CHAPTER 2

Framework and Program Design

The following are the main objectives of this study, which is entitled, "Regional Program on Reducing Vulnerability to Climate Change in Southern Caucasus Agriculture Systems":

- Increase stakeholder awareness of the threat of climate change to the agriculture sector and seek their input to shape the results and, in some cases, the methods applied in the study.
- Analyze the vulnerability and potential impacts of climate change on agricultural systems at multiple levels—agricultural region, national, and regional.
- Integrate agricultural sector analysis with in-depth modeling of water supply and demand, with the understanding that climate change will affect the agriculture sector both directly and indirectly through its effect on the availability of irrigation water.
- Combine biophysical modeling with economic benefit-cost (B-C) analysis and qualitative assessment to develop a prioritized menu of potential adaptation options for each subnational agricultural region and at the national level.
- Create mechanisms for fostering regional cooperation to address the potential impacts of climate change on agriculture.

Study Approach

The study was conducted in the three countries of the South Caucasus region—Armenia, Azerbaijan, and Georgia—at the country and agricultural region levels. The study scope included the agriculture, livestock, and water resources sectors, or, more succinctly, systems within the managed agriculture sector. Time and resource constraints meant that the study excluded the forestry, fisheries, biodiversity, and urban/peri-urban agricultural systems.

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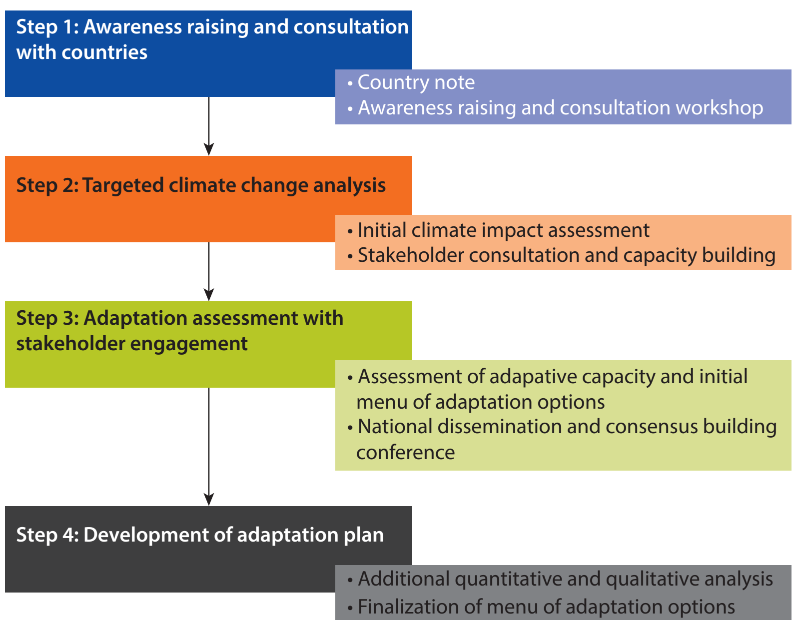
The study was conducted in three stages from January 2012 through April 2013. The study team followed four main steps, summarized in figure 2.1, described as follows:

Step 1: Awareness Raising and Consultation with Countries

Country notes. A "Country Note on Climate Change and Agriculture" (World Bank 2012a, 2012b, 2012c) was developed for each country as a background document for all stakeholders and to serve as an engagement tool for awareness raising and consultation. The country note provided a summary of available country-specific information with a focus on climate and crop projections, adaptation options, policy development, and institutional involvement in agriculture and climate change.

Awareness raising and consultation workshop. An initial country-level awareness raising and consultation workshop was held in each country in consultation with key stakeholders at the technical level, including local experts from national, private-sector, and nongovernmental institutions, as well as representatives of other development organizations. The objectives of the workshops were to raise stakeholder awareness of agriculture and climate change issues, discuss the country note, identify any other relevant analytical work in the country, elicit ideas on potential adaptation responses, agree on information gaps and needs for additional analysis, and identify local partners to engage in the development and implementation of country specific analytical approaches

Figure 2.1 Flow Chart of Major Study Steps



for climate change impact assessment and analysis of adaptation options, including data collection, analysis, and dissemination follow-up activities. After the awareness raising and consultation workshop was completed, an inception report was developed, which served as a work plan for the subsequent steps.

