Public Disclosure Authorized
Public Disclosure Authorized
Public Disclosure Authorized

87811

A WORLD BANK STUDY

# Reducing the Vulnerability of Armenia's Agricultural Systems to Climate Change

## IMPACT ASSESSMENT AND ADAPTATION OPTIONS

Nicolas Ahouissoussi, James E. Neumann,
Jitendra P. Srivastava, Brent Boehlert,
and Steven Sharrow

THE WORLD BANK

# Reducing the Vulnerability of Armenia's Agricultural Systems to Climate Change

A WORLD BANK STUDY

# Reducing the Vulnerability of Armenia's Agricultural Systems to Climate Change

## *Impact Assessment and Adaptation Options*

Nicolas Ahouissoussi, James E. Neumann, Jitendra P. Srivastava,
Brent Boehlert, and Steven Sharrow

THE WORLD BANK
Washington, D.C.

1 2 3 4 17 16 15 14



ISBN (paper): 978-1-4648-0147-1
ISBN (electronic): 978-1-4648-0147-1
DOI: 10.1596/978-1-4648-0147-1

*Cover photo:* (c) Arusyak Alaverdyan. Further permission required for reuse.

*Cover design:* Debra Naylor.

**Library of Congress Cataloging-in-Publication Data**

# Contents

**Boxes**



**Figures**




http://dx.doi.org/10.1596/978-1-4648-0147-1

## Maps



## Tables




http://dx.doi.org/10.1596/978-1-4648-0147-1

http://dx.doi.org/10.1596/978-1-4648-0147-1

# Foreword

Within any economy, agriculture is the sector that is most sensitive to climate change. In Armenia, however, the risks are even more pronounced because the majority of the rural population depends on agriculture for their livelihoods. Climate change threatens to hamper food production and curb rural incomes unless farmers get the help they need through improved water management and use, wider access to technology and information, and better farming practices.

Armenian farmers are already experiencing warmer days and nights, more variable precipitation, and more frequent and intense climate events such as floods, drought and untimely frosts. Their livelihoods depend on their ability to mitigate these adverse effects of climate change with help from the Government and the private sector. The country faces rapidly narrowing windows of opportunity to not only protect farmers from climate change impacts but also to realize the benefits that the changes can offer.

This publication outlines the policy options available to Armenia, based on a rigorous evaluation of the impacts of climate change on agricultural systems. It provides a solid foundation for taking strategic and, in many cases, immediate action to implement "climate-smart" agriculture in the country.

This work not only identifies key priorities for policies, programs and investments to reduce the vulnerability of Armenia's agricultural systems to climate change, but it reflects a broad and inclusive process of stakeholder engagement and consultation, critical for the success of future actions. Its approach to analyzing climate change impacts, assessing adaptive capacity, and mapping out policy options and farm-level responses was tested at sub-national, national and regional levels throughout the South Caucasus and could be used as a model for other countries.

The climate-smart agriculture agenda contributes to a potential "triple win" of increasing productivity, building resilience, and reducing emissions. Pursuing this agenda requires understanding the strengths and weaknesses of current farming systems at the grass-roots level, projecting the potential effects of climate change on these systems, and identifying practical and effective measures that can be taken to increase the resilience of these systems while minimizing greenhouse gas emissions – exactly the approach used in this book. The recommendations of this book can guide further agriculture investments, policy, and capacity building toward a climate-smart approach to agricultural development.

The study underlines the importance and urgency of capacity-building to empower Armenia to initiate control of its own climate resilience, while also providing specific guidance to finance opportunities in the rapidly emerging climate adaptation sector. The World Bank is partnering with the Government through ongoing projects in this important area, and looks forward to continuing its engagement and support going forward.

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

Juergen Voegele
*Sector Director, Agriculture*
*and Environmental Services*


http://dx.doi.org/10.1596/978-1-4648-0147-1

# 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 Armenia, 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 off 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 multistage 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 Armenia's Agricultural Systems to Climate Change*, is the culmination of efforts by the Armenian 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 Armenia'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 Armenia. 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 activities, which were reviewed by local counterparts at the October 11, 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. Armenia is one of three countries participating in the program, with the other country participants being Azerbaijan and Georgia.


http://dx.doi.org/10.1596/978-1-4648-0147-1

# 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 Arusyak Alaverdyan, and in collaboration with a team from Industrial Economics, Incorporated. We are grateful to Dina Umali-Deininger, Sector Manager, Agriculture and Rural Development, Sustainable Development Department, Europe and Central Asia Region, for the valuable support and guidance, to Henry Kerali, Country Director, South Caucasus Country Unit, for his support in furthering the agenda on climate change in agriculture, and Jean-Michel Happi, Armenia Country Manager. We also gratefully acknowledge Larysa Hrebianchuk for providing administrative support.

Members of the Industrial Economics team include James Neumann, and the overall project manager, Kenneth M. Strzepek, Peter Droogers, Stephen Sharrow, and Brent Boehlert. Dr. Droogers led the crop modeling component and capacity-building efforts in the area of crop modeling, focusing on extension of crop modeling capacities for the Armenian 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 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 Armenia, we are grateful for policy guidance and support provided by the Ministry of Agriculture, the Ministry of Environment, and the Hydromet Service. We are also extremely grateful to the Steering Committee, chaired by Armen Poghosian, Deputy Minister of Agriculture, without which the Study would not have been possible. The Study greatly benefitted from valuable inputs, comments, advice, and support provided by academia, civil society and NGOs, farmers, the donor community, and development partners in Armenia throughout this work.

The funding for this study by the Bank-Netherlands Partnership Program (BNPP) is gratefully acknowledged.


http://dx.doi.org/10.1596/978-1-4648-0147-1

# About the Authors

**Nicolas Ahouissoussi** is Senior Agriculture Economist in the World Bank's Europe and Central Asia Region, Agricultural and Rural Development Unit. Prior to joining the ECA Region, he was Senior Agriculture Economist in the World Bank's Africa Region. He has about 30 years of work experience in the economic and agriculture sectors, of which seventeen were for the World Bank. He holds a PhD in Agricultural and Applied Economics from the University of Georgia, USA.

**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.

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

**Dr. Steven Sharrow** is Emeritus Professor of Rangeland Management and Agroforestry at Oregon State University. He specializes in range livestock production, pasture management, rainfed and irrigated field crop production, and agroforestry in low rainfall areas of North Africa, the Middle East, Eastern Europe, and Central Asia. As co-director of the Agroforestry Project within the Egypt National Agricultural Research Project, he led research and extension efforts that "made the desert bloom" during the early to mid-1990s by growing trees and crops together in irrigated and nonirrigated areas of Egypt and by using trees to reclaim salt-affected farmland in the Nile River delta. During the past several years, he has focused on assisting rural farmers to modernize their rainfed cereal production systems in the southern Caucasus region.


http://dx.doi.org/10.1596/978-1-4648-0147-1

# 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 |


http://dx.doi.org/10.1596/978-1-4648-0147-1

# Executive Summary

## Introduction

Agricultural production is inextricably tied to climate, making agriculture the most climate-sensitive of all economic sectors. In countries such as Armenia, 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 Armenia 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 Armenian farmers in March 2012. The second phase of the Study involved


http://dx.doi.org/10.1596/978-1-4648-0147-1

quantitative and qualitative analysis of climate change impacts and adaptation options. Additionally, a second consultation with Armenian 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 three agricultural regions of Armenia under a range of future climate change scenarios.

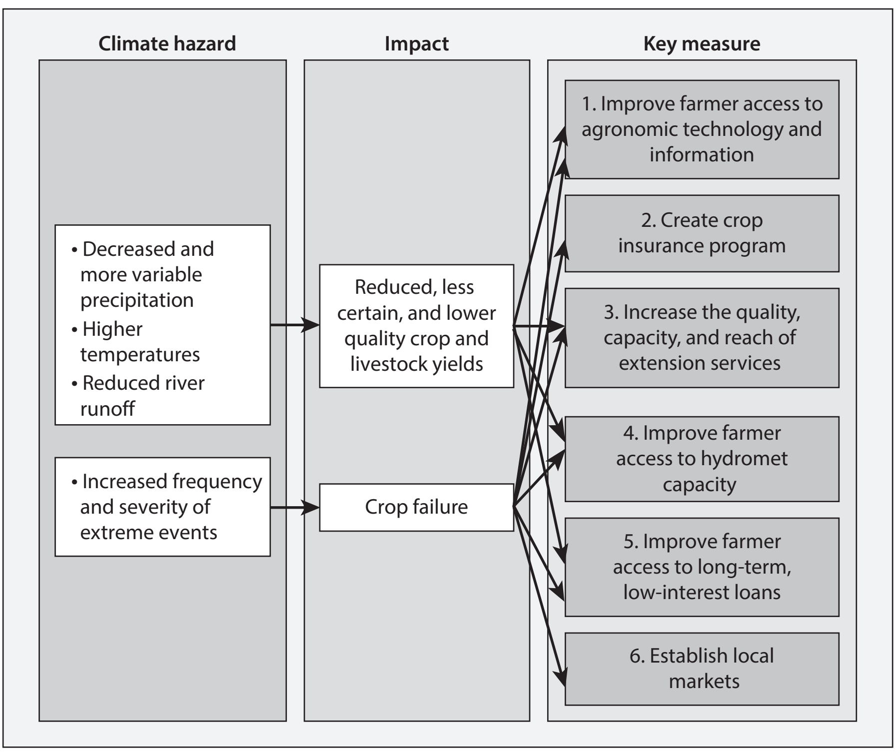
Figure ES.1 summarizes the Study's findings regarding priority actions for adaptation at the national level. Figure ES.2 summarizes the recommended measures for the Lowlands agricultural region within Armenia, as an example of the Study's regional-level findings. These findings reflect extensive discussion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

## Key Climate Change Challenges for Armenia's Agricultural Sector

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

*Temperature will increase in all three agricultural regions, accelerating the historical trend*. The Study indicates this trend will accelerate in Armenia in the near future, as shown in map ES.1 below. Although uncertainty remains regarding the

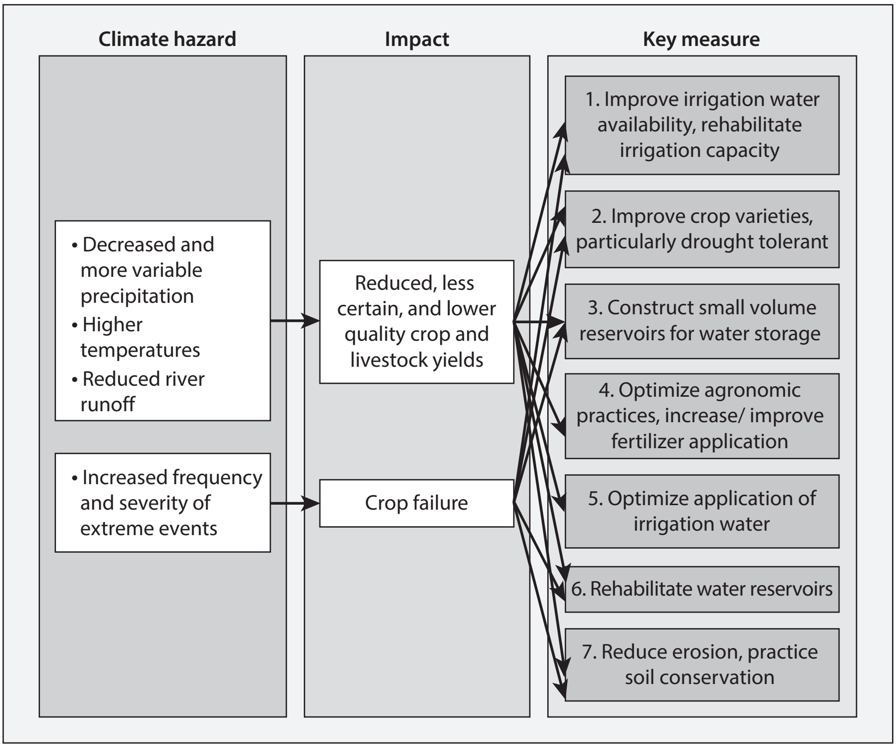
**Figure ES.1 Climate Change Risks and Recommended Adaptation Measures at the National Level**





http://dx.doi.org/10.1596/978-1-4648-0147-1

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



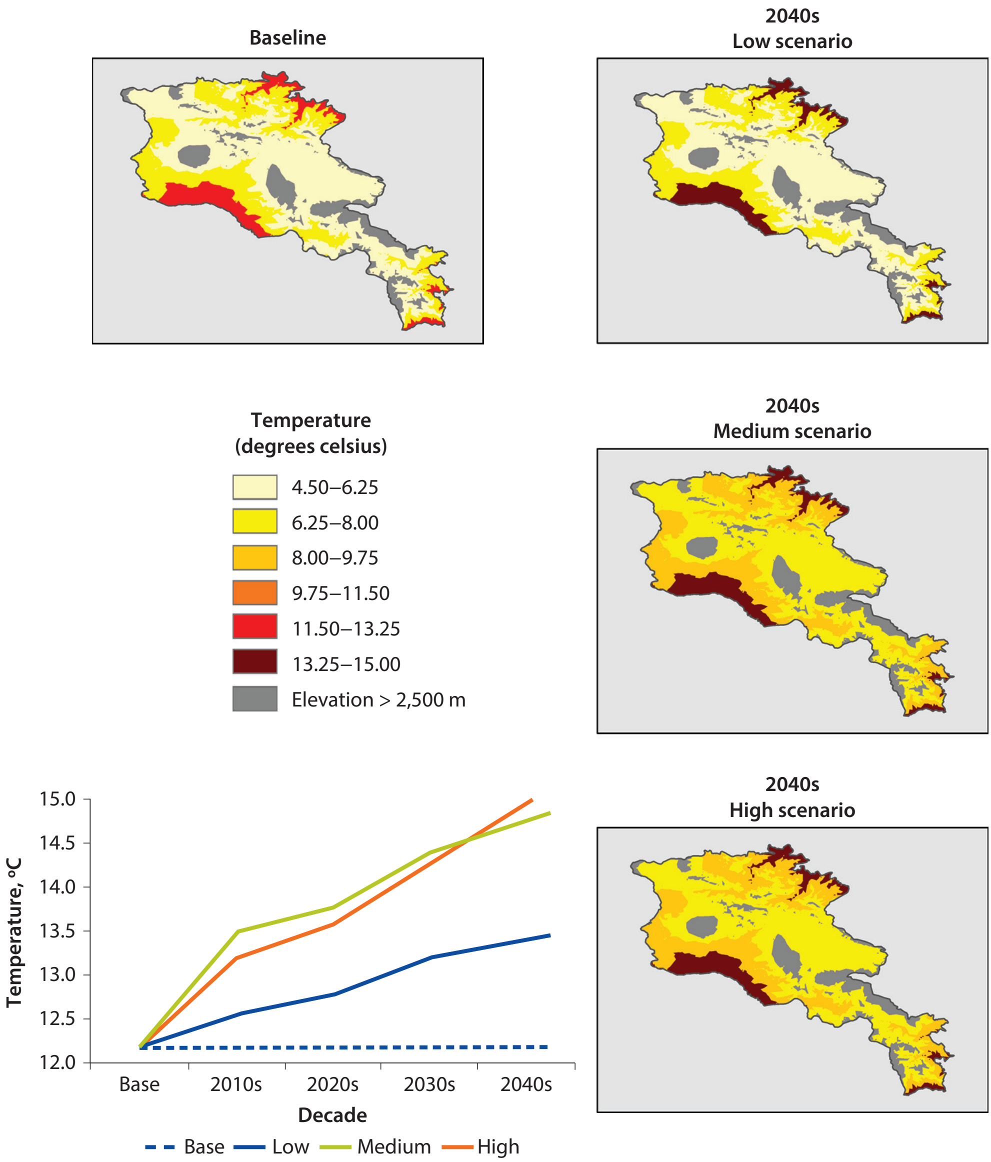

degree of warming that will occur in Armenia, the overall warming trend is clear and is evident in all three agricultural regions. Over the next 50 years, the average increase in temperature will be about 2.6°C. This can be compared with the 0.85°C increase in temperature observed over the last 80 years. Temperature-related impacts are expected to be particularly severe in the Ararat Valley, due to the fact that temperatures are already relatively high in this area.

*Precipitation will become more variable in Armenia 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 across the nation could decrease by a total of 52 millimeters by the 2040s. Most of this decrease will occur in the Mountainous agricultural region. Under the Low and High Impact scenarios, however, changes in precipitation range from a modest increase under the Low Impact scenario to a 23 percent decrease under the High Impact scenario. In addition climate change could potentially increase the frequency and magnitude of flooding. For the agricultural sector, floods are particularly problematic as they can delay or prevent planting or harvesting, or destroy crops.

*Climate impacts will be greatest from July to October—a key period for agricultural production.* Forecasts of annual averages are less important for agricultural


http://dx.doi.org/10.1596/978-1-4648-0147-1

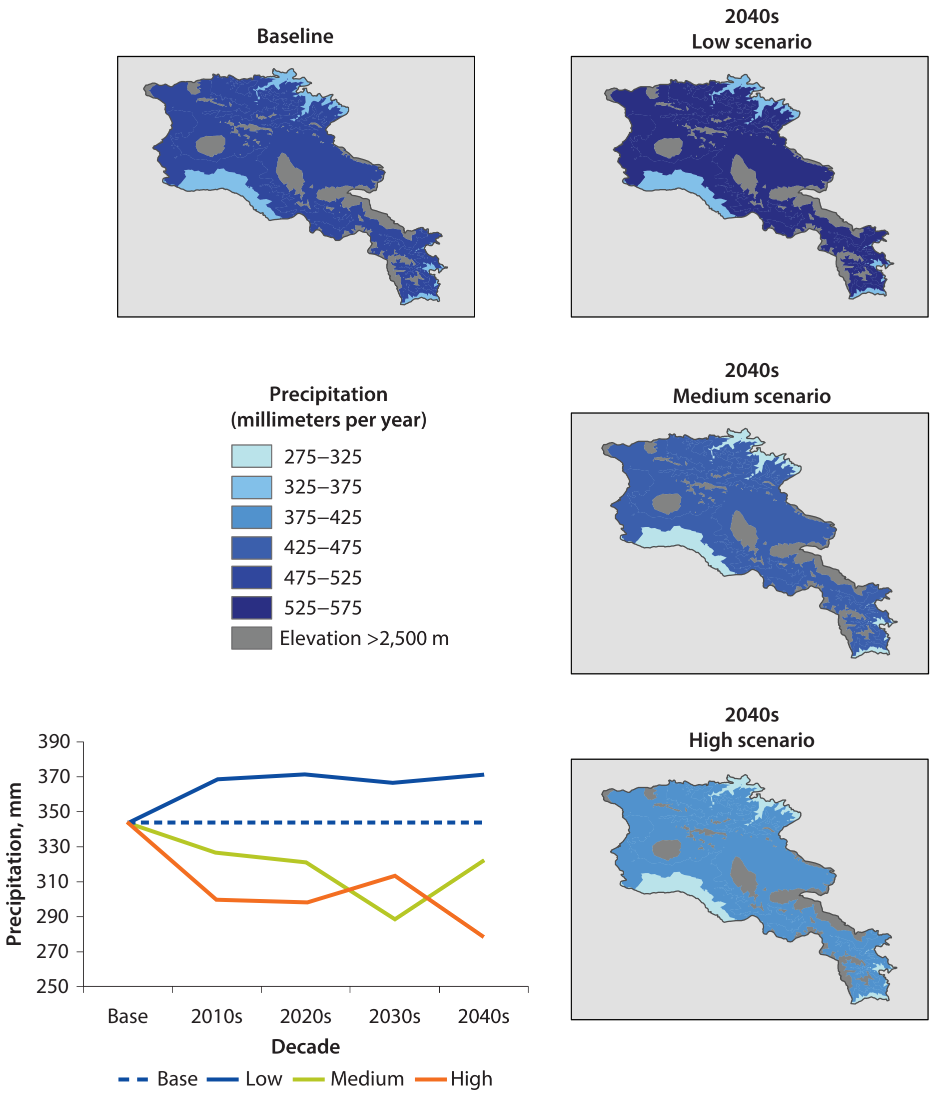
**Map ES.1 Effect of Climate Change on Average Annual Temperature in the 2040s under the Low, Medium, and High Impact Climate Scenarios**




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

production than the seasonal distribution of temperature and precipitation. For temperature, climate change has the greatest impact from July to October relative to current conditions. This summer temperature increase can be as much as 5°C in the Intermediate agricultural region of Armenia, when temperatures are already highest. In addition, forecast precipitation declines are greatest in the July to August period.

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




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

*Farmers are not suitably adapted to current climate.* The "adaptation deficit" is large in Armenia. 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.

*The direct temperature and precipitation effect of future climate change on crops is mainly negative.* Climate change is expected to result in increased yields of some crops in the Intermediate and Mountainous agricultural regions, but reduced


http://dx.doi.org/10.1596/978-1-4648-0147-1

yields for all crops in the Lowlands region, where higher temperatures will cause heat stress. Wheat and watermelon yields and irrigated tomato yields could increase in the Intermediate and Mountainous agricultural regions, whereas alfalfa, apricot, grape, potato, and rainfed tomato yields are expected to decline in these regions.

*Water resources are currently sufficient for irrigation demands in most regions; however, in the Upper Araks basin water shortages are forecasted under all climate change scenarios.* Armenia currently relies on irrigation, mostly in the Ararat Valley, where virtually all of the agricultural land is irrigated. The effect of climate change on crop yields in areas where irrigation water shortages are forecast will be substantial. Increased demand for water during the July through September period, coupled with decreases in runoff in the April through November period, will likely lead to crop losses of over 50 percent for all irrigated agriculture in the Lowlands agricultural region of the Upper Araks basin under the high impact scenario. This region accounts for a large portion of the economic production of the Armenian agriculture sector.

*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 Armenia. However, it can be expected that increased temperatures will negatively affect the health of livestock.

