7 to −4
	Wheat	−7 to −4	39 to 72	−6 to −4	−6 to −4
Rainfed	Corn	−7 to −2	24 to 49	−6 to −3	−6 to −3
	Grapes	−21 to −4	−7 to −4	−6 to −4	−9 to −4
	Mandarin	−6 to −4	N/A	−6 to −4	N/A
	Pasture	15 to 17	52 to 91	8 to 16	13 to 34
	Potato	−23 to −4	−19 to −4	−11 to −4	−22 to −4
	Tomato	−30 to −3	42 to 51	−26 to −3	−31 to 0
	Wheat	−6 to −4	39 to 72	−6 to −4	−6 to −4

Source: World Bank data.
Note: "N/A" indicates that the crop is not grown in the agricultural region specified.

The impact of climate change on irrigation water demand for specific crops was also assessed (table 3.3). Results indicate that irrigation water requirements will increase for corn, grapes, potatoes, and tomatoes under the Medium and

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Table 3.3 Change in Irrigation Water Requirements Relative to Current Situation (Percent Change to 2040s) under the Low, Medium, and High Climate Scenarios for Each Crop and Agricultural Region

Scenario	*Crop*	*Eastern Lowlands*	*Eastern Mountainous*	*Western Lowlands*	*Western Mountainous*
High	Corn	–1	–4	100	200
	Grapes	–1	1	283	3,025
	Mandarin	1	N/A	[a]	N/A
	Potato	0	0	550	352
	Tomato	0	–2	144	86
	Wheat	–1	–4	[a]	[a]
Medium	Corn	–1	1	33	0
	Grapes	–2	2	50	525
	Mandarin	1	N/A	[a]	N/A
	Potato	–3	–1	75	84
	Tomato	0	–1	28	26
	Wheat	0	–3	[a]	[a]
Low	Corn	–1	–1	0	–100
	Grapes	–2	1	0	0
	Mandarin	1	N/A	[a]	N/A
	Potato	2	–1	6	–8
	Tomato	–1	2	–1	–12
	Wheat	0	0	[a]	[a]

Source: World Bank data.
Notes: Results are average changes in irrigation water requirements. Declines in requirements are shown in shades of green, with darkest representing biggest declines; increases in requirements are shaded orange, with darkest representing the biggest increases. "N/A" indicates that the crop is not grown in the agricultural region specified.
a. Indicates that the irrigation water requirement is zero under the baseline and between 0 and 1 millimeter in the 2040s.

High Impact scenarios in the Western Lowlands and Mountainous regions. In the Eastern agricultural regions, results are mixed and are generally less strong than those in the Western regions. For certain crops and under certain climate scenarios, irrigation water requirements may decrease. However, even under the Low Impact scenario, certain crops are expected to experience an increase in irrigation water requirements (for example, grapes and tomatoes in the Eastern Mountainous region and mandarin and potatoes in the Eastern Lowlands region).

Livestock production: Climate change has direct and indirect effects on the subsector. The direct effect is linked to higher than optimal temperatures where heat can affect animal productivity and, in the case of extreme events, may lead to elevated mortality rates related to extreme heat stress. There is limited information to characterize the direct effects of climate on livestock—the currently available methodologies are far less sophisticated than the crop and water resources modeling techniques applied in this Study, and are generally not appropriate to apply for Georgia. A screening analysis suggests that in the country, the direct effects of climate change on most livestock, in the absence of adaptation,

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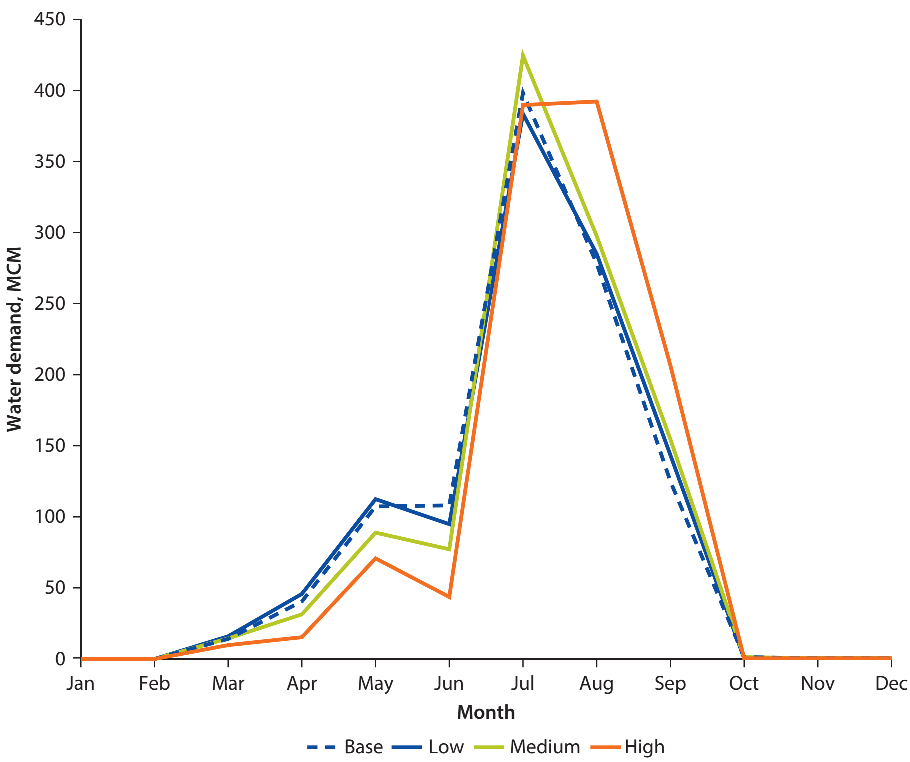
could be negative and potentially large. The indirect effect of climate change on the subsector could be linked to the changes in corn and pasture yields. Based on the impact assessment, corn yields are expected to decrease in most regions, while pasture yields are expected to increase across the country. However, the net indirect effects of such changes are uncertain.

Impacts on Water Availability for Agriculture

Irrigation Demand and Runoff

A "water availability analysis" was conducted at the river basin level using the Water Evaluation and Planning tool (WEAP), which compares forecasts of water demand for all sectors, including irrigated agriculture, with water supply results under climate change derived from the CLIRUN model. Crop irrigation requirements are affected by both temperature and precipitation, as water demand is directly linked to both crop yield and to evapotranspiration. These irrigation needs are derived from the AquaCrop Model. A comparison of total monthly irrigation demands for Georgia for the current baseline, and under the three climate scenarios for the 2040s are presented in figure 3.1. The figure shows that water demand is expected to increase in the July to September period under the

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



Source: World Bank data.

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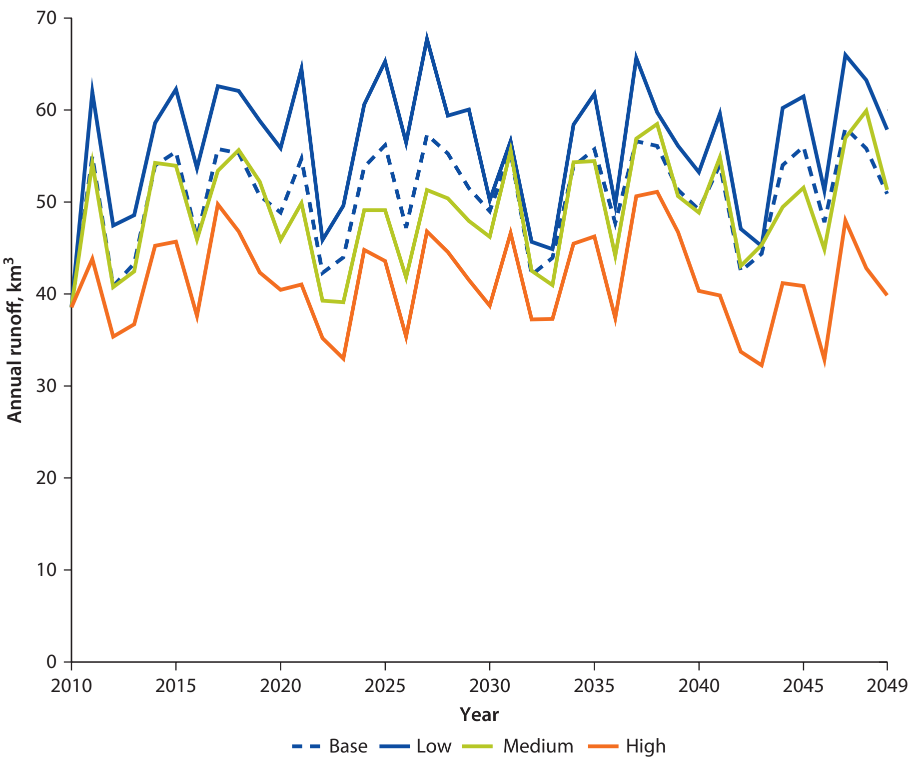
Medium and High Impact scenarios relative to the baseline. In addition, higher precipitation forecasts for June under the Medium and High Impact scenarios result in a lower water demand compared to the baseline.

The annual runoff across the climate scenarios for all basins between 2010 and 2050, as estimated by the CLIRUN model is presented in figure 3.2 and the comparison of the mean monthly runoff in the 2040s under the baseline and three climate scenarios is given in figure 3.3.

As expected, relative to current estimates, runoff declines under the High and Medium Impact scenarios after 2030 but increases under the Low Impact scenario. Variability across the scenarios increases significantly after 2020. In terms of monthly effects, although annual runoff under the Low Impact scenario is forecast to increase, runoff during the late spring and late summer months declines under all three scenarios relative to baseline conditions. This is partly due to reductions in snowpack that decreases runoff from snowmelt during those periods. These reductions occur in months when: (i) crop water demand is the highest, and (ii) AquaCrop forecasts an increase in crop demand under climate change. It should be noted that under the High and Medium Impact scenarios, a significant decline in river runoff is projected during the late summer months,

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



Source: World Bank data.

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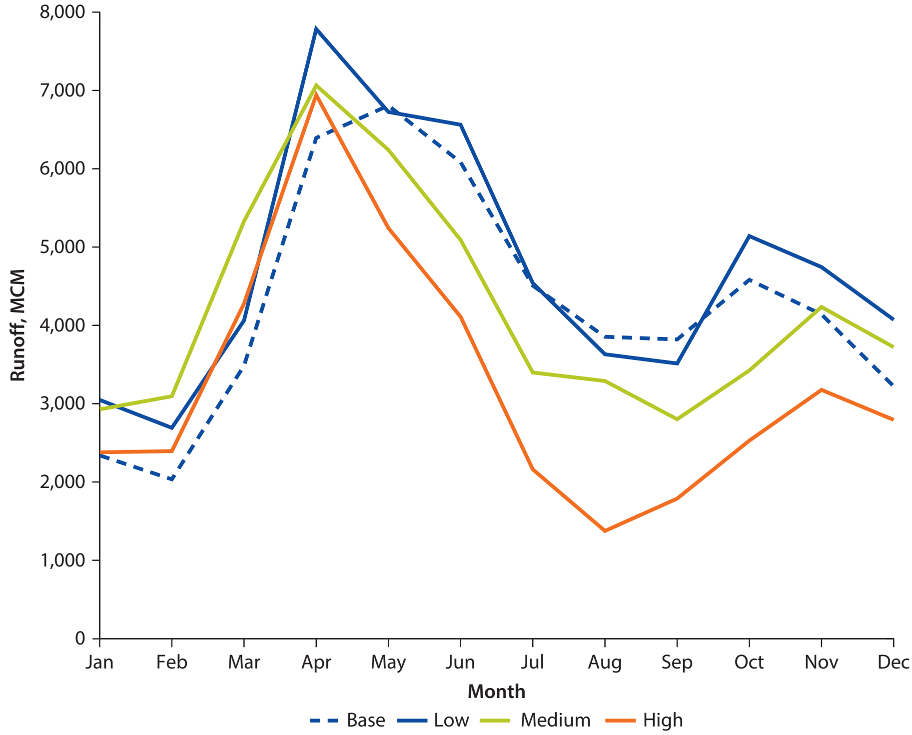
Figure 3.3 Mean Monthly 2040s Runoff for All Georgian Basins



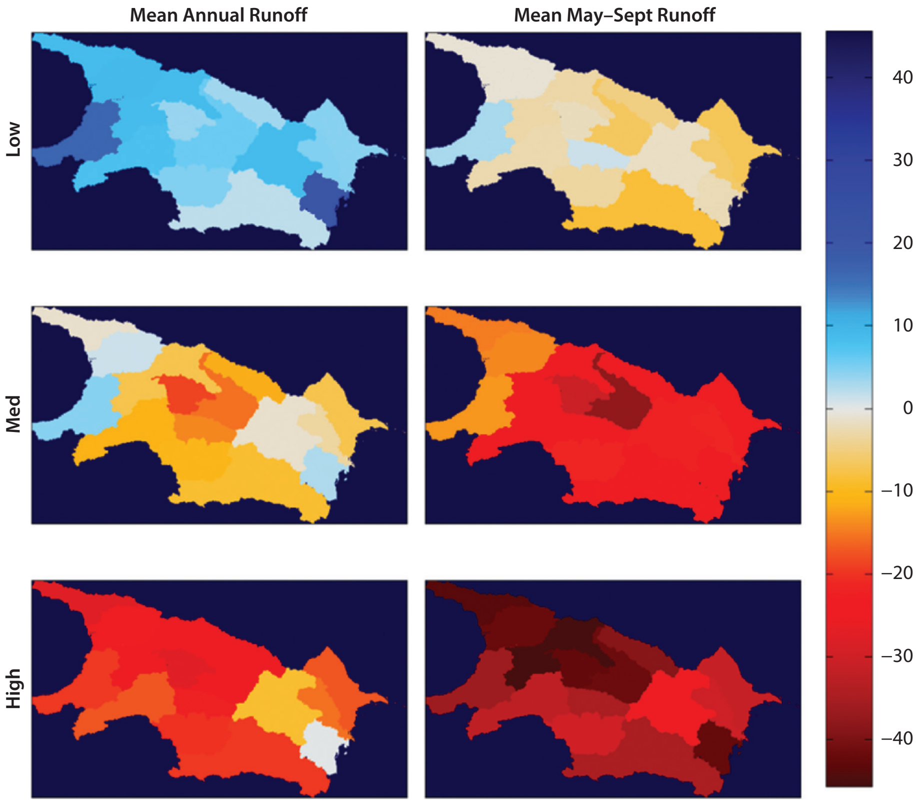
Source: World Bank data.

when reservoir storage volume is the lowest. However, in the same period crop water demand remains high.

The mean percentage change in runoff from the historical baseline to the 2040s under the three climate scenarios and across the 15 basins in the Southern Caucasus is presented in map 3.1. The set of maps on the left show the change when all months of the year are considered, and those on the right indicate only the period from May to September, when the highest irrigation demands occur. Although all of the basins are projected to have higher mean annual runoff under the Low Impact scenario when all months are considered, all of the basins across all of the scenarios show reduced mean runoff during the irrigation season, with the exception of the Coruh Nehri under the Low Impact scenario.

Forecasts of changing water demand and supply were utilized in the WEAP model to estimate potential irrigation water shortages under climate change. The results indicate that irrigation water shortages already occur under the baseline, and rise significantly under climate change. Table 3.4 presents unmet irrigation demands for the five Georgian basins under the baseline and three climate scenarios in the 2040s.

Map 3.1 Mean Percentage Change in 2040s Runoff Relative to the Historical Baseline



Source: World Bank data.