Step 2: Targeted Climate Change Analysis

Initial climate impact assessment. The study provides forecasted changes in temperature and precipitation at the agricultural region level, which are used to inform quantitative analysis of crop yield and irrigation water resource system impacts that could occur without adaptation measures.

Stakeholder consultation and capacity building. The study team solicited feedback from stakeholders on the results of the initial climate impact assessment and provided a capacity-building opportunity for local stakeholders to learn about the potential impacts of climate change on the agriculture sector.

Step 3: Adaptation Assessment with Stakeholder Engagement

Assessment of adaptive capacity and initial menu of adaptation options: After assessing each country's existing adaptive capacity, the study team developed an initial menu of adaptation options, tailored to the agricultural regions in each country. This draft menu of options was then vetted with farmers at a second stakeholder consultation.

National dissemination and consensus-building conferences. A national conference was organized in each country in order to discuss and raise awareness of the results of the impact assessment and the initial menu of adaptation options. Stakeholders worked together at the conferences to build consensus on the priorities for action and explore ways to integrate adaptation recommendations into country policies, programs, and investments. The conferences were co-hosted by the ministries of agriculture and environment along with World Bank country offices. The organizers sought high-level representation from agencies with national policy-making responsibility, such as ministries of finance and economics. Representatives of farmers and other civil society organizations also participated, and development partners who could help support adaptation actions were invited.

Step 4: Development of Adaptation Plan

Additional quantitative and qualitative analysis. The study team undertook additional analysis based on feedback received during the stakeholder consultations and national conferences. The analytic tools employed in these analyses are detailed in the following section.

Finalization of analysis and menu of adaptation options. Finally, country-specific menus of adaptation options were finalized and disseminated. The recommended options are based on the results of quantitative analysis (B-C assessments), as well as qualitative analysis by stakeholders and experts.

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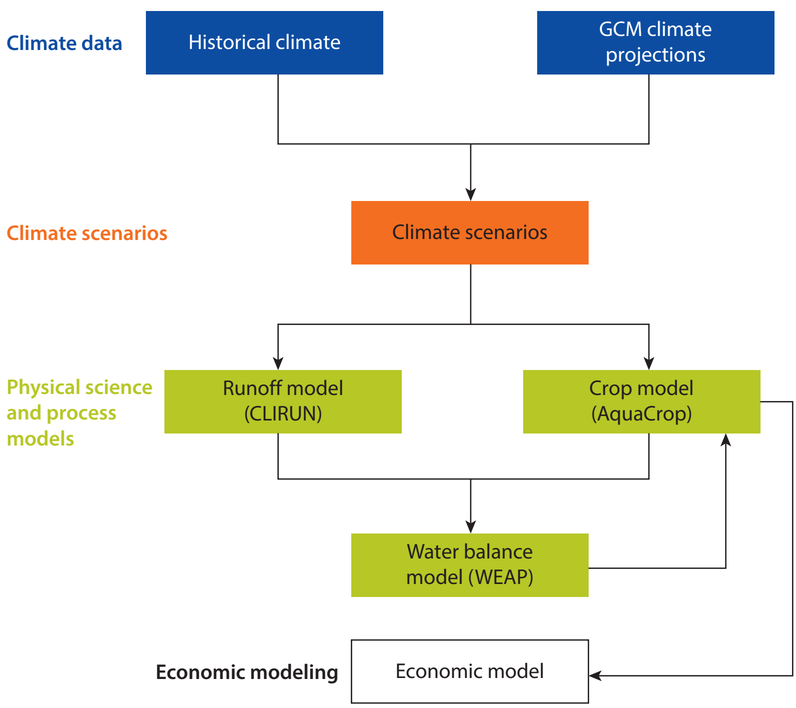
Analytic Tools

Overall four analytic steps, involving four types of analytic tools, were required to develop the menu of adaptation options. As shown in figure 2.2, these analytic steps were carried out sequentially from top to bottom, with the exception of the interaction between the crop and water balance modeling, which is discussed here. The tools in figure 2.2 were needed to complete the initial impact assessment in four steps as follows: (1) gather baseline data and identify major agricultural growing regions in each country, (2) develop climate projections, and (3) use baseline and climate projection data to conduct the impact assessment. The study team then carried out an additional analytic step to develop a tailored adaptation menu, specifically: (4) evaluation of adaptation options for each agricultural region in each country.

