

# CPWF Project Report

## **Integrating Knowledge from Computational Modeling with Multi-stakeholder Governance: Towards More Secure Livelihoods through Improved Tools for Integrated River Basin Management**

Project Number PN40

Governance and Modeling Author Team

International Food Policy Research Institute and Partners



CGIAR Challenge Program on  
**WATER & FOOD**

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## **Program Preface**

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase water productivity for agriculture—that is, to change the way water is managed and used to meet international food security and poverty eradication goals—in order to leave more water for other users and the environment.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

## **Project Preface**

Integrating Knowledge from Computational Modeling with Multi-stakeholder Governance: Towards More Secure Livelihoods Through Improved Tools for Integrated River Basin Management

The project aimed at contributing to the overall goal of managing land and water resources in river basins in an economically efficient, environmentally sustainable and socially acceptable way by developing integrated simulation models in close collaboration with multiple stakeholders and by promoting their use as decision-tools in multi-stakeholder governance systems. The project was implemented in the Upper East Region of Ghana and the Maule Region of Chile. The project first conducted an analysis of multi-stakeholder governance structures, and then developed two decision-support tools on that basis: (a) Mathematical-Programming-Based Multi-Agent Systems (MP-MAS), which combine economic, hydrological and agronomic models and allow for simulating policy scenarios; and (b) influence-network mapping (Net-Map), a participatory method for research and organizational development.

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## List of acronyms and technical terms

ARI	Advanced Research Institute
CASEN	Encuesta de Caracterización Socioeconómica, National Socio-Economic Survey (Chile)
CdA	Comunidad de Agua, Water User Community (Chile)
CGIAR	Consultative Group on International Agricultural Research
CIDA	Canadian International Development Agency
CIREN	Centro de Información de Recursos Naturales (Chile)
CNR	Comisión Nacional de Riego, National Irrigation Commission (Chile)
CPWF	Challenge Program on Water and Food
CROPWAT	Computer program for the calculation of crop water and irrigation requirements(developed by FAO, see <a href="http://www.fao.org/nr/water/infores_databases_cropwat.html">http://www.fao.org/nr/water/infores_databases_cropwat.html</a> )
CRR	Comisión Regional de Riego, Reginal Irrigation Commission (Chile)
DANIDA	Danish International Development Assistance
DFID	Department for International Development
DGA	Dirección General de Aguas, General Water Directorate (Chile)
DOH/SMI	Dirección Obras Hidráulicas / San Martín Ingenieros (Chile)
EDIC-CEDEC	Irrigation Engineering Consortium (Chile)
FAO	Food and Agriculture Organization of the United Nations
GIDA	Ghana Irrigation Development Authority
GLSS	Ghana Living Standard Survey
GSSP	Ghana Strategy Support Program (run by IFPRI)
GTZ	Gesellschaft für Technische Zusammenarbeit (German Agency for Development Cooperation)
ICARDA	International Center for Agricultural Research in the Dry Areas
IFPRI	International Food Policy Research Institute
IFU-IMK	Institute for Meteorology and Climate Research - Atmospheric Environmental Research (Germany)
IGM	Project 'Integrating Governance and Modeling' (co-led by IFPRI and UHOH, see <a href="http://www.uni-hohenheim.de/igm">http://www.uni-hohenheim.de/igm</a> )
ILRI	International Livestock Research Institute
INDAP	Instituto Nacional de Desarrollo Agropecuario, National Agricultural Development Institute (Chile)
INIA	Instituto de Investigaciones Agropecuarias, National Agricultural Research Institute (Chile)
InnovaChile	Innovation department of the Ministry of the Economy (Chile)
ISSER	Institute of Statistical Social and Economic Research, University of Ghana, Legon (Ghana)
JdV	Junta de Vigilancia, Watch Committee (umbrella organization of

	water user communities at the river basin level) (Chile)
LA/AIDS	Linear Approximation of the Almost Ideal Demand System
MILP	Mixed integer linear programming
MoFA	Ministry of Food and Agriculture (Ghana)
MP-MAS	Mathematical Programming Based Multi-Agent System (developed by UHOH, see <a href="http://mp-mas.uni-hohenheim.de">http://mp-mas.uni-hohenheim.de</a> )
NARS	National Agricultural Research System
Net-Map	An interview-based mapping tool, also referred to as influence-network mapping (see <a href="http://netmap.wordpress.com/">http://netmap.wordpress.com/</a> )
NGO	Non-governmental organization
ODEPA	Oficina de Estudios y Políticas Agrarias (Chile)
PRODESAL	Programa de Desarrollo Agrícola Local (Chile)
UNDP	United Nations Development Program
UFZ	Helmholtz-Center for Environmental Research (Germany)
UHOH	Universität Hohenheim (Germany)
UTalca	Universidad de Talca (Chile)
WARM	Water Resources Management
WaSiM-ETH	Water Flow and Balance Simulation Model (developed by the Eidgenössische Technische Hochschule (ETH), the Swiss Federal Institute of Technology, see <a href="http://www.wasim.ch/en/index.html">http://www.wasim.ch/en/index.html</a> )
WATSAN	Water and Sanitation Committee (Ghana)
WRC	Water Resources Commission (Ghana)
WRI	Water Resources Institute (Ghana)
WUA	Water User Association (Ghana)

## RESEARCH HIGHLIGHTS

The research project “Integrating Governance and Modeling” used advanced modeling techniques to assist policy-makers and stakeholders in Ghana and in Chile to use water resources more effectively for agricultural development and poverty reduction. In Ghana, research was conducted in the White Volta Basin, which represents an early stage of river basin development. In Chile, the Maule basin was chosen as a case of advanced basin development. The two cases represent the Volta and the Andes benchmark basins of the Challenge Program on Water and Food.