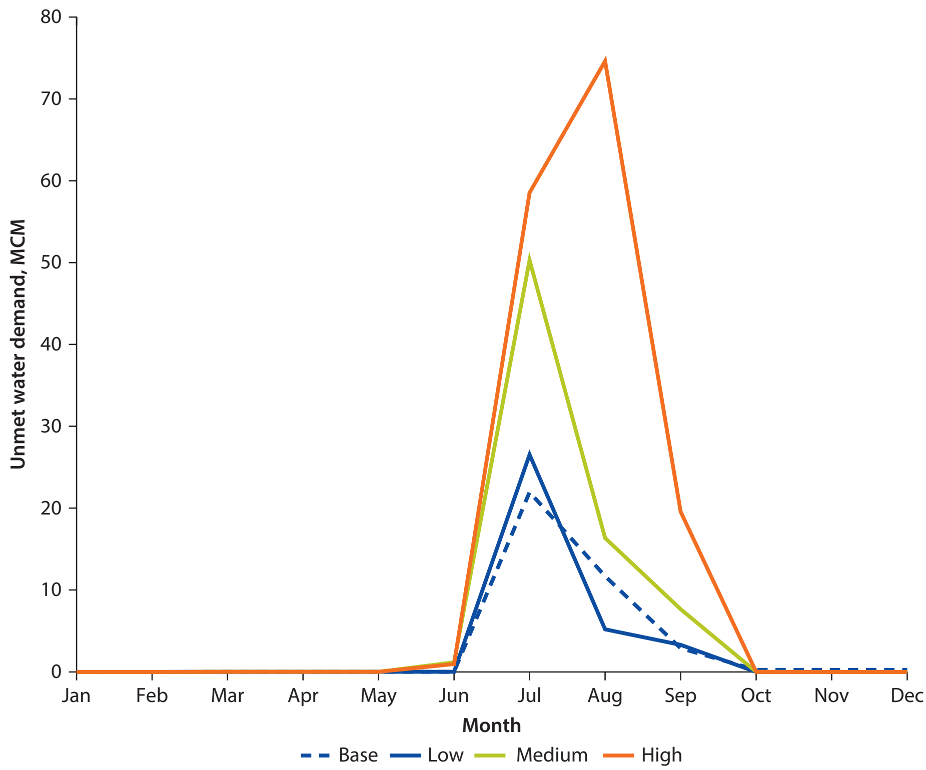
Table 3.4 Forecast Annual Irrigation Water Shortfall in 2040s by Basin and Climate Scenario

	Forecast annual irrigation water shortfall by 2040s (thousand cubic meters and percent or irrigation water demand)			
Basin	*Base scenario*	*Low Impact scenario*	*Medium Impact scenario*	*High Impact cenario*
Rioni	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Mtkvari/Upper Kura	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Debed	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Iori	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Alazani	36.5 (14.8%)	35.1 (14.1%)	75.5 (30.5%)	153.7 (61.2%)
Total	36.5 (3.4%)	35.1 (3.2%)	75.5 (6.9%)	153.7 (13.6%)

Source: World Bank data.

Under the four scenarios, demands are met in the 2040s in all but one of the five basins (the Alazani). Under the historical baseline, 14.8 percent of irrigation demands within the Alazani are not met, which translates to 3.4 percent of overall national Georgian irrigation demands. Under the High Impact scenario, 61.2

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



Source: World Bank data.

percent of irrigation demands within the Alazani are not met, which translates to a 13.6 percent deficit nationwide. Figure 3.4 presents the mean unmet irrigation demand across all basins in the 2040s under the baseline and the Low, Medium, and High Impact scenarios, showing that unmet demand rises substantially under the Medium and High Impact scenarios compared to the baseline in the June to October period.

Irrigation Water Shortages

The resulting mean decadal changes in irrigated crop yields in the Alazani, adjusted for 2040s water availability, are presented in table 3.5. As indicated in the table, water shortages for irrigation have potentially very large implications for crop yields of all types, increasing the total impact of climate change on crops to as much as a 67 percent reduction in yield.

Georgia's Current Adaptive Capacity

Assessing adaptive capacity in Georgia'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

Table 3.5 Effect of Climate Change on Crop Yields in 2040s Relative to Current Yields for Irrigated Crops

Crop	*Agricultural region/river basin*	
	Eastern Lowlands	*Eastern Mountainous*
	Alazani	*Alazani*
Baseline		
Corn	−15	−15
Grapes	−13	−13
Mandarin	−15	N/A
Potato	−15	−15
Tomato	−15	−15
Wheat	−15	−15
Low Impact scenario		
Corn	−16	6
Grapes	−16	−16
Mandarin	−18	N/A
Potato	−18	−17
Tomato	−18	29
Wheat	−17	20
Medium Impact scenario		
Corn	−33	3
Grapes	−30	−30
Mandarin	−34	N/A
Potato	−34	−34
Tomato	−35	23
Wheat	−34	17
High Impact scenario		
Corn	−64	−42
Grapes	−55	−55
Mandarin	−64	N/A
Pasture	−46	−30
Potato	−66	−64
Tomato	−67	−33
Wheat	−64	−33

Source: World Bank data.
Notes: Results are percentage change in yields from current yields to projected 2040 yields. 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" indicates that the crop is not grown in the agricultural region specified. Estimates assume no CO_2 fertilization effects.

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 rainfed 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

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require investments. Currently, the country ranks low in agricultural sector by all factors that determine a country's overall adaptive capacity. It should be noted that agricultural systems which are poorly adapted to current climate are indicative of low adaptive capacity also for future climate changes.

Adaptive Capacity Regarding Current Institutional Capacities at the National Level

In any country, a high level of adaptive capacity in the agricultural sector is characterized by a number of factors at the national level: (i) high level of functionality in the provision of hydrometeorological and relevant geo-spatial data to farmers to support good farm-level decision-making; (ii) provision of other agronomic information through well-trained extension agents and well-functioning extension networks; (iii) in-country research oriented toward innovations in agronomic practices in response to forecast climate changes; and (iv) well-maintained collective water infrastructure that meets the needs of the farming community, along with systems to resolve conflicts between farmers and other users over water provision. In Georgia, some of these conditions exist, but most are currently inadequate and/or lacking including: (i) meteorological data; (ii) extension service; (iii) rural finance; and (iv) market access.

The ability to collect, generate, and provide meteorological data to farmers is inadequate. Farmers have noted that they have limited meteorological information available to support their decision making.

The current agricultural extension service is not oriented toward ameliorating risks from climate. Many farmers are aware of extension services, but they indicate that demonstration plots and greater access to information would be helpful. 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, now privatized, have little or no connections to extension. Agricultural research institutes remain an important part of Georgia State University, but 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.

Many farms are small and have limited resources for adaption investments. Both local data and our 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.

C*rop insurance.* Increasingly prevalent inclement weather including drought, hail, spring frost, and flooding are major issues for farmers in the region. Many farmers are unable to afford insurance.

Farmers' access to rural finance is limited. Small farmers that demand credit with favorable terms (a reasonable grace period, low-interest rates, long term loans) are discouraged by the following factors: (i) high interest rates; (ii) stringent collateral requirements (Banks usually require as collateral 100–200 percent of the loan amount with guarantees that are fixed assets); (iii) small loan sizes;

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(iv) limited outreach in the rural areas; and (iv) cumbersome and long procedures that are discouraging the farmers.

Agricultural marketing is a common problem. A large portion of farmers are involved in subsistence and semi-subsistence farming and are frequently exposed to marketing problems. The farming community as a whole identifies the following problems that are interlinked by their nature: (i) low commodity prices, (ii) inability to market the produce even though the market is not saturated, (iii) distance to the markets, and (iv) lack of access to agro-processing. The underlying reasons include poor quality of the products due to poor production and post-harvest practices, timing of marketing, mode of sale, lack of storage facilities, lack of adequate information related to production and marketing, and problems regarding transportation.

The recently completed elections in Georgia may provide an opportunity to re-align some agricultural policies to address the issues identified above. A draft *Georgian Agriculture and Food Sector Development Strategy for Enhancement of Rural Development and Poverty Reduction over the period 2013–20* was circulated prior to elections, with the goal to create an environment that would promote stable growth of agricultural production, ensure food safety and fully eliminate rural poverty through sustainable development of the agriculture and food sector. The key elements of this strategy, while not yet formally adopted, include the following items relevant to the Study:

(i) *Finance:* Increases in state spending for rural infrastructure and development; enabling of credit unions for farmers, which operated well in some prior periods but require new enabling legislation; development of a state-sponsored agricultural development fund to provide low interest loans; and creation of a weather insurance program.
(ii) *Infrastructure and equipment:* State spending for rehabilitating irrigation and drainage infrastructure, and leasing programs to enable mechanization of farms.
(iii) *Market enabling:* Foster food processing industries to create local markets for produce, and support of farmer cooperatives to foster land consolidation and provide enhanced market power for competitive commodity prices at the local level.
(iv) *Agronomic practices:* Promote greater use of windbreak zones and forest areas to reduce erosion of soils, and provide mechanisms for farmers to share and exploit knowledge on best farming practices.

Adaptive Capacity at the Farm Level: Farmer Consultations

An early consultation was carried out in the Kachreti District, in the Eastern Lowlands agricultural region, to announce that an assessment of adaptive capacity would be undertaken. Farmers from nearby villages attended the consultation meeting held on April 11, 2012.

In the area surrounding Katchereti, the primary climate issues are drought, floods, high winds, hail, and cold, particularly events that are more frequent and severe than in the past. Farmers specifically mention the rapid transitions

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between seasons, namely, winter cold to summer heat and summer heat to winter cold, without the usual spring or fall transition. These weather changes have been very detrimental to both crops and to livestock, and have sometimes been accompanied by an increase in disease and pest problems. Farmers have been trying to adapt by changing both their practices and their crops.

The specific points emphasized by the farmers included the following:

Agricultural marketing is a problem. The problem arises because of poor market access, lack of transport to buyers and limited processing facilities.

Water control is not possible at the farm-level. Irrigation infrastructure is aging and needs rehabilitation. Investments are needed for sprinklers that could be used to protect tender trees from frost damage but the cost is a major bottleneck. Water lost to runoff is a serious problem, which then becomes a flooding problem downstream.

Crops and livestock varieties and crop selection are poorly suited to emerging climate challenges. In recent years, cereal planting was delayed due to too cold or too wet or too dry soil at the planting time. Early maturing varieties that fit these kinds of circumstances are not available. There is a need for updated information and inputs to shift to new crop rotation systems. Sunflower-wheat or sunflower-barley rotations that used to be common are no longer profitable due to low market prices of sunflower. On the other hand, pasture-based livestock production is also affected by climate change due to shortened growing season in spring.

Winds cause soil erosion, limit water availability for crops, and damage tree crops.

Adaptive Capacity in Crop Production

One observable indicator of adaptive capacity is the degree to which current agricultural crop yields and practices keep pace with those in other countries with similar agro-ecologies for key crops. The result of such an assessment gives a sense of "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 that current marginal production may have little resilience to climate stresses, and a high potential to be devastated by climate changes. In this context, relative yields of wheat and grapes, two important crops for Georgia were reviewed through analysis of Food and Agriculture Organization (FAO) data.

Wheat Yields: FAO statistics indicate that in Georgia, the average of irrigated and rainfed wheat yield is about 1.5 ton/ha. This is significantly less than European averages (5.4 ton/ha) where there is more favorable climate and soils and also less than World averages (2.9 ton/ha in 2010). (Figure 3.5) One reason is that Georgia has a relatively low portion of irrigated crops (about four percent as of 2008), making their overall average wheat yield relatively low as well (World Bank 2013a). Sutton et al. (2008) also attributes 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. For wheat, there is significant room for enhancing adaptive capacity to current climate in Georgia, and the Study indicated that the adaptation options for improving wheat yields have very high benefit-cost (B-C) ratios.

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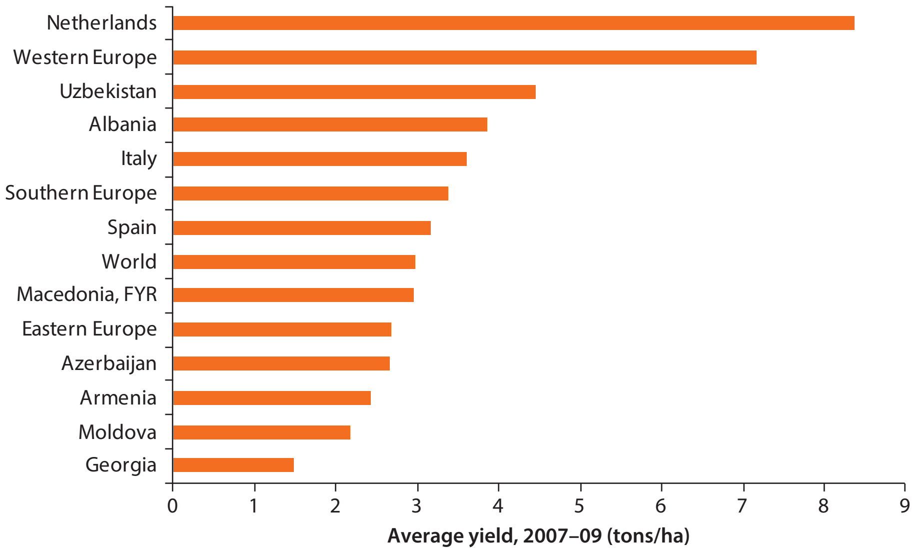
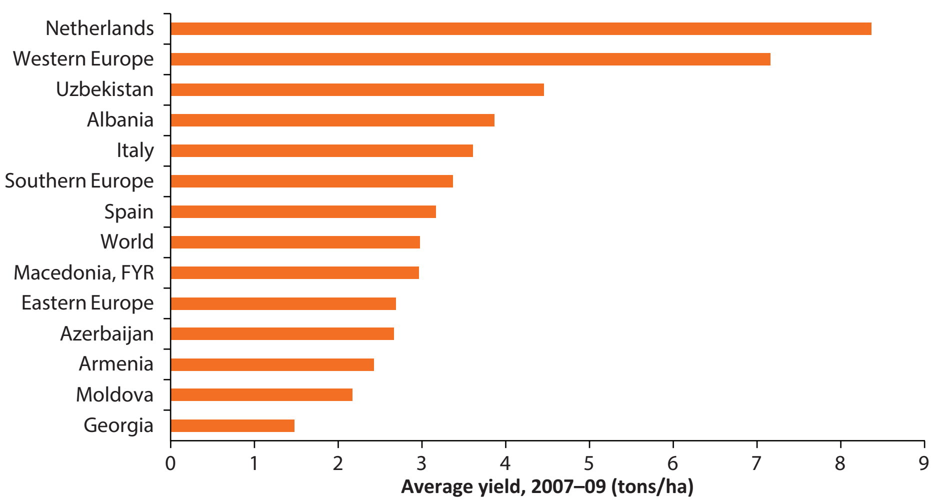
Figure 3.5 Wheat Yield in Selected Countries, Average of 2007–09



Source: FAOSTAT 2012.

Grape Yields: Average yields are about 4.1 ton/ha in Georgia, which is about 20 percent less than other Eastern European countries and significantly less than the world average of 9 ton/ha (figure 3.6). Although most grapes are rainfed, yields have more potential. Yields of high quality wine grapes, including in areas where yields are limited by appellation regulations, typically exceed 5 ton/ha. However, yields of table grapes are higher.

Figure 3.6 Grape Fresh Yields in Selected Countries, Average of 2007–09



Source: FAOSTAT 2012.

CHAPTER 4

Assessment of Menu of Adaptation Options and Recommendations

Adaptation Assessment

The impact assessment findings are potential impacts, laying a baseline for the adaptation assessment. The adaptation assessment is then primarily focused on assessing the costs and benefits, either qualitatively or quantitatively, of planned adaptation measures. This menu combines assessment of adaptation measures across multiple dimensions, including greenhouse gas mitigation potential, to arrive at a ranked list of measures for adoption.

Adaptation is defined as actions to build resilience to climate change—more formally it is the ability of a human or natural system to: adapt, that is, to adjust to climate change, including to climate variability and extremes; prevent or moderate potential damages; take advantage of opportunities; or cope with the consequences. Adaptation actions are governed by adaptive capacity, which as outlined above reflects a wide range of socioeconomic, policy and institutional factors, at the farm level, and regional and national levels in a country. Adaptive capacity is not a static concept, however—it can be enhanced by investments, changes in policies, and enhancing know-how.

A relevant concept is the Adaptation Deficit. Controlling and eliminating this deficit in the course of development is a necessary, but not sufficient, step in the longer-term project of adapting to climate change. Development decisions that do not properly consider current climate risks add to the costs and increase the deficit. As climate change accelerates, the adaptation deficit has the potential to rise much higher unless a serious adaptation program is implemented. The term is used in the Study to indicate the difference between the current yields and potential yields in agriculture for the current climate. Failure to adapt adequately to existing climate risks largely accounts for the adaptation deficit.