Achieving the goals stated at the beginning of this chapter dictated certain aspects of the modeling approach. For example, the study team immediately identified that a simulation modeling approach to the quantitative work would be most appropriate. Simulation modeling can be demanding—simulating the processes of crop growth and water resource availability requires extensive data inputs and careful calibration. In addition, simulation modeling can present difficult issues in modeling a future economic baseline that incorporates innovation over time in those situations where it may be important to the analysis to do so.[1]

Figure 2.2 Flow Chart of Analytic Tools for Key Analytic Steps



Note: CLIRUN = Climate and Runoff Hydrologic Model; GCM = General Circulation Model; WEAP = Water Evaluation and Planning System.

The payoff is that the modeling system can estimate the incremental change in crop output and water supply in response to changes in climatic conditions and agricultural and water resource management techniques. Other approaches, such as econometric and statistical models of crop yield, are often unable to incorporate adaptation or, if they do incorporate it, cannot estimate the incremental effects of specific measures.[2] A further advantage of the simulation approach is that it provides an opportunity for stakeholder involvement at several stages of the analytic process: designing scope, adjusting parameters, selecting inputs, calibrating results, and incorporating adaptation measures of specific local interest (for example, in half of the countries, hail nets, crop insurance, water storage, and improved drainage capacity were major issues, in each case involving a different pair of countries).

Analytic Step 1: Gather Baseline Data and Identify Agricultural Regions

The first analytic step involved gathering baseline meteorological, soil, and water resources data from in-country and global sources. Data requirements include the following:

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

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

In addition, each country was divided into agricultural growing regions developed in collaboration with local experts. Areas within each region 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.

Analytic Step 2: Develop Climate Projections

Climate change analyses require some forecasts of how temperature, precipitation, and other climate variables of interest might change over time. Because of the great uncertainty in climate forecasts, it is best in this type of study

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to attempt to characterize a range of alternatives as well as a "central case" forecast.

In this study the guiding principle used to select future climate scenarios was based on measures most likely to be relevant to negative or positive impacts of climate change on the agriculture sector. Because both temperature and precipitation affect agricultural productivity, scenarios were selected based on an index of soil moisture—the "climate moisture index" (CMI)—believed to be well correlated with potential agricultural production. The climate projections combine information from the baseline datasets with projections of changes in climate obtained from General Circulation Model (GCM) results prepared for the United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. (IPCC 2007).

As detailed in box 2.1, three climate scenarios were developed for each country, defined by the CMI, which measures the aridity of a region.[3] Using CMI values, the team selected for each country the driest, wettest, and a "medium" scenario from among 56 future climate change forecast scenarios developed by IPCC. Then both daily and monthly temperature and precipitation forecasts were generated to be used in the subsequent crop and water resources models.

Analytic Step 3: Conduct Impact Assessment

The goal of the impact assessment was to develop a rigorous quantitative assessment of the biophysical risks of climate change to agriculture if no adaptation were conducted. Subsequently the same model set was applied to estimate the marginal effect of individual adaptation measures on yields, which could then be valued and compared to the costs of those measures to assess the economics of alternative adaptation responses. As shown in figure 2.2, three general categories of biophysical models were used to develop the impact and adaptation assessments: crop models, a hydrological river runoff model, and a water balance model. The specific model choices within those categories were as follows:

- ***Crop models.*** Crop models analyze changes in crop yields and crop water and irrigation requirements. Different crop models were used in various combinations across the study countries (1) to assess which model could best provide a reasonable degree of confidence in the crop yield results; (2) to incorporate the effects of changes in temperature, precipitation, and irrigation water availability simultaneously; and (3) to be practically applied under multiple conditions to assess the marginal effect of individual adaptation measures needed to support B-C analyses. In prior work (Sutton, Srivastava, and Neumann 2013), the study team concluded that the Food and Agricultural Organization (FAO) AquaCrop model provided the best combination of high confidence in yield results, flexibility, and the ability to estimate marginal effects of adaptation measures; therefore the AquaCrop model was used here.

- ***River runoff models.*** These models are used to estimate the effects of climate change on the quantity of surface water available for irrigation and other uses.

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Box 2.1 Developing a Range of Future Climate Change Scenarios

Analyzing climate change requires forecasting how temperature, precipitation, and other climate variables might change over time. The great uncertainty in these forecasts makes it necessary in a study like this to characterize a range of alternatives as well as a "central case" forecast. For temperature and precipitation projections, three climate scenarios were developed for the three countries: Low, Medium, and High Impact Scenarios.