## Analysis of the Vulnerability of Armenia's Agricultural Sector to Climate Change

Seasonal changes in climate have clear implications for crop production in both irrigated and rainfed agricultural systems in Armenia. 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 for many of the country's key crops, yields are expected to decrease in the period of 2040–50 relative to current yields under the medium climate forecast scenario. Yields of rainfed apricot and grape crops, in particular, are expected to decline 28 and 24 percent, respectively, in the Lowlands agricultural region. In the Intermediate agricultural regions, yields of rainfed grape and potato crops are expected to decline 12 and 14 percent, respectively. In the Mountainous region, however, yields of tomato and wheat crops are expected to increase in both irrigated and rainfed systems.

Although table ES.1 reflects the assumption that irrigation water will not be constrained, changes in temperature and precipitation resulting from climate change are expected to impact water resources in Armenia. 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


http://dx.doi.org/10.1596/978-1-4648-0147-1

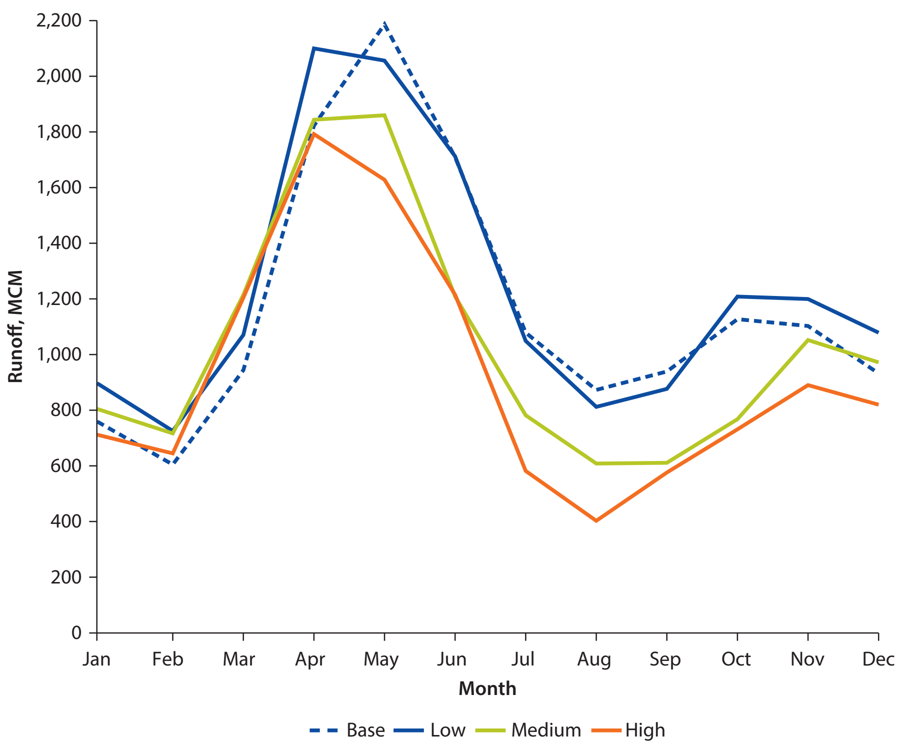
**Table ES.1 Effect of Climate Change on Crop Yields in the 2040s under the Medium Impact Climate Scenario (No Adaptation and No Irrigation Water Constraints)**

| *Irrigated/rainfed* | *Crop* | *Lowlands (%)* | *Intermediate (%)* | *Mountainous (%)* |
|---|---|---|---|---|
| Irrigated | Alfalfa | −5 | −7 | −2 |
| | Apricot | −5 | −5 | −5 |
| | Grapes | −7 | −5 | −5 |
| | Potato | −12 | −9 | −5 |
| | Tomato | −16 | 6 | 50 |
| | Watermelon | −12 | 10 | N/A |
| | Wheat | −6 | 1 | 38 |
| Rainfed | Alfalfa | −3 | −8 | −1 |
| | Apricot | −28 | −7 | −5 |
| | Grapes | −24 | −12 | −1 |
| | Potato | −14 | −14 | −8 |
| | Tomato | −19 | −8 | 34 |
| | Watermelon | −18 | 0 | N/A |
| | Wheat | −8 | 1 | 38 |

*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.

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




*Source:* World Bank data.

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, under the High Impact scenario, 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 relative to historic demands. The net effect of the predicted rising demands and falling supply is a significant reduction in water available for irrigation. Irrigation water shortages by the 2040s are predicted to occur in the Upper Araks basin, while no shortage of irrigation water is forecast for the other Armenian basins.

Three climate change stressors therefore combine to yield an overall negative impact on crop yields in Armenia: (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 Armenia 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 on the Upper Araks basin, which feeds the Ararat Valley. The net effect of these three factors on irrigated agriculture in the Upper Araks basin is illustrated in figure ES.4 below. The top 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 bottom panel shows the combined effect of all three factors mentioned above, including the forecast irrigation water shortages for the Upper Araks basin. The net effect of these factors on crop yields is dramatic, and provides an important focus for adaptation efforts to mitigate potential losses. While the water resources modeling does not indicate water shortages for the Lower Araks basin, changes in transboundary water withdrawal rates could alter that finding and lead to shortages in that part of the Araks basin as well.

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 Armenia's agricultural sector to climate change are evaluated based on the results of quantitative modeling, qualitative


http://dx.doi.org/10.1596/978-1-4648-0147-1

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

| Crop | Lowlands(%) | Intermediate(%) | Mountainous(%) |
|---|---|---|---|
| Alfalfa | −5 | −7 | −2 |
| Apricot | −5 | −5 | −5 |
| Grapes | −7 | −5 | −5 |
| Potato | −12 | −9 | −5 |
| Tomato | −16 | 6 | 50 |
| Watermelon | −12 | 10 | 50 |
| Wheat | −6 | 1 | 38 |

Upper Araks

| Crop | Lowlands(%) | Intermediate(%) | Mountainous(%) |
|---|---|---|---|
| Alfalfa | −48 | −49 | −46 |
| Apricot | −48 | −47 | −47 |
| Grapes | −42 | −41 | −41 |
| Potato | −51 | −49 | −47 |
| Tomato | −53 | −41 | −17 |
| Watermelon | −51 | −39 | −17 |
| Wheat | −48 | −44 | −24 |

*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.

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 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:* All regions identified irrigation as a key focus area for improving resilience to climate changes and extremes, now and in the future. Specific measures discussed included: (i) improving existing irrigation schemes; (ii) improving water use efficiency by investing in drip and sprinkler irrigation; (iii) rehabilitating water reservoirs (mainly in Lowlands and Intermediate regions); and (iv) increasing national water storage capacity, in part through building small-scale reservoirs in vulnerable higher elevation regions.

*Hydromet forecasts:* Farmers currently use forecasts made available through the television, but these are aimed at too broad a geographic area and do not provide information specific for agriculture (for example, information that


http://dx.doi.org/10.1596/978-1-4648-0147-1

would allow them to know when to apply pesticides, when to irrigate, or when to plant). Today, many farmers still plant when the snow is at a certain level on Mount Ararat.

*Extension services:* The extension service run by the government is active and well-funded, but few farmers seem to use the trainings or other educational opportunities offered by the service. The farmers indicated that they would be interested in more practical and targeted training, such as demonstration plots.

*Seed selection:* Some farmers indicated that their seedlings and plants are tolerant to weather changes, but most said their seedlings and plants were not tolerant. Generally, farmers prefer to produce and use their own seeds, and will clean and replant seeds from season to season. Sometimes they will use seeds from the extension service, but these are often not tailored to the specific climate and soil conditions of their region. Ideally, the service would provide heat and drought tolerant crops to address anticipated warmer and drier conditions.

*Crop insurance:* While insurance does exist, it is currently too expensive for most farmers. Both hail and spring frost are major issues for farmers in the region, with estimates of annual losses on the order of 10 percent of annual production for some crops, which may account for as much as US$100 to US$150 million in annual losses nationwide. Subsidized programs for crop insurance would greatly stabilize their incomes and improve their capacity to re-invest in farming, but insurance schemes must be carefully designed for affordability and in recognition of cash and credit constraints if there is to be sufficient uptake of insurance among poor, smallholder farmers.

*Bank loans:* Most farmers indicate they have access to high-interest, short-term bank loans for agricultural development, but it is difficult to obtain low-interest, long-term bank loans for agricultural development.

*Infrastructure:* To moderate temperatures and improve yields, some farmers have been constructing greenhouses. Few farmers attending the stakeholder meeting had greenhouses, however, as most of these farmers were smallholders.

### *Options for National Policy and Institutional Capacity Building*

Six measures for adaptation at the national level were identified based on quantitative and qualitative analysis of potential net benefits, which included evaluations and recommendations from farmer stakeholder and expert groups.

*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.

*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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 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 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 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 non-monthly payment). This is a pressing need for tailoring techniques to shifting climatic conditions without harming ecosystems of the country.

*Improve access to local markets*. Specific recommendations to improve the marketability of produce and livestock in rural areas of Armenia include the following: (i) change farmers' perception of marketing. Train them to focus on quality of products that they produce. Poor quality is not marketable, or if marketed a low price is inevitable; (ii) invest in market information gathering and dissemination, including mass media, fax, telephone and real-time computer access systems; (iii) create, train and support producer associations (cooperatives) and small and medium-scale enterprises to improve the bargaining power of small farmers; (iv) provide storage facilities including cold storage that enable farmers to inventory their products for periods when the market is not saturated.

### *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 Armenian 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 improving and/or augmenting irrigation infrastructure, particularly in the Lowland agricultural region; optimizing application of irrigation water at the farm level (particularly in the Mountainous agricultural region); constructing small-scale reservoirs for water storage; and providing more climate-resilient seed varieties along with focused training on how best to cultivate them effectively.

Irrigation water shortages in the Upper Araks basin appear likely to occur under climate change (and even if climate does not change in the future, as a shortage can occur from competition with growing demand from non-agricultural water users), but can be addressed through a range of adaptive measures. For example, improvements in farmer trainings could help ensure more efficient on-farm water use during dry seasons, and additional investment in the current irrigation infrastructure could help make better use of available water resources in the agricultural sector. The economic analysis suggests that the benefits of these investments would likely exceed the construction costs under most scenarios.

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 Armenia, 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 Armenian agriculture. It is hoped, however, that the awareness of climate risks and the analytic capacities built over the course of this


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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* | *Improve farmer access to agronomic technology and information* | *Create crop insurance program* | *Improve crop varieties* | *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 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |


http://dx.doi.org/10.1596/978-1-4648-0147-1

study provide not only a greater understanding among Armenian 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.

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 Armenia. 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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

CHAPTER 1

# The Study: Design, Methodology, and Limitations

## Overview of Approach

### *Background*

In countries such as Armenia, 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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 Armenia 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 Armenia
(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*

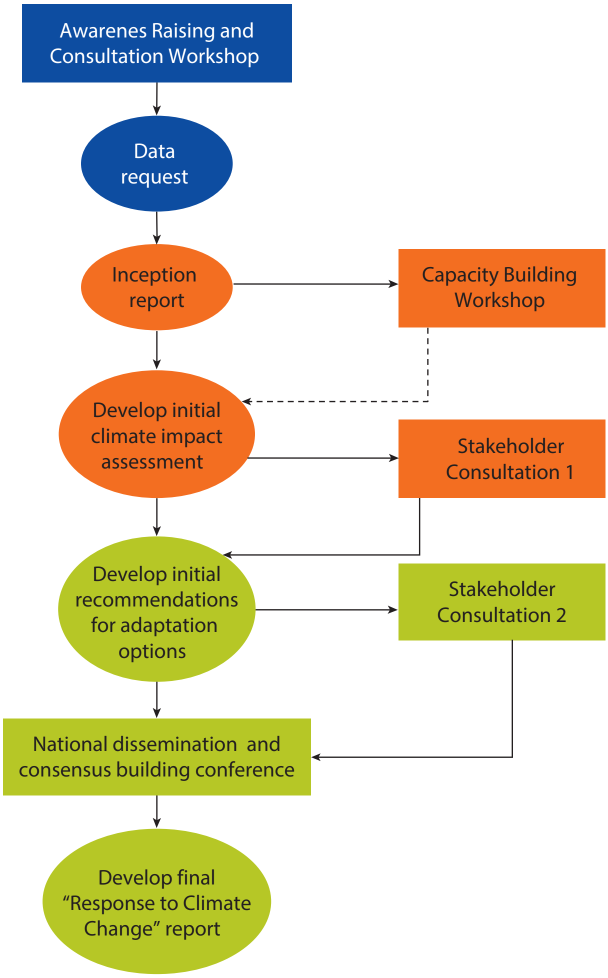
The Study was conducted in three stages: Awareness Raising; Quantitative and Qualitative Analysis; and Finalization of the Analysis and Menu of Adaptation Options (figure 1.1).

*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 Armenian farmers in March 2012. The culmination of the first phase was the finalization of a Country Report, which summarized existing information on the country context, 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 three agricultural regions of Armenia, to key crops important to the Armenian 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 Armenian


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Figure 1.1 Flow Chart of Phases of the Study**




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.

### *Geographic Scope*

Armenia is a small country located in the Southern Caucasus region. Its neighbors are Azerbaijan to the east and southwest, Georgia to the north, the Islamic Republic of Iran to the south and Turkey to the west. Administratively, Armenia is divided into 10 provinces plus Yerevan, the capital city.

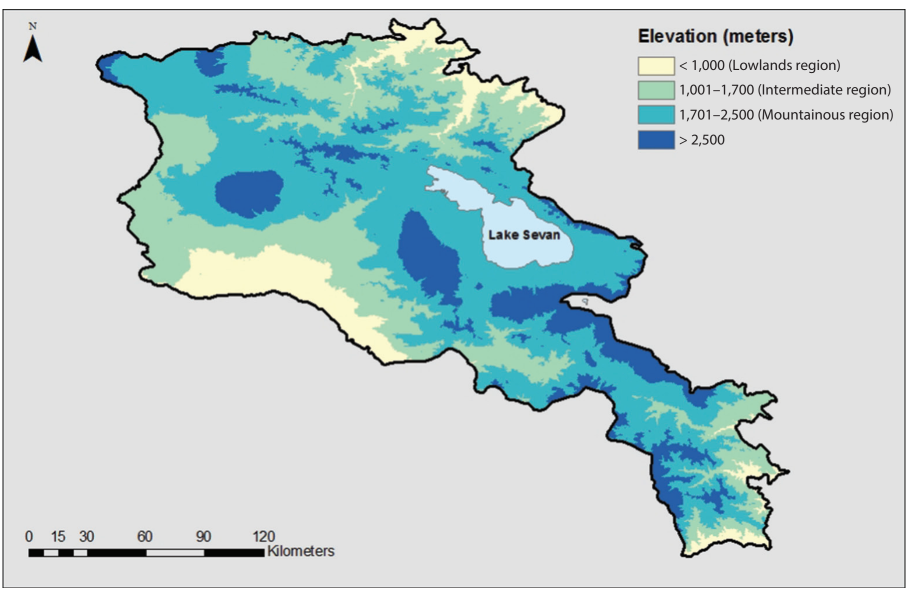
For the purposes of the Study, Armenia was grouped into three agricultural regions according to elevation (map 1.1): Lowlands, Intermediate, and Mountainous. These regions were developed in collaboration with local experts. The Mountainous region (shown in blue-green in map 1.1) encompasses areas with an elevation between 1,700 and 2,500 meters; the Intermediate region (shown in in light green) encompasses areas with an elevation between 1,000 and 1,700 meters; and the Lowlands region (shown in yellow) encompasses areas with an elevation that ranges from below sea level to 1,000 meters, and includes the Ararat valley. A fourth region with very high elevations of over 2,500 meters is not included in this study, as agricultural production in this area is limited.

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, 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 Armenia'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 Armenia; (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

**Map 1.1 Agricultural Regions of Armenia**




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

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: winter wheat; potato; tomato; apricot; grapes; alfalfa; and watermelon.

### *Developing Future Climate Scenarios*

The first step in understanding the exposure of Armenia'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.

**Box 1.1 Developing a Range of Future Climate Change Scenarios for Armenia**

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 Armenia: 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 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 |

*Note:* GCM = Global Circulation Model; IPCC = Intergovernmental Panel on Climate Change


http://dx.doi.org/10.1596/978-1-4648-0147-1

### *Time Period and Other Parameters*

In order to assess the impact of future climate scenarios on Armenia'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.

## Methodology

### *The Framework for Evaluating Investment in Adaptation*

The Study provides a framework for evaluating alternatives for investment in adaptation for the Armenian 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 Armenian 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


http://dx.doi.org/10.1596/978-1-4648-0147-1

resilience of the Armenian agricultural sector to climate change. Two types of results from the Study should therefore be most critical for Armenian 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 Armenian 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 Armenian farmers currently lack the training 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 Armenia, three climate scenarios are defined based on the average CMI[1] across the country (box 1.1.), (i) 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.

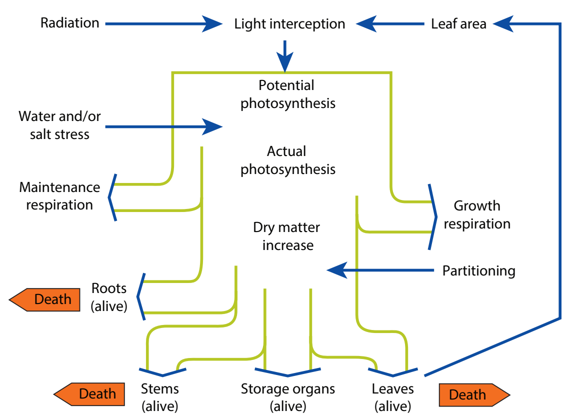
(ii) *Crop, water runoff and water basin modeling.* Based on the assessment of the country-specific analytical requirements, three modeling tools were used in the Study: (i) AquaCrop for crop modeling (for the selected crops), (ii) CLIRUN for water runoff projections, and (iii) Water Evaluation and Planning System (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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

## 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 and (ii) ability to evaluate the effects of water stress and estimate crop water demand, both key issues in Armenia 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 demand 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).


http://dx.doi.org/10.1596/978-1-4648-0147-1

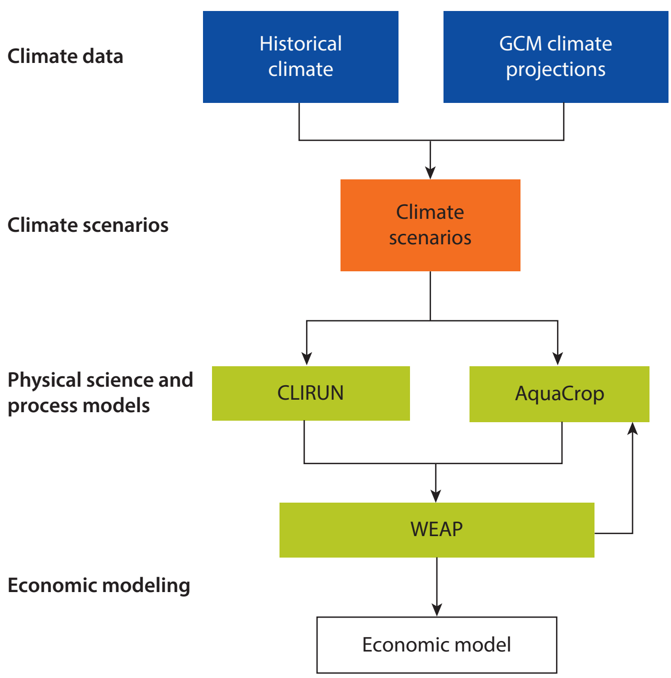
### *Analysis and Assessments*

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.

**Figure 1.2 Steps in Quantitative Modeling of Adaptation Options**




*Note:* GCM = Global Circulation Model; WEAP = Water Evaluation and Planning System.

*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 nonagricultural 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 agricultural water demand shortfalls within each river basin. These shortfalls may be generated by rising nonagricultural 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 Armenia (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 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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

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) Armenian 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 Armenia. Based on the expert assessment, adaptation options were ranked on a scale from one to four.

### *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 Armenia. 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?


http://dx.doi.org/10.1596/978-1-4648-0147-1

- 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?

## 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 Armenia, 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 Armenia, a wide range of historic meteorological data was available through public sources, including global data from the World Meteorological Organization. As a result of concerns expressed by the Hydromet Institute, however, some additional locally available hydrologic and meteorological daily timescale data was not made available to the Expert Consultant Team. 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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 schedule 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 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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

CHAPTER 2

# Overview of Agricultural Sector and Climate in Armenia

## Overview of Armenia's Agricultural Sector

### *Agriculture and the Economy*

Agriculture has traditionally been a significant and stable part of the Armenian economy. Agriculture's contribution to the country's gross domestic product (GDP) has declined from 45 percent in 1994 to 21 percent in 2011 (World Bank 2013a). Although the sector has declined slightly in terms of economic importance, Armenia is still an agrarian society, with agriculture providing 44.2 percent of total employment in 2008 (World Bank 2013a). With 36 percent of the population living in rural areas in 2011, and with 35.8 percent of the population living under the poverty line in 2010, much of Armenia's population is poor and highly vulnerable to any event that affects the agricultural sector (World Bank 2013a). The country's agricultural sector is mainly geared toward subsistence farming, but surplus production is marketed. Currently, the sector does not meet Armenia's food needs and is still reliant on government subsidies.

In 2010, the total value of agricultural production was about US$856 million.[1] As shown in table 2.1, about 47 percent of the value of production was accounted for by the livestock sector while crops accounted for the remainder.

The household farms sector, which includes a large number of peasant farms but also includes personal households, gardening companies, and urban population engaged in agriculture, accounts for the vast majority of the roughly 286,000 hectares sown in 2011 and produces over 90 percent of agricultural output.

**Table 2.1 Value of Agricultural Products in Armenia in 2010**

| *Agricultural products* | *Value (millions of constant 2004–06 US$)* |
|---|---|
| Cereals | $67 |
| Fibers | $2 |
| Fruits, nuts, and tree crops | $209 |
| Vegetables | $173 |
| Livestock | $403 |
| **Total output of industry** | **$856** |

*Source*: FAOSTAT 2012.


http://dx.doi.org/10.1596/978-1-4648-0147-1

These smallholder farmers usually have fragmented land areas from one to three hectares, and they face constraints of small area, limited profits, and scarce financial means. In many cases, farmers' experience and know-how is not sufficient to achieve a successful farming operation in a market-driven economy. They need tailored advice but there is no effective and efficient extension system in place to provide the service on required scale and quality.