Economic Analyses (Benefit-cost)

Quantitative benefit-cost (B-C) analyses were conducted for eight adaptation options identified based on the analyses described in the Study as well as various discussions with farmers and other stakeholders. The first group included four options and detailed analyses were conducted. The second group comprised five

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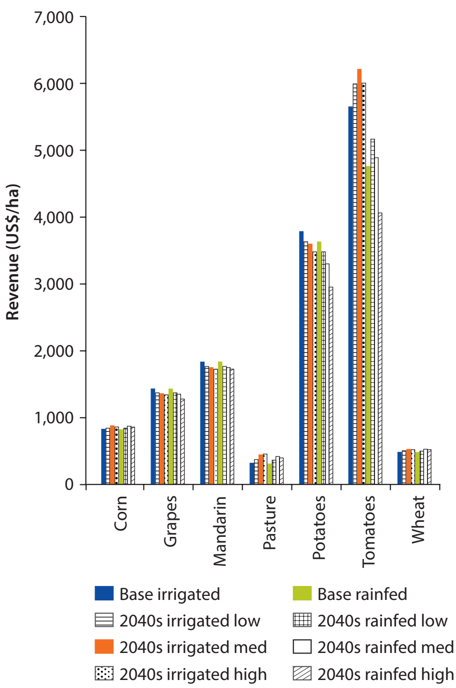
options but the analyses carried out were comparatively less detailed. The options in the first group are the following: (i) improving irrigation capacity and efficiency by new investments or rehabilitation to optimize application of irrigation water; (ii) improving drainage capacity and efficiency by new investments or rehabilitation; (iii) shifting to new crop varieties in irrigated areas; and (iv) optimizing fertilizer application.

All of these options will require that investments be made so that an efficient and effective extension system is also put in place to ensure that the information on the benefits of the adaptation measures reach the farmers and adopted. In the case of last two options, the analyses show that farmers will incur little or no net cost from these. Currently these are assumed to be not pursued because of inadequate access of farmers to knowledge regarding good farming practices as has been confirmed by farmers and various other stakeholders.

The second group of options are: (i) improving hydrometeorological services; (ii) improving extension services; (iii) optimizing basin-level application of irrigation water; (iv) adding water storage capacity; and (v) installing hail nets for selected crops. The revenues for crops (US$/ha), under rainfed and irrigated conditions, as compared to current conditions with those with climate change in 2040s (before adaption actions taken), are presented in figure 4.1.

For comparison purposes across years, the price forecasts used are current prices rather than the “high” 2040 price forecasts. Figure 4.1 indicates that the

Figure 4.1 Estimated Crop Revenues per Hectare in the 2040s before Adaptation Actions



Source: World Bank data.

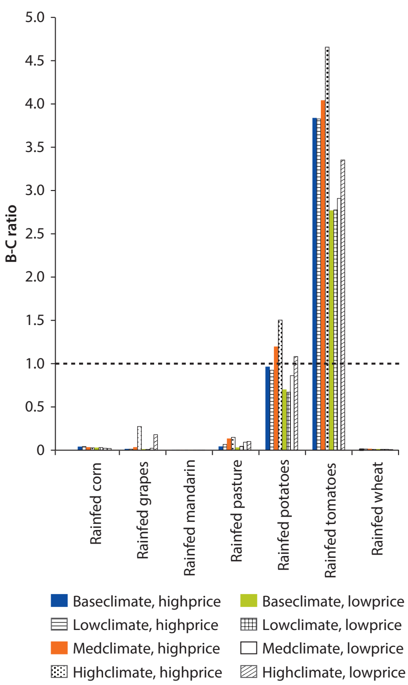
highest-value crops now, and in the future, are potatoes. Irrigated corn and irrigated wheat provide comparable revenues per hectare. Adopting adaptation options has the potential for further yield and revenue enhancement, because adaptation can address: (i) current yield deficits relative to full yield potential (closing the "adaptation deficit"), and (ii) enhance farmers' abilities to both minimize risks and exploit opportunities presented by climate change.

Economic Analysis for First Group of Options

Each adaptation option detailed below was assessed in terms of benefits and costs, and the results are displayed in graphs that show the B-C ratios for the baseline and each climate scenario, and under 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 crop/scenario/price forecast combinations where benefits exceed costs. Higher bars indicate higher B-C ratios and, for the option examined, are more likely to be good investments. Summaries and ranking of the quantitative results for each agricultural region are presented in subsequent sections.

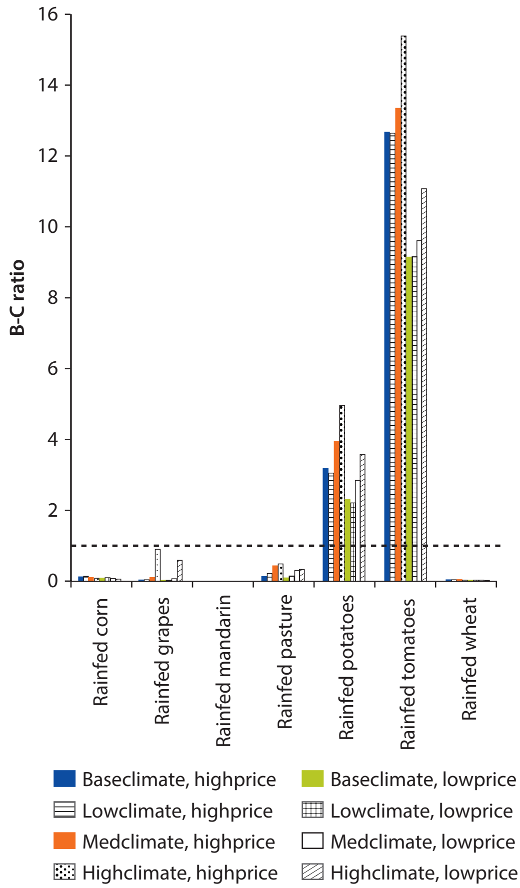
Option 1.1: Improving Irrigation Capacity and Efficiency through New Investments or Rehabilitation The results for adding irrigation capacity or rehabilitating existing irrigation capacity are presented in figures 4.2 and 4.3. The option is analyzed

Figure 4.2 Illustrative Benefit-Cost Analysis Results for New Irrigation Infrastructure in the Eastern Lowlands Agricultural Region



Source: World Bank data.

Figure 4.3 Illustrative Benefit-Cost Analysis Results for Rehabilitated Irrigation Infrastructure for Crops in the Eastern Lowlands Agricultural Region



Source: World Bank data.

for the incremental costs and benefits of switching from rainfed to irrigated for the model farms in each of the agricultural regions—the graph presents B-C ratios for the Eastern Lowlands agricultural region for each of the focus crops. The B-C ratio for new irrigation infrastructure exceeds 1 only for rainfed tomatoes (under all scenarios) and potatoes (under certain scenarios) in the Eastern Lowlands agricultural region. Because rehabilitation is less expensive than new infrastructure, but the benefits are the same, B-C ratios for rehabilitated infrastructure are higher than for new infrastructure. Figure 4.4 illustrates the B-C ratios of optimizing application of irrigation water, indicating high B-C ratios only in the High Impact scenario and again only for potatoes and tomatoes.

Option 1.2: Improving Drainage Capacity and Efficiency through New Investments or Rehabilitation The results of the analysis of improving drainage are presented in figures 4.5 and 4.6 below, for the Western Lowlands agricultural region. Figure 4.5 presents results for new investments, and figure 4.6 presents results for reha-

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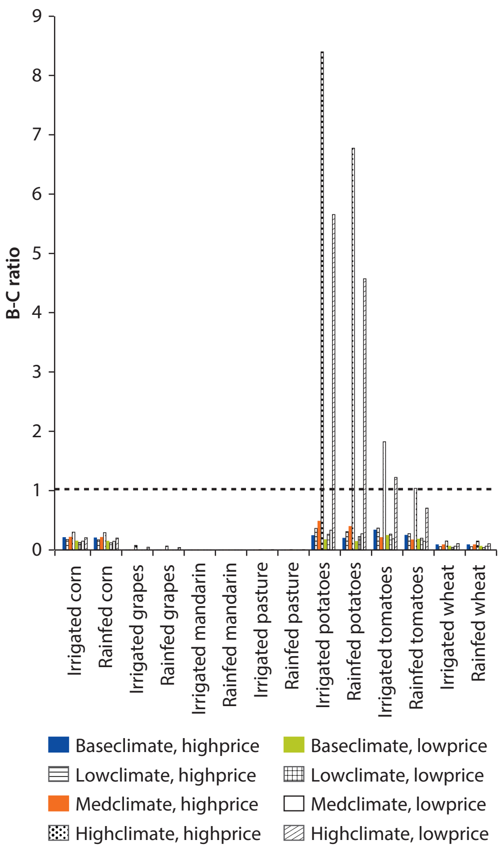
Figure 4.4 Illustrative Benefit-Cost Analysis Results for Optimizing the Application of Irrigation Water in the Eastern Lowlands Agricultural Region

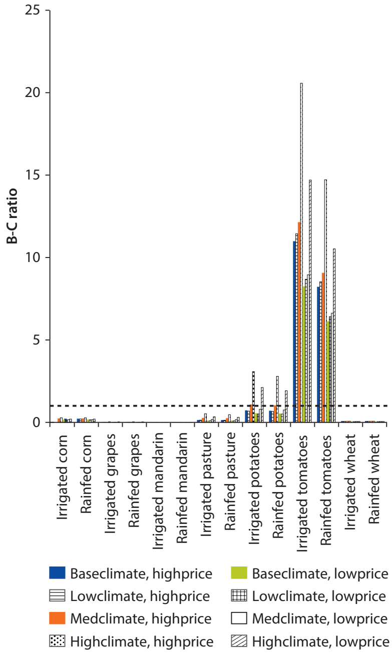


Source: World Bank data.

bilitation of existing drainage infrastructure. This option involves on-farm improvement of drainage and entails both capital and maintenance costs, estimated on a per hectare basis. Costs are higher for new drainage infrastructure than for rehabilitated infrastructure, but the estimated yield increase is the same, so B-C ratios are higher where it is possible to rehabilitate existing infrastructure. The yield effect in the calculations likely underestimates the benefits because the modeling reflects only the continuous yield improvements and does not reflect additional benefits derived from improved drainage during extreme flood events. The results indicate that improved drainage can be most beneficial to improve yields of tomatoes, while B-C ratios are generally less than 1 for other crops. Generally, the high cost of new drainage infrastructure may limit the feasibility of such an option.

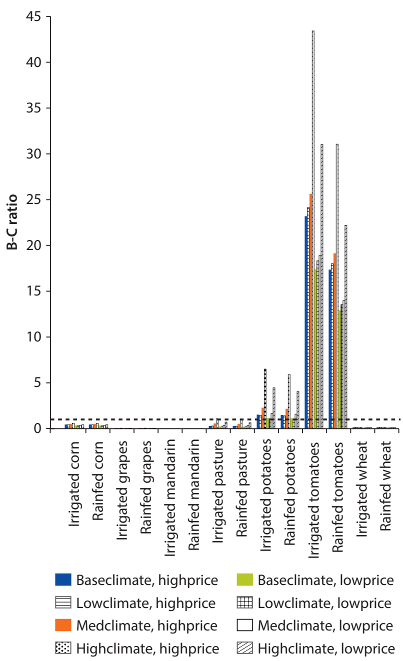
Option 1.3: Shifting to New Crop Varieties A potentially promising adaptation option is to provide access to new crop varieties to farmers who might otherwise not be aware of the benefits of these varieties. The results for changing crop

Figure 4.5 Illustrative Benefit-Cost Analysis for Improved Drainage in the Western Lowlands Agricultural Region: New Drainage Infrastructure



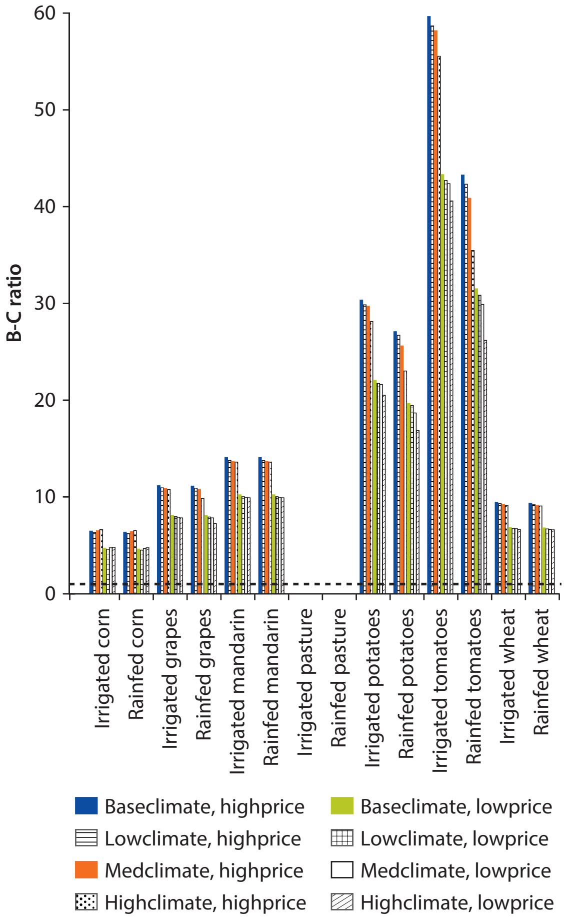
Source: World Bank data.

Figure 4.6 Illustrative Benefit-Cost Analysis for Improved Drainage in the Western Lowlands Agricultural Region: Rehabilitated Drainage Infrastructure



Source: World Bank data.

Figure 4.7 Illustrative Benefit-Cost Analysis for Optimizing Crop Varieties in the Eastern Lowlands Agricultural Region



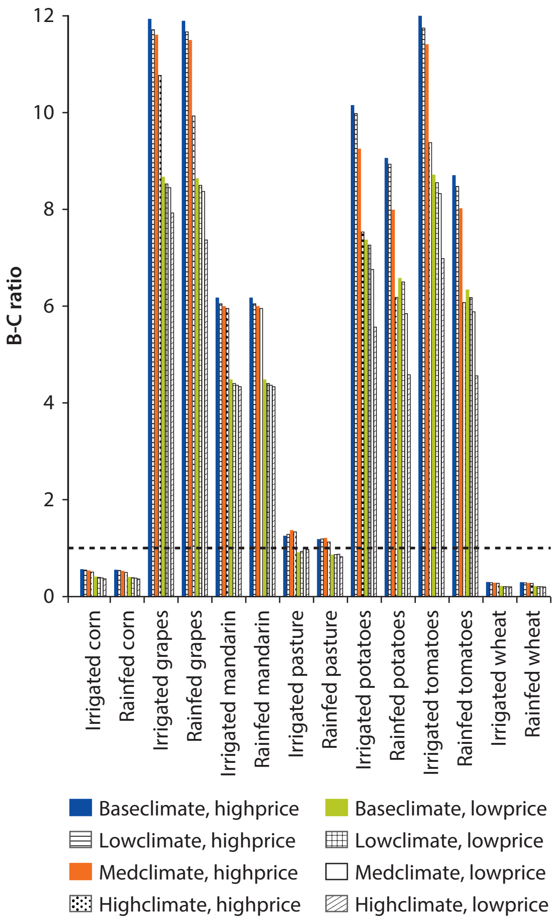
Source: World Bank data.

varieties for the Eastern Lowlands agricultural region are presented in figure 4.7. For this option, it is estimated that the primary cost would be investments in applied research (that is, ensuring that internationally available varieties will thrive in Georgian fields), supported by extension to transfer the knowledge to farmers. This may be funded through the national budget or alternatively and if practicable, by farmer cooperatives or agribusiness concerns. For changes in crop variety, only the results for the Eastern Lowlands agricultural region are presented as analyses showed similar results for the other agricultural regions. For this option yields are estimated to benefit from the change from current to new crop varieties (with new properties to include responsiveness to irrigation and fertilizer applications, heat resistance, disease tolerance or resistance, higher yields, and better-quality produce). These new varieties are those within the options available from the AquaCrop model database. It would be expected that improvements in extension services would assist farmers in these modifications to the crop varieties that would also be reflected into changing of cropping patterns.