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

Each scenario in the study corresponds to a specific General Circulation Model (GCM) result combined with greenhouse gas (GHG) emissions scenarios. These SRES (*Special Report on Emissions Scenarios*) emissions scenarios were among those used by the Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment of the science of climate change (IPCC 2000, 2007). The study relied on the three most commonly used GHG emissions scenarios: B1, A1b, and A2. As shown in table B2.1.1, a "wet" CMI scenario means that the location experienced the smallest impact (or change in) CMI—that is, the Low Impact Scenario. A dry scenario corresponds to high potential impact (High Impact Scenario). The Medium Impact Scenario reflects a central estimate of change in aridity. The specific global GCM selected for the medium scenario is closest in consistency with the model mean CMI from a total of 56 readily available GCM/SRES combinations.

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

Table B2.1.1 Measurement Bases for Climate Impact Scenarios

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

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Both temperature and precipitation changes affect river runoff volumes. The Climate and Runoff Hydrologic Model (CLIRUN) model was used to analyze changes in water runoff.

- ***Water balance models.*** These models combine information about the spatial layout of the water supply system with water demand and supply projections to assess whether certain uses might result in water shortages. Using the

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inputs from the river runoff model to characterize water supply, the crop modeling to characterize changes in irrigation water demand, and other analyses that project water demand from other users (such as hydropower and municipal water supply), this analysis used the water balance model primarily to identify potential shortages in water available for agriculture under climate change (Hughes, Chinowsky, and Strzępek 2010; Lehner et al. 2011; SEDAC 2011). The Water Evaluation and Planning System (WEAP) model was used in this analysis.

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

The various modeling tools used in this analytic step are briefly described in box 2.2. If provided with less irrigation water than he or she demands, a farmer can either evenly distribute the remaining water over his cropland so that each crop receives less water (that is, deficit irrigation), or meet all the irrigation needs of a fraction of the crops, leaving the remaining fraction unwatered. The sensitivity of each crop planted to water shortages determines which approach will produce higher yields. For this important step in the analysis, information from FAO on the relationship between relative crop yield and relative water deficit—called the yield response factor (Ky)—was used to estimate the change in yield resulting from a reduction in water availability for each crop, relevant basin area, and climate scenario (FAO 1998).

Analytic Step 4: Evaluation of Adaptation Options

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

Criteria for Evaluting Adaptation Options

Criterion 1: Net Economic Benefits

Assessments of net economic benefits, conducted at the farm level on a per hectare basis, considered available estimates of the incremental cash costs for implementing the option, as well as the revenue implications of increasing crop yields. The net economic benefit model evaluates a subset of the adaptation options in

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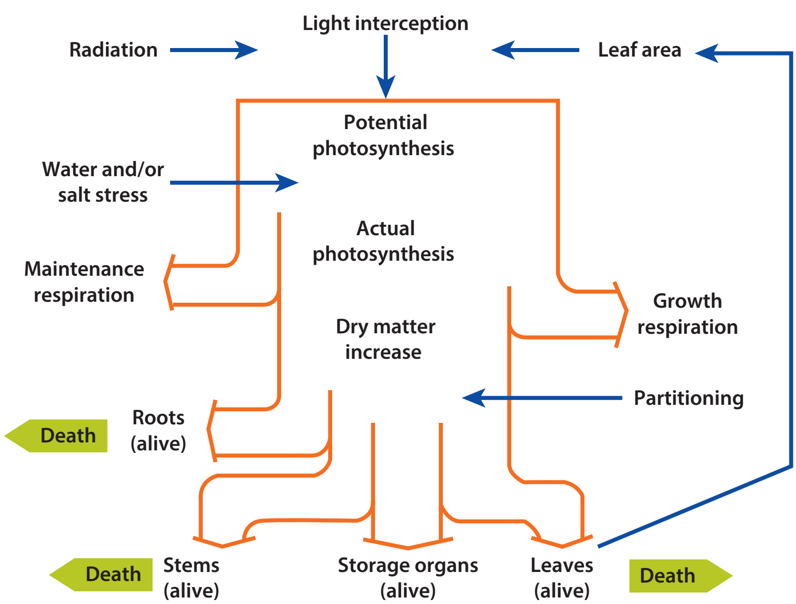
Box 2.2 Description of Modeling Tools for Impact Assessment

The three models used in this study are AquaCrop, Climate and Runoff Hydrologic Model (CLIRUN), and Water Evaluation and Planning System (WEAP). These models are in the public domain, have been applied world-wide frequently, and have a user-friendly interface. A brief description of each of these models follows.