### *Agricultural Resource Base*

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

*Climate, Land, and Soils:* Armenia has a highland continental climate, meaning hot summers and cold winters. The mean temperature in Armenia is 5.5°C, with the hottest regions such as the Ararat Valley averaging 12 to 14°C and the coldest regions averaging temperatures below zero (UNFCCC 2010). Summers are warm with a mean temperature of 16 to 17°C; however, the hottest regions typically have a high around 24 to 26°C, and extremes there can reach 38 to 40°C (FAO 2008). Average winter temperatures are approximately –7°C. On average, Armenia receives 592 millimeters of precipitation annually, but levels vary significantly by region. In the Ararat Valley and Meghri region, annual precipitation is only about 200 to 250 millimeters, while some mountainous regions can receive as much as 1,000 millimeters each year. The average precipitation in the Ararat Valley during the summer is generally no greater than 32 to 36 millimeters (FAO 2008; UNFCCC 2010).

Agriculture in Armenia is at risk due to both existing environmental hardships and new climatic challenges, including higher temperatures and reduced precipitation; increased evaporation from the soil due to secondary salinization (an increase of the salt-to-water ratio in the soil due to anthropogenic factors); and erosion, which is worsened by flooding, droughts, and strong winds. The most serious problems for Armenia's agricultural sector are the loss of water due to inefficient irrigation practices; soil salinization; erosion; overgrazing; inappropriate cultivation practices; and pollution. Additionally, Armenian agriculture is considered at high risk due to limited land resources. Approximately 11 percent of land degradation in Armenia is due to human activities (compared to only 23 percent of human-induced degradation due to agriculture in Europe overall), but most of the human-induced degradation is due to agriculture.

Severe climatic phenomena, which are occurring with increasing frequency and duration as a result of climate change, and also threaten Armenia's agricultural sector. Extreme events in recent years, such as hail, spring frosts, and mudflows, have cost US$15 to 20 million annually in agricultural damages. Other estimates indicate that from 2000 to 2005, drought, frost, and floods have cost US$107 million in damages. In September 2006 alone, droughts and forest fire cost Armenia US$9 million in economic losses. Currently, mountainous areas in the north, east, and southern parts of the country suffer from seasonal flooding, hailstorms, and drought. The Ararat valley region is subject to droughts, early frosts, and dry conditions. The central region north of Yerevan


http://dx.doi.org/10.1596/978-1-4648-0147-1

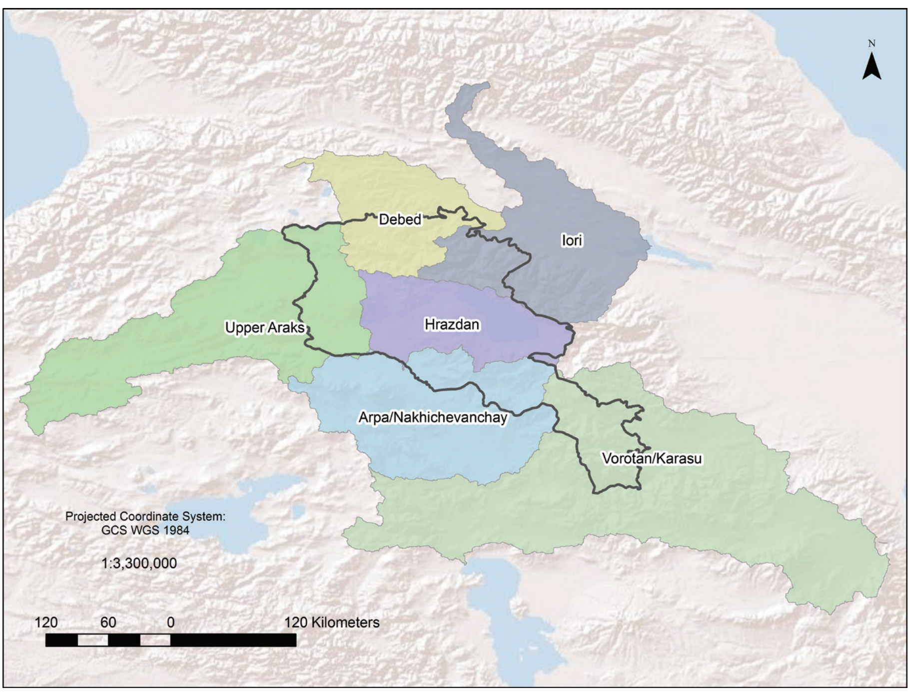
is affected by hailstorms, drought, and early frosts. The northwest region is subject to all these types of extreme events.

While much of the land degradation occurring in Armenia is due to anthropogenic factors (for example, cultivation practices, overgrazing, and deforestation), there are also natural causes such as land cover patterns and soil properties. Farm-level practices leading to erosion and soil degradation include inappropriate crop rotations, soil tillage on steep slopes, burning crop residues, and poor soil fertility management. Erosion can lead to sedimentation of waterways and reduced functioning of reservoirs and irrigation infrastructure.

*Water Resources and Irrigation:* There are two major river basins in the country: the Araks in the southwest and the Kura in the northeast. Lake Sevan, one of the highest fresh-water lakes in the world, is by far the largest lake in Armenia with a volume of 33.4 km$^3$ (UNFCCC 2010). In addition to Lake Sevan, there are roughly 100 other lakes in the mountains of Armenia with a combined volume of 0.8 km$^3$. Insufficient and uneven annual distribution of precipitation can be harmful to agriculture. There is a heavy reliance on irrigation in the Ararat Valley, where more than 80 percent of the value of agricultural product is currently obtained from irrigated land.

The major river basins of Armenia include the Upper Araks, Debed, Iori, Hrazdan, Apra/Nakhichevanchay, and Vorotan/Karasu (map 2.1). Most of these

**Map 2.1 River Basins in Armenia**



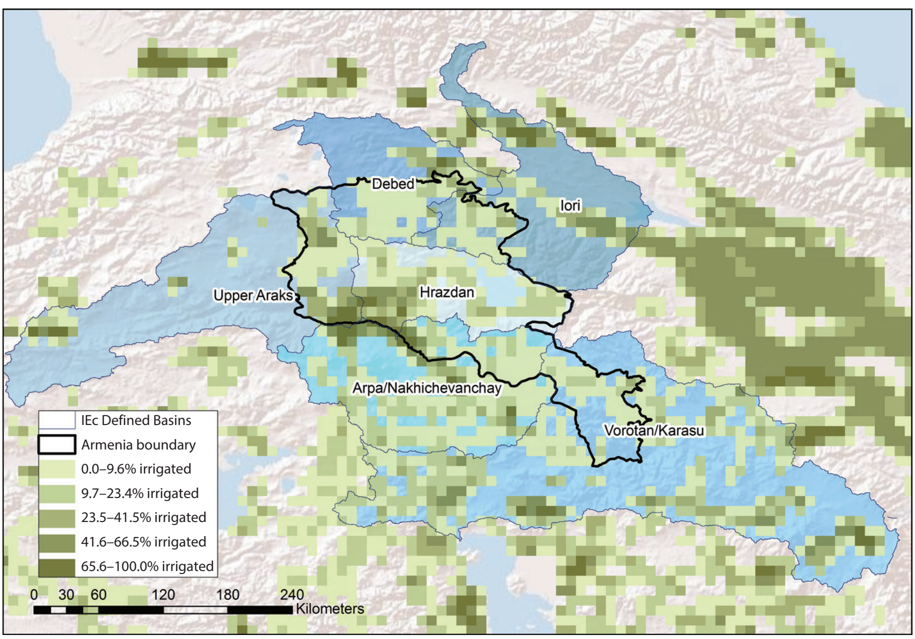

*Sources:* © Industrial Economics. Used with permission; reuse allowed via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0.

basins extend beyond Armenia's border, but the focus of the Study is on changes in water supply and demand within Armenia's territory.

Total annual irrigation and livestock water withdrawals across Armenia are approximately 1.86 billion $m^3$, representing 66 percent of water withdrawals in the country (FAO 2009). 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 2011; Republic of Armenia Ministry of Environment, unpublished data). In total, there are 291,014 hectares of irrigation across the country. Basin subtotals do not add to the total hectares irrigated as a few administrative regions could not be mapped for the spatial analysis and part of Armenia falls outside of these six basins.

*Pollution from Agricultural Activities:* High pesticide and fertilizer application rates were used to boost Armenia's agricultural output during Soviet Era—the high application rates have decreased dramatically since the late 1980s. However, wastes (for example, livestock production) are gradually becoming a threat for the environment since there is no specific system in place for their collection and use. Farmers dispose of waste on their own and, in many cases, end up polluting land, water and air.

**Map 2.2 Irrigated Areas in Armenia**




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

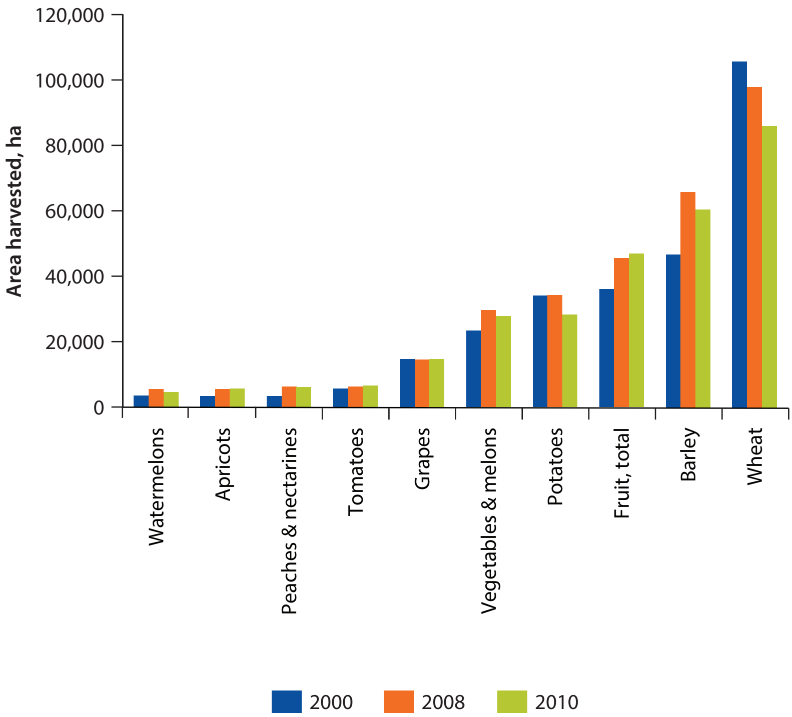

http://dx.doi.org/10.1596/978-1-4648-0147-1

**Table 2.2 Size of Irrigated Areas in Armenia's River Basins**

| *River basin* | *Size of irrigated area (ha)* |
|---|---|
| Upper Araks | 87,884 |
| Debed | 22,016 |
| Arpa/Nakhichevanchay | 42,725 |
| Hrazdan | 105,711 |
| Iori | 16,529 |
| Vorotan/Karasu | 16,149 |
| **Total** | **291,014** |

*Source:* World Bank data.

**Figure 2.1 Areas Planted by Crop in Armenia, 2000–10**




*Source*: FAOSTAT 2012.

*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 8 percent of agricultural land (figure 2.1) and contribute 13 percent of total crop outputs (FAOSTAT 2012; World Bank 2013a). It should be noted that given the spatial variability of soils and climate, and access to water, infrastructure, and other inputs, many areas of Armenia outside of the lower-elevation areas are unsuitable for high-value vegetable production and hence the reliance on more resilient, less input-intensive crops such as wheat, maize, and forage in the more mountainous areas.


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Table 2.3 Livestock Count by Agricultural Region**

| | *Lowlands* | *Intermediate* | *Mountainous* | *>2,500 meter[a]* |
|---|---|---|---|---|
| Cattle | 50,600 | 177,000 | 278,000 | 70,700 |
| Goats | 3,930 | 11,300 | 12,200 | 2,270 |
| Sheep | 109,000 | 119,000 | 189,000 | 93,700 |
| Pigs | 12,900 | 8,270 | 47,000 | 44,400 |
| Chickens | 468,000 | 1,170,000 | 1,860,000 | 496,000 |

*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).

a. While crop cultivation may be limited above 2,500 meters, and therefore this region is not analyzed in the crop analyses, livestock does exist and is therefore mentioned here.

Trends within the field crop sector over the last decade indicate both declines and increases in areas planted overall, with a substantial decline in the area planted in wheat and potatoes, and increases in apricots, watermelons and tomatoes from the beginning of the current decade (figure 2.1). Crop area of the six crops shown in figure 2.1 declined by about 13 percent from 2001 to 2010 (FAOSTAT 2012).

As noted above, livestock has long been an important component of the Armenian agricultural economy. Between 2006 and 2010 livestock counts have decreased, while the gross production value of livestock increased by 32 percent from 2006 to 2011. Stocks of all animals declined, and the most significant declines from 2006 to 2011 were goats, pigs, and chickens, by 30 percent, 18 percent, and 14 percent, respectively (FAOSTAT 2012).

Table 2.3 indicates there is significant variation in livestock counts among the agricultural regions. When livestock is broken down further by count per unit area, the density of cattle, goats, and chickens is relatively similar across agricultural regions, but sheep are much more prevalent per unit area in the Lowlands agricultural region, and pigs are less prevalent in the Intermediate and Mountainous agricultural regions. Note that, while agricultural production may be limited above the 2,500 meters elevation contour, livestock continues to be a viable agricultural operation in the highest elevation areas.

## Exposure of Armenia'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 redistribution 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).

Over the last 80 years, Armenia's mean annual temperature has increased 0.85°C (UNFCCC 2010). Analysis of temperature indicators suggested a trend of increased number of days per annum with a daily maximum over 25°C in over 80 percent of the stations analyzed (UNDP 2011).

Concurrently, annual precipitation decreased by 6 percent compared to the 1961–90 baseline period (UNFCCC 2010). This decrease in precipitation has not been distributed uniformly around the country with the northeastern and central (Ararat valley) regions becoming more arid and the southern and northwestern areas and Lake Sevan basin experiencing increased precipitation.

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). Changes in glacier composition can potentially reduce long-term river flow in Armenia.

### *Forecast Climate Changes for Armenia*

The effect of climate change on annual average temperature and average annual precipitation in Armenia 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 an increasing trend in extreme heat events.

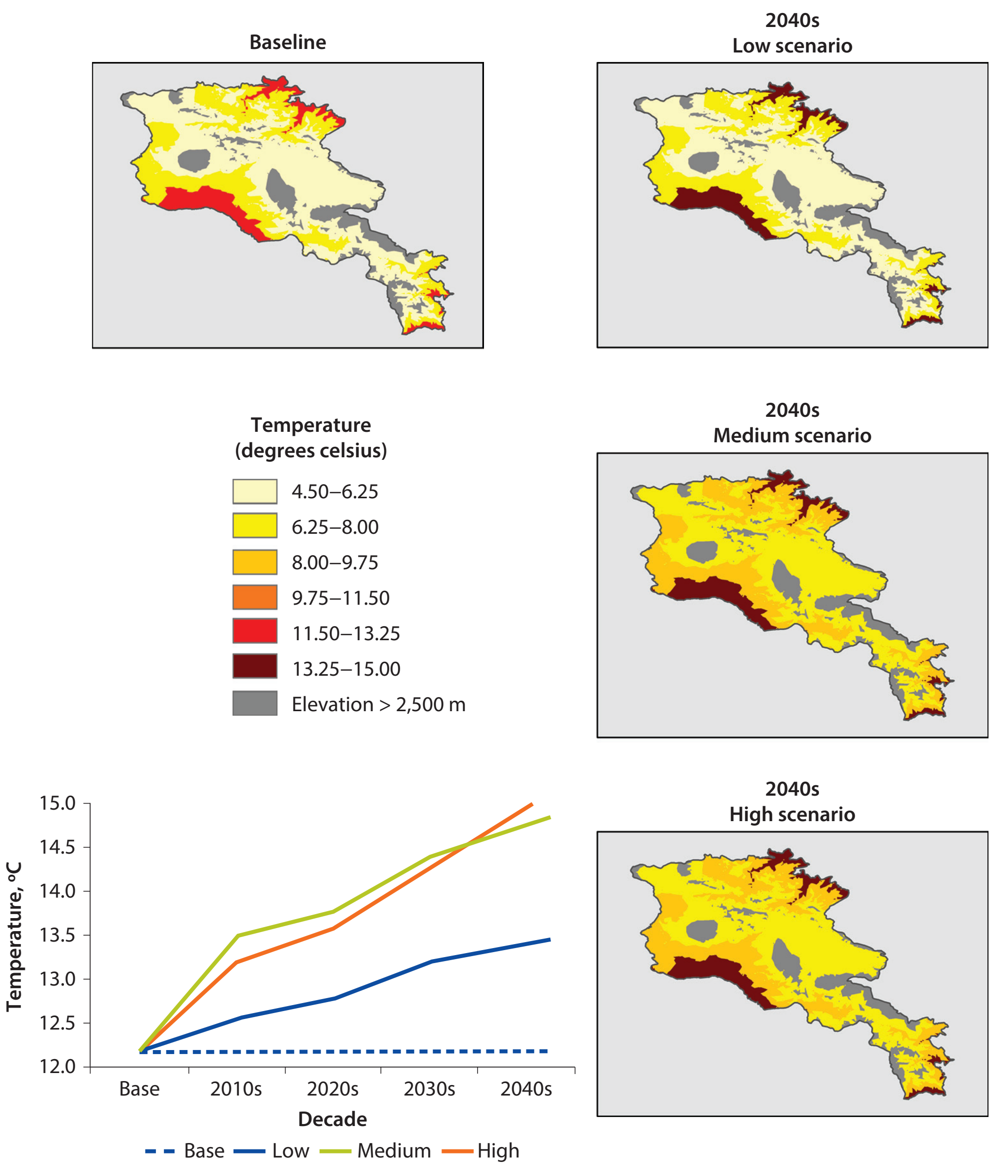
The data analysis supports the conclusion that the historical trend in temperature will accelerate in Armenia in the near future. Although there remains uncertainty in the degree of warming that will occur in the country, the overall warming trend is clear and is evident in all four agricultural regions. Although there remains uncertainty in the degree of warming that will occur in Armenia, the overall warming trend is clear and is evident in all three agricultural regions, with average warming over the next 50 years for the medium scenario of about 2.6°C, much greater than the increase of less than 0.85°C observed over the last 80 years (UNFCCC 2010). 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.

In all scenarios, the warming trend relative to current conditions is about the same magnitude across the three agricultural regions. However, the range of current temperatures across the agricultural regions is quite large. For example, average temperatures in the Mountainous agricultural region could be as much as 8°C higher than those in the Lowland agricultural region.

*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 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.