As indicated in figure 4.7, B-C ratios are highest for new varieties of irrigated tomatoes, with high ratios of up to 60 to 1. B-C ratios for potatoes, rainfed tomatoes, mandarin, grapes, wheat, and corn are lower but still significantly greater than 1. In most cases, the benefits of shifting to new varieties reflects the adaptation deficit, in that better varieties could result in substantial yield gains regardless of the change in climate.[1]

Option 1.4: Optimizing Fertilizer Application The results for optimized application (relative to current use of fertilizer) for the Eastern Lowlands agricultural region are presented in figure 4.8. The graph shows high B-C ratios for irrigated and rainfed grapes, mandarin, potatoes, and tomatoes, and much lower ratios for

Figure 4.8 Illustrative Results of Benefit-Cost Analysis for Optimized Fertilizer Use in the Eastern Lowlands Agricultural Region



Source: World Bank data.

corn, pasture, and wheat. The costs for fertilizer in the analysis include only the purchasing cost and do not reflect indirect costs. The 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 greater than 1 for potatoes, grapes, and irrigated tomatoes, when other non-quantified social costs are considered it is possible that the B-C ratio could drop to less than 1.

Economic Analyses for the Second Group of Options

In addition to the detailed economic analyses described above, analyses were conducted with limited data for the potential benefits and costs for the following options: (i) improving hydrometeorological network; (ii) enhancing extension services; (iii) optimizing basin-level water efficiency; (iv) increasing water storage capacity; and (v) installing hail net for selected crops. It should be noted that these analyses are informative for the ranking of options but provide less certainty than the more detailed analyses in the above section.

Option 2.1: *Improving the Hydrometeorological Network* It was not possible to monetize most of the benefits of this alternative, some of which include flood forecasting, improved forecasting of crop life stages, and less frequent and/or more precise fertilizer and chemicals application. Direct comparison of costs and benefits of these nonmonetized benefits is not possible, therefore this option was only 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. Based on a set of assumptions outlined in prior work (World Bank 2013b), it was estimated that the annualized capital and annual O&M improvements in hydrometeorological capacity could cost US$0.72 per irrigated hectare per year. The cost would be considerably lower if rainfed hectares were included. Across all crops, agricultural regions, and scenarios, yields would need to increase an average of 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.

Option 2.2: *Enhancing Extension Services* The costs of improving extension services are a component of the B-C analyses of the optimized fertilizer application and improved irrigation water application options presented above. In addition, a break-even analysis for expanding extension services was also conducted for this option as a stand-alone measure.

To estimate costs for an enhanced extension service, the Study used information from broader regional analyses. An assumption was made based on prior regional work that about 20 percent of the total number of farmland hectares in Georgia could benefit from improved extension that a reasonable program of extension would cost about US$850,000 (2011) per year, and that the resulting program would have an annual cost per hectare of US$13.93 (Sutton, Srivastava, and

Neumann 2013). The average break-even yield increase required to justify this cost, across all crops, agricultural regions, and scenarios is therefore about 1.3 percent.

The yield increase required to justify the program is achievable in Georgia, based on comparison 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 (Alston et al. 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 (Cerdán-Infantes, Maffioli, and Ubfal 2008). Another study (van den Berg and Jiggins 2007) found that farmer field schools reduced pesticide use on cotton by 34 to 66 percent. In a project to reform the Indian agriculture extension system, IFPRI found that Farmer Field School increased graduates' cotton yields by four to 14 percent (Glendenning 2010).

Option 2.3: Optimizing Basin-Level Water Efficiency The benefit of improving water efficiency was evaluated in the basin where the Study indicates that future irrigation water shortages are likely: the Alazani basin. Improving irrigation efficiency was examined from the baseline of 40 percent (based on FAO data) in 5 percent increments, up to a high of 65 percent. The benefit is increased profit from additional irrigation water to bring back to cultivation additional acreage—for example, under the High Impact scenario in the Alazani basin, a 5 percent increase in efficiency makes available an additional 128 million cubic meters of water to meet irrigation demand, reducing the unmet demand from 56 percent to 42 percent, and allows up to an additional 4,800 hectares to be irrigated each year by the 2040s. The results are presented in figure 4.9, and reveal that the costs of substantial improvements in basin-wide water efficiency are generally not justified by the yield-enhancing benefits of additional irrigation potential, as B-C ratios for increased efficiency under *nearly* all scenarios are less than 1.

Option 2.4: Increasing Water Storage Capacity The costs and benefits of developing new storage capacity to provide additional water during periods of unmet water demand were analyzed. The benefits of increased water storage capacity are in reducing unmet irrigation water demand, thus providing additional net revenues from cultivating crops. The value of additional crop cultivation is net revenue from the mix of crops identical to those currently cultivated in the basin. The limitations of the approach are substantial.[2] Where detailed studies of basin dynamics could not be conducted and the implications of storage for transboundary flows and compliance with international water treaties were not analyzed. Estimated costs of constructing storage are estimates drawn from Ward et al. (2010), and range between US$0.14 and US$0.34 per cubic meter, depending on the volume of storage and the average slope of the basin.

The range of results is presented in figure 4.10 for the Alazani basin 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, with storage

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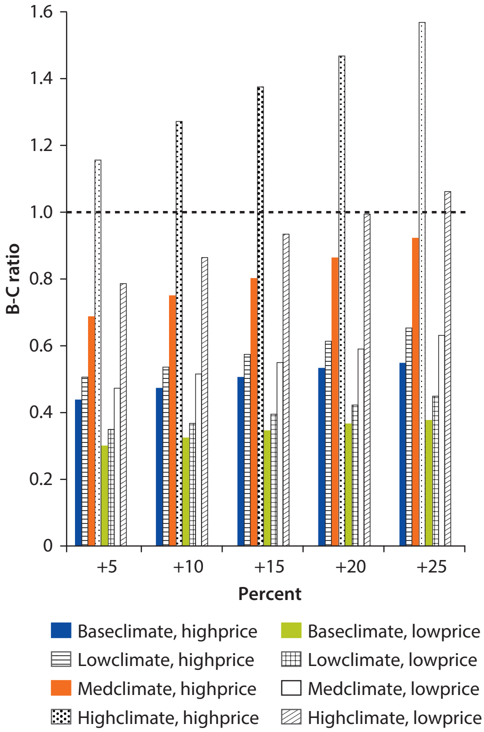
Figure 4.9 Impact of Optimizing Basin-Wide Irrigation Efficiency in the Alazani Basin



Source: World Bank data.

showing favorable B-C ratios in the Alazani basin for 5, 25 and 100 million cubic meter levels under all scenarios. 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 Alazani basin, these relationships imply that about 150 additional hectares can be irrigated for each 1 million cubic meters of storage capacity added, but this value decreases rapidly after the 100 million cubic meter level.

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. It should also be noted that in practice, as water shortages manifest, stored water might justifiably be diverted to higher value crops. Even with those caveats, these results generally support the conclusion of local farmers that increased storage capacity could be an effective adaptation strategy.

Option 2.5: Installing Hail Nets for Selected Crops Hail nets were mentioned by farmers 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 conducted for Northeastern Spain provides estimates for the costs

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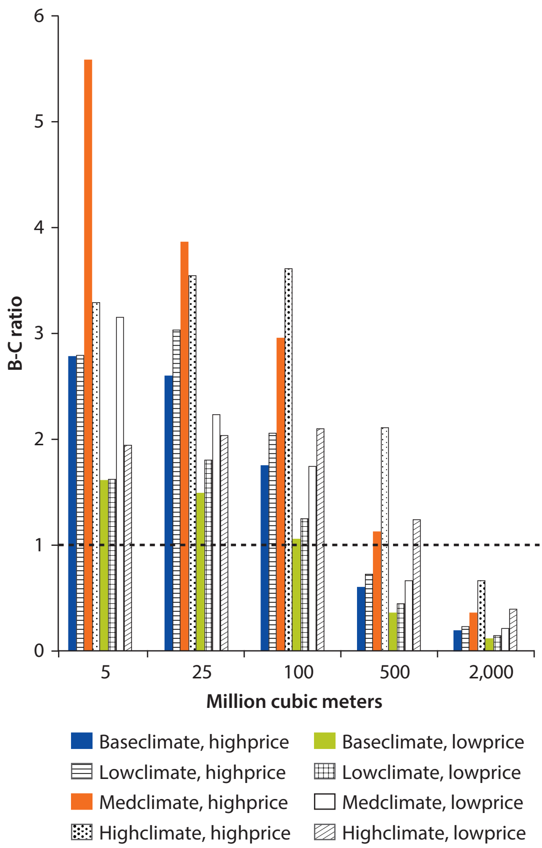
Figure 4.10 Preliminary Analysis of the Benefits and Costs of Water Storage in the Alazani Basin

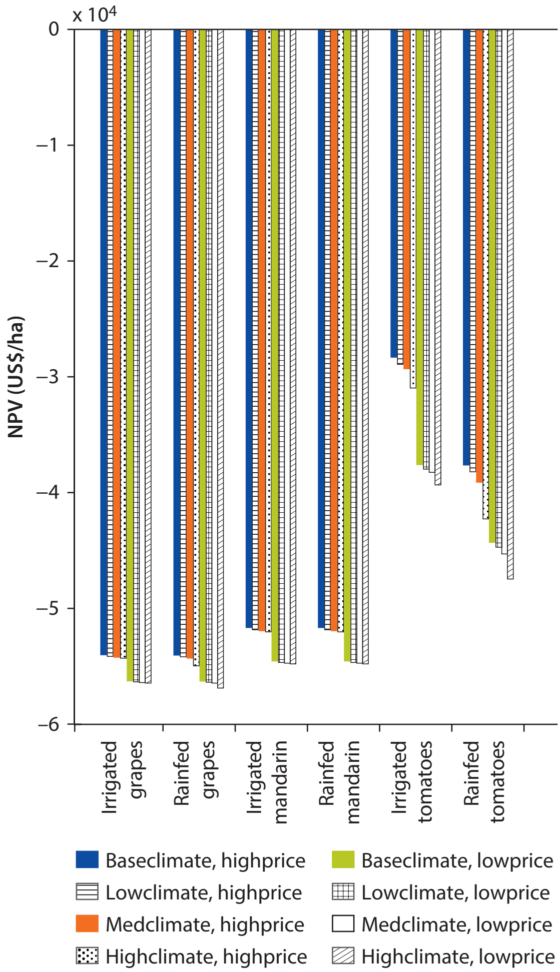


Source: World Bank data.

of hail nets for apple crops as compared to crop insurance (Iglesias and Alegre 2006). The Study has found slight benefits of hail nets relative to crop insurance, but implicitly assumes that crop insurance is already a wise investment, and does not evaluate the baseline risk of hail damage each year relative to insurance premiums.

Hail nets have both capital investment costs and yield and income implications where they reduce sunlight infiltration which reduces yield, but 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 selected crops in the Eastern Lowlands agricultural region. The result is illustrated in figure 4.11 below, in net present value terms. For all scenarios, net present values are negative, reflecting that costs exceed benefits. The B-C ratios for this measure never exceed 0.6 for any combination in any agricultural region. Contrary to the expectations of the Georgian farmers this analysis reflecting local

Figure 4.11 Illustrative Results of Net Present Value Analysis for Hail Nets to Protect Selected Crops in the Eastern Lowlands Agricultural Region



Source: World Bank data.
Note: NPV = net present value.

conditions indicates that hail nets would not yield any benefits that could cover the investment costs.

Net Benefit Estimates for Agricultural Regions

The previous section highlights selected results for B-C ratios with a focus on the Intermediate agricultural region. Benefit-cost ratios are useful, but another useful measure is net present value benefits, which indicates the per hectare benefits minus the per hectare costs over the full period of this analysis, starting in 2015 and ending in 2050. Ranges of results reflect variation across climate and commodity price scenarios.

The net benefit estimates for the four agricultural regions are summarized in tables 4.1 through 4.3. The tables list what are considered to be the four to six adaptation measures with the highest overall net benefits. The results indicate that the four measures that have the highest rankings in the Eastern Mountainous agricultural region apply to the entire country, while optimizing the application of irrigation water is the only cost-effective measure in the Eastern Lowlands agricultural region, and rehabilitated and new drainage systems are only viable options in the Western Lowlands and Western Mountainous agricultural regions. In general, net benefits are higher in low-elevation agricultural regions. Only those crops with a positive net benefit are listed. Those that are not included in the list have a negative or very near zero net benefit for the measure.

The ranking of benefits also considers that some B-C 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. But these costs exclude the unquantifiable but 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 option listed.

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 Georgian agriculture.

Table 4.1 Adaptation Measures with Highest Net Benefits: Eastern Lowlands Agricultural Region

Description of recommended adaptation measure	*Crop focus*	*Illustrative present value economic results per hectare (2015–50 000 US$2009)*			
		Estimated revenue gain	*Estimated costs*	*Net revenues*	*Notes*
Improve varieties	Irrigated corn	$1.7 to 2.4	$0.40	$1.3 to 2	Costs are for provision of seed and extension to support uptake
	Rainfed corn	$1.6 to 2.4		$1.3 to 2	
	Irrigated grapes	$2.8 to 4		$2.5 to 3.6	
	Rainfed grapes	$2.6 to 3.9		$2.3 to 3.6	
	Irrigated mandarin	$3.6 to 5		$3.2 to 4.6	
	Rainfed mandarin	$3.6 to 5		$3.2 to 4.6	
	Irrigated potatoes	$7.4 to 11		$7.1 to 10	
	Rainfed potatoes	$6.1 to 9.7		$5.7 to 9.3	
	Irrigated tomatoes	$15 to 21		$14 to 21	
	Rainfed tomatoes	$9.5 to 15		$9.1 to 15	
	Irrigated wheat	$2.4 to 3.4		$2 to 3	
	Rainfed wheat	$2.4 to 3.3		$2 to 3	
Rehabilitate old irrigation systems	Rainfed potatoes	$5.9 to 13	$2.70	$3.2 to 11	
	Rainfed tomatoes	$24 to 41		$22 to 38	

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Table 4.1 Adaptation Measures with Highest Net Benefits: Lowland Agricultural Region *(continued)*

Description of recommended adaptation measure	*Crop focus*	*Illustrative present value economic results per hectare (2015–50 000 US$2009)*			*Notes*
		Estimated revenue gain	*Estimated costs*	*Net revenues*	
Create new irrigation systems	Rainfed potatoes	$5.9 to 13	$8.80	$-2.9 to 4.4	
	Rainfed tomatoes	$24 to 41		$16 to 32	
Optimize application of irrigation water	Irrigated potatoes	$0.06 to 1.8	$0.20	$-0.2 to 1.6	Costs are for extension & hydromet
	Rainfed potatoes	$0.05 to 1.5		$-0.2 to 1.3	
	Irrigated tomatoes	$0.04 to 0.4		$-0.2 to 0.2	
	Rainfed tomatoes	$0.03 to 0.2		$-0.2 to 0.008	
Optimize fertilizer application	Irrigated grapes	$5.6 to 8.3	$0.70	$4.9 to 7.6	Costs do not include environ. damages
	Rainfed grapes	$5.2 to 8.3	$0.70	$4.5 to 7.6	
	Irrigated mandarin	$7.9 to 11	$1.80	$6.1 to 9.2	
	Rainfed mandarin	$7.9 to 11	$1.80	$6.1 to 9.2	
	Irrigated pasture	$1.3 to 1.9	$1.40	$-0.1 to 0.5	
	Rainfed pasture	$1.1 to 1.6	$1.40	$-0.2 to 0.3	
	Irrigated potatoes	$10 to 18	$1.80	$8.3 to 16	
	Rainfed potatoes	$8.4 to 16	$1.80	$6.5 to 14	
	Irrigated tomatoes	$13 to 21	$1.80	$11 to 20	
	Rainfed tomatoes	$8.3 to 15	$1.80	$6.5 to 14	

Source: World Bank data.