AquaCrop

This model was developed and is maintained and supported by the Food and Agricultural Organization (FAO); it is the successor of the well-known CROPWAT package. The model is mainly parametric-oriented and therefore less data-demanding. It has the following strengths: (1) the simplicity to evaluate the impact of climate change and evaluation of adaptation strategies on crops and (2) the ability to evaluate the effects of water stress and estimate crop water demand. Figure B2.2.1 illustrates some of the main crop growth processes reflected in AquaCrop.

Figure B2.2.1 AquaCrop Model



CLIRUN

The Climate and Runoff Hydrologic Model (CLIRUN) 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. CLIRUN can be used to estimate monthly runoff in a catchment. 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

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Box 2.2 Description of Modeling Tools for Impact Assessment *(continued)*

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 (PET) models is also available for use in CLIRUN. Actual evapotranspiration is a function of potential and actual soil moisture states following the FAO method.

WEAP

WEAP—was developed by the Stockholm Environment Institute (SEI) and is maintained by the SEI U.S. Center. 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, 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, and existing as well as potential major schemes and their various demands of water. The WEAP application used in the study models demands and storage in aggregate, providing a good base for future more-detailed modeling. For more information, see the *WEAP User Guide*, available at http://www.weap21.org (Sieber and Purkey 2011).

terms of both their net present value (NPV—total discounted benefits less discounted costs) and their B-C ratio (B-C ratio—total discounted benefits divided by discounted costs) over the time period of the study. Ranking based solely on NPV would tend to favor projects with higher costs and returns, considering that the B-C ratio highlights the value of smaller scale adaptation options suitable for small-scale farming operations.

The economic model used here produces the optimal timing of adaptation project implementation by maximizing the NPV and the B-C ratio based on different project start years. This is particularly relevant to infrastructural adaptation options, such as irrigation systems and reservoir storage, whose high initial capital expenses may not be justified until crop yields are sufficiently enhanced. Finally, the model estimates NPV and B-C ratios for yield outputs under each dimension of the analysis, namely: (1) climate scenarios, (2) agricultural regions or (in the case of water supply options) river basins, (3) crops, (4) low and high agricultural commodity price forecasts, and (5) irrigated versus rainfed crops. Generating these metrics requires several key pieces of information, which include the following:

- ***Crop yields*** with and without the adaptation option in place, which are derived from the crop modeling. Changes in yields are modeled based on adaptations such as those that increase water availability, open irrigation in currently rainfed areas, optimize application of inputs, or result in more optimal use of crop varieties.[4]

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- ***Management multiplier*** to convert from experimental to field yields: agronomic and crop modeling experts developed these estimates in consultation with local experts as part of their capacity-building work.
- ***Crop prices*** through 2050 were derived using national crop price data from FAO for current conditions and as a baseline to develop price projections under one scenario with constant prices and another based on the International Food Policy Research Institute (IFPRI) global price change forecast.
- ***Exchange rates*** between global and local crop prices were factored in.
- ***Discount rate*** to estimate the present value of future revenues and costs. The base case analyses employ a 5 percent discount rate consistent with recent World Bank economics of adaptation to climate change analyses (for example, World Bank 2013), but sensitivity tests using a 10 percent discount rate were also employed.
- ***Capital and operations and maintenance (O&M) costs*** of each adaptation input (for example, irrigation infrastructure). Local data were sought to characterize costs of adaptation options, and in some cases these data were provided. Overall, these can be difficult to obtain or generalize, and, as a result, in many cases estimates were derived from prior World Bank work or broader research.

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

- Adding new irrigation capacity
- Rehabilitating existing irrigation infrastructure
- Improving water use efficiency in fields
- Adding new drainage capacity
- Rehabilitating existing drainage infrastructure
- Changing crop varieties
- Optimizing agronomic inputs (particularly fertilizer use)

Two of these options—improving water use efficiency and changing crop varieties—include costs for extension programs because extension must be enhanced to achieve the full benefits of the adaptation option. In addition, screening level analyses were conducted for four other options: expanding research and development, improving basin-level water use efficiency, adding new water storage capacity, and installing hail nets for selected crops.[5] These further analyses were more limited because of the lack of benefit information (requiring a "break-even" approach) or the inability to conduct the analysis at a crop-specific, model-farm level (for example, expanding research and development).