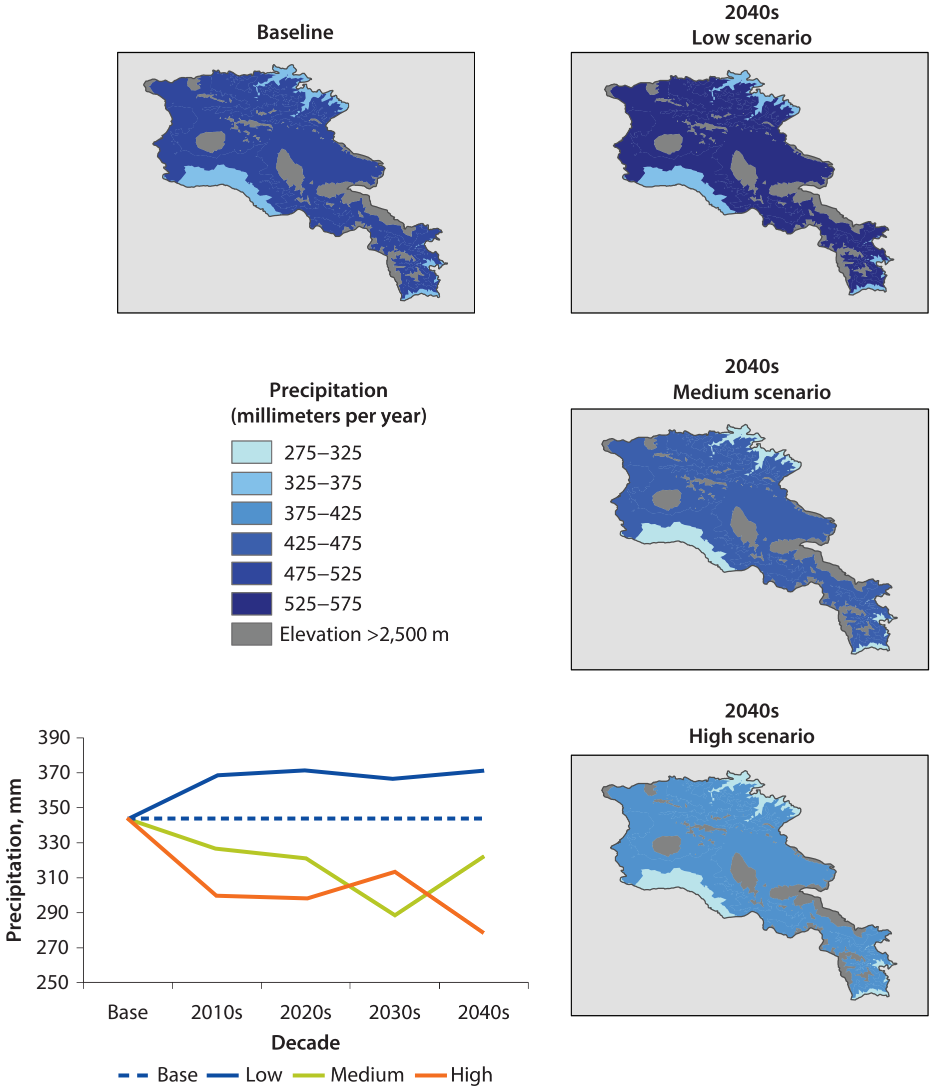
Precipitation changes are much more uncertain than temperature changes, as indicated when comparing map 2.3 with map 2.4. The Medium Impact Scenario

**Map 2.3 Effect of Climate Change on Annual Average Temperature from 2010 to 2050 for Low, Medium, and High Impact Climate Scenarios**




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

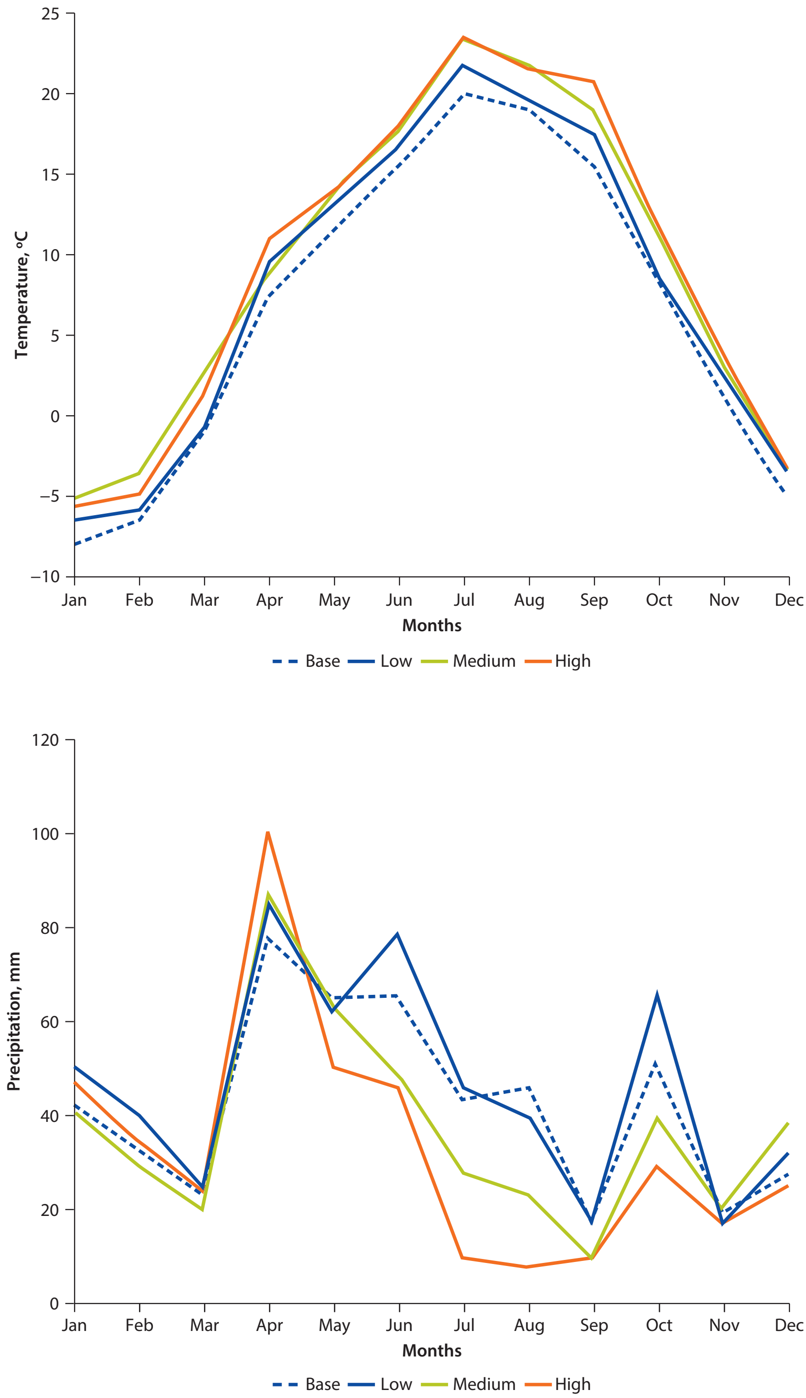
**Map 2.4 Effect of Climate Change on Average Annual Precipitation from 2010 to 2050 for the Climate Scenarios**




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

indicates a decline in precipitation nationally of about 52 millimeters per year, with most of this decline occurring in the Intermediate agricultural region. The range of precipitation outcomes across the Low and High Impact alternative scenarios, however, is large, ranging from a modest increase under the Low Impact scenario to an almost 19 to 28 percent decline under the High Impact scenario. Uncertainty at the regional level is even higher, and annual precipitation declines in the highest elevation agricultural region could be as large as 144 millimeters per year.

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




*Source:* World Bank data.

The yearly averages, however, are less important for agricultural production than the seasonal distribution of temperature and precipitation. For temperature, increases are highest in the period of July to October relative to current conditions. This summer temperature increase can be as much as 5°C in the Intermediate agricultural region of Armenia, when temperatures are already the highest. In addition, forecast precipitation declines are greatest in the key July to August period, when precipitation is already near its lowest. Figure 2.2 presents the monthly baseline and forecast temperatures and precipitation for the Intermediate 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 (see map 2.4), rainfall events are expected to be more variable, with a high probability of daily to multiday events being larger and less frequent. For the agriculture sector in Armenia, 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 (see previous discussion in the Overview section earlier in this chapter). Less serious flood events can reduce crop productivity. Prolonged waterlogging is detrimental to many crops.

## Note

1. Note that the National Statistical Service of the Republic of Armenia (http://www.armstat.am/en/) reports higher estimates, but appears to include a broad range of value-added agribusiness as well, which are excluded from FAOSTAT compilations.


http://dx.doi.org/10.1596/978-1-4648-0147-1

CHAPTER 3

# Impacts of Climate Change on Armenia's Agricultural Sector

## Impacts on Crops and Livestock Systems in Armenia

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 3.1–3.3.

*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 Armenia, 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 are more negatively affected by climate change than irrigated crops. The Lowlands agricultural region has more pronounced negative effects, and effects are more moderate to positive at higher elevations.

*Low Impact scenario:* This scenario indicates for most crops a net negative impact across agricultural regions, but to a lesser extent than in the Medium and High scenarios, as the increased rainfall amounts provide more water available to the plants. The higher temperatures also result in a higher evaporative water demand, counteracting the increased rainfall. Most of the crops are affected negatively by the decreased net water availability.

*Crops:* In general, the results indicate that among the seven crops selected at the beginning of the Study, only tomato, wheat, and watermelon, under some scenarios, experience increased yields, and those only in the mountainous region (where the absolute yields of tomato and watermelon are already low) and the Intermediate region, whereas the others (apricot, grapes, alfalfa, and potato), as well as *all* crops in the high production Lowland region, experience decreases in yields (tables 3.1 and 3.2). The decreases in yields are particularly significant for tomatoes and rainfed grapes in the Lowlands region (note that most apricots are


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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* | *Lowlands (%)* | *Intermediate (%)* | *Mountainous (%)* |
|---|---|---|---|---|
| Irrigated | Alfalfa | −5 | −7 | −2 |
| | Apricot | −5 | −5 | −5 |
| | Grapes | −7 | −5 | −5 |
| | Potato | −12 | −9 | −5 |
| | Tomato | −16 | 6 | 50 |
| | Watermelon | −12 | 10 | N/A |
| | Wheat | −6 | 1 | 38 |
| Rainfed | Alfalfa | −3 | −8 | −1 |
| | Apricot | −28 | −7 | −5 |
| | Grapes | −24 | −12 | −1 |
| | Potato | −14 | −14 | −8 |
| | Tomato | −19 | −8 | 34 |
| | Watermelon | −18 | 0 | N/A |
| | Wheat | −8 | 1 | 38 |

*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* | *Lowlands* | *Intermediate* | *Mountainous* |
|---|---|---|---|---|
| Irrigated | Alfalfa | −10 to −5 | −12 to 2 | 7 to 8 |
| | Apricot | −7 to −4 | −6 to −4 | −6 to −4 |
| | Grapes | −10 to −4 | −6 to −4 | −6 to −4 |
| | Potato | −15 to −6 | −14 to −4 | −6 to −4 |
| | Tomato | −20 to −7 | −1 to 8 | 33 to 50 |
| | Watermelon | −15 to −7 | 7 to 8 | N/A |
| | Wheat | −7 to −4 | −1 to 1 | 21 to 39 |
| Rainfed | Alfalfa | −10 to −4 | −12 to 4 | −6 to 6 |
| | Apricot | −36 to −12 | −12 to −4 | −6 to −4 |
| | Grapes | −35 to −7 | −20 to −6 | −4 to −2 |
| | Potato | −14 to −6 | −16 to −5 | −8 to −4 |
| | Tomato | −17 to −8 | −20 to 6 | −4 to 31 |
| | Watermelon | −14 to −11 | −10 to 5 | N/A |
| | Wheat | −5 to −5 | −1 to 1 | 15 to 21 |

*Source:* World Bank data.

*Note:* "N/A" indicates that the crop is not grown in the agricultural region specified.

irrigated, so the large rainfed apricot decline is likely to be less important). As expected, irrigation increases yields and reduces yield variability.

For the irrigated crops, the climate impact on irrigation water demand for specific crops was also assessed, as a key input to the water resources analyses (table 3.3, changes in crop irrigation water requirements are highlighted,


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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* | *Lowlands* | *Intermediate* | *Mountainous* |
|---|---|---|---|---|
| High | Alfalfa | 0 | 1 | –1 |
| | Apricot | 2 | 1 | 3 |
| | Grapes | 1 | 1 | 2 |
| | Potato | 2 | –2 | 0 |
| | Tomato | 0 | 0 | 3 |
| | Watermelon | 0 | 0 | N/A |
| | Wheat | 0 | 2 | –7 |
| Medium | Alfalfa | –1 | –1 | 1 |
| | Apricot | 0 | 0 | 1 |
| | Grapes | 1 | –1 | –1 |
| | Potato | 0 | 3 | 0 |
| | Tomato | 0 | 0 | –6 |
| | Watermelon | 0 | 0 | N/A |
| | Wheat | 1 | –1 | 2 |
| Low | Alfalfa | –1 | 2 | 0 |
| | Apricot | 0 | –1 | –1 |
| | Grapes | 0 | 0 | 0 |
| | Potato | –2 | 1 | –1 |
| | Tomato | 1 | 0 | –1 |
| | Watermelon | 1 | 0 | N/A |
| | Wheat | 1 | 0 | 5 |

*Source:* World Bank data.

*Notes:* Results are average changes in irrigation water requirements. Declines in requirements are shown in green and increases in requirements are shaded orange. "N/A" indicates that the crop is not grown in the agricultural region specified.

increases in water demand are noted in orange and decreases in green). For all of the scenarios, there is a small change in water required to maintain the current yields. Changes in irrigation water demand seem to be most variable in the Mountainous agricultural region, whereas changes in the Lowlands and Intermediate agricultural regions only range from –2 to +3 percent. The result is consistent with the climate scenarios for Armenia, which suggest increases in temperature (which increase irrigation water demand) coupled with increases in precipitation (which reduces irrigation water demand), at least for the Low and Medium impact scenarios. Precipitation is projected to decrease in the High Impact scenario, however, which leads to some increases in irrigation water demand. The relatively large extent of irrigation in Armenia means that even modest changes in irrigation water requirements in percentage terms can result in large increases in irrigation water demand in absolute terms.

**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


http://dx.doi.org/10.1596/978-1-4648-0147-1

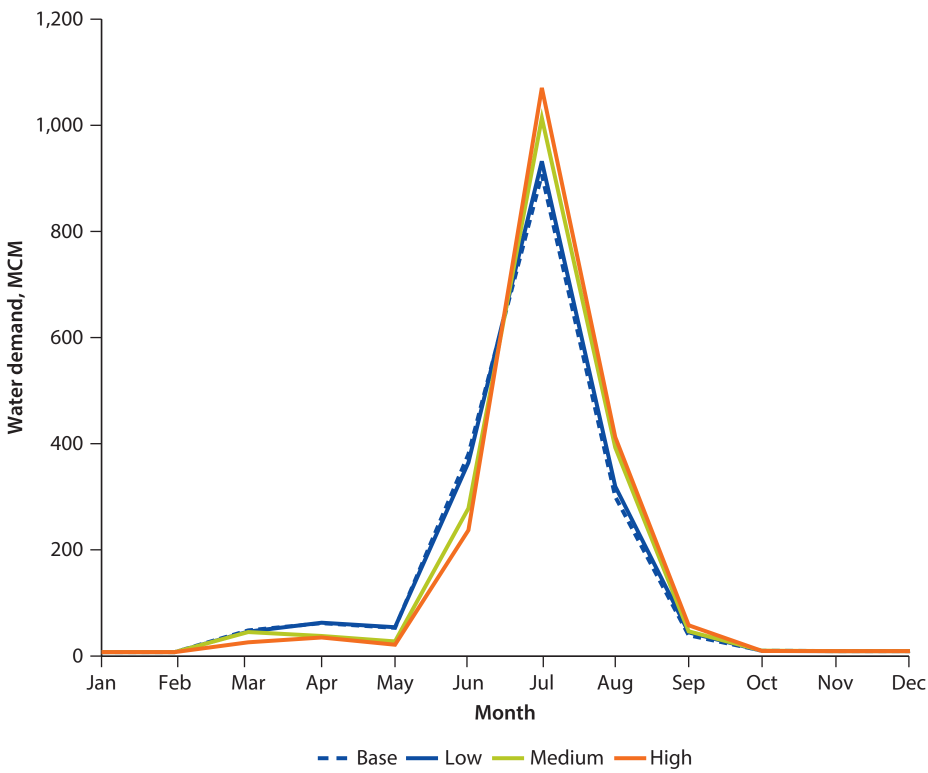
available methodologies are far less sophisticated than the crop and water resources modeling techniques applied in this Study, and are generally not appropriate to apply for Armenia. A screening analysis suggests that in the country, the direct effects of climate change on most livestock, in the absence of adaptation, could be negative and potentially large. The indirect effect of climate change on the subsector could be linked to the changes in alfalfa yields. Based on the impact assessment, alfalfa yields are expected to decrease in most areas.

## 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 Armenia for the current baseline, and under the three climate scenarios for the 2040s are presented in figure 3.1. In the presence of

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




*Source:* World Bank data.

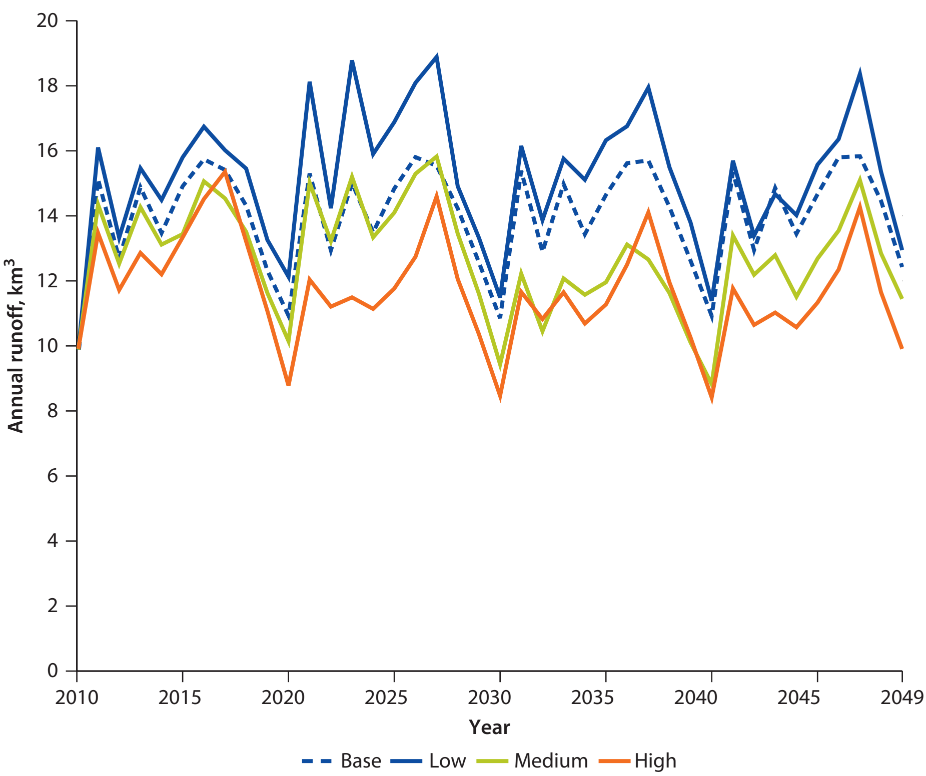

http://dx.doi.org/10.1596/978-1-4648-0147-1

higher spring temperatures, crops demand less water in June, but more water during the period of July–September.

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 scenarios, a significant decline in river runoff is projected during the late summer months, when reservoir storage volume is the lowest. However, in the same period crop water demand remains high. Across the five basins, similar patterns are observed in the changes of flow.

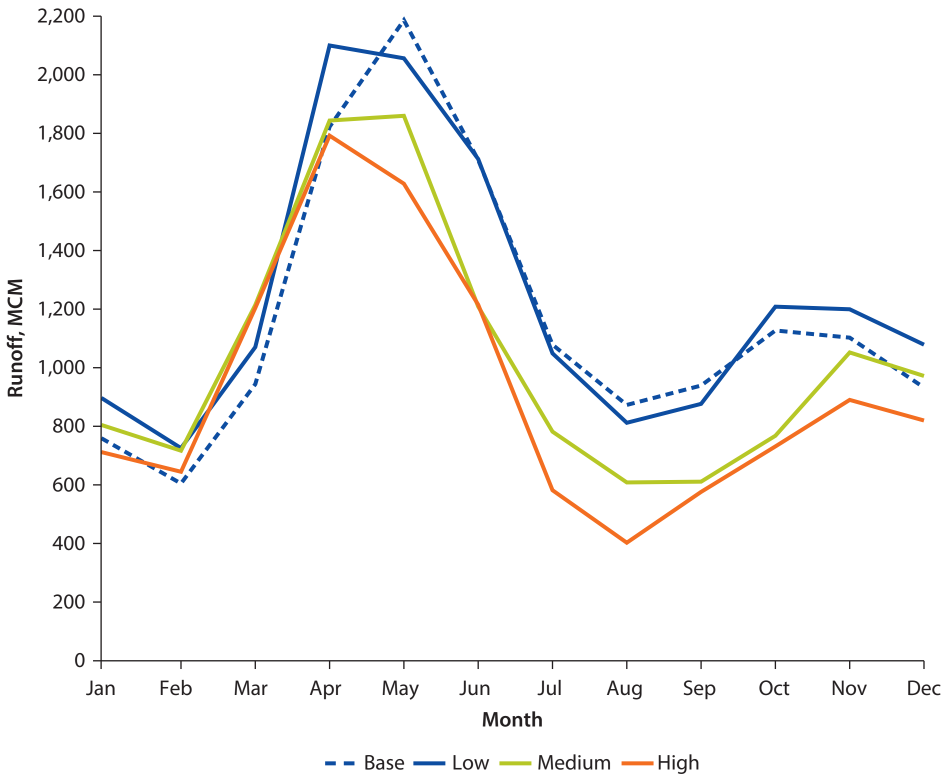
**Figure 3.2 Annual Runoff for All Armenian Basins, 2011–50**




*Source:* World Bank data.


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Figure 3.3 Mean Monthly 2040s Runoff for All Armenian Basins**




*Source:* World Bank data.

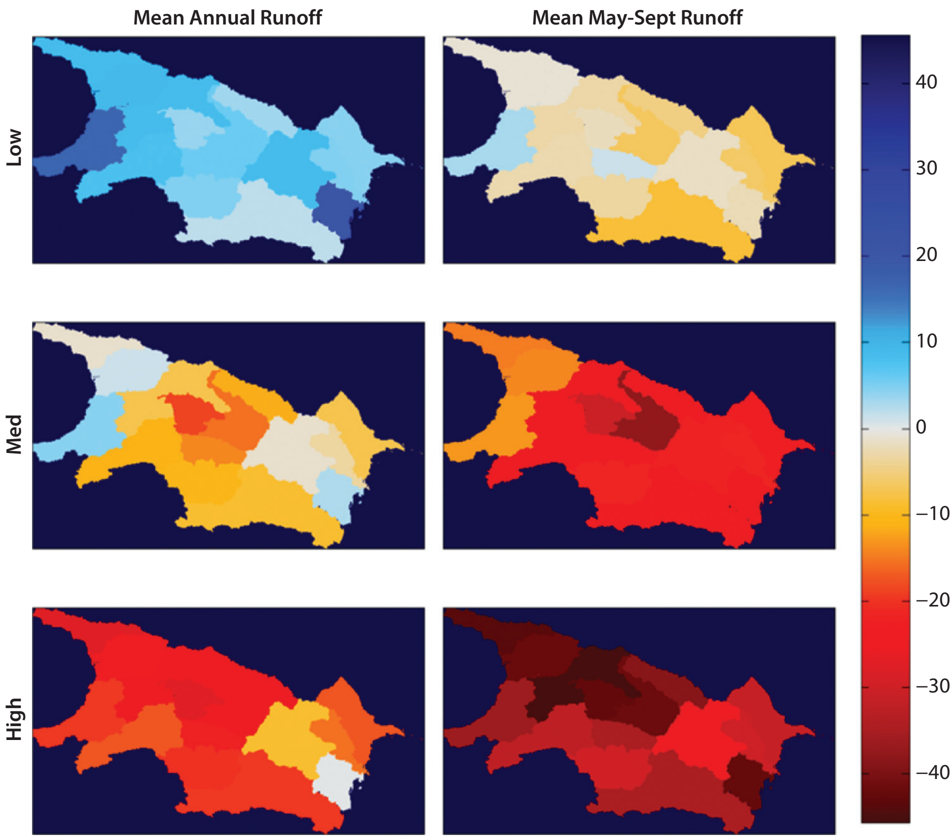
The mean percentage change in runoff from the historical baseline to the 2040s under the three climate scenarios and across the 15 basins in the Southern Caucasus is presented in map 3.1. The set of maps on the left show the change when all months of the year are considered, and those on the right indicate 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 Armenian basins across all of the scenarios (except for Hrazdan under the Low Impact scenario) show reduced mean runoff during the irrigation season.