Table 4.2 Adaptation Measures with Highest Net Benefits: Eastern Lowlands Agricultural Region

Description of recommended adaptation measure	*Crop focus*	*Illustrative present value economic results per hectare (2015–50 000 US$2009)*			*Notes*
		Estimated revenue gain	*Estimated costs*	*Net revenues*	
Improve varieties	Irrigated corn	$1.3 to 2.3	$0.40	$1 to 2	Costs are for provision of seed and extension to support uptake
	Rainfed corn	$1.3 to 2.3		$1 to 2	
	Irrigated grapes	$2.8 to 4		$2.5 to 3.6	
	Rainfed grapes	$2.8 to 4		$2.5 to 3.6	
	Irrigated potatoes	$7.7 to 11		$7.3 to 10	
	Rainfed potatoes	$6.7 to 10		$6.4 to 9.9	
	Irrigated tomatoes	$14 to 25		$13 to 25	
	Rainfed tomatoes	$12 to 21		$12 to 20	
	Irrigated wheat	$0.8 to 2.6		$0.4 to 2.3	
	Rainfed wheat	$0.8 to 2.6		$0.4 to 2.3	
Rehabilitate old irrigation systems	Rainfed potatoes	$2.3 to 9.8	$2.70	$-0.4 to 7.1	
	Rainfed tomatoes	$9.2 to 31		$6.5 to 29	
Create new irrigation systems	Rainfed potatoes	$2.3 to 9.8	$8.80	$-6.5 to 1	
	Rainfed tomatoes	$9.2 to 31		$0.4 to 22	

table continues next page

Table 4.2 Adaptation Measures with Highest Net Benefits: Eastern Lowlands Agricultural Region *(continued)*

Description of recommended adaptation measure	*Crop focus*	*Illustrative present value economic results per hectare (2015–50 000 US$2009)*			
		Estimated revenue gain	*Estimated costs*	*Net revenues*	*Notes*
Optimize fertilizer application	Irrigated grapes	$6 to 8.3	$0.70	$5.2 to 7.6	Costs do not include environ. damages
	Rainfed grapes	$5.9 to 8.3	$0.70	$5.2 to 7.6	
	Irrigated pasture	$1.1 to 2	$1.40	$-0.3 to 0.6	
	Rainfed pasture	$1.1 to 1.8	$1.40	$-0.3 to 0.4	
	Irrigated potatoes	$13 to 18	$1.80	$11 to 16	
	Rainfed potatoes	$11 to 17	$1.80	$9.1 to 16	
	Irrigated tomatoes	$14 to 26	$1.80	$12 to 24	
	Rainfed tomatoes	$13 to 21	$1.80	$11 to 19	

Source: World Bank data.

Table 4.3 Adaptation Measures with Highest Net Benefits: Eastern Lowlands Agricultural Region

Description of recommended adaptation measure	*Crop focus*	*Illustrative present value economic results per hectare (2015–50 000 US$2009)*			
		Estimated revenue gain	*Estimated costs*	*Net revenues*	*Notes*
Improve varieties	Irrigated corn	$1.5 to 2.2	$0.40	$1.1 to 1.8	Costs are for provision of seed and extension to support uptake
	Rainfed corn	$1.5 to 2.2		$1.1 to 1.8	
	Irrigated grapes	$2.8 to 4		$2.5 to 3.6	
	Rainfed grapes	$2.8 to 4		$2.5 to 3.6	
	Irrigated mandarin	$3.6 to 5		$3.2 to 4.6	
	Rainfed mandarin	$3.6 to 5		$3.2 to 4.6	
	Irrigated potatoes	$7.3 to 11		$6.9 to 11	
	Rainfed potatoes	$6.9 to 11		$6.6 to 11	
	Irrigated tomatoes	$27 to 50		$26 to 50	
	Rainfed tomatoes	$21 to 36		$21 to 35	
	Irrigated wheat	$2.4 to 3.3		$2 to 3	
	Rainfed wheat	$2.4 to 3.3		$2 to 3	
Rehabilitate old irrigation systems	Rainfed tomatoes	$8.8 to 25	$2.70	$6.2 to 22	
Create new irrigation systems	Rainfed tomatoes	$8.8 to 25	$8.80	$0.02 to 16	
Rehabilitate existing drainage infrastructure	Irrigated pasture	$0.08 to 0.4	$0.40	$-0.3 to 0.03	Benefits do not reflect increased risk of floods with climate change
	Irrigated potatoes	$0.4 to 2.5		$0.03 to 2.1	
	Rainfed potatoes	$0.4 to 2.2		$0.02 to 1.9	
	Irrigated tomatoes	$6.9 to 16		$6.6 to 16	
	Rainfed tomatoes	$5.1 to 12		$4.8 to 11	

table continues next page

Table 4.3 Adaptation Measures with Highest Net Benefits: Eastern Lowlands Agricultural Region *(continued)*

		Illustrative present value economic results per hectare (2015–50 000 US$2009)			
Description of recommended adaptation measure	*Crop focus*	*Estimated revenue gain*	*Estimated costs*	*Net revenues*	*Notes*
Create new drainage infrastructure	Irrigated potatoes	$0.4 to 2.5	$0.80	$-0.4 to 1.7	Benefits do not reflect increased risk of floods with climate change
	Rainfed potatoes	$0.4 to 2.2		$-0.4 to 1.4	
	Irrigated tomatoes	$6.9 to 16		$6.1 to 16	
	Rainfed tomatoes	$5.1 to 12		$4.3 to 11	
Optimize fertilizer application	Irrigated grapes	$5.8 to 8.3	$0.70	$5.1 to 7.6	Costs do not include environ. damages
	Rainfed grapes	$5.8 to 8.3	$0.70	$5.1 to 7.6	
	Irrigated mandarin	$7.9 to 11	$1.80	$6.1 to 9.2	
	Rainfed mandarin	$7.9 to 11	$1.80	$6.1 to 9.2	
	Irrigated pasture	$1.1 to 1.8	$1.40	$-0.3 to 0.4	
	Rainfed pasture	$1.1 to 1.7	$1.40	$-0.3 to 0.4	
	Irrigated potatoes	$11 to 18	$1.80	$9.2 to 16	
	Rainfed potatoes	$11 to 18	$1.80	$8.9 to 16	
	Irrigated tomatoes	$8.9 to 17	$1.80	$7 to 15	
	Rainfed tomatoes	$7.5 to 16	$1.80	$5.7 to 14	

Source: World Bank data.

Qualitative Assessments (Expert Assessment)

This section describes the qualitative approach to identifying and evaluating adaptation options, with a focus on those adaptation options that are not amenable to the quantitative assessment. The qualitative analyses are based on the judgment of the Expert Consultant Team. The list in table 4.4 below provides the overall scope for the adaptation measures reviews by the experts. The list includes four categories of adaptation options, starting with the set requiring most investment:

- Infrastructure-related: these are "hard" adaptation options covering improvements of agriculture sector infrastructure, including developing water resources, infrastructure improvements or expansions for water available for irrigation
- Programmatic: strengthening existing agriculture and related programs or creating new ones
- On-Farm: farm-level measures comprising the largest portion of the list
- Indirect: these are not directly aimed at the agriculture sector, but which would benefit agriculture.

Options that have been evaluated quantitatively in this chapter are highlighted in bold in the table. Additionally, ratings of adaptations from the expert assessment are in the last column.

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Table 4.4 List of Adaptation Options for Consideration

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Experts' assessment level of importance 1=most recommended, 2=highly recommended, 3=recommended, 4=recommended only through specific local needs*
A. Infrastructure-related			
Farm protection	**Hail protection systems (nets)**	**A.1**	**Defer to economic analysis**
	Install plant protection belts	A.2	4
	Lime paint on greenhouses to reduce heat	A.3	3
	Vegetative barriers, snow fences, windbreaks	A.4	4
	Move crops to greenhouses	**A.5**	**Defer to economic analysis**
	Smoke curtains to address late spring and early fall frosts	A.6	3
	Build or rehabilitate forest belts	A.7	4
Livestock protection	Increase and improve shelter and water points for animals, provide storage for harvested forage and feed	A.8	1
	Plant windbreaks to provide shelter for animals from extreme weather	A.9	2
Water management	Enhance flood plain management (for example, wetland management)	A.10	3
	Construct levees	A.11	4
	Drainage systems	**A.12**	**2 (More important in high-rainfall areas)**
	Irrigation systems: new, rehabilitated, or modernized, including drip irrigation	**A.13**	**Defer to economic analysis**
	Water harvesting and efficiency improvements	**A.14**	**3**
B. Programmatic			
Extension and market development	Demonstration plots and/or knowledge sharing opportunities	B.1	1
	Education and training of farmers via extension services (new technology and knowledge-based farming practices)	**B.2**	**2**
	National research and technology transfer through extension programs	**B.3**	**2**
	Private enterprises, as well as public or cooperative organizations for farm inputs (for example, seeds, machinery)	B.4	2
	Strong linkages with local, national, and international markets for agricultural goods	B.5	3

table continues next page

http://dx.doi.org/10.1596/978-1-4648-0148-8

Table 4.4 List of Adaptation Options for Consideration *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Experts' assessment level of importance 1=most recommended, 2=highly recommended, 3=recommended, 4=recommended only through specific local needs*
Livestock management	Fodder banks	B.6	4 for traditional fodder banks 2 for increasing forage conservation plantings
Information systems	Better information on pest controls	B.7	4
	Estimates of future crop prices	B.8	4
	Improve monitoring, communication and distribution of information (for example, early warning system for weather events)	B.9	2
	Information about available water resources	B.10	4
Insurance and subsidies	Crop insurance	B.11	More detailed assessment is required
	Subsidies and/or supplying modern equipment	B.12	4
R&D	**Locally relevant agricultural research in techniques and crop varieties**	**B.13**	**1**
C. On-farm			
Crop yield management	Change fallow and mulching practices to retain moisture and organic matter, including the use of polyethylene sheets	C.1	2
	Change in cultivation techniques	C.2	4
	Conservation tillage	C.3	2
	Crop diversification	C.4	4
	Crop rotation	C.5	2
	Heat- and drought-resistant crops/varieties/hybrids	C.6	4
	Increased input of agro-chemicals and/or organic matter to maintain yield	**C.7**	**2**
	Manual weeding	C.8	4
	More turning over of the soil	C.9	4
	Strip cropping and contour tillage	C.10	1 for low-tech contour tillage, 3 for terracing
	Switch to crops and crop varieties appropriate to temp, precipitation	**C.11**	**2**
	Optimize timing of operations (planting, inputs, irrigation, harvest)	**C.12**	**2 (But need knowledge to optimize timing)**
Land management	Allocate fields prone to flooding from sea-level rise as set-asides	C.13	3 (needs more study for Georgia)
	Mixed farming systems (crops, livestock, and trees)	C.14	1

table continues next page

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Table 4.4 List of Adaptation Options for Consideration *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Experts' assessment level of importance 1=most recommended, 2=highly recommended, 3=recommended, 4=recommended only through specific local needs*
	Shift crops from areas that are vulnerable to drought	C.15	1 (for crops that are vulnerable to climate events)
	Switch from field to tree crops (agro-forestry)	C.16	2 (Integrate field and tree crops, agro-forestry)
Livestock management	Livestock management (including breed choice, heat tolerant, change shearing patterns, change breeding patterns)	C.17	1
	Match stocking rates to forage production and overall feed availability	C.18	3
	Pasture management (rotational grazing, etc.) and improvement	C.19	2
	Rangeland rehabilitation and management	C.20	1
	Supplemental feed	C.21	1
	Vaccinate livestock	C.22	2 (vaccinate livestock and control parasites)
Pest and fire management	Develop sustainable integrated pesticide strategies	C.23	4
	Fire management for forest and brush fires	C.24	4
	Integrated Pest Management	C.25	3
	Introduce natural predators	C.26	4
Water management	Intercropping to maximize use of moisture	C.27	4
	Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night)	**C.28**	2 for most 1 for deficit irrigation
	Use water-efficient crops and crop varieties	**C.29**	2
D. Indirect adaptations			
Market development	Physical infrastructure and logistical support for storing, transporting, and distributing farm outputs	D.1	2 for transportation system 1 for rural development
Education	Increase general education level of farmers	D.2	2
Water management	Improvements in water allocation laws and regulations	D.3	4
	Institute water charging or tradable permit schemes	D.4	4
	Integrated water resource management	D.5	2

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

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Recommendations of the Expert Consultant Team

Based on the expert assessment, adaptation options are ranked on a scale from "1" to "4" in the last column of table 4.4, above. Options favored by the team include the following:

Improve irrigation infrastructure and educate on irrigation practices at farm level (Options A.13, B.2, C.28, and C.29). There appears to be a strong potential for benefits from additional investment in irrigation infrastructure, including storage capacity where investments would rely on the results of economic analyses. The team suggests that while such may be appropriate in many agricultural regions, it is critical to differentiate between large scale and small scale schemes. Irrigation infrastructure is evaluated quantitatively, and the experts concluded that their recommendation would be conditional on the results of those quantitative analyses. Farmer training and rehabilitating some of the existing infrastructure will also help optimize the use of irrigation water, in addition to the use of new crop varieties.

Increase general knowledge level of farmers (Options B.1, B.2, B.3, and D.2; possibly coupled with B.13). More specifically, this option involves improving the existing extension capacity to improve agronomic practices supported by demonstrations. This option could also be coupled with investment in adaptive research focused on testing of varieties that are adapted for future climate conditions (hotter and drier). It is recommended that field crops' varieties and seeds be replaced at least every decade (five years for wheat and barley seeds) to address changing biological and environmental conditions as well as to compensate for the lost regeneration capacity of seeds. Training farmers on the risks and benefits of planting new varieties (for example, more responsive to irrigation and fertilizer applications, heat resistant, disease tolerant or resistant, higher yielding with better quality) is needed to take best advantage of this "turnover" in planting practices.

Improve capacity of hydrometeorological services (Option B.9). Additional capabilities are needed from the hydrometeorological institution(s) in Georgia to provide additional information most relevant to farmer decision making, especially an early warning system for weather events. The improvements in hydromet infrastructure must be reinforced with an effective meteorological information sharing network at the local and national level to maximize benefit for the producers.

Switch to crops and varieties appropriate to future climate regime (Options C.11, C.6, C.17 and B.2). This option requires a combination of increased awareness at the national level and effective farmer training and extension to advise on varieties best suited to the emerging temperature and precipitation trends. This option has medium- and a long-term components, the medium-term one allowing access to a broader range of existing seed and crop varieties of currently grown crops (option C.11). The long-term component involves access to evolving research on drought- and heat-stress tolerant varieties that may not currently be widely deployed in fields (option C.6). Along with crops, livestock breeds should also be analyzed, where the breeding cycle, assisted by artificial insemination

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programs, could be tailored to the timing of the forage and feed availability for livestock.

Strip-cropping and contour tillage (Option C.10). The option is designed to improve water management and reduce soil erosion. Simpler rather than more complex approaches are suggested, for example contour tillage rather than elaborate and expensive terracing.

Livestock shelter and improved animal husbandry practices (Options A.8, A.9, B.6, C.20, and C.21). Increasing shade and shelter and the number of watering points in grazing land are considered critical. Salt licks are highly recommended. Specifically, shelter from extreme events can be provided by planting windbreaks. Plantations of forage for harvesting and on-farm investments for winter storage could also be useful. Agricultural land that is not currently under annual crop production or marginal crop land on slopes could be used for perennial forage crops. As longer-term measures, rangeland rehabilitation and participatory communal management are recommended.

Farm protection through plastic tunnels and smoke curtains (A.5 and A.6). More use of plastic tunnels to passively warm crops with sunlight would be useful as a response to the threat of late spring and early fall frosts. This option is evaluated in the economic analysis, and the experts concluded that their recommendation would be conditional on the results of those quantitative analyses. Additionally, smoke curtains can address late spring and early fall frosts.

Crop yield management including conservation tillage, crop rotation, and optimizing timing of operations (C.3, C.5, and C.12). Although conservation tillage is recommended, it should be noted that it increases pesticide use. International techniques can be adopted to improve current rotations at a low cost. Optimizing the timing of production practices is recommended but in Georgia conditions, it is difficult to apply mainly due to the unavailability of farm equipment. Furthermore, agricultural advice is needed to make judgments about timing of various operations.

More systematic land management including mixed farming systems, shifting crops from areas that are vulnerable to climate events (for example, from lowlands to highlands, away from areas vulnerable to drought and flooding from sea-level rise), and agro-forestry practices (integrating field and tree crops on the same land) are recommended (C.14, C.15, C.16, and C.13).

Farmer Consultations and Outcomes

An important component of the Study is to inform and consult stakeholders, farmers, and farmers' associations, on the predicted impacts of climate change on agriculture and water resources. The team first met with farmers for a one day stakeholder workshop in April 2012 in Kachreti. A total of 22 local farmers participated, representing production of the following agricultural products: livestock (cattle, sheep, goats, pigs), field crops (maize, wheat, barley, sunflowers), horticultural crops (grapes, peaches, nectarines, apricots, plums, cherries, kiwi, persimmon), and vegetables (potato, eggplant, peppers, watermelon).