Criterion 2: Robustness to Different Future Climate Conditions

A key consideration in the quantitative analysis was assessing whether the option yields benefits across the range of possible future climate outcomes. These outcomes include quantitative and qualitative projections of net benefits of adaptation options across three climate change scenarios, two price scenarios, multiple crops, and four decades. All options were assessed relative to climate conditions in three alternative climate scenarios: Low, Medium, and High Impact. B-C ratios and NPV calculations were developed for each of the three scenarios, providing a means for assessing robustness to future climate conditions.[6]

Criterion 3: "Win-Win" Potential

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

Criterion 4: Stakeholder Recommendations

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

Criterion 5: Greenhouse Gas Mitigation Potential

Once an initial set of options was identified as high priority, the team then also analyzed the GHG mitigation potential of adaptation options. For this study, adaptation effectiveness for agriculture was the highest priority criterion, with GHG mitigation potential identified as an ancillary benefit once the option was established as cost-effective, highly desired by stakeholders, or possessing "win-win" potential.

Limitations and Key Challenges

While the approaches developed and applied in this assessment need to be as robust and accurate as possible, they must also reflect local data availability and must avoid unnecessary complexity to achieve the goals of in-country capacity-building and stakeholder involvement. The framework was designed to be suitable for a wide range of crops (for example, maize, wheat, tomato, wine grapes, apple, alfalfa, and cotton) selected for focus in the early stages of each country analysis. The resulting methodology is suitable to simulate and evaluate a range of adaptation options for various climate change scenarios, cropping systems, and agricultural water regimes.

A study with so broad a scope necessarily has significant limitations. For example, assumptions must be made about many important aspects of agricultural and livestock production in each country, the limits of simulation modeling techniques for forecasting crop yields and water resources must be considered,

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and time and resource constraints must be factored in. The overall methodology was designed to yield results sufficiently precise to ensure that the adaptation measures will yield benefits in excess of costs and are robust to future climate change. Some of the options will require additional, more detailed examination and analysis to ensure that specific adaptation measures are implemented in a manner that maximizes their value to agriculture in each country.

Nevertheless, while more detailed modeling could yield more precise impact and B-C results, pursuing a more detailed approach would not necessarily alter the ranking of options or suggest that options evaluated to be highly cost-effective might instead be poor investments. In order to look broadly across many crops, areas, and adaptation options, however—particularly for adaptation options that may be relatively new to each of the countries supported in the study—it was necessary to develop general data and characterizations of these options. While the study team took great care to use the best available data and applied state-of-the-art modeling and analytic tools, they recognized that analysis of outcomes 40 years into the future, across a broad and varied landscape of complex agricultural and water resources systems, involves uncertainty. As a result, the team attempted to evaluate the sensitivity of results to one of the most important sources of uncertainty—how future climate change will unfold—through the use of the multiple climate scenarios.[7]

Other costs and benefits that do not affect farm expenditures or revenues are excluded from the quantitative analysis, mainly owing to the lack of available data. For example, while increasing fertilizer use may lead to social costs in terms of negative effects on nearby water quality, it is very difficult to quantify those effects without consideration of the site-specific characteristics that may be unique to individual farms.

A potentially larger question, more difficult to address, involves projecting the evolution and development of agricultural systems over the next 40 years, with or without climate change. The future context in which adaptation will be adopted is clearly important but very difficult to forecast. Other important limitations involve the necessity of examining the efficacy of adaptation options for a "representative farm." The result is an important initial step in the process of evaluating and implementing climate adaptation options for the agriculture sector using the current best available methods.

The researchers hope, however, that the awareness of climate risks and the analytic capacities built through the course of this study provide not only a greater understanding among agricultural institutions of the basis of the results, but also an enhanced capability to conduct the more detailed assessment that will be needed to further pursue the most promising adaptation measures.