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 basins under the baseline and three climate scenarios in the 2040s.

Under the four scenarios, demands are met in the 2040s in all but one of the six basins. Under the historical baseline, 20.6 percent of irrigation demands within the Upper Araks are not met, which because the Upper Araks is a large


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Map 3.1 Mean Percentage Change in 2040s Runoff Relative to the Historical Baseline (left: all months, right: the period from May to September)**




*Source:* World Bank data.

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

*thousand cubic meters and percent of irrigation water demand in the basin*

| | *Climate Scenario* | | | |
|---|---|---|---|---|
| *Basin* | *Base* | *Low* | *Medium* | *High* |
| Upper Araks | 121.9 (20.6%) | 140.4 (23.2%) | 273.3 (44.6%) | 346.4 (55.4%) |
| Debed | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Arpa/Nakhichevanchay | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Hrazdan | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Iori | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Vorotan/Karasu | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Total | 121.9 (7.0%) | 140.4 (7.9%) | 273.3 (15.3%) | 346.4 (19.2%) |

*Source*: World Bank data.


http://dx.doi.org/10.1596/978-1-4648-0147-1

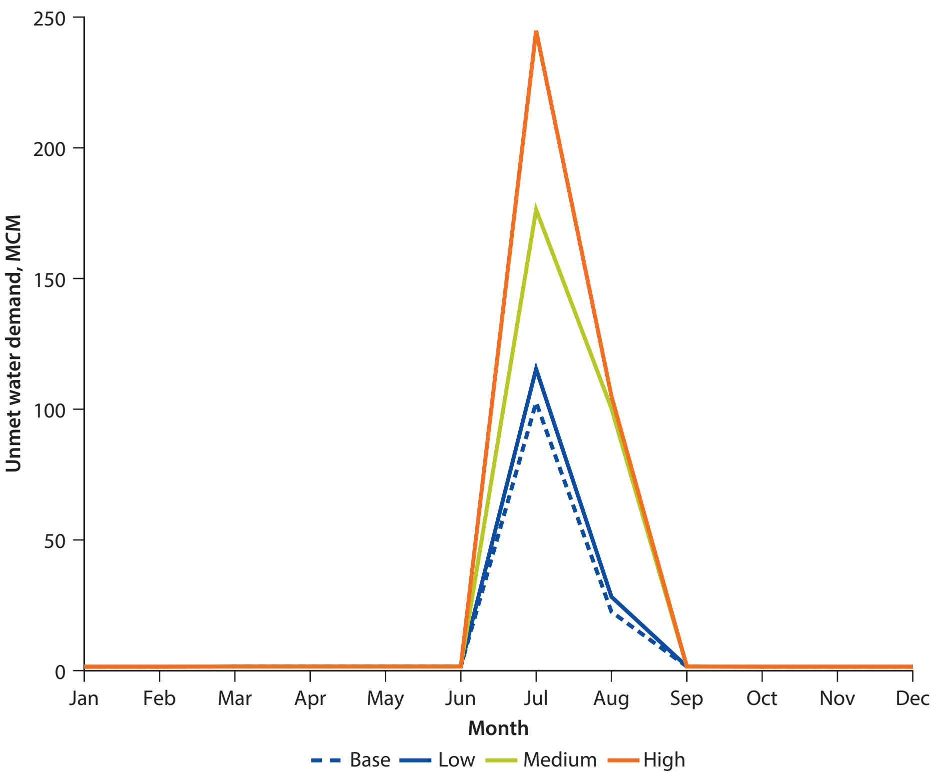
basin which supports a significant portion of Armenian irrigated agriculture, translates to 7.0 percent of overall national Armenian irrigation demands.

Under climate change, overall irrigation shortages across all basins are projected to increase to 7.9 percent under the low impact scenario, 15.3 percent under the medium impact scenario, and 19.2 percent under the high impact scenario by the 2040s. Under the Medium and High Impact scenarios, over 44 percent of irrigation demands are unmet in the Upper Araks basin. Although mean annual runoff increases in the low impact scenario, unmet demands rise in all scenarios relative to the baseline because, as described above, irrigation demands are higher and available runoff is lower during the summer months. This effect is evident in figure 3.4 that indicates mean monthly unmet irrigation demand.

### *Irrigation Water Shortages*

In order to evaluate how crop yields may be affected by reductions in basin-level water availability, the results of the crop and water impact analyses were combined. The Food and Agriculture Organization (FAO) crop sensitivity factors are used to estimate the change in yield resulting from a reduction in

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




*Source:* World Bank data.

water availability for each crop, unique agricultural region-basin area, and climate scenario. This information was combined with basin-level water deficits from WEAP to adjust mean changes in crop yields (see tables 3.1 and 3.2). In doing this it was assumed that each farm will receive the percentage of water available at the basin level based on the water deficits projected by WEAP under three impact scenarios (table 3.4). For example, WEAP projects an irrigation water deficit of 44.6 percent in the Upper Araks basin under the medium climate scenario in the 2040s; from this was assumed that each farm in the Upper Araks basin receives 55.4 percent of the water necessary to meet all irrigation needs. It is assumed that each farm in this basin receives only 44.6 percent of the water required to meet all irrigation demands. In all other basins, the results indicate that no irrigation water shortages will be experienced. An important caveat to this finding, however, is that shortages could result if the estimates of transboundary water use were to increase—currently transboundary water use estimates reflect only limited information for countries outside the study scope.

In the case of less water availability, depending on the irrigation method, a farmer can either irrigate a larger area in his farm providing less water (that is, irrigation deficit) than the required amount for the crop(s) or irrigate one or some parts of the field meeting the required amount for the crop(s) he selects, leaving the remaining part of the field unirrigated. At the high end of yield impacts, crops that have Ky values greater than one will have no irrigation deficiency. This will result in irrigating less area in the farm and the crop yield will fall by the water deficit percentage. At the low-end of yield impacts, crops that have Ky values less than one will experience yield reduction by the water deficit percentage multiplied by the Ky value.

The resulting mean decadal changes in irrigated crop yields, adjusted for 2040s water availability, are presented in table 3.5. 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 64 percent reduction in yield, which could be devastating to the region's agriculture.

## Armenia's Current Adaptive Capacity

Assessing adaptive capacity in Armenia's agricultural sector is challenging because adaptive capacity reflects a wide range of socioeconomic, policy, and institutional factors, at the farm, regional, and national levels. Considerations in determining the variation in adaptive capacity across the country also include current climatic exposure (described above), social structures, institutional capacity, knowledge and education, and access to infrastructure. Specifically, areas under marginal 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 require investments. Currently, the country ranks low in

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

| | *Agricultural region/river basin* | | |
|---|---|---|---|
| | *Lowlands* | *Intermediate* | *Mountainous* |
| *Crop* | *Upper Araks (%)* | *Upper Araks (%)* | *Upper Araks (%)* |
| ***Baseline*** | | | |
| Alfalfa | −21 | −21 | −21 |
| Apricot | −21 | −21 | −21 |
| Grapes | −18 | −18 | −18 |
| Potato | −21 | −21 | −21 |
| Tomato | −21 | −21 | −21 |
| Watermelon | −21 | −21 | N/A |
| Wheat | −21 | −21 | −21 |
| ***Low Impact scenario*** | | | |
| Alfalfa | −27 | −22 | −18 |
| Apricot | −26 | −26 | −26 |
| Grapes | −23 | −23 | −23 |
| Potato | −28 | −26 | −26 |
| Tomato | −28 | −17 | 2 |
| Watermelon | −28 | −17 | N/A |
| Wheat | −27 | −24 | −7 |
| ***Medium Impact scenario*** | | | |
| Alfalfa | −48 | −49 | −46 |
| Apricot | −48 | −47 | −47 |
| Grapes | −42 | −41 | −41 |
| Potato | −51 | −49 | −47 |
| Tomato | −53 | −41 | −17 |
| Watermelon | −51 | −39 | N/A |
| Wheat | −48 | −44 | −24 |
| ***High Impact scenario*** | | | |
| Alfalfa | −60 | −61 | −52 |
| Apricot | −59 | −58 | −58 |
| Grapes | −53 | −50 | −50 |
| Potato | −62 | −62 | −58 |
| Tomato | −64 | −56 | −33 |
| Watermelon | −62 | −52 | N/A |
| Wheat | −59 | −55 | −38 |

*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, and increases are shaded green. "N/A" indicates that the crop is not grown in the agricultural region specified. Estimates assume no $CO_2$ fertilization effects.

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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

### *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 Armenia, 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 current agricultural extension service is not oriented toward ameliorating risks from climate*. While many farmers are aware of the extension service, only a small portion make use of their services. Additionally, the current extension service has limited capacity to advise on adapting agricultural systems to the climate risks outlined in the Study. This is a common finding among the countries included in the broader regional study, and is also not uncommon in many other countries. Additionally, farmers indicate that demonstration plots and greater access to information would be helpful. In agriculture, climatically induced risks are part of the system. Farmers are risk averse but they need knowledge and experience and other means (finance, mechanization, inputs) to manage the risks. Farmers need tailored advice for a wide range of topics including ameliorating risks from climate, but there is no effective and efficient extension system in place to provide the service on required scale and quality.

*Agricultural research capabilities have few connections to extension*. Agricultural research institutes, remain an important part of the Armenian agricultural system, 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. Further, research could be better focused on leveraging advances in seed varieties and farming practices shown to be effective in other countries, and coordinating with the extension service to demonstrate these results locally, particularly for small-scale farmers.

*Crop insurance is not affordable or not available.* Both hail and spring frost are major issues for farmers in the region, with estimates of annual losses on the order of 10 percent of annual production for some crops, which may account for as much as US$100 to US$150 million in annual losses nationwide (WWF 2008, Kalantaryan, personal communication). Farmers are unable to afford insurance, but subsidized programs would greatly stabilize their incomes and improve their capacity to re-invest in farming.

*Financial and credit issues.* A decline in agricultural output in 2010 stemmed, in part, from economic troubles. Factors included limited access to credit for


http://dx.doi.org/10.1596/978-1-4648-0147-1

farmers, a 32 percent decrease in agricultural support from the Armenian government, and a shortage of fuel, fertilizer, and quality seeds. Additionally, little governmental support to farmers in marginal areas existed. Attempts to address these problems are being made; for example, new governmental agricultural policies aim to boost local production by subsidizing credit rates, resulting in low credit rates for farmers, with the lowest rates for the poor. Subsidies have been in place for irrigation for some time, and more recently, in 2006, the government initiated a new subsidy for agriculture aimed at convincing farmers to use non-cultivated land lots and improve competitiveness of small farms. The "Wheat Seed Production Development Program" allocated US$1.44 million to produce high-quality seeds from 2010 to 2014. Nonetheless, farmers consistently note that credit for equipment and agricultural inputs is not available.

*The ability to collect, generate, and provide meteorological data to farmers is inadequate if not lacking.* Current capacity in hydrometeorological institutions needs to be improved, as farmers lack basic climatic and meteorological data for their regions—except weather forecasts on public TV—that they can utilize in operational farm management. Specifically, most farmers do not have the financial means to obtain specific hydromet services.

*Agricultural marketing is a common problem*. More must be done to improve markets if the agricultural sector's potential is to be realized in Armenia. Although a number of projects that targeted marketing were financed by international donors, still the problem prevails. In the country, a large portion of farmers involved in subsistence and semi-subsistence farming and are frequently exposed to marketing problems. The farming community as a whole complain about 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.

### Adaptive Capacity at the Farm Level: Farmer Consultations

An early consultation was carried out in Yeghegnadzor, in the Intermediate agricultural region, to inform an assessment of adaptive capacity. Farmers and local government officials from nearby villages attended the meetings that were held in April 2012.

Surveys administered at the consultation revealed that the vast majority of farmers were concerned with drought. Other concerns included changes in the cropping season; worsening hail and winter frost; warming, including average and high temperature increases; continued increase in crop water demand, where increased use is a social issue as people have to pay more for water; increased risk of agricultural pests, diseases, and weeds; and increased irrigation requirements.


http://dx.doi.org/10.1596/978-1-4648-0147-1

Several points were identified during the farmer consultations that need to be addressed to enable them to cope with impacts of climate change. These are:

*Hydromet forecasts.* Farmers currently use forecasts made available through the television, but these are aimed at too broad a geographic area and do not provide information specific for agriculture (for example, information that would allow them to know when to apply pesticides, when to irrigate, when to plant). Today, many farmers still plant when the snow is at a certain level on Mount Ararat.

*Extension services.* The extension service run by the government is active and well funded, but few farmers seem to use the trainings or other educational opportunities offered by the service. The farmers made it clear, however, that they want demonstration plots and greater access to information through extension.

*Seed selection.* Some farmers claimed that crop varieties that they use are tolerant to weather changes, but most reported on the contrary. Generally, they indicated that they prefer their own seeds that they clean and repeatedly use in years. However, they are not aware of the fact that as a result of this repeated cycle the genetic purity and identity can be lost over the years and decrease in productivity is inevitable. They claim that the varieties provided by the extension service are not adapted to the local agro-ecology. Ideally, the service would provide heat and drought tolerant crops to address anticipated warmer and drier conditions.

*Crop insurance.* While insurance does exists, it is too expensive for farmers. Both hail and spring frost are major issues for farmers in the region, with estimates of annual losses on the order of 10 percent of annual production for some crops, which may account for as much as US$100 to US$150 million in annual losses nationwide.[1] Subsidized programs for crop insurance would greatly stabilize their incomes and improve their capacity to re-invest in farming.

*Bank Loans.* Most farmers indicate they have access to high interest short-term bank loans for agricultural development, but it is difficult to obtain low interest long-term bank loans for agricultural development.

*Infrastructure.* To moderate temperatures and improve yields, some farmers have been constructing greenhouses. Few farmers attending the stakeholder meeting had greenhouses, as most of these farmers were smallholders.

### Adaptive Capacity in Crop Production

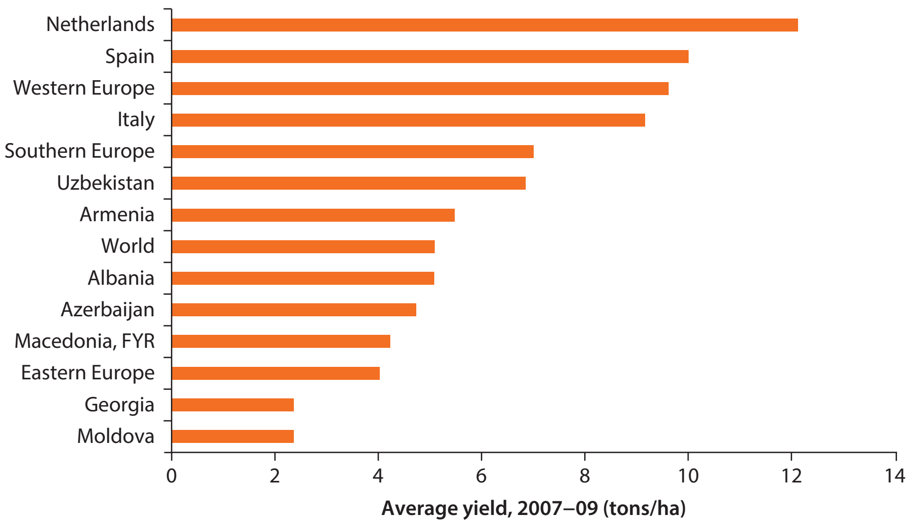
One observable indicator of adaptive capacity is the degree to which current agricultural crop yields and practices keep pace with those in other countries with similar agro-ecologies for key crops. The result of such an assessment gives a sense of "adaptation deficit," or the degree to which agricultural systems may be not be adapted to current climate. If crop yields are relatively low by inter-


http://dx.doi.org/10.1596/978-1-4648-0147-1

national 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 Armenia, were reviewed through analysis of FAO data.

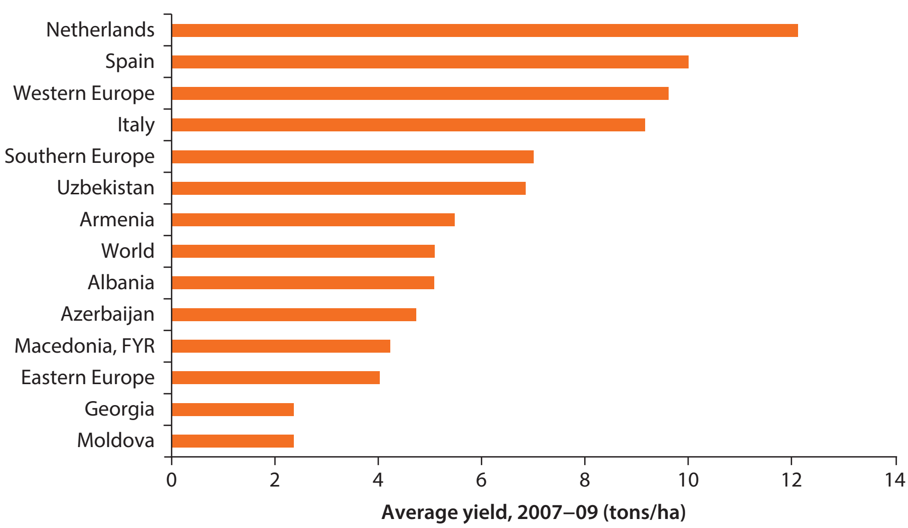
*Wheat Yields:* FAO statistics indicate that in Armenia, the average of irrigated and rainfed wheat yield is about 2.4 ton/ha. This is less significantly less than

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




*Source:* FAOSTAT 2012.

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




*Source:* FAOSTAT 2012.

European (5.4 ton/ha) that has more favorable climate and soils and slightly less than World averages (2.9 ton/ha in 2010). (figure 3.5) Sutton et al. (2008) 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 Armenia. The Study indicated that the adaptation options for improving wheat yields have very high benefit-cost (B-C) ratios.

*Grape Yields:* Average yields are about 14.4 ton/ha in Armenia, which is almost 180 percent higher than Eastern European countries and 60 percent higher than the world average of 9 ton/ha (figure 3.6).

## Note

1. Estimates of annual losses are from WWF Norway (2008), and from discussion during the first farmer consultation and independent consultant Tigran Kalantaryan, who facilitated the farmer consultations.


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 three options and detailed analyses were conducted. The second group comprised five


http://dx.doi.org/10.1596/978-1-4648-0147-1

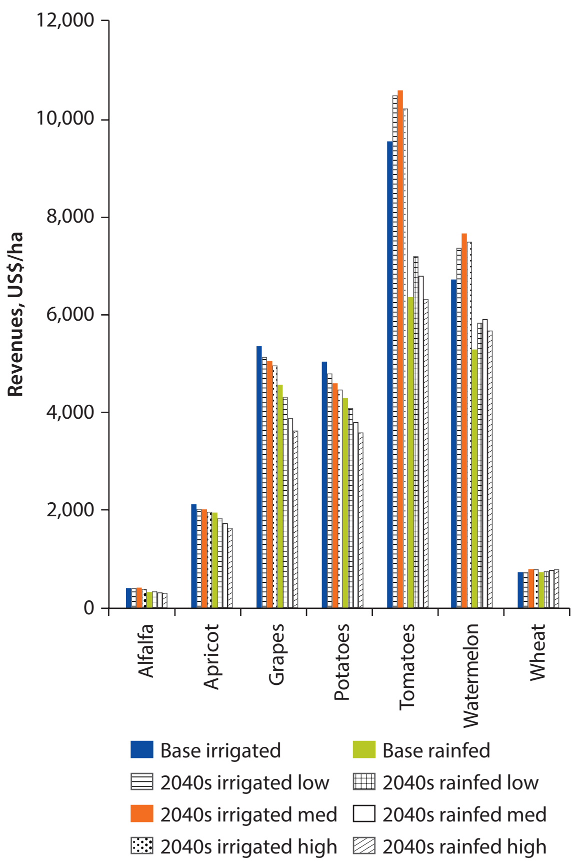
options but the analyses carried out were comparatively less detailed. The options in the first group are the following: (i) improving irrigation capacity and efficiency by new investments or rehabilitation to optimize application of irrigation water; (ii) shifting to new crop varieties; and (iii) optimizing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

**Figure 4.1 Estimated Crop Revenues Per Hectare in the 2040s Before Adaptation Actions**




*Source:* World Bank data.

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 highest-value crops now, and in the future, are tomatoes and watermelon. Irrigated grapes and irrigated potatoes 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*

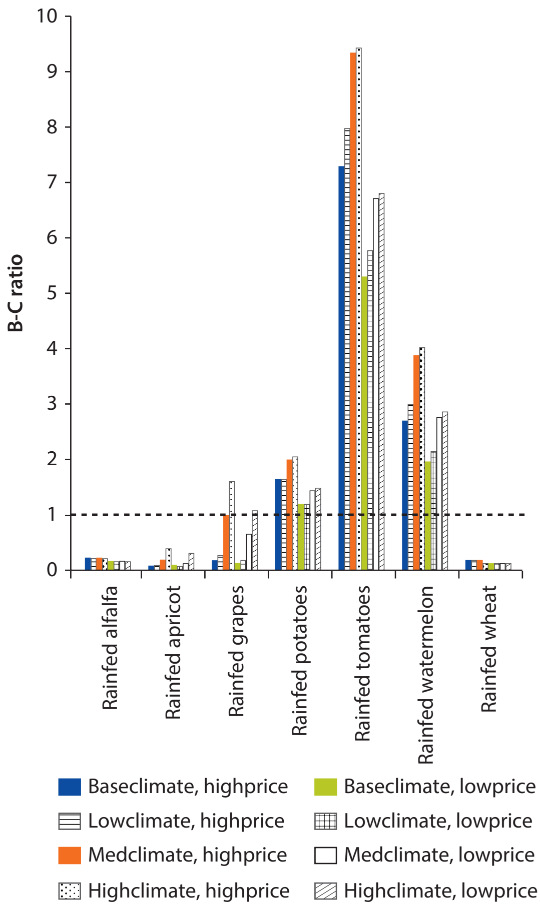
Each adaptation option detailed below was assessed in terms of benefits and costs, and the results are displayed in graphs that show the B-Cratios for the baseline and each climate scenario, and under two price scenarios. The dashed line near the bottom of the graph shows a B-C ratio of one. Bars that 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 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 Intermediate agricultural region for each of the focus crops. The results in these figures indicate that B-C ratios are relatively high in this agricultural region for tomatoes, watermelon and potatoes, and lower for grapes, alfalfa, apricots and wheat. Generally, B-C ratios are highest under both high impact climate scenarios, and are significantly higher than the adaptation options under base climate conditions. Even where the B-C ratios are low, the results are not meant to imply that farmers should switch to high-value crops in all instances, or that irrigation does not have climate risk reduction benefits for other crops. Rather, the screening level analysis suggests that in areas where high-value crops are not being grown as part of the typical rotation, rehabilitated irrigation infrastructure should be carefully analyzed before moving forward.