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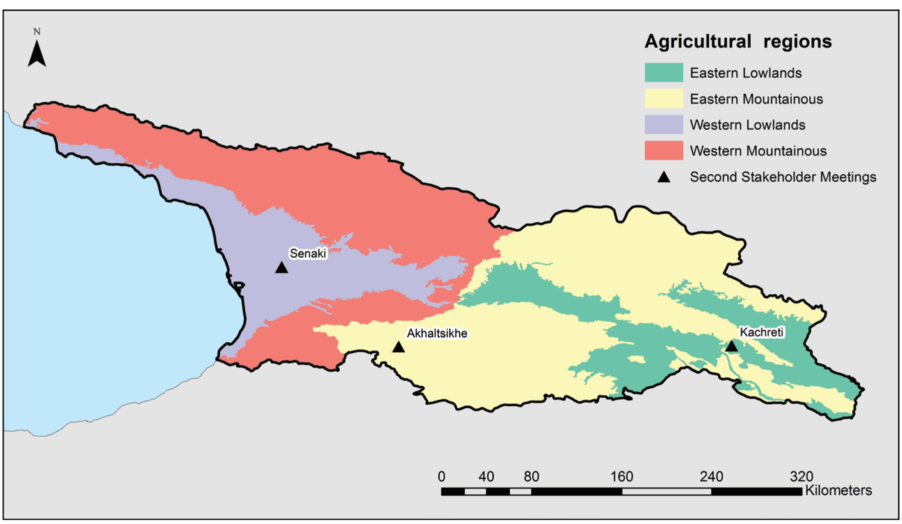
Participants were asked whether any of them have witnessed changes in climate, from a list provided by the organizers, and what they have done, or would do, to mitigate their effects. All confirmed that several of the impacts have been felt on local farms. Although farmers are becoming more flexible in their response to climate events through some training, their adaptive capacity remains poor because of poorly maintained irrigation and drainage systems, limited financial resources, and lack of support from and access to the available extension services.

Drawing upon information obtained from the first meeting, a second set of farmer consultations were conducted in October 2012 at three locations (Kachreti, Akhaltsike, and Senaki), representing different agricultural regions of Georgia (map 4.1). A half-day consultation was held at each location using a collaborative consultation approach designed to elicit both qualitative and quantitative information about current farming practices, observed impacts of climate change and how they are adapting to these changes.

At each consultation, both farmers and local government officials were in attendance. Because meetings were held in rural agricultural communities, all participants came from farming households, regardless of their current employment. The participants were provided with an overview of the Study and the potential impacts of climate change on crop yields and water availability in Georgia. They were then asked if they have witnessed such impacts and what they have done, or would do, to mitigate their effects. A list of potential climate adaptations was then presented by the Expert Team and discussed. The participants were asked to remove any irrelevant adaptations and to add to the list those which they believed would be effective. Participants were divided up into groups

Map 4.1 Locations of the Second Stakeholder Consultations



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of 3–5 people and each group then ranked all of the listed adaptations in relative order of importance.

Adaptation options were ranked separately for national-level responses that required a multiregional approach compared to more local adaptations that can be addressed within a region. Not surprisingly, adaptation rankings varied between regions to reflect differences in their current climates, topography, and other natural properties. The results of this process are reported separately for each of Georgia's four agricultural regions. Consultations were not held in the Western Mountainous agricultural region.

Current Regional Adaptive Capacity

Senaki—Western Lowlands Agricultural Region: The meeting was held on October 5, 2012. Twenty-four people attended people, including farmers, agriculture students, and extension agents. Farm sizes ranged from 1 hectares to 6 hectares, with a median farm size of 2 hectares. The local area produces a variety of crops including citrus, hazelnuts, vegetables, and other orchard crops.

The most important weather-related impact noted in this region is hail, which can be problematic during the spring and fall. Flooding can be problematic, but neither frost nor droughts were cited as concerns. Generally, the participants have observed increased weather variability in this region that has made farming more challenging.

Owing to an excess of rainfall, the most important adaptation options to farmers in this region are improving drainage systems and increasing and improving the application of fertilizer, although improving livestock management and wind breaks are also highly ranked alternatives (table 4.5). Rehabilitation of irrigation systems, optimizing the timing of irrigation water application, and construction of small water reservoirs are also key concerns.

Kachreti—Eastern Lowlands Agricultural Region: The consultation was held on October 3, 2012. The 17 participants included full-time farmers and extension

Table 4.5 Ranked Recommendations from the Senaki Consultation

Adaptation option	*Points*
Improve drainage systems	31
Optimize agronomic practices (fertilizer)	31
Improve livestock nutrition and shelter	27
Create wind breaks	25
Construct small reservoirs	17
Adjust variety of crops based on elevation	15
Rehabilitate irrigation infrastructure	9
Optimize irrigation water application	7
Use irrigation to prevent frost damage	7
Access to farm equipment	7
Improve crop and livestock varieties	5
Make soil testing available	2

Source: World Bank data.

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personnel who farmed part-time. Farm sizes ranged from 1.5 hectares to 76 hectares, with a median size of 10 hectares. Key crops grown in the region include field crops (maize, wheat, barley, sunflowers), horticultural crops (grapes, peaches, nectarines, apricots), and vegetables (potato, eggplant, peppers, watermelon). Livestock are also raised in the region, including cattle, sheep, goat, and pigs.

The largest issue in the region is drought, although hail and high winds are also of concern. Temperatures have been rising generally, although last year an early winter occurred that caused extensive frost damage.

Highly ranked adaptation options (table 4.6) include rehabilitating irrigation systems, increasing and improving the application of fertilizer, optimizing the timing of irrigation water application, and improving wind breaks. Improving livestock nutrition and shelter, improving drainage systems, and several other adaptation options were considered to be important as well.

Akhaltsikhe—Eastern Mountainous Agricultural Region: The Eastern Mountainous agricultural region consultation was held in Akhaltsikhe on October 9, 2012. Twenty participants were present, including farmers, agriculture students, and two professors. The major crop in the region is potatoes, but vegetables and grapes are also grown. Participants reported that the primary focus of agricultural activities in the region is livestock.

Extreme events of concern include drought and hail events. Frost is also problematic, but it always has been. Generally, flooding has not been an issue in the region. Participants have observed that farming has become more challenging due to increased meteorological variability.

Both rehabilitation of irrigation systems and optimizing the timing of irrigation water application received the highest overall scores from the stakeholder groups (table 4.7). Improving livestock nutrition and shelter, and optimizing agronomic practices were also highly recommended.

Table 4.6 Ranked Recommendations from the Kachreti Consultation

Adaptation option	*Points*
Rehabilitate irrigation infrastructure	27
Optimize agronomic practices (fertilizer)	22
Create wind breaks	18
Optimize irrigation water application	18
Improve livestock nutrition and shelter	12
Irrigation to prevent frost damage	10
Provide drainage	8
Adjust variety of crops based on elevation	7
Construct small reservoirs	6
Improve access to farm equipment	5
Make seeds locally available	1

Source: World Bank data.

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Table 4.7 Ranked Recommendations from the Akhaltsikhe Consultation

Adaptation option	*Points*
Rehabilitation of irrigation	36
Optimize irrigation water application	28
Optimize agronomic practices (fertilizer)	17
Improve livestock nutrition and shelter	17
Improve crop and livestock varieties	15
Create wind breaks	14
Use irrigation to prevent frost damage	14
Adjust variety of crops based on elevation	12
Improve access to farm equipment	10
Anti-hail nets	6
Local seed production	4
Construct small reservoirs	3

Source: World Bank data.

Current National-Level Adaptive Capacity and Responses

There was general agreement across all three regions about the need to improve extension services. This adaptation, along with improving market access and access to long-term, low-interest loans, was by far the highest ranked item of the adaptations recommended by farmers (table 4.8). The need to expand farmer support services to crop insurance, researching new crop/livestock varieties, and improving hydrometeorological capacity form a second tier or needed enhancements. While farmers said that crop insurance was sometimes available on the private market, they could not afford to pay the premiums. They were very interested in securing insurance against losses such as hail and frost. In addition, loans are currently difficult for farmers to obtain and those available are most often short-term and at high interest rates.

Generally, farmers have observed the changing climate and have already begun responding—the response is a mix of closing the long-standing adaptation deficit and responding to changing climatic conditions. Many have begun planting crops earlier, moving their crops to higher elevation areas, changing crop rotations, and changing the timing of irrigation on their fields.

Table 4.8 Stakeholder-Ranked National-Level Climate Adaptations

Adaptation option	*Points*
Improve extension services	56
Improve market access	51
Provide low interest, long-term loans to farmers	46
Create crop insurance program	41
Research new crop/livestock varieties	40
Improve hydrometeorological capacity	36
Rehabilitate road infrastructure	2

Source: World Bank data.

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The adaptive capacity of farmers in Georgia is clearly challenged by climate change. The combination of droughts, frost, hail, and warming is especially disruptive. While the current on-farm adaptation responses have been partially successful, implementation of new programs and policies and infrastructure investments are needed. This includes improved extension services, drainage and irrigation systems, improved agronomic input application, as well as improved access to markets and financing support.

National Conference Results

The National Dissemination and Consensus-Building Conference, held in Tbilisi in October 2012, provided another opportunity to consult with Georgia's experts to identify the highest priority adaptation and mitigation options at both the national and agricultural region level. The overall program included a detailed presentation of the technical and farmer consultation findings (as outlined in this report), and a half-day consensus-building exercise among participants, with region-focused groups providing rankings and information for the multi-criteria assessment calculations.

The small groups were presented with tables that summarized the results of the completed B-C analysis, expert assessment, win-win assessment, and mitigation assessment. The agenda for the process was in three parts: (i) Rank the actions/policies for the focus region from the provide table in order of importance, including crossing off any options that are not relevant, identifying other actions or policies that should be considered, and ranking the resulting overall set of options; (ii) rate the importance of three technical criteria by allocating 100 total points across: (1) B-C analysis (net economic benefit), (2) potential to help with or without climate change, and (3) greenhouse gas mitigation potential, to reflect the relative importance the group places on achieving each objective; and (iii) report back on findings to the full conference in plenary session.

Rankings of the groups, as reported back in the conference, are presented in table 4.9 below. The National Group focused on national-scale policies, while the Regional Group provided additional measures for consideration unique to their regions. Across the regions, there was broad support for improving irrigation water availability, optimize agronomic practices, and improving crop varieties. One group considered measures for both the Eastern and Western Mountainous regions, because of the close similarities between these areas in Georgia.

The results of the weighting of criteria are presented in table 4.10 below, for each focus group. Generally, win-win potential analysis is considered an important objective by all groups, with half the weight being allocated to that objective by the regional groups. Among the other two objectives, B-C analysis generally received greater weight than mitigation potential.

Assessment of Greenhouse Gas Mitigation Potential of Adaptation Options

Many of the adaptive measures recommended above also yield co-benefits in the form of climate change mitigation. This section discusses the team's assessment of each option's potential for greenhouse gas mitigation and highlights the

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Table 4.9 Ranking of Adaptation Measures by Small Groups

		Ranking of measure by group			
Adaptation measure	*Specific focus area*	*National*	*Western Lowlands*	*Eastern & Western Mountainous*	*Western Lowlands*
Target research and development to climate risks	Locally relevant agricultural research	1			
Increase the quality, capacity, and reach of extension services	Demonstration plots, training, education	2			
Improve farmer access to hydro-meteorological capacity	Short-term temperature and precipitation forecasts	3			
Improve market access	Link markets, market development	4			
Create crop insurance program	To promote investments in agricultural crops susceptible to drought and hail	5			
Improve intersectoral and interagency coordination in planning and implementation		6			
Improve irrigation water availability	Rehabilitate irrigation capacity		3	3	
Optimize agronomic practices	Increase and improve fertilizer application		1	1	2
Improve crop varieties	Drought-tolerant varieties		2	2	
Research and improve livestock nutrition, management, and health	Include research on sheltering techniques		4	1	4
Optimize and/or improve irrigation techniques	Sprinkler, drip irrigation				3
Rehabilitate drainage systems and/or improve drainage canals					1
Undertake reforestation	Including mixed farming			4	

Source: World Bank data.

Table 4.10 Results of Small Group Multi-Criteria Weighting Exercise

Small group agricultural regions	*Percent weight of specific criteria*		
	Benefit-cost analysis (%)	*Win-win potential (%)*	*Mitigation potential (%)*
Eastern Lowlands	35	50	15
Eastern and Western Mountains	25	50	25
Western Lowlands	35	50	15
National Policy	50	35	15

Source: World Bank data.

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 4.11.

Adaptive practices can significantly reduce nitrous oxide and methane emissions. Nitrous oxide emissions are largely driven by fertilizer overuse which increases soil nitrogen content and generates nitrous oxide. By improving

Table 4.11 Greenhouse Gas Mitigation Potential of Adaptation Options

Adaptation measure	*Adaptation option reference number*	*Mitigation impact*	*Mitigation potential (MT CO_2-Equiv per ha per yr)[a]*	*Experts' assessment (1=most recommended 2=highly recommended, 3=recommended, 4=not recommended or no comment)*	*Benefit-cost analysis result*
Irrigation systems: new, rehabilitated, or modernized (including drip irrigation; irrigation using less power)	A.13	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	N/A	Defer to economic analysis	High for some crops and regions
Change fallow and mulching practices to retain moisture and organic matter	C.1	Increases carbon inputs to soil and promotes soil carbon sequestration; reduces energy used in transportation; reduces energy consumption for production of agrochemicals.	N/A	2	N/A
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.	0.8	2	N/A
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.	1.4	2	N/A
Strip cropping, contour bunding (or ploughing) and farming	C.10	Increases carbon inputs to soil and fosters soil carbon sequestration.	N/A	1	N/A

table continues next page

Table 4.11 Greenhouse Gas Mitigation Potential of Adaptation Options *(continued)*

Adaptation measure	*Adaptation option reference number*	*Mitigation impact*	*Mitigation potential (MT CO_2-Equiv per ha per yr)*[a]	*Experts' assessment (1=most recommended 2=highly recommended, 3=recommended, 4=not recommended or no comment)*	*Benefit-cost analysis result*
Optimize timing of operations (planting, inputs, irrigation, harvest)	C.12	More efficient fertilizer use reduces N losses, including NO_2 emissions; More efficient irrigation minimizes CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	0.9	2	High for using fertilizer and using irrigation water more efficiently
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.	N/A	2	N/A
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.	4.3	2	N/A
Livestock management (including animal breed choice, heat tolerant, change shearing patterns, change breeding patterns)	C.17	Reduces CH_4 emissions.	N/A	1	N/A
Match stocking densities to forage production	C.18	Reduces CH_4 emissions by speeding digestive processes.	N/A	3	N/A
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.	2.4	2	N/A
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.	1.9	1	N/A

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Table 4.11 Greenhouse Gas Mitigation Potential of Adaptation Options *(continued)*

Adaptation measure	*Adaptation option reference number*	*Mitigation impact*	*Mitigation potential (MT CO_2-Equiv per ha per yr)*[a]	*Experts' assessment (1=most recommended 2=highly recommended, 3=recommended, 4=not recommended or no comment)*	*Benefit-cost analysis result*
Intercropping to maximize use of moisture	C.27	Increases carbon inputs to soil and fosters soil carbon sequestration.	N/A	4	N/A
Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night)	C.28	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	0.6	2	High for using irrigation water more efficiently
Use water-efficient crop varieties	C.29	Minimize CO_2 emissions from energy used for pumping while maintaining high yields and crop-residue production.	N/A	2	High for improving crop varieties

Sources: Congress of the United States 2007; Weiske 2007; EPA 2005; Smith et al. 2005; Medina and Iglesias 2010; Paustian et al. 2006; and Smith et al. 2008.
a. See appendix A.

fertilizer application techniques, nitrous oxide emissions can be reduced while maintaining crop yields, specifically through more efficient allocation, timing, and placement of fertilizers. 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 productivity thereby reducing overall methane emissions. Alternative uses of animal manure (for example, biogas production) and improved feed quality quickens digestive processes, resulting in reduced methane emissions. Finally, adaptive measures such as conservation agriculture and manual weeding may also reduce the emissions associated with agricultural production and 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 Georgia. As a transition country (Non-Annex 1), Georgia has submitted two National Communications to the United Nations Framework Convention on Climate Change, and some agricultural policies address adaptation and mitigation priorities in the agricultural sector. Some mitigation projects in Georgia are already underway.