Notes

1. In this analysis, the economic and physical baseline is current yields, which represents a simplification of the expectation for these countries but is a reasonable expectation for agricultural productivity without planned adaptation interventions. Because the

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purpose of this study is to evaluate measures that might enhance resilience to both current and future climate, it is not clear whether modeling of an alternative baseline that includes agricultural innovation (and adoption) is appropriate or important. Using a baseline of increasing yield, for example, implies that some adaptive actions (such as new varieties) would be adopted as "autonomous" adaptations, at some cost to either the country or the farmers. This study examines marginal gains in crop yields and farm-level revenue from this baseline for individual measures that the team believes are unlikely to be adopted without additional adaptation plans and investments. It is certain that projecting a baseline of future crop yields that differs from the constant yield assumption used here adds significant complexity and uncertainty to the results.

2. Some might argue that simulation modeling is so demanding of inputs that it yields less precise or even inaccurate estimates. The difficulties of simulation modeling make calibration of the models to current conditions, wherever possible, most important. The Ricardian approach, an econometric evaluation of historical agricultural sector performance, is sometimes put forward as an alternative method for estimating the impacts of climate change on yields and revenue in response to climate change. However, the Ricardian approach, which relies on an econometric estimation of a climate response function based on current data, implicitly reflects adaptive responses in the current system and therefore lacks the ability to estimate the incremental benefits of specific adaptation options. Furthermore, only currently practiced adaptive measures are reflected in the estimation—whereas in many cases in developing countries agricultural systems are poorly adapted to current climate, reflecting an "adaptation deficit"—and new measures should be introduced.
3. 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.
4. For changes in varieties, the team looked not at the yield benefits of newly developed seed varieties, but rather at adopting currently available varieties that are either not used at present or that would optimize yields for future conditions. A separate analysis reviews possible returns from investment in research to develop new varieties and technologies.
5. Note that some analysts have suggested that improving water use efficiencies, such as lining irrigation channels, may have little value if both surface water and groundwater are used for irrigation, because losses from the channels would be gains to the groundwater aquifers. However, the cost of collecting and delivering the water to the fields must be taken into account, so while the water may not be lost to the hydrologic system, additional pumping costs would be incurred to recover water lost from irrigation channels.
6. An interesting finding is that in most cases quantitative results for adaptation options were less sensitive to uncertainties in climate forecasts than to uncertainties in future prices. This was also true for CO_2 fertilization effects on yield.
7. The following chapters, which show the climate projections for each country, demonstrate that using multiple climate scenarios is a critical step and that use of only one scenario would suggest more certainty in climate forecasts than is warranted, particularly for precipitation projections that are critical for agriculture.

References

FAO (Food and Agriculture Organization of the United Nations). 1998. *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56, Rome: FAO (accessed December 9, 2013), http://www.fao.org/docrep/x0490e/x0490e00.htm#Contents.

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

IPCC (Intergovernmental Panel on Climate Change). 2000. *Special Report on Emissions Scenarios: A Special Report of Working Group III of the IPCC*, edited by N. Nakicenovic and R. Swart. Cambridge, U.K.: Cambridge University Press.

———. 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. New York: Cambridge University Press.

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, NASA Socioeconomic Data and Applications Center (SEDAC), New York (accessed October 10, 2013), http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01.

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

Sieber, J., and D. Purkey. 2011. *Water Evaluation and Planning System User Guide*. Somerville, MA: Stockholm Environment Institute.

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.

World Bank. 2012a. "The Republic of Armenia: Climate Change and Agriculture Country Note—June 2012." World Bank, Washington, DC (accessed January 17, 2014), http://siteresources.worldbank.org/ARMENIAEXTN/Resources/CN_Armenia_FINAL.pdf.

———. 2012b. "The Republic of Azerbaijan: Climate Change and Agriculture Country Note—June 2012." World Bank, Washington, DC (accessed January 17, 2014), http://siteresources.worldbank.org/AZERBAIJANEXTN/Resources/CN_Azerbaijan_FINAL.pdf.

———. 2012c. "Georgia: Climate Change and Agriculture Country Note—June 2012." World Bank, Washington, DC (accessed January 17, 2014), http://siteresources.worldbank.org/GEORGIAEXTN/Resources/CN_Georgia_FINAL.pdf.

———. 2013. "Armenia, Azerbaijan and Georgia: Where Climate-Resilient Agriculture Means Less Poverty." World Bank, Washington, DC (accessed December 9, 2013), http://go.worldbank.org/1A06SPQM50.

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