*Option 1.2: 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 varieties for the Intermediate agricultural region are presented in figure 4.5. 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 Armenian fields), supported by extension to transfer the knowledge to farmers.


http://dx.doi.org/10.1596/978-1-4648-0147-1

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

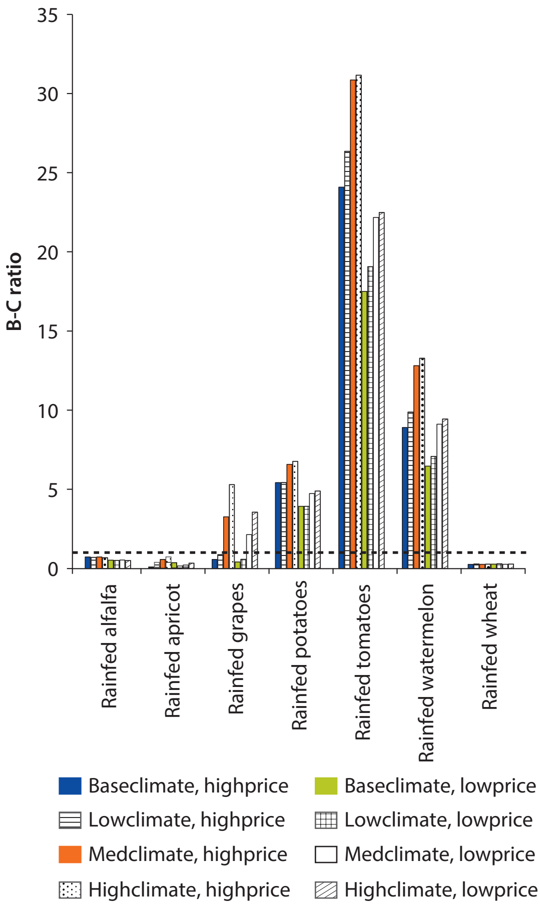



*Source:* World Bank data.

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 Intermediate 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 4.5, B-C ratios are highest for irrigated tomatoes, with high ratios of up to over 100 to one. B-C ratios for all crops other than alfalfa are

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

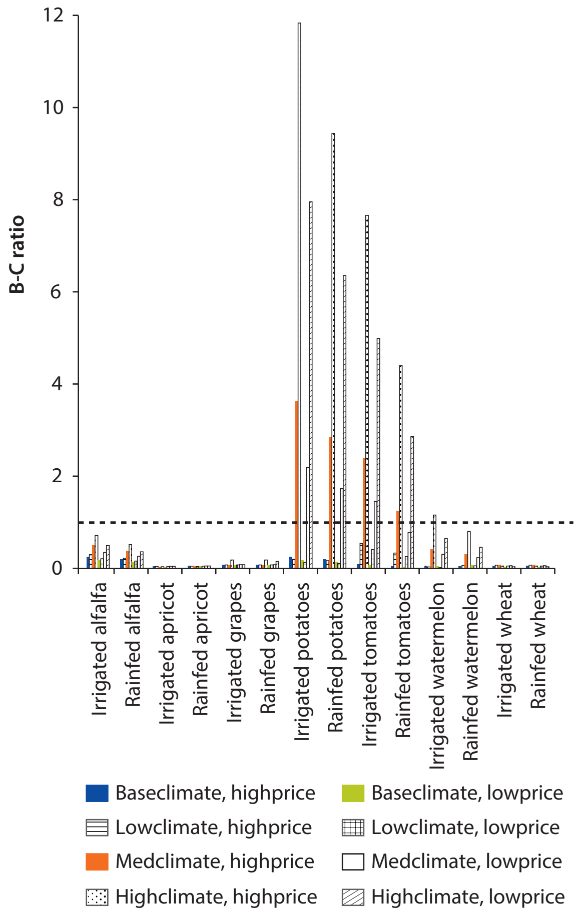



*Source:* World Bank data.

significantly greater than one, with the highest being apricots, watermelons, then grapes and potatoes. 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 1.3: Optimizing Fertilizer Application*. The results for optimized application, relative to current use of fertilizer for the Intermediate Agricultural region are presented in figure 4.6. The graph shows high B-C ratios for all crops aside from alfalfa and wheat are above 1, with B-C ratios reaching nearly 45 to 1. Grapes have the highest B-C ratio but the B-C ratios for tomatoes, apricots, watermelon and potatoes are also very high. 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

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



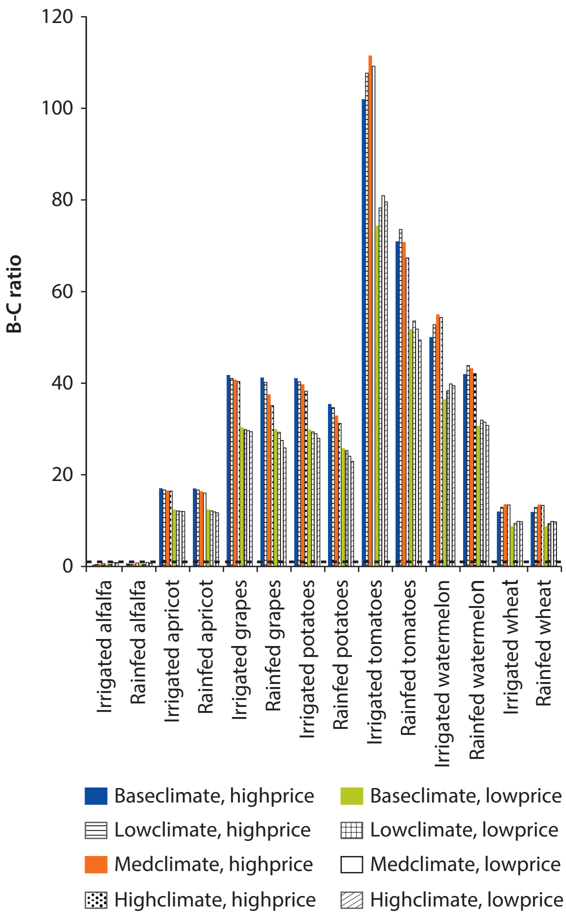

*Source*: World Bank data.

option are greater than one for a broad range of crops, when the above mentioned other nonquantified costs are considered, the B-C ratio may become 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.

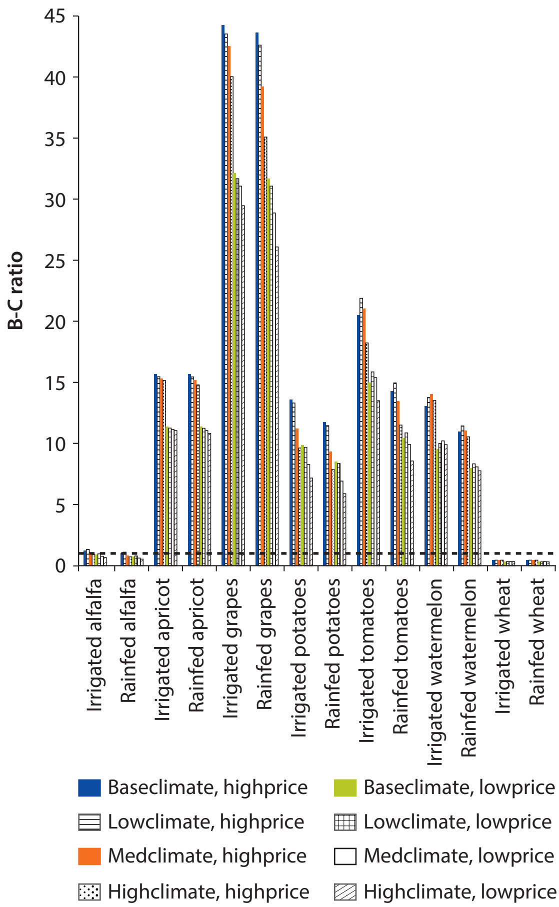
**Figure 4.5 Illustrative Benefit-Cost Analysis for Optimizing Crop Varieties in the Intermediate Agricultural Region**




*Source:* World Bank data.

*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 (Sutton, Srivastava, and Neumann 2013), it was estimated that the annualized capital and annual operation and maintenance (O&M) improvements in hydrometeorological capacity could cost US$0.74 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

**Figure 4.6 Illustrative Results of Benefit-Cost Analysis for Optimized Fertilizer Use in the Intermediate Agricultural Region**




*Source:* World Bank data.

of less than 0.05 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.

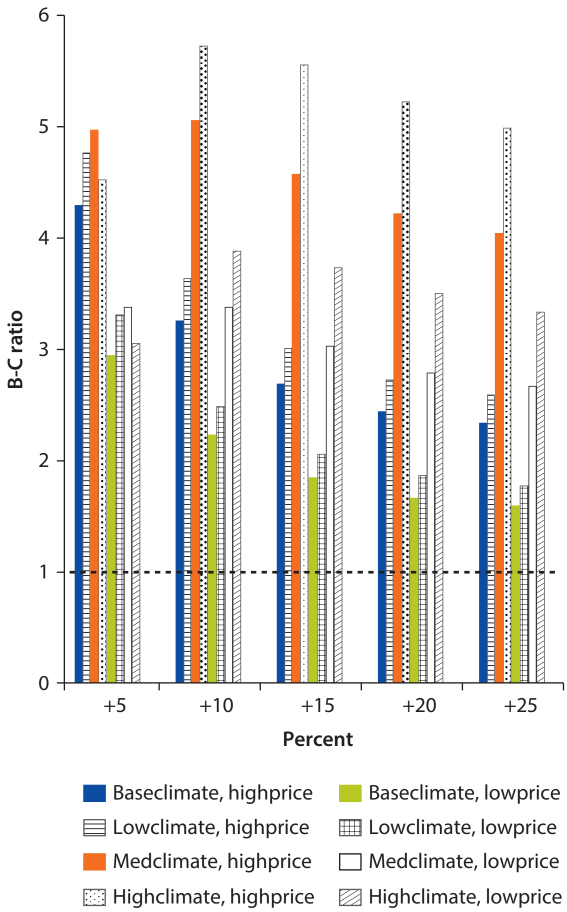
To estimate costs for an enhanced extension service, the Study used information from broader regional analyses. An assumption was made based on prior regional work that about 20 percent of the total number of farmland hectares in Armenia could benefit from improved extension that a reasonable program 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$3.11 (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 0.9 percent.

The yield increase required to justify the program is achievable in Armenia, 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, International Food Policy Research Institute (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 Upper Araks basin. Improving irrigation efficiency was examined from the baseline of 50 percent (based on Food and Agriculture Organization [FAO] data) in five percent increments, up to a high of 75 percent. The results are presented in figure 4.7. The benefit is increased profit (not revenue) from additional irrigation water to bring back to cultivation additional acreage—for example, under the medium impact climate change scenario in the Upper Araks basin, a five percent increase in efficiency makes available an additional 113 million cubic meters of water to meet irrigation demand, reducing the unmet demand from 46 percent to 32 percent, and allows an additional 19,000 hectares to be irrigated each year by the 2040s. In the Upper Araks basin it appears that the costs of substantial improvements in basin-wide water efficiency are justified by the yield-enhancing benefits of additional irrigation potential for five to 25 percent increases in efficiency.

*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.

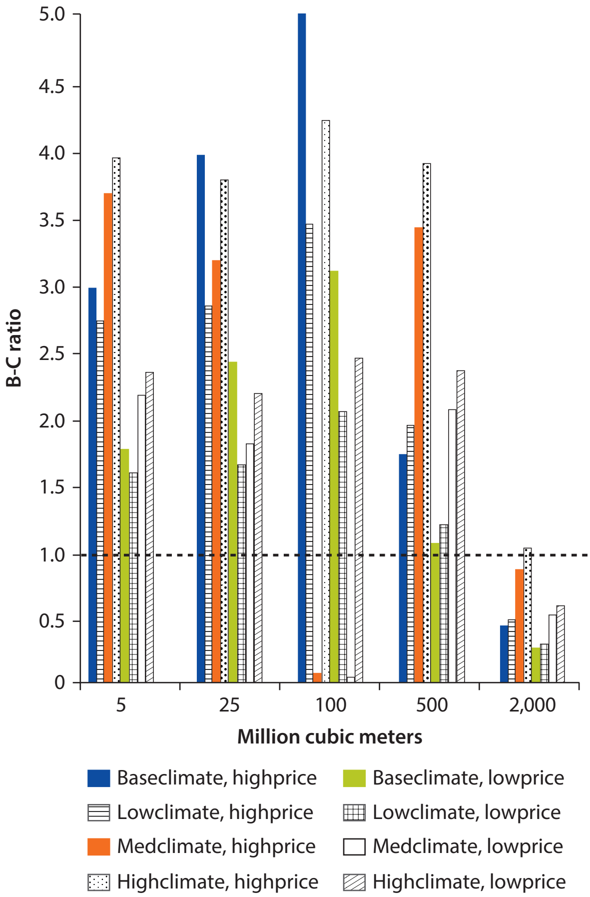
**Figure 4.7 Impact of Optimizing Basin-wide Irrigation Efficiency in the Upper Araks Basin**




*Source:* World Bank data.

The range of results is presented in figure 4.8 for the Upper Araks basin where continued water shortages are forecast with climate change. B-C 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 showing favorable B-C ratios in the Upper Araks basin for storage capacity of 5, 25, and 500 million cubic meters across scenarios, and showing favorable B-C ratios for storage of 100 million cubic meters except under the medium impact scenario, while a storage level of 2,000 million cubic meters has a B-C ratio less than 1. 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 Upper Araks basin, these relationships imply that with an increase of 100 million cubic meters of storage, about 300 additional hectares can be irrigated for each one million cubic meters of storage capacity added. This value decreases above the 500 million cubic meter level.

**Figure 4.8 Preliminary Analysis of the Benefits and Costs of Water Storage in the Upper Araks Basin**




*Source:* World Bank data.

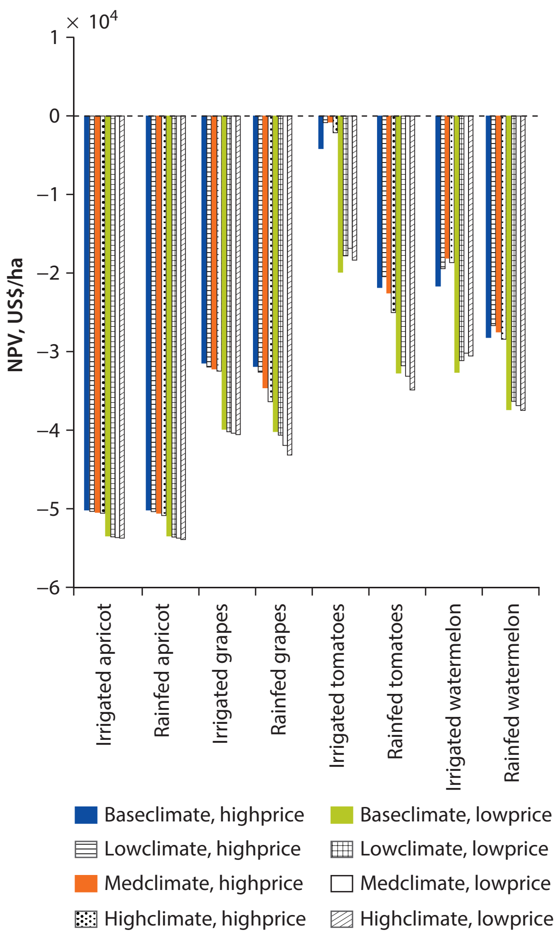
These results should be considered with caution, however, as they reflect only a zero-order analysis of the viability of storage across the basin, at a very coarse resolution, without the benefit of detailed study of the feasibility of constructing additional water storage. It should also be noted that 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 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 Intermediate Agricultural region. The result is illustrated in figure 4.9 below, in net present value terms. For all scenarios, net present values are negative, reflecting costs in exceeding benefits. The B-C ratios for this

**Figure 4.9 Illustrative Results of Net present value Analysis for Hail Nets to Protect Selected Crops in the Intermediate Agricultural Region**




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

measure never exceed one for any combination in any agricultural region. Contrary to the expectations of the Armenian farmers this analysis reflecting local 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. B-C 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 five to seven adaptation measures with the highest overall net benefits. The results indicate

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

| *Description of recommended adaptation measure* | *Crop focus* | *Illustrative present value economic results per hectare (000 2009 US$ 2015–50)* | | | |
|---|---|---|---|---|---|
| | | *Estimated revenue gain* | *Estimated costs* | *Net revenues* | *Notes* |
| Improve varieties | Irrigated apricot | $4.3 to 6 | $0.40 | $3.9 to 5.7 | Costs are for provision of seed and extension to support uptake |
| | Rainfed apricot | $2.7 to 4.6 | | $2.3 to 4.2 | |
| | Irrigated grapes | $10 to 15 | | $10 to 14 | |
| | Rainfed grapes | $4.7 to 8.3 | | $4.3 to 7.9 | |
| | Irrigated potatoes | $10 to 14 | | $9.6 to 14 | |
| | Rainfed potatoes | $6.8 to 10 | | $6.5 to 9.7 | |
| | Irrigated tomatoes | $27 to 38 | | $27 to 38 | |
| | Rainfed tomatoes | $11 to 15 | | $11 to 15 | |
| | Irrigated watermelon | $14 to 19 | | $14 to 19 | |
| | Rainfed watermelon | $7.6 to 11 | | $7.2 to 11 | |
| | Irrigated wheat | $3.7 to 5.1 | | $3.3 to 4.8 | |
| | Rainfed wheat | $3.6 to 5 | | $3.2 to 4.7 | |
| Rehabilitate old irrigation systems | Rainfed apricot | $7.4 to 16 | $2.70 | $4.7 to 13 | |
| | Rainfed grapes | $35 to 58 | | $33 to 56 | |
| | Rainfed potatoes | $21 to 29 | | $18 to 27 | |
| | Rainfed tomatoes | $82 to 120 | | $80 to 120 | |
| | Rainfed watermelon | $46 to 66 | | $44 to 63 | |
| Create new irrigation systems | Rainfed apricot | $7.4 to 16 | $8.80 | $–1.4 to 7.3 | |
| | Rainfed grapes | $35 to 58 | | $27 to 50 | |
| | Rainfed potatoes | $21 to 29 | | $12 to 21 | |
| | Rainfed tomatoes | $82 to 120 | | $73 to 110 | |
| | Rainfed watermelon | $46 to 66 | | $38 to 57 | |

*table continues next page*


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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 (000 2009 US$ 2015–50)* | | | |
|---|---|---|---|---|---|
| | | *Estimated revenue gain* | *Estimated costs* | *Net revenues* | *Notes* |
| Optimize application of irrigation water | Irrigated alfalfa | $0.3 to 0.5 | $0.20 | $0.09 to 0.3 | Costs are for extension & hydromet |
| | Rainfed alfalfa | $0.2 to 0.4 | | $0 to 0.1 | |
| | Irrigated grapes | $0.3 to 2.6 | | $0.03 to 2.4 | |
| | Rainfed grapes | $0.1 to 1.1 | | $-0.09 to 0.8 | |
| | Irrigated potatoes | $4.4 to 9.2 | | $4.2 to 9 | |
| | Rainfed potatoes | $3 to 6.2 | | $2.8 to 6 | |
| | Irrigated tomatoes | $2.6 to 9.8 | | $2.3 to 9.5 | |
| | Rainfed tomatoes | $1 to 3.7 | | $0.7 to 3.5 | |
| | Irrigated watermelon | $0.7 to 3.1 | | $0.5 to 2.9 | |
| | Rainfed watermelon | $0.4 to 1.6 | | $0.1 to 1.4 | |
| Optimize fertilizer application | Irrigated apricot | $5.6 to 11 | $0.70 | $4.9 to 10 | Costs do not include environ. damages |
| | Rainfed apricot | $3.6 to 8.2 | $0.70 | $2.9 to 7.5 | |
| | Irrigated grapes | $5.4 to 24 | $0.70 | $4.7 to 24 | |
| | Rainfed grapes | $3.1 to 14 | $0.70 | $2.4 to 13 | |
| | Irrigated potatoes | $9.2 to 17 | $1.80 | $7.4 to 15 | |
| | Rainfed potatoes | $6.4 to 12 | $1.80 | $4.5 to 10 | |
| | Irrigated tomatoes | $13 to 24 | $1.80 | $11 to 23 | |
| | Rainfed tomatoes | $5.1 to 10 | $1.80 | $3.3 to 8.4 | |
| | Irrigated watermelon | $14 to 22 | $1.80 | $12 to 20 | |
| | Rainfed watermelon | $7.6 to 12 | $1.80 | $5.8 to 11 | |

*Source*: World Bank data.