The World Bank's Agricultural Research, Extension, and Training Project, now complete, disseminated agricultural knowledge to increase sustainable agricultural production and reduce pollution of natural resources. Specifically, the project mitigated climate change through the adoption of 200 bio-gas digesters that reduced methane emissions and timber use.

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Additionally, an afforestation project with hazelnut plantations in western Georgia is underway through Agrigeorgia, LLC, Georgia, and GET-Carbon USA, working with communities in the Samegrelo Region of Georgia. The project aims to reclaim abandoned lands in the sustainable production of food that can be sold locally and internationally, to increase employment and technology transfer to local communities, and to use carbon finance to increase economic returns and reduce risk. The project is scheduled to last from 2007 through 2057, involve 250 households, and could have a benefit of 300,000 tons of carbon dioxide mitigation.

Recommendations

This section covers: (i) high-priority options at the national level and (ii) recommendations specific to each agricultural region. The discussions include summaries of the ranked lists developed at the National Conference held in Tbilisi in October 2012.

Recommendations at the National Level

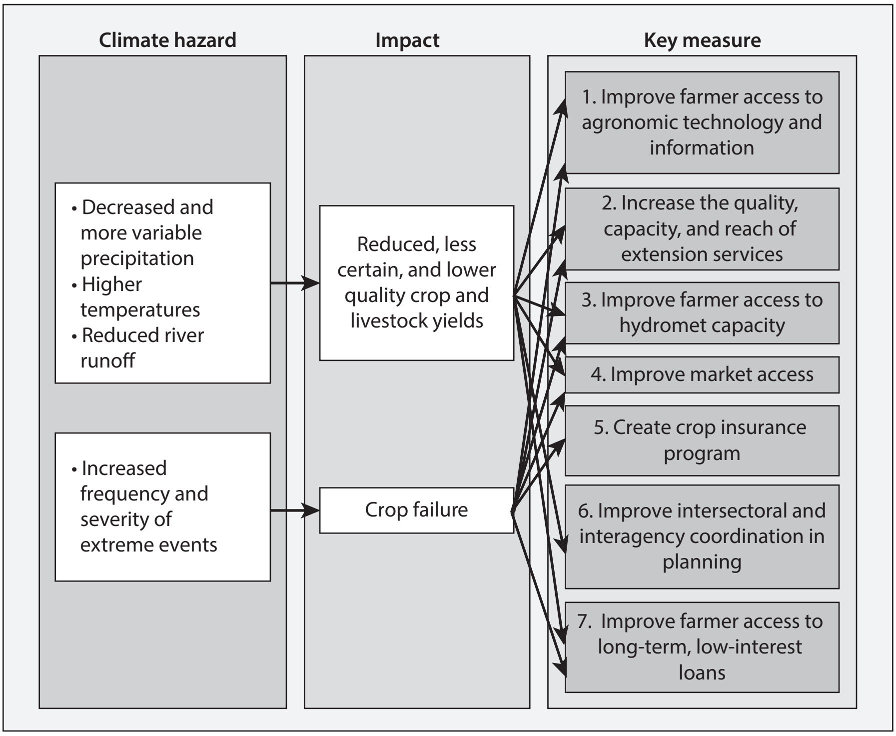
Seven measures for adoption at the national level were identified based on the qualitative analysis of potential net benefits by the international expert team, together with recommendations from farmer stakeholder and expert groups, and reflecting extensive discussions at the Georgian National Conference. The seven measures identified by the Study for adoption at the national level focused on several broad areas including agricultural extension and training, hydrometeorological information, crop insurance, and rural finance. There are many interdependencies among these options, suggesting a coordinated strategy of implementation is needed. For example, an effective extension system is required to help the farmers to build capacity to make educated decisions in tailoring their production techniques to shifting climatic conditions and identify present and future choices to acquire new technologies. 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.

Primarily based on the qualitative analysis of potential net benefits and suggestions from the farmer consultations, the options were ranked and the following recommendations were developed (figure 4.12):

Improve farmer access to agronomic technology and information. Through the availability of low-interest, long-term loans, farmers could acquire technologies to improve crop yields—for example, obtaining new seed varieties or investing in drip irrigation. Currently, farmers do not have access to such loans for agricultural activities and therefore are not able to make investments. Additionally, information could be improved by extension services and demonstration plots that could potentially lead to the use of better technologies. This recommendation clearly interlinks with several other priority measures on this list.

Improve the quality, capacity, and reach of the extension service, both generally and for adapting to climate change. The capacity and effectiveness of the existing

Figure 4.12 National-level Recommended Measures



extension services could be improved through: (i) competent extension agents with up-to date knowledge equipped with necessary means to provide services at the required scale, coverage, and quality, and (ii) use of a wide range of extension methods including farmer meetings, training courses, exposure visits, farmer-to-farmer extension, demonstrations, and use of mass media. This is important to close the adaptation deficit, and in the long-term measure to ensure yield gains are not undermined by future climate change. The economic analysis suggests that expansion of extension services is very likely to yield benefits in excess of estimated costs. However, it should be noted that lack of access to resources and the inefficient operation of complementary agricultural services will seriously constrain the impact of extension.

Ensure farmers access to good-quality hydrometeorological information. The need for better local capabilities for hydrometeorological data, particularly for short-term temperature and precipitation forecasts is substantial in Georgia. In order to support better farm-level decision making such as irrigation scheduling, developing an early warning system for upcoming extreme events for example frost and effective pest and disease forecasting for optimum chemical use, farmers' access to good-quality hydrometeorological information is a must. Improved applications of weather and climate information using an integrated and

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coordinated approach will help to increase and sustain agricultural productivity and profitability by reducing production cost at the farm-level. 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.

It is important to carry out a thorough capacity and needs assessment and gap analysis of the national meteorological system and identify areas for improvement. It should be underlined that good-quality hydrometeorological information and its infrastructure is also key to the crop insurance programs particularly to those that are weather index-based, an automatic calculation that uses the recorded weather data at the nearest authorized weather station. Such programs require enhancement of the national weather station network since the shortage of real-time and historical weather data is often a major hurdle in implementation. On the other hand, an effective extension system is required to help the farmers to build capacity to make educated decisions in tailoring their production techniques to shifting climatic conditions and identify present and future choices to acquire new technologies.

Enable local markets. It was emphasized that more must be done to improve markets for the agricultural sector's potential to be realized. However, it should be underlined that without improvements on the producer side, issues related to marketing can be solved only partially. Efforts should be made to stabilize semi-subsistent farmers' erratic marketing links by providing support to developing their knowledge and skills to produce surplus and in good quality.

Investigate options for crop insurance, particularly for drought. Crop insurance is not viable for the vast majority of agricultural producers. This conclusion was supported in our farmer workshops, but farmers remain eager to explore insurance options. One possible way to expand coverage could be via the piloting of a privately run weather index-based insurance program. This approach has many potential advantages over traditional multiple-peril crop insurance, including simplification of the product, standardized claim payments to farmers in a district based on the index, avoidance of individual farmer field assessment, lower administrative costs, timelier claim payments after loss, and easier accommodation of small farmers within the program. The drawback of an index-based approach may be the inability to readily insure coverage of damage from pests. In addition, insurance systems need to be carefully designed to maintain incentives for farmers to invest in damage mitigation, such as through better water use efficiency. In considering crop insurance options, countries will need to take into account new information about the enabling conditions necessary for these programs to be effective, particularly when smallholder and subsistence farmers are targeted. For example, pilot insurance schemes based on weather indices have encountered low demand in many locations, partly because poor farmers are cash and credit constrained and, therefore, cannot afford premiums to buy insurance that pays out only after the harvest (Binswanger-Mkhize 2012). Poorly designed insurance schemes may also slow autonomous adaptation by insulating farmers from climate-induced risks. In general, countries may first need to consider

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improving market access and credit constraints, in order to better create enabling conditions suitable for crop insurance to be effective.

Improve intersectoral and interagency coordination and planning. At the National Conference, national institutional stakeholders themselves noted that multiple sectors and agencies are not coordinated in their approach to the agricultural sector—ideally government expertise in agronomy, livestock husbandry, irrigation, hydrometeorology, environmental concerns, subsidy policy, marketing, and rural finance and development can be coordinated to enhance the climate resilience of the agricultural sector for both the current situation and future challenges of climate change.

Improve farmers' access to rural finance to enable them to access new technologies. Through the availability of low-interest, long-term loans, farmers could acquire technologies to improve crop and livestock yields—for example, buying seeds of new crop varieties, investing in drip irrigation or water troughs for the livestock. This is a pressing need for tailoring techniques to shifting climatic conditions without harming ecosystems of the country. However, the current rural finance system with its relatively high interest rate combined with stringent collateral requirements and limited outreach prohibits access to credit for many rural households despite the demand. Lending institutions need to fine-tune their loan products to the specificities of rural investments (periodicity of cash-flow, longer maturity needed to match the specific crop and livestock production cycles and non-monthly payment).

Recommendations at the Agricultural Region Level

Recommendations for each agricultural region to improve the resilience of Georgia's agricultural sector to climate change are presented in figures 4.13 to 4.16. These reflect the five ranking criteria applied to rank measures. All measures indicated reflect a favorable economic evaluation. Other additional criteria that affect the analysis are further ranked. Ultimately, the rankings also reflect consideration of the results of the National Conference.

- Net economic benefits (benefits minus costs) ranked in order of their B-C ratio on a five-point scale
- Expert assessment of ranking for those options that cannot be evaluated in economic terms, with each measure receiving a score from one to four
- "Win-win" potential means a measure with a high potential for increasing the welfare of Georgian farmers, with or without climate change, with each measure receiving a score from one to three
- Favorable evaluation by the local farming community (stakeholder consultations), using the scoring system applied in those consultations
- Potential for greenhouse gas emission mitigation, using a score of one to three. This is sometimes referred to as "win-win-win" potential (triple win), as options that meet this criterion include those with high potential for increasing the welfare of the farmers, with or without climate change, while also reducing greenhouse gas emission.

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Figure 4.13 Eastern Lowlands Region Recommended Measures

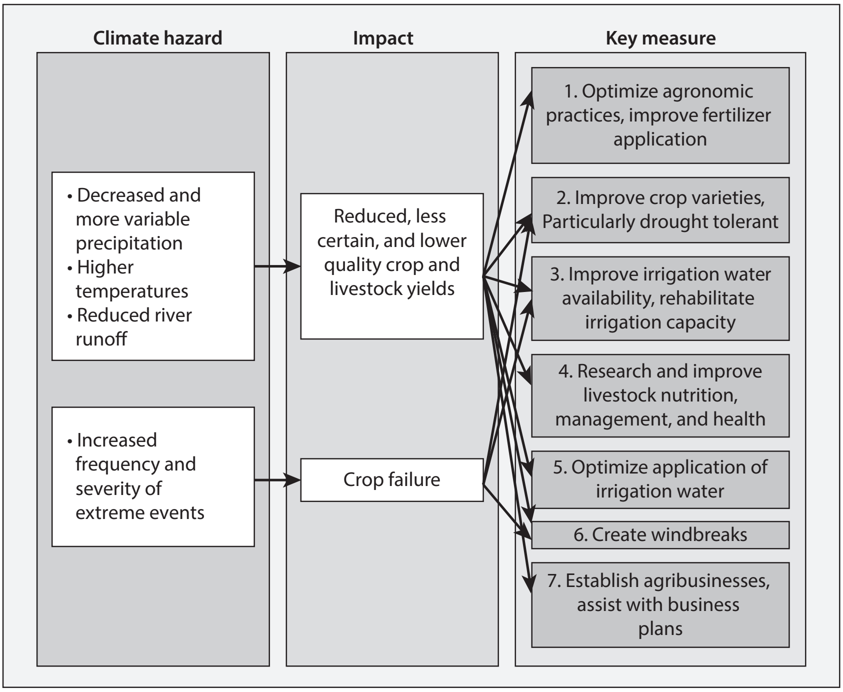

Figure 4.14 Eastern Mountainous Agricultural Region Recommended Measures

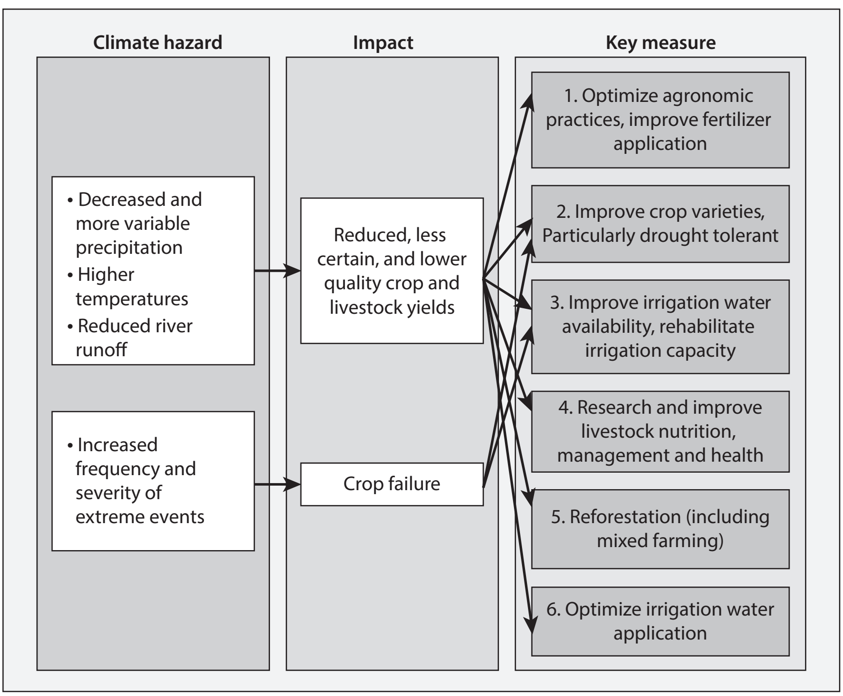

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Figure 4.15 Western Lowlands Agricultural Region Recommended Measures

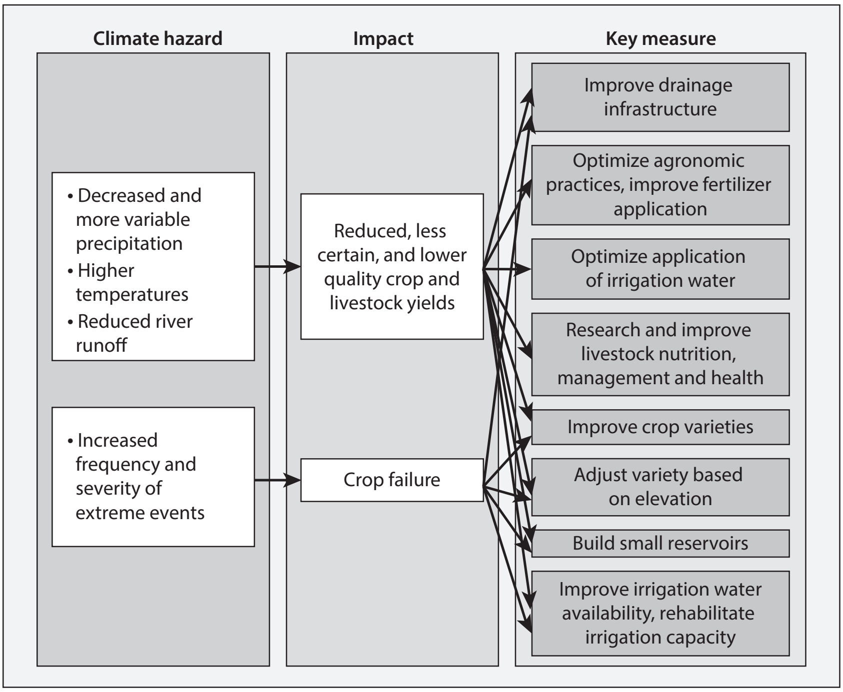
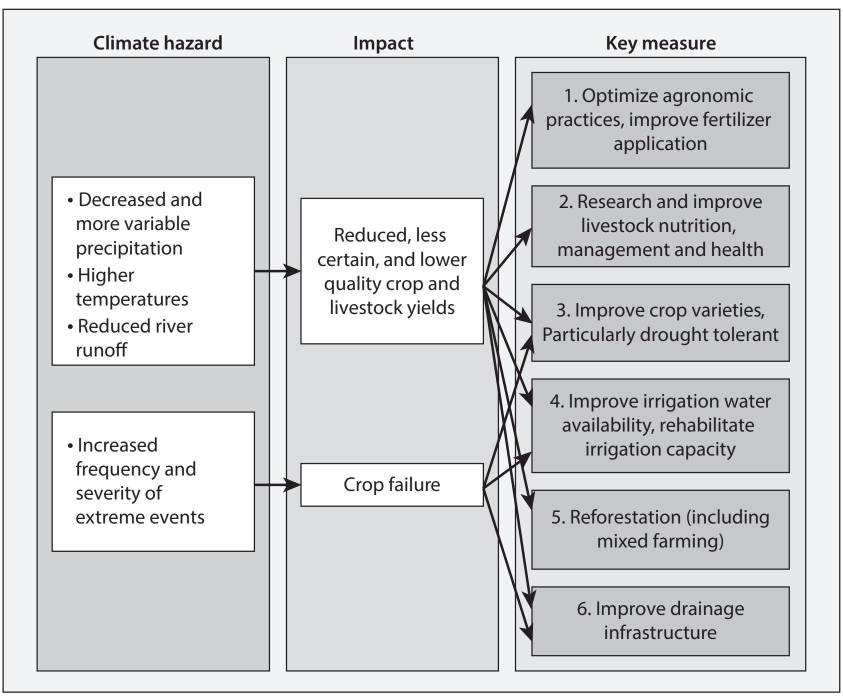


Figure 4.16 Western Mountainous Agricultural Region Recommended Measures



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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 Georgian agricultural region. Decreasing the adaptation deficit of the sector is a long-term process, but there are several measures that could be undertaken immediately to strengthen the sector's adaptive capacity. At the agricultural region and farm-level, high priority adaptation measures include optimizing fertilizer application (all agricultural regions); improving irrigation systems (all agricultural regions), and providing more climate resilient crop varieties and agronomic information for increased productivity (all agricultural regions).