The project applied the MP-MAS computer modeling approach (“Mathematical Programming Based Multi Agent System”) to develop a decision-support tool. MP-MAS simulates how farmers interact with each other and react to changes in their economic and natural environment. A key innovation of the project was the development of the decision-support tool in close interaction with multiple stakeholders, including water user associations and members of the irrigation and agricultural administration. This interaction, which was organized in form individual consultations, workshops and training sessions, ensured that the MP-MAS simulations addressed the needs and priorities of different stakeholders and took their local knowledge into account.

In Chile, the application of MP-MAS helped water user associations and the irrigation administration better understand how the benefits from investing in the Ancoa dam will be distributed. This will assist both the farmers and the administration to make optimum use of this large-scale investment. The application of MP-MAS also showed that the government needs to pay more attention to reaching smallholder farmers when reforming the subsidy programs for irrigation investments. MP-MAS simulation results also made it clear that smallholders with insufficient water rights who benefit from unused water resources and spill-overs in the system may not only fail to benefit, but even lose income sources as a consequence of irrigation investments, thus underlining the needs to identify alternative income sources for them. Both the water user associations and the irrigation administration in Chile have decided to use MP-MAS for their future planning and management purposes.

In Ghana, the application of the MP-MAS showed that farmers who have access to irrigation would triple their fertilizer use if they get access to credit, even without subsidizing the fertilizer. In view of the international policy debate on fertilizer use in Africa, this is an important insight that shows how relevant access to irrigation is in making fertilizer more profitable. MP-MAS simulation results also show that farmers in the semi-arid North of Ghana who do not have access to irrigation will not move out of poverty, even if they have access to fertilizer and credit. MP-MAS simulations also indicated that pumping out water directly from the river is not a viable option under current price relations, thus throwing light on a much debated policy option in the region.

The project also revealed that even though investing in small-scale reservoirs is a promising strategy to expand access to irrigation in Northern Ghana, this strategy is confronted with major governance challenges. A survey conducted under the project showed that out of 19 small reservoirs constructed with substantial donor funding between 2000 and 2006 in the Upper East Region of the country, only 3 were in fact used for irrigation. Problems in procurement and construction of the reservoirs were identified as major problems, next to shortcomings in the required technical expertise. The findings of the project suggest that donor agencies—before investing in new small reservoirs—should urgently address these problems, for example by strengthening the accountability of contractors and the irrigation administration to local water user organizations and their elected representatives.

The project also led to the development of Net-Map, an innovative method for research and organizational development, which combines social network analysis with participatory mapping techniques. Net-Map, which is easy to use, makes it possible to identify, visualize and understand how different stakeholders can better interact with each other to achieve their desired outcomes. The method was used in Ghana to support the establishment of the White Volta Basin Board, and in Chile to understand the process of reforming the irrigation legislation. In 2008, Eva Schiffer won the 2008 CGIAR Young Promising Scientist Award for developing Net-Map. Meanwhile, the method has been used in more than 25 different projects in Africa, Europe and Asia, supported by international agencies and national research institutes. Topics for which Net-Map proved useful range from strategies to prevent the spread of Avian flu in Ethiopia to understanding local governments in India.

## EXECUTIVE SUMMARY

### Background

In recent years, multi-stakeholder governance structures, such as River Basin Management Boards, have gained increasing importance for the management of water resources. To become more effective in their decision-making, such platforms benefit from access to policy-relevant information about the bio-physical and the socio-economic parameters that determine the opportunities and challenges of water use. In particular, they benefit from information about the economic, social and environmental impacts of different development and management options for water resources. In recent years, there have been major advances in developing bio-economic models that can provide such information by combining hydrological, agronomic and economic information for the simulation of different policy scenarios. Agent-based models, which capture the interaction of different water users, are a particularly promising approach in this regard. Yet, prior to the project, they had hardly been applied to inform multi-stakeholder decision bodies in charge of river basin management.

### Objectives

The project aimed at contributing to the overall goal of managing land and water resources in river basins in an economically efficient, environmentally sustainable and socially acceptable way by developing integrated simulation models in close collaboration with multiple stakeholders and by promoting their use as decision-tools in multi-stakeholder governance systems. To contribute to this overall goal, the project pursued the following three *objectives*:

1. To analyze multi-stakeholder governance structures;
2. To use agent-based modeling techniques for the development of decision-support tools that can be applied to simulate policy scenarios, while taking both bio-physical and socio-economic information into account; and
3. To use these models as decision-tools for planning processes in multi-governance structures and to monitor their use.