**Table 4.2 Adaptation Measures with Highest Net Benefits: Intermediate Agricultural Region**

| *Description of recommended adaptation measure* | *Crop focus* | *Illustrative present value economic results per hectare (000 2009 US$ 2015–50)* | | | |
|---|---|---|---|---|---|
| | | *Estimated revenue gain* | *Estimated costs* | *Net revenues* | *Notes* |
| Improve varieties | Irrigated apricot | $4.3 to 6 | $0.40 | $4 to 5.7 | Costs are for provision of seed and extension to support uptake |
| | Rainfed apricot | $4.2 to 6 | | $3.9 to 5.7 | |
| | Irrigated grapes | $11 to 15 | | $10 to 14 | |
| | Rainfed grapes | $9.3 to 15 | | $9 to 14 | |
| | Irrigated potatoes | $10 to 15 | | $9.7 to 14 | |
| | Rainfed potatoes | $8.3 to 13 | | $7.9 to 12 | |
| | Irrigated tomatoes | $28 to 40 | | $28 to 40 | |
| | Rainfed tomatoes | $18 to 27 | | $17 to 26 | |
| | Irrigated watermelon | $14 to 20 | | $13 to 19 | |
| | Rainfed watermelon | $11 to 16 | | $11 to 15 | |
| | Irrigated wheat | $3.4 to 4.9 | | $3 to 4.5 | |
| | Rainfed wheat | $3.4 to 4.8 | | $3 to 4.5 | |

*table continues next page*


http://dx.doi.org/10.1596/978-1-4648-0147-1

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

| *Description of recommended adaptation measure* | *Crop focus* | *Illustrative present value economic results per hectare (000 2009 US$ 2015–50)* | | | *Notes* |
|---|---|---|---|---|---|
| | | *Estimated revenue gain* | *Estimated costs* | *Net revenues* | |
| Rehabilitate old irrigation systems | Rainfed grapes | $1.5 to 14 | $2.70 | $–1.1 to 11 | |
| | Rainfed potatoes | $10 to 18 | | $7.8 to 15 | |
| | Rainfed tomatoes | $51 to 83 | | $48 to 80 | |
| | Rainfed watermelon | $19 to 35 | | $16 to 33 | |
| Create new irrigation systems | Rainfed grapes | $1.5 to 14 | $8.80 | $–7.3 to 5.3 | |
| | Rainfed potatoes | $10 to 18 | | $1.7 to 9.2 | |
| | Rainfed tomatoes | $51 to 83 | | $42 to 74 | |
| | Rainfed watermelon | $19 to 35 | | $10 to 27 | |
| Optimize application of irrigation water | Irrigated potatoes | $0.03 to 2.7 | $0.20 | $–0.2 to 2.4 | Costs are for extension & hydromet |
| | Rainfed potatoes | $0.03 to 2.1 | | $–0.2 to 1.9 | |
| | Irrigated tomatoes | $0.09 to 1.7 | | $–0.1 to 1.5 | |
| | Rainfed tomatoes | $0.06 to 1 | | $–0.2 to 0.8 | |
| | Irrigated watermelon | $0.004 to 0.3 | | $–0.2 to 0.04 | |
| Optimize fertilizer application | Irrigated alfalfa | $0.9 to 1.8 | $1.40 | $–0.5 to 0.4 | Costs do not include environ. damages |
| | Rainfed alfalfa | $0.7 to 1.5 | $1.40 | $–0.6 to 0.1 | |
| | Irrigated apricot | $7.9 to 11 | $0.70 | $7.2 to 10 | |
| | Rainfed apricot | $7.8 to 11 | $0.70 | $7 to 10 | |
| | Irrigated grapes | $21 to 31 | $0.70 | $20 to 30 | |
| | Rainfed grapes | $19 to 31 | $0.70 | $18 to 30 | |
| | Irrigated potatoes | $13 to 24 | $1.80 | $11 to 23 | |
| | Rainfed potatoes | $11 to 21 | $1.80 | $8.9 to 19 | |
| | Irrigated tomatoes | $25 to 40 | $1.80 | $23 to 38 | |
| | Rainfed tomatoes | $16 to 27 | $1.80 | $14 to 26 | |
| | Irrigated watermelon | $18 to 26 | $1.80 | $16 to 24 | |
| | Rainfed watermelon | $14 to 21 | $1.80 | $12 to 19 | |

*Source*: World Bank data.

**Table 4.3 Adaptation Measures with Highest Net Benefits: Mountainous Agricultural Region**

| *Description of recommended adaptation measure* | *Crop focus* | *Illustrative present value economic results per hectare (000 2009 US$ 2015–50)* | | | *Notes* |
|---|---|---|---|---|---|
| | | *Estimated revenue gain* | *Estimated costs* | *Net revenues* | |
| Improve varieties | Irrigated apricot | $4.3 to 6 | $0.40 | $4 to 5.7 | Costs are for provision of seed and extension to support uptake |
| | Rainfed apricot | $4.3 to 6 | | $4 to 5.7 | |
| | Irrigated grapes | $11 to 15 | | $10 to 14 | |
| | Rainfed grapes | $11 to 15 | | $10 to 14 | |
| | Irrigated potatoes | $10 to 14 | | $10 to 14 | |
| | Rainfed potatoes | $9.8 to 14 | | $9.4 to 14 | |
| | Irrigated tomatoes | $26 to 44 | | $26 to 44 | |
| | Rainfed tomatoes | $24 to 38 | | $24 to 38 | |

*table continues next page*

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

| *Description of recommended adaptation measure* | *Crop focus* | *Illustrative present value economic results per hectare (000 2009 US$ 2015–50)* | | | *Notes* |
|---|---|---|---|---|---|
| | | *Estimated revenue gain* | *Estimated costs* | *Net revenues* | |
| | Irrigated watermelon | $13 to 22 | | $13 to 21 | |
| | Rainfed watermelon | $13 to 21 | | $12 to 20 | |
| | Irrigated wheat | $2.6 to 4.8 | | $2.2 to 4.5 | |
| | Rainfed wheat | $2.6 to 4.8 | | $2.2 to 4.4 | |
| Rehabilitate old irrigation systems | Rainfed potatoes | $1.6 to 5.9 | $2.70 | $−1.1 to 3.3 | |
| | Rainfed tomatoes | $12 to 41 | | $9.1 to 39 | |
| | Rainfed watermelon | $2.1 to 7.7 | | $−0.6 to 5 | |
| Create new irrigation systems | Rainfed tomatoes | $12 to 41 | $8.80 | $2.9 to 33 | |
| Optimize fertilizer application | Irrigated alfalfa | $2 to 3.4 | $1.40 | $0.6 to 2 | Costs are for extension & hydromet |
| | Rainfed alfalfa | $1.7 to 3.1 | $1.40 | $0.3 to 1.8 | |
| | Irrigated apricot | $7.9 to 11 | $0.70 | $7.2 to 10 | |
| | Rainfed apricot | $7.9 to 11 | $0.70 | $7.2 to 10 | |
| | Irrigated grapes | $22 to 31 | $0.70 | $22 to 30 | |
| | Rainfed grapes | $22 to 31 | $0.70 | $22 to 30 | |
| | Irrigated potatoes | $18 to 25 | $1.80 | $16 to 23 | |
| | Rainfed potatoes | $17 to 24 | $1.80 | $15 to 22 | |
| | Irrigated tomatoes | $27 to 45 | $1.80 | $25 to 43 | |
| | Rainfed tomatoes | $25 to 40 | $1.80 | $23 to 38 | |
| | Irrigated watermelon | $17 to 29 | $1.80 | $15 to 27 | |
| | Rainfed watermelon | $17 to 28 | $1.80 | $15 to 26 | |

*Source*: World Bank data.

that roughly the same five measures have the highest overall rankings in the Lowland and Intermediate agricultural regions while optimizing application of irrigation water is too expensive to be a viable option in the Mountainous agricultural region. Net benefits are higher in low-elevation agricultural regions, except for irrigation infrastructure adaptations. Only those crops with a positive net benefit are listed; for all other crops not listed in the table, there is a negative or very near zero net benefit for the measure.

The ranking of benefits also considers that some 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 section, where results of the quantitative and qualitative evaluations are


http://dx.doi.org/10.1596/978-1-4648-0147-1

combined to arrive at an overall set of recommended climate adaptation options for Armenian agriculture.

### *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.

**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 |

*table continues next page*


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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* |
|---|---|---|---|
| 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 |
| Livestock management | Fodder banks | B.6 | 4 for traditional fodder banks<br>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 |

*table continues next page*

**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* |
|---|---|---|---|
| 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 Armenia) |
| | Mixed farming systems (crops, livestock, and trees) | C.14 | 1 |
| | 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 (agroforestry) | 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) |

*table continues next page*


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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* |
|---|---|---|---|
| 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<br>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<br>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.

### *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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 Armenia 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 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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

*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 Armenia 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 their outcomes

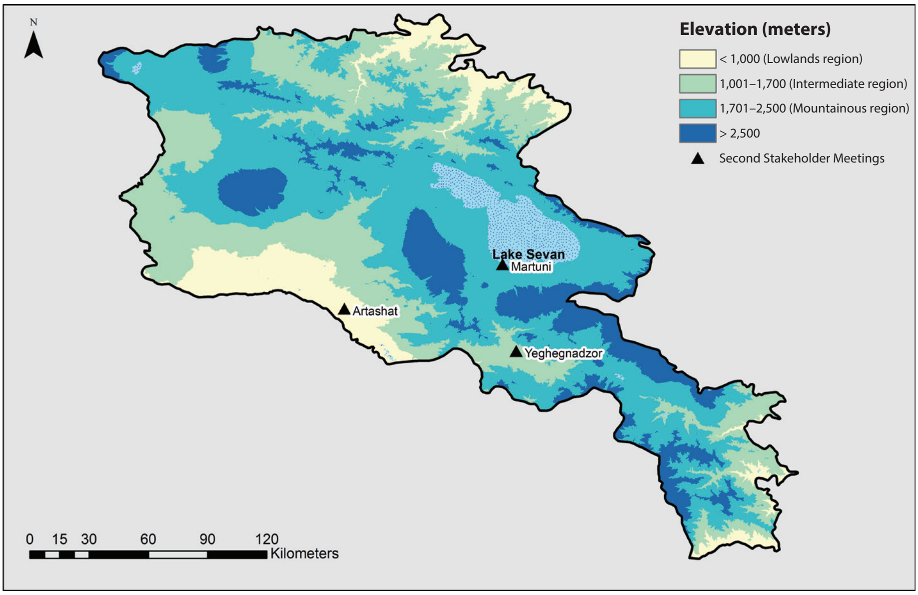
An important component of the Study is to inform and consult stakeholders, farmers, and farmers' associations, on the predicted impacts of climate change on agriculture and water resources. The team first met with farmers for a one day stakeholder workshop in April 2012, in Yeghegnadzor. In attendance were farmers and local government officials. A total of 19 farmers participated including 13 who grow grapes and 15 who grow other fruits including peaches, apricots, watermelon, plums, tomatoes, apples, dewberries, and raspberries. Other crops grown by farmers include: onions, grains, almonds, greens, and tobacco. Additionally, five of the farmers had livestock and one was a beekeeper.

Participants were asked if they have witnessed climate change impacts and what they have done, or would do, to mitigate their effects. All confirmed that several of the impacts have been felt on local farms. Although farmers are becoming more flexible in their response to climate events through education, their adaptive capacity is still quite limited because of poorly maintained irrigation and drainage systems, limited financial resources, and inadequate support from and access to extension services.

Drawing upon information obtained from the first meeting, a second set of farmer consultations were conducted in October 2012 at three locations (Martuni, Artashat, and Yeghegnadzor) representing different agricultural regions of Armenia (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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Map 4.1 Locations of the Second Stakeholder Consultations**






At each consultation, a mixture of farmers, college students in agriculture, 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 careers. Local stakeholders were provided with an overview of the Study and the potential impacts of climate change on crop yields and water availability in Armenia. They were then asked if they have witnessed these impacts and what they have done, or would do, to mitigate their effects. A list of potential climate adaptations was then presented and discussed. Attendees were then asked to remove any irrelevant adaptations and to add any additional adaptations which they believed would be effective to the list. Participants were divided up into groups of three to five people and each group then ranked all of the listed adaptations in relative order of importance.[3]

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 Armenia's three agricultural regions.

### *Current Regional Adaptive Capacity*

*Artashat—Lowlands Agricultural Region:* The meeting was held on October 10, 2012. There were 13 participants including 9 full-time farmers and 4 local officials who also farmed. The local area produces a variety of crops


http://dx.doi.org/10.1596/978-1-4648-0147-1

including wheat, vegetables, watermelons, grapes, and orchard fruits as well as livestock.

The climate is sufficiently mild that two crops a year can be grown with irrigation. Although they did notice somewhat warmer temperatures in this already warm climate, farmers mentioned that they had suffered from the climate was becoming less stable with drought, hail, and heat waves that wilted crops becoming more frequent.

The importance of irrigation to support agricultural production is apparent in the adaptation rankings (table 4.5), with the top three climate adaptation options being clearly related to irrigation activity. Farmers stressed the need for adequate irrigation water to ensure both quantity and quality of orchard and vineyard production.

Livestock are an important part of the agricultural economy as they can beneficially use field crop aftermath and rainfed rangeland. Improved livestock husbandry, health, and optimizing the production and storage of livestock forage ranked fifth along with improved crop production practices and improved crop/livestock genetics.

Local orchardists reported some innovative attempts to reduce climatic risk by interplanting crops with different climate sensitivities. Two examples of this were an apricot orchard planted with every other tree a peach to hedge against early spring frosts that might damage apricots but not the later flowering peaches, and a vineyard with tomatoes planted in between the rows of vines.

*Yeghegnadzor—Intermediate Agricultural Region:* The Intermediate region consultation was held on October 10, 2012. Thirteen full-time farmers participated.

Farmers reported that they had generally noticed that the climate was becoming warmer and extreme weather events were more frequent. The most important weather-related impact noted is drought, which is especially burdensome due to variability and extremes. Changes in the cropping season, hail, winter frost, warming, and increasing water demand also negatively affect crop

**Table 4.5 Ranked Recommendations from the Artashat Consultation**

| *Adaptation option* | *Points* |
|---|---|
| Rehabilitation of water reservoirs | 26 |
| Rehabilitation of irrigation | 25 |
| Optimize application of water | 20 |
| Reduce erosion and soil conservation | 15 |
| Improve livestock nutrition and shelter | 9 |
| Optimize agronomic practices (fertilizer) | 9 |
| Improve crop varieties, particularly those tolerant to droughts | 9 |
| Restoration of pastures by improved agronomic practices | 7 |
| Adjust type of crops based on elevation | 6 |
| Hail rockets | 4 |

*Source:* World Bank data.

production in this region of Armenia. With the crop seasons shifting, farmers plant earlier, but spring freezing can harm crops. Hail has also worsened recently, especially in the spring when it hits early vegetation. Winter frost is noted, especially during the winter of 2002 when trees were completely frozen. Warming, including average and high temperature increases, have a variety of effects, but specifically worrisome are increased incidences of diseases, pests and weeds as well as emerging of new types. Lastly, crop water demand continues to increase, where increased water use is a social issue as people have to pay more for water.

Generally, farmers have observed the changing climate and have already begun responding. Many have begun planting crops earlier to respond to higher temperatures earlier in the season, moving their crops to higher elevation areas, changing crop rotations, and changing the timing of irrigation. Highly ranked adaptation options (table 4.6) include rehabilitation of ageing irrigation systems and relocating orchards to less frost prone sites, as well as application of a variety of other basic improved practices dealing with crop and livestock production.

*Martuni—Mountainous Agricultural Region:* The Mountainous agricultural region consultation was held in Martuni on October 12, 2012. There were 22 participants, including 20 full-time farmers and two local officials who also farm. Farmers in this region are reliant on irrigation for crop and orchard production, with nonirrigated land often used as unimproved pasture. Major crops include wheat, potatoes, and cabbage.

The major climatic changes noticed were increased temperature evidenced as more frequent heat waves and droughts. Farmers reported that disease and pest problems were also increasing, perhaps as a byproduct of climate change that damaged plants, making them more susceptible to attack.

The high rankings given to irrigation-related adaptations (table 4.7) clearly reflect the importance of irrigation to crop and fruit production in this region. Farmers keep livestock, but have limited pasture to support them and are aware of the need improve basic animal husbandry practices. Availability of forage currently limits livestock production to present levels.

**Table 4.6 Ranked Recommendations from the Yeghegnadzor Consultation**

| *Adaptation option* | *Points* |
|---|---|
| Rehabilitation of irrigation | 26 |
| Adjust type of crops based on elevation | 23 |
| Optimize agronomic practices (fertilizer) | 15 |
| Improve crop varieties, particularly those tolerant to droughts | 13 |
| Reduce erosion and soil conservation | 12 |
| Improve livestock nutrition and shelter | 11 |
| Hail rockets | 8 |
| Optimize application of water | 8 |
| Restoration of pastures by improved agronomic practices | 6 |
| Rehabilitation of water reservoirs | 3 |

*Source:* World Bank data.


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Table 4.7 Ranked Recommendations from the Martuni Consultation**

| *Adaptation option* | *Points* |
|---|---|
| Rehabilitate irrigation systems | 24 |
| Construct small volume reservoirs | 19 |
| Provision of agricultural equipment | 19 |
| Improve crop varieties | 9 |
| Improve livestock nutrition and shelter | 7 |
| Optimize application of irrigation water | 5 |
| Optimize agronomic practices | 4 |
| Change cropping patterns, especially by altitude | 4 |
| More modern irrigation technologies | 3 |

*Source:* World Bank data.

**Table 4.8 Stakeholder-ranked National-Level Climate Adaptations**

| *Adaptation option* | *Points* |
|---|---|
| Provide low interest, long-term loans to farmers | 81 |
| Create crop insurance program | 71 |
| Establish local markets | 39 |
| Improve farmer access to agronomic technology and information | 34 |
| Improve extension services | 33 |
| Improve hydrometeorological capacity | 24 |
| Produce local seeds within region | 8 |
| More direct linkage between government and farmers | 4 |
| More modern irrigation technologies | 3 |

*Source:* World Bank data.

### *Current National-Level Adaptive Capacity and Responses*

There was general agreement across all three regions about the need for low interest, long-term loans. This adaptation along with crop insurance was by far the highest ranked item of the adaptations recommended by farmers (table 4.8). Currently loans are difficult for farmers to obtain and those available are most often short-term and at high interest rates.

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. The need to expand farmer support services such as hydromet, market access, and extension services form a second tier of needed adaptation enhancements in farmer rankings.

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.

The adaptive capacity of farmers in Armenia is clearly challenged by climate change. The combination of droughts, frost, hail, and warming is especially


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 crop insurance, improved hydromet forecasts, improved water storage, irrigation systems, as well as farmer training and information access about weather-related farming practices.

### National Conference Results

The National Dissemination and Consensus-Building Conference, held in Yerevan in October 2012, provided another opportunity to consult with Armenia'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 multicriteria 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, and as a result presented an entirely different focus from the region-focused groups. The region-focused groups provided additional measures for consideration unique to their regions. Across the regions, there was broad support for improving irrigation water availability, optimizing irrigation practices, and building small-scale reservoirs. No group was formed to consider the Intermediate region.

The results of the weighting of criteria are presented in table 4.10 below, for each focus group. Generally, B-C analysis is considered an important objective by all groups, with each group allocating half the weight to that objective. Among the two other objectives, more weight was allocated to win-win potential than mitigation potential, with the national group putting zero weight on 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 specific adaptive measures that demonstrate the greatest opportunities for emissions


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Table 4.9 Ranking of Adaptation Measures by Small Groups**

| | | *Ranking of measure by group* | | | |
|---|---|---|---|---|---|
| *Adaptation measure* | *Specific focus area* | *National* | *Lowland* | *Intermediate* | *Mountainous* |
| Improve farmer access to agronomic technology and information | Crop varieties; more efficient use of water | 1 | | No Group Formed, No Ratings | |
| Create crop insurance program | To promote investments in agricultural crops susceptible to drought and hail | 2 | | | |
| Increase the quality, capacity, and reach of extension services | Demonstration plots | 3 | | | |
| Improve farmer access to hydro-meteorological capacity | Short-term temperature and precipitation forecasts | 4 | | | |
| Improve irrigation water availability | Rehabilitate irrigation capacity | | 1 | | 2 |
| Optimize agronomic practices | Increase and improve fertilizer application | | 4 | | |
| Improve crop varieties | Drought-tolerant varieties | | 2 | | 3 |
| Research and improve livestock nutrition, management, and health | Include research on sheltering techniques | | | | 4 |
| Optimize and/or improve irrigation techniques | Sprinkler, drip irrigation | | | | 2 |
| Construct small volume reservoirs for water storage | | | 3 | | 5 |
| Improve agricultural practices | Increase capacity, knowledge, and pasture management skill | | | | 1 |

*Source:* World Bank data.

**Table 4.10 Results of Small Group Multicriteria Weighting Exercise**

| | *Percent weight of specific criteria:* | | |
|---|---|---|---|
| *Small group agricultural region focus* | *Benefit cost analysis (%)* | *Win-Win potential (%)* | *Mitigation potential (%)* |
| Lowland region | **50** | **40** | **10** |
| Mountainous region | **50** | **30** | **20** |
| National policy | **50** | **50** | **0** |

*Source:* World Bank data.

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 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


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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 |
| 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 |

*table continues next page*


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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* |
|---|---|---|---|---|---|
| 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 |
| Intercropping to maximize use of moisture | C.27 | Increases carbon inputs to soil and fosters soil carbon sequestration. | N/A | 4 | 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 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.
*Note:* N/A = not applicable because there is no known mitigation potential.
a. See appendix A.

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 Armenia. Armenia, as a transition country (Non-Annex 1), 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 Armenia are already underway. One World Bank project that addresses mitigation is the Natural Resources Management and Poverty Reduction Project in Armenia, which promotes the adoption of sustainable natural resource management practices and the alleviation of rural poverty in places where there was severe environmental degradation. The global environmental objective is to preserve the mountain, forest and grassland ecosystems in the southern Caucasus, through enhanced protection and sustainable management. Specifically to mitigate climate change, the project proposes demonstrations of bio-gas production installations that would reduce methane emissions while reducing the use of timber. In addition, Armenia has several projects that have been funded through the Clean Development Mechanism which allows Annex I countries to implement mitigation projects in non-Annex I countries (UNFCCC 2010).