Irrigation water shortages in the Alazani basin appear likely and can be addressed through a range of adaptive measures. At the same time, climate change could exacerbate existing flooding issues in some areas, requiring rehabilitation of drainage capacity, especially in the western portion of Georgia. All of these measures also have high B-C ratios, dependent on the region and scenario, and are favored by Georgian farmers.

Due to its broad scope, the Study necessarily involves significant limitations. These include the need to make simplifying assumptions about many important aspects of agricultural and livestock production in Georgia, and the limitations of simulation modeling techniques for forecasting crop yields and water resources. As a result, certain recommendations may require a more detailed examination and analysis than could be accomplished here in order to ensure that specific adaptation measures are implemented in a manner that maximizes their value to Georgian agriculture.

It is hoped, however, that the awareness of climate risks and the analytic capacities built over the course of this study provide not only a greater understanding among Georgian 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.

The recommendations provided here can serve as a starting point for pursuing a strategic plan for national-level and agricultural region-level adaptation measures in Georgia. In addition, it is desirable that the countries of the South Caucasus address climate change through collaboration on issues such as climate-related data sharing and crisis response. There are many challenges to achieving these objectives, but fortunately there are a wide range of existing models of regional-scale institutional arrangements throughout the world, encompassing the scope of regional cooperation for water resources planning, agricultural research and extension, and enhanced hydrometeorological service development and data provision.

Notes

1. The costs for this adaptation option may be underestimated as there may be additional costs to farmers for more expensive varieties, and possibly other direct costs for nutrient, pesticide, and water inputs to achieve the envisaged yields.
2. Please see chapter 1, the section "Limitations," regarding projections.

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APPENDIX A

Mitigation Potential of Agricultural Adaptation Options

Table A.1 summarizes the findings of the analysis of the mitigation potential of the adaptation options considered in the Study. The table indicates those options for which mitigation potential is considered a co-benefit, and provides the sources used for quantifying this potential, where applicable.

Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
A. Infrastructural adaptations					
Farm protection	**Hail protection systems (nets)**	**A.1**	N/A		
	Install plant protection belts	A.2	N/A		
	Lime dust on greenhouses to reduce heat	A.3	N/A		
	Built vegetative barriers, snow fences, windbreaks	A.4	N/A		
	Move crops to greenhouses	**A.5**	N/A		
	Use smoke curtains to address late spring and early fall frosts	A.6	N/A		
	Build or rehabilitate forest belts	A.7	N/A		
Livestock protection	Increase shelter and water points for livestock	A.8	N/A		
	Plant windbreaks to provide shelter for livestock from extreme weather	A.9	N/A		

table continues next page

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Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
Water management	Enhance flood plain management (for example, wetland management)	A.10	N/A		
	Construct levees	A.11	N/A		
	Built or rehabilitate drainage systems	**A.12**	**N/A**		
	Built or rehabilitate irrigation systems or modernize irrigation methods (including drip irrigation, irrigation using less power, and the better use of local water sources)	**A.13**	**Mitigation potential but not quantified**		
	Improve water harvesting and efficiency	**A.14**	**N/A**		
B. Programmatic adaptations					
Extension and market development	Demonstration plots and/or knowledge sharing opportunities	B.1	N/A		
	Educate and train farmers via extension services (new technology and knowledge-based farming practices)	**B.2**	N/A		
	Support national research system mainly for adaptive research and improve research and extension linkage for technology transfer	**B.3**	N/A		
	Make farm inputs (for example, seeds, machinery) available through private enterprises, as well as public or cooperative organizations	B.4	N/A		
	Establish strong linkages with local, national, and international markets for agricultural commodities	B.5	N/A		

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Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
Livestock management	Plant high-quality fodder species to supplement the available dry season forage (fodder banks)	B.6	N/A		
	Provide better information on pest controls	B.7	N/A		
Information systems	Make future crop price estimates available for farmers	B.8	N/A		
	Improve monitoring, communication and distribution of information (for example, early warning system for weather events)	B.9	N/A		
	Provide information about available water resources	**B.10**	N/A		
Insurance and subsidies	Initiate crop insurance	B.11	N/A		
	Supply and/or provide subsidies for modern equipment	B.12	N/A		
R&D	**Support agricultural research on agronomic practices and crop varieties that seek local solutions**	**B.13**	**N/A**		
C. Farm management adaptations					
Crop yield management	Change fallow and mulching practices to improve moisture retention and enhance organic matter content	C.1	Mitigation potential but not quantified		
	Change in cultivation techniques	C.2	N/A		
	Promote conservation tillage	C.3	reduced tillage—reduced GHG emissions by reducing aeration and incorporation of crop remains to the ground	0.17 (–0.52 to 0.86)	Medina and Iglesias 2010

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Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
			Use of low- or no-till practices increases soil carbon	0.3–0.6 (also reduces CO_2 emissions from machinery, 40% for low till and 70% for no-till)	Paustian et al. 2006
			Reduced conservation tillage	1.5–2.7 0.7–1.7	EPA 2005; Congress of the United States 2007
			Reduced tillage	0.2 (0 to 0.2)	Smith et al. 2005
			Zero and/or conservation tillage	>0 to 3	Weiske 2007
			Croplands—tillage and residue management	0.53 (–.04 to 1.12)	Smith et al. 2008
	Promote crop diversification	C.4	N/A		
	Practice climate smart crop rotation	C.5	Crop rotation—Introduce different crops in the same plot against time to improve the utilization of soil nutrients	0.39 (0.07–0.71)	Medina and Iglesias 2010
			Use of high-residue crops and grasses increases soil carbon	0.3–0.7	Paustian et al. 2006
			Improved rotations, cover crops, elimination of summer fallow	0.5–1.0 0.30–1.2	Congress of the United States 2007
			Crop residues Improved rotations	0.7 (0.1 to 0.7) 0.5 (0.17 to 0.76)	Smith et al. 2005
			Permanent revegetation of set-asides (increased soil carbon, part of afforestation)	3-Jan	Weiske 2007

table continues next page

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Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
			Croplands—set-aside and LUC	5.36 (1.17 to 9.51)	Smith et al. 2008
	Shift to heat- and drought-resistant crops/varieties/hybrids	C.6	N/A		
	Optimize fertilizer application to maintain yield levels	**C.7**	N/A		
	Manual weeding	C.8	N/A		
	More turning over of the soil	C.9	N/A		
	Practice strip cropping, contour bunding (or ploughing) and farming	C.10	Mitigation potential but not quantified		
	Switch to crops, varieties appropriate to temp, precipitation	**C.11**	N/A		
	Optimize timing of operations (planting, inputs, irrigation, harvest)	C.12	Fertilizer use/type—Change in the amounts of application in the location or type of fertilizer, such as applying in cracks or ruptures, to reduce GHG emissions	0.33 (–0.21 to 1.05)	Medina and Iglesias 2010
			Improved fertilizer management	0.2–0.5	Congress of the United States 2007
			Use of manure/byproducts on pasture	1.7–4.4	Congress of the United States 2007
			N fertilization (inorganic)	0.2 (0.1 to 0.3)	Smith et al. 2005
			Cropland—nutrient management	0.62 (0.02 to 1.42)	Smith et al. 2008
Land management	Withdrawal of flood (sea-level rise)-prone land production as set-asides	C.13	Mitigation potential but not quantified		

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Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
	Practice mixed farming systems (arable and tree crops, livestock)	C.14	N/A		
	Shift crop production from areas that are vulnerable to drought	C.15	N/A		
	Switch from arable crops to tree crops (agroforestry)	C.16	Permanent crops—A transition from arable crops to timber, such as restoration of hedges and edges with tree species or reforestation of farmland, can help sequester GHGs	0.17 (–0.52 to 0.86)	Medina and Iglesias 2010
			Afforestation increases soil carbon	0.35	Paustian et al. 2006
			Afforestation of cropland	7.2–16	Congress of the United States 2007
			Afforestation of pastureland	6.7 to 19	Congress of the United States 2007
			Convert arable land to woodland	0.4 (0.3 to 0.5)	Smith et al. 2005
			Croplands—agroforestry	0.53 (–0.04 to 1.12)	Smith et al. 2008
Livestock management	Improve livestock management (including animal breed choice, heat tolerant, change shearing patterns, change breeding patterns)	C.17	Mitigation potential but not quantified		
	Match stocking densities to forage production	C.18	Mitigation potential but not quantified		

table continues next page

Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
	Improve pasture management (rotational grazing, vegetation improvement in terms of quality and quantity etc.)	C.19	Cultivating of grain legumes in the same parcel can increase the fixation of nitrogen in the soil and improve the utilization of nutrients	0.39 (0.07 to 0.71)	Medina and Iglesias 2010
			The introduction of legumes can increase soil carbon	0.7	Paustian et al. 2006
			Pastureland management	1.0 to 4.4	Congress of the United States 2007
			Grazing management	2.7 to 12	Congress of the United States 2007
			Grazing management on rangeland and pasture	0.17 to 4.69	Congress of the United States 2007
			Grassland—grazing, fertilization, fire	0.8 (0.11 to 1.5)	Smith et al. 2008
	Improve rangeland management (rotational grazing, vegetation improvement in terms of quality and quantity)	C.20	Fertilization and improved grazing systems increases soil carbon	0.3	Paustian et al. 2006
			Rangeland management	0.5 to 1.5	Congress of the United States 2007
			Degraded—restoration	4.45 (0.32 to 8.51)	Smith et al. 2008
	Increasing production of supplemental feed	C.21	N/A		
	Promote vaccination programs for livestock production	C.22	N/A		

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Table A.1 Summary of Adaptation Measures and Potential Mitigation Levels *(continued)*

Category	*Adaptation measures and investments*	*Adaptation option reference number*	*Mitigation description*	*Mitigation potential (metric tons CO_2 equivalent per ha per yr)*	*Source*
Pest and fire management in forestland	Develop sustainable integrated pesticide strategies	C.23	N/A		
	Fire management for forest and brush fires	C.24	N/A		
	Integrated Pest Management	C.25	N/A		
	Introduce natural predators	C.26	N/A		
Water management	Practice intercropping to maximize use of moisture	C.27	Mitigation potential but not quantified		
	Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night, use of efficient irrigation techniques)	**C.28**	Improved irrigation management	0.5	Congress of the United States 2007
			Irrigation	0.075 (0.05 to 0.1)	Smith et al. 2005
			Croplands—water management	1.14 (–0.55 to 2.82)	Smith et al. 2008
	Use water-efficient crop varieties	**C.29**	**Mitigation potential but not quantified**		
D. Indirect adaptations					
Market development	Improve physical infrastructure and logistical support for storing, transporting, and distributing farm outputs	D.1	N/A		
Education	Increase general education level of farmers	D.2	N/A		
Water management	Improve water allocation laws and regulations	D.3	N/A		
	Institute water charging or tradable permit schemes	D.4	N/A		

Note: Adaptation options in bold are those that are evaluated quantitatively. CO_2 = carbon dioxide N/A = not applicable because there is no known mitigation potential.

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Glossary

The source of these definitions is the IPCC AR4 Working Group II report, Appendix I: Glossary, unless otherwise noted.

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 deficit. Controlling and eliminating this deficit in the course of development is a necessary, but not sufficient, step in the longer-term project of adapting to climate change. Development decisions that do not properly consider current climate risks add to the costs and increase the deficit. As climate change accelerates, the adaptation deficit has the potential to rise much higher unless a serious adaptation program is implemented. The term is used in the Study to indicate the difference between the current yields and potential yields in agriculture for the current climate. Failure to adapt adequately to existing climate risks largely accounts for the adaptation deficit (Study Authors).

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

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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 2013).

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, C3 plants show a larger response to elevated CO_2 than C4 plants.

Catchment. An area that collects and drains water.

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

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

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

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

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

Climate risk. Denotes the result of the interaction of physically defined hazards with the properties of the exposed systems—that is, their sensitivity or social vulnerability. Risk can also be considered as the combination of an event, its

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likelihood and its consequences—that is, risk equals the probability of climate hazard multiplied by a given system's vulnerability (UNDP 2004).

Climate (change) scenario. A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use as input to climate change impact models. A "climate change scenario" is the difference between a climate scenario and the current climate.

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

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

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

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

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 2004).

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

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definition, the characteristics of what is called "extreme weather" may vary from place to place. Extreme weather events typically include floods and droughts.

Food security. A situation that exists when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development, and an active and healthy life. Food insecurity may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level.

Forecast. See climate projection.

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

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

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

Irrigation water-use efficiency. Irrigation water-use efficiency is the amount of biomass or seed yield produced per unit of irrigation water applied, typically about 1 ton 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

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driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative storyline." See also (climate change) scenario.

Sector. A part or division, as of the economy (for example, the manufacturing sector, the services sector) or the environment (for example, water resources, forestry) (UNDP 2004).

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; Nakicenovic et al. 2000), and the resulting climate change and sea-level rise scenarios. Four families of socioeconomic scenarios—A1, A2, B1, and B2—represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns and global versus regional development patterns.

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

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

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

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

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thus actual evapotranspiration, is less than potential evapotranspiration demands.

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

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

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

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Agriculture is one of the most climate-sensitive of all economic sectors. Georgia is one of the many countries where the majority of the rural population depends on agriculture—directly or indirectly—for their livelihood. Further, changes in climate and their impacts on agricultural systems and rural economies are already evident throughout Europe and Central Asia. The risks associated with climate change therefore pose an immediate and fundamental problem in the country.

Reducing the Vulnerability of Georgia's Agricultural Systems to Climate Change, is the culmination of efforts by Georgian institutions and researchers, the World Bank, and a team of international experts to jointly undertake an analytical study to address potential impacts climate change may have on Georgia's agricultural sector, but, more importantly, to develop a list of prioritized measures to adapt to those impacts.

Specifically, this study provides a menu of options for climate change adaptation in the agricultural and water resources sectors, along with specific recommended actions that are tailored to distinct agricultural regions within Georgia. These recommendations reflect the results of three inter-related activities, conducted jointly by the expert team and local partners: 1) quantitative economic modeling of baseline conditions and the effects of certain adaptation options; 2) qualitative analysis conducted by the expert team of agronomists, crop modelers, and water resource experts; and 3) input from a series of participatory workshops for farmers in each of the agricultural regions.

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