## 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 Yerevan in October 2012.

### *Recommendations at the National Level*

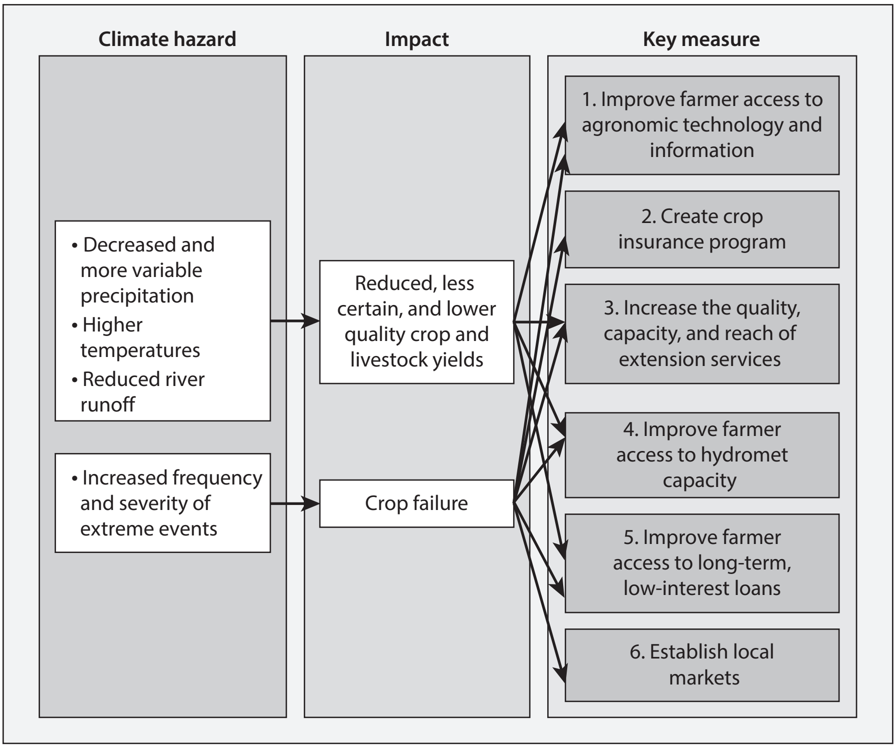
The six measures identified by the Study for adoption at the national level focused on the following areas: (i) access to technology; (ii) crop insurance; (iii) improving extension; (iv) hydrometeorological information; (v) rural finance; and (vi) enabling local markets. These measures that came to the forefront as "options" in the National Conference, with a focus on the first four farmer workshops identified the last two as important to pursue at the national level. Measures for consideration at the national level focus on policy and institutional capacity that have value on their own, or which are essential to ensure that farm level and private sector actions are applied to their best advantage. Based on the work at the National Conference, qualitative analysis of potential net benefits, and suggestions from the farmer consultations, the options were ranked (figure 4.10). It should be noted that these recommendations are all interdependent.

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

*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


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Figure 4.10 National-level Recommended Measures**




of the existing extension and research agencies be improved in agronomic practices and livestock management at the farm level, including implementation of more widespread demonstration plots and access to better information on the availability and best management practices of high-yield crop varieties and livestock. This recommendation is a measure to close the adaptation deficit. The economic analysis suggests that expansion of extension services is very likely to yield benefits in excess of estimated costs.

*Improve capacity of hydrometeorological institutions.* The farmer meetings noted the need for better local capabilities for hydrometeorological data, particularly for short-term temperature and precipitation forecasts. Those capabilities are acutely needed in the short-term to support better farm-level decision making. Improved applications of weather and climate information using an integrated and coordinated approach will help to increase and sustain agricultural productivity, and reduce 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.

*Improve farmers' access to rural finance to enable them to access new technologies.* Farmers could acquire technologies through well-targeted and affordable credits


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 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 nonmonthly payment). This is a pressing need for tailoring techniques to shifting climatic conditions without harming ecosystems of the country.

*Enable local markets.* Agricultural marketing is a common problem. Specific recommendations to improve the marketability of produce and livestock in rural areas of Armenia include the following: (i) Change farmers' perception of marketing. Train them to focus on quality of products that they produce. Poor quality is not marketable, or if marketed a low price is inevitable; (ii) invest in market information gathering and dissemination, including mass media, fax, telephone, and real-time computer access systems; (iii) create, train, and support producer associations (cooperatives) and small and medium-scale enterprises to improve the bargaining power of small farmers; and (iv) provide storage facilities including cold storage that enable farmers to inventory their products for periods when the market is not saturated.

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.

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. In such a system, it is recommended as a guideline that there be at least 20 years of historical data and the missing data should not exceed 3 percent of the total daily dataset (IFAD 2011). In this context, 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.

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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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.

A systematic approach has to be pursued first in order to create the adequate legal, institutional and organizational framework in which insurance products and other risk management tools can work efficiently (Herbold 2010). In other words, there is a need for government commitment to creating an enabling legal and regulatory environment that ensures the sale and management of insurance product(s) are fair to both buyers and sellers.

In general, intermediaries and delivery channels of insurance products have limited or no business (nor representatives) in rural areas. Therefore, distribution is best organized through a party with existing links to farmers or farmers groups that could include cooperatives and microfinance institutions working through borrower or credit groups. Such intermediaries are limited in number, lack financial resources for expansion into rural areas and usually lack capacity to assume this task. Therefore, the third recommendation would be to facilitate the development of these intermediaries and delivery channels.

Although farmers demanded crop insurance during consultations, the rural communities of Armenia are not familiar with insurance practices and would need to be exposed to basic concepts of insurance transactions quite early in the development of any such system.

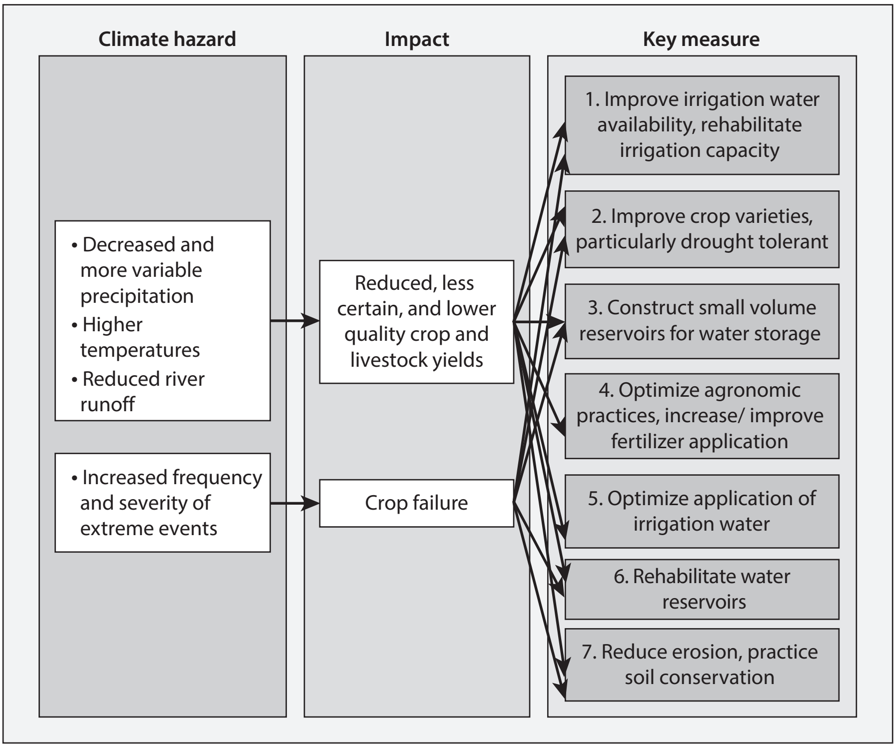
### *Recommendations at the Agricultural Region Level*

Recommendations for each agricultural region to improve the resilience of Armenia's agricultural sector to climate change are presented in figures 4.11 to 4.13. These reflect the five ranking criteria applied to rank measures. All measures indicated reflect a favorable economic evaluation.

- 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 Armenian 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.


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Figure 4.11 Lowland Agricultural Region Recommended Measures**




Ultimately, the rankings also reflect consideration of the results of the National Conference.

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 Armenia, 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 Armenian 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 Armenian 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 Armenia. In addition, it is desirable that the countries of the South


http://dx.doi.org/10.1596/978-1-4648-0147-1

**Figure 4.12 Intermediate Agricultural Region Recommended Measures**

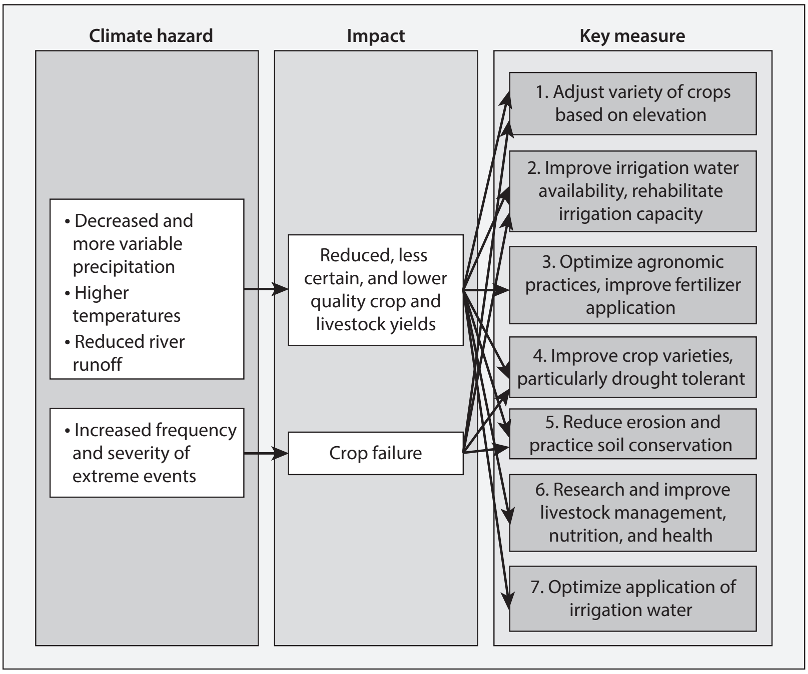
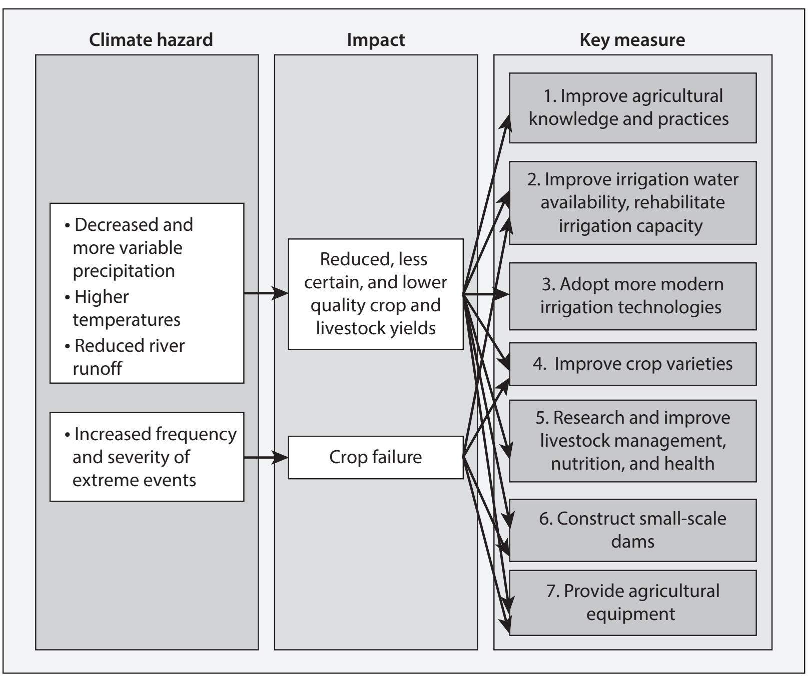



**Figure 4.13 Mountainous Agricultural Region Recommended Measures**



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", and in particular the section on limitations regarding projections.
3. Relative rating scores were developed by adding the scores of each option across groups. For example, an option ranked first out of 9 options would be given 9 points while one ranked last would be given one point.


http://dx.doi.org/10.1596/978-1-4648-0147-1

## 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*


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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 | | |

*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* |
|---|---|---|---|---|---|
| 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 |

*table continues next page*


http://dx.doi.org/10.1596/978-1-4648-0147-1

**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<br>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<br>0.30–1.2 | Congress of the United States 2007 |
| | | | Crop residues<br>Improved rotations | 0.7 (0.1 to 0.7)<br>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*

**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 | | |

*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* |
|---|---|---|---|---|---|
| | 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 | | |

*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* |
|---|---|---|---|---|---|
| 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. N/A = not applicable because there is no known mitigation potential.


http://dx.doi.org/10.1596/978-1-4648-0147-1

# 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).


http://dx.doi.org/10.1596/978-1-4648-0147-1

*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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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


http://dx.doi.org/10.1596/978-1-4648-0147-1

*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).


http://dx.doi.org/10.1596/978-1-4648-0147-1

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

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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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 appendix A that aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000.

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

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


http://dx.doi.org/10.1596/978-1-4648-0147-1

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

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

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


http://dx.doi.org/10.1596/978-1-4648-0147-1

# Bibliography

Adams, R. M., B. A. McCarl, K. Segerson, C. Rosenzweig, K. J. Bryant, B. L. Dixon, R. Connor, R. E. Evenson, and D. Ojima. 1999. "The Economic Effects of Climate Change on US Agriculture." In *Impact of Climate Change on the United States Economy*, edited by R. Mendelsohn and J. E. Neumann, 74–98. Cambridge, UK: Cambridge University Press.

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

Binswanger-Mkhize, H. P. 2012. "Is There Too Much Hype about Index-based Agricultural Insurance?" *The Journal of Development Studies* 48 (2): 187–200.

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

Cerdán-Infantes, P., A. Maffioli, and D. Ubfal. 2008. *The Impact of Agricultural Extension Services: The Case of Grape Production in Argentina*. Washington, DC: Inter-American Development Bank, Office of Evaluation and Oversight. http://www.iadb.org/intal/intalcdi/PE/2009/03159.pdf (accessed February 1, 2011).

Congress of the United States, Congressional Budget Office. 2007. "A CBO Paper: The Potential for Carbon Sequestration in the United States." Pub. No. 2931. http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/86xx/doc8624/09-12-carbonsequestration.pdf (accessed October 7, 2013).

FAO. 2008. "AQUASTAT—FAO's Information System on Water and Agriculture: Armenia." http://www.fao.org/nr/water/aquastat/countries_regions/armenia/index.stm (accessed October 17, 2013).

———. 2009. "Irrigation in the Middle East Region in Figures: AQUASTAT Survey—2008." FAO Water Reports, No. 34, FAO, Rome, Italy. ftp://ftp.fao.org/docrep/fao/012/i0936e/i0936e00.pdf (accessed October 10, 2013).

———. 2011. "AQUASTAT—Global Map of Irrigated Areas (GMIA)." http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm (accessed March 12, 2011).

FAOSTAT. 2012. "Agriculture Statistics Database." http://faostat.fao.org (accessed March 12, 2011).

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


http://dx.doi.org/10.1596/978-1-4648-0147-1

Herbold, J. 2010. "Crop Insurance in Developing Economies: The Insurer's and Re-insurer's Perspective." *Rural 21* 44 (4). http://www.munichre.com/app_pages/www/@res/pdf/reinsurance/business/non-life/systemagro/rural_21_crop_insurance_developing_economies_en.pdf (accessed October 7, 2013).

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

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

International Fund for Agricultural Development (IFAD). 2011. *Weather Index-based Insurance in Agricultural Development: A Technical Guide*. Rome, Italy: World Food Programme and IFAD. http://www.ifad.org/ruralfinance/pub/WII_tech_guide.pdf (accessed October 7, 2013).

Kalantaryan, T. 2012. Information on estimated annual crop losses provided during the first farmer consultation.

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

Lehner, B., C. Reidy Liermann, C. Revenga, C. Vorosmarty, B. Fekete, P. Crouzet, P. Doll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J. C. Robertson, R. Rodel, N. Sindorf, and D. Wisser. 2011. *Global Reservoir and Dam Database, Version 1 (GRanDv1): Dams, Revision 01*. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01 (accessed October 10, 2013).

Medina, F., and A. Iglesias. 2010. "Agricultural Practices with Greenhouse Mitigation Potential in Mediterranean Countries: Evaluation and Policy Implications." 9th European IFSA Symposium, Vienna, Austria, July 4–7, 2010. http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2010/2010_WS3.1_Medina.pdf (accessed October 10, 2013).

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T. Yong Jung, T. Kram, E. Lebre La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H.-H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, and Z. Dadi. 2000. *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press. http://www.grida.no/climate/ipcc/emission/index.htm (accessed October 24, 2013).

Paustian, K., J. Antle, J. Sheehan, and E. Paul. 2006. "Agriculture's Role in Greenhouse Gas Mitigation." Pew Center on Global Climate Change. http://www.c2es.org/publications/agriculture-role-greenhouse-gas-mitigation (accessed October 7, 2013).

Republic of Armenia Ministry of Environment. 2012. Data on percentage of irrigated areas in each agricultural region provided following the Awareness Raising Workshop.

Roberts, R. A. J. 2005. *Insurance of Crops in Developing Countries*. Rome, Italy: Food and Agriculture Organization. FAO Agricultural Services Bulletin 159. http://www.fao.org/docrep/008/y5996e/y5996e00.htm (accessed October 24, 2013).

Smith, P., O. Andren, T. Karlsson, P. Perala, K. Regina, M. Rounsevell, and B. V. Wesemael. 2005. "Carbon Sequestration Potential in European Croplands Has Been Overestimated." *Global Change Biology* 11 (12): 2153–63.

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

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

Stockholm Environment Institute (SEI). 2013. *WEAP: Water Evaluation and Planning System—User Guide*. http://www.weap21.org/ (accessed October 11, 2013).

Stokes, C. R., S. D. Gurney, M. Shahgedanova, and V. Popovnin. 2006. "Late-20th-century Changes in Glacier Extent in the Caucasus Mountains, Russia/Georgia." *Journal of Glaciology* 52 (176): 99–109.

Sutton, W., J. Srivastava, and J. Neumann. 2013. *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*. Washington, DC: World Bank.

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

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

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

United Nations Development Programme (UNDP). 2004. "Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies, and Measures." Edited by B. Lim and E. Spanger-Siegfried. New York, NY: UNDP.

UNDP. 2011. Regional Climate Change Impacts Study for the South Caucasus Region. Tblisi, Georgia: ENVSEC and UNDP. (Accessed October 17, 2013), http://www.envsec.org/publications/cc_report.pdf.

United Nations Framework Convention on Climate Change (UNFCCC). 2009. *Albania's Second National Communication to the Conference of Parties under the United Nations Framework Convention on Climate Change*. Tirana, Albania: Republic of Albania Ministry of Environment, Forestry and Water Administration. (Accessed October 11, 2013), http://unfccc.int/resource/docs/natc/albnc2.pdf.

UNFCCC. 2010. *Second National Communication on Climate Change: A Report Under the United Nations Framework Convention on Climate Change*. Yerevan, Armenia: Republic of Armenia, Ministry of Nature Protection.

United States Environmental Protection Agency (EPA). 2005. *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*. Washington, D.C.: EPA. (Accessed October 7, 2013), http://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryID=85583.

Van den Berg, H. and J. Jiggins. 2007. Farmer Field Schools Reap Long-Term Rewards. *Pesticide News* 78. (Accessed February 1, 2011), http://www.pan-uk.org/archive/Projects/Fairness/PN/pn78pp6-7.pdf.


http://dx.doi.org/10.1596/978-1-4648-0147-1

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

Weiske, A. 2007. *Potential for Carbon Sequestration in European Agriculture*. Institute for Energy and Environment. (Accessed October 7, 2013), http://www.ieep.eu/assets/311/D10a_appendix_carbon_sequestration.pdf.

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley. 1998. *Groundwater and Surface Water A Single Resource*. Denver, Colorado: U.S. Geological Survey Circular 1139.

World Agroforestry Centre. 2013. "Agroforestry Systems." (Accessed October 24, 2013), http://worldagroforestry.org/research/agroforestry-systems.

World Bank. 2009. *Adapting to Climate Change in Europe and Central Asia*. Washington, D.C.: World Bank. (Accessed October 7, 2013), http://www.worldbank.org/eca/climate/ECA_CCA_Full_Report.pdf.

———. 2011. "Adaptation Notes – Key Words and Definitions." (Accessed October 24, 2013), http://go.worldbank.org/KIF9678RQ0.

———. 2013a. "Armenia Data: World Development Indicators." (Accessed October 7, 2013), http://data.worldbank.org/country/Armenia.

———. 2013b. "Agriculture and Climate Change: Europe and Central Asia." (Accessed October 7, 2013), www.worldbank.org/eca/climateandagriculture.

World Wildlife Fund (WWF) Norway, WWF Caucasus Programme. 2008. *Climate Change in Southern Caucasus: Impacts on nature, people and society*. By Dr. Magnus Sylvén, Mag. Art. Rasmus Reinvang, and Dr. Žanete Andersone-Lilley. (Accessed October 7, 2013), http://assets.wwf.no/downloads/climate_changes_caucasus___wwf_2008___final_april_2009.pdf.

## Environmental Benefits Statement

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

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

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

green press INITIATIVE

Agriculture is one of the most climate-sensitive of all economic sectors. Armenia 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 Armenia's Agricultural Systems to Climate Change* is the culmination of efforts by the Armenian institutions and researchers, the World Bank, and a team of international experts to jointly undertake an analytical study to address the potential impacts climate change may have on Armenia'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 Armenia. 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.

*Reducing the Vulnerability of Armenia's Agricultural Systems to Climate Change* is part of the World Bank Studies series. These papers are published to communicate the results of the Bank's ongoing research and to stimulate public discussion. The study is one of three produced under the World Bank program "Reducing Vulnerability to Climate Change in European and Central Asian Agricultural Systems." The other countries included in this series are Azerbaijan and Georgia. World Bank Studies are available individually or on standing order. This World Bank Studies series is also available online through the World Bank e-library (www.worldbank.org/elibrary).

ISBN 978-1-4648-0147-1
SKU 210147

THE WORLD BANK