### Research regions

To meet these objectives and generate results that are widely applicable, research under this project was conducted in two river basins that represent different stages of river basin development: The White Volta Basin, located in the Upper East Region of Ghana was selected as a case representing an early stage of basin development. This case was contrasted with the Maule Basin in Chile, which represents an advanced stage of river basin development.

### Methods

For the analysis of governance structures, the team combined different methods: Interviews with experts and focus groups were used for an initial assessment, together with visits to selected communities. An innovative method called Net-Map was developed, which combines social network analysis with participatory mapping techniques. Next to assessing governance structures, Net-Map was also used to support the organizational development of the White Volta Basin Board.

For the development of decision-support tools, the Mathematical Programming Based Multi-Agent System (MP-MAS) was applied, which is a multi-agent model of land use change developed at Hohenheim University. MP-MAS simulates the interactions of farm households with other households and with the biophysical environment. The software combines household models with crop growth models and hydrological models.

Household and community-level surveys were carried out in Chile and Ghana to generate data for MP-MAS. The surveys also provided in-depth studies on specific governance problems, using econometric methods. Stakeholder workshops were held regularly to ensure that the computer-based decision tools could be developed and validated in close interaction with the concerned stakeholders. Stakeholder interaction was equally relevant for the development and use of Net-Map. More information on the methods applied can be found at <http://www.uni-hohenheim.de/igm> .

## Research findings

### Governance structures

*Ghana:* The analysis of governance structures in Ghana showed that efforts to improve water resources management by involving user groups had mixed results. In the case of drinking water, which was included in the Ghana study due to its high importance, Water and Sanitation Committees (WATSANs) were found to be effective in mobilizing resources for contributions to the construction of drinking water facilities and for their maintenance. However, WATSANs were hardly involved in the construction of facilities, even though this did not result in major problems. The study also indicated that accountability in WATSANs is not created through competitive elections (as is often assumed), but rather through community consensus of leaving WATSAN leaders in place as long as they perform satisfactorily. In the case of small reservoirs, however, the situation was found to be different. The infrastructure quality of the small reservoirs was rather low, and the fact that the Water User Associations had no say in infrastructure construction was found to be one of the underlying problems. In fact, out of 19 small reservoirs constructed between 2000 and 2006 with considerable donor funding, only 3 were used for irrigation, mainly due to construction problems, which are linked to governance challenges. The study indicated that there is an urgent need to resolve the governance challenges involved in the construction of small reservoirs before investing more resources in this strategy to expand irrigation. The project also paid special attention to the White Volta Basin Board, a multi-stakeholder governance body that was established during the research period. Net-Map was applied to assist the board members to better understand the networks they need rely on to pursue their developmental and environmental goals effectively.

*Chile:* Chile is internationally recognized for its market-oriented approach to water resources management. In line with earlier findings from the literature, the analysis of governance structures indicated that trade in water rights plays a limited role in practice. The study found that the Chilean model has other interesting lessons to offer for Ghana and other countries. The Chilean state remains deeply involved in financing irrigation infrastructure through an extensive subsidy program. The system, which is based on a competitive grant model, avoids infrastructure quality problems (such as those encountered in Ghana) through a combination of highly effective public sector organizations and strong private incentives. The distributional implications of the program have gradually improved over time, especially due to a legal change in 1999, which stipulates that competitive grants targeted to smallholder farmers must equal the number of grants for commercial holdings. Water sector governance in Chile is also characterized by a far-reaching devolution of water management to water user organizations and their umbrella organizations. While the latter have become increasingly professionalized, the study found that the water user organizations at the community-level still face the typical problems of collective action. A simulation analysis based on an econometric analysis of the water user associations found that collection of fees for maintenance could be increased by 9% and farm revenues by 11%, if measures are taken to improve the functioning of water user organizations, especially in areas where membership is heterogeneous and where the leaders of the organizations are not well connected to higher levels.

### Development and application of decision-support tools

*Ghana*: In collaboration with the stakeholders in the region, two sets of scenarios were identified and modeled using the MP-MAS computer model: (1) a set of scenarios that focused on increased access to credit, and (2) a set of scenarios that simulated pumping water directly from the river for a third season maize crop.

- (1) The *credit scenarios* showed that just by relaxing the farmers' credit constraint, farm incomes increase on the average by almost 50%, and fertilizer use more than triples, even at current fertilizer prices. Reducing the fertilizer price by 20% without relaxing access to credit, however, leads to a minor increase in fertilizer use and farm incomes. Differentiating the results by farm type reveals that farmers with access to either small-scale or large-scale irrigation are able to take a much bigger advantage of the availability of credit, as their incomes increase by 52% and 85%, respectively. Rainfed farms only experience an income increase of 22% as a consequence of having access to credit. Considering the current political debate about subsidizing fertilizer in Africa, this is an important finding. It indicates that providing access to credit and irrigation at the same time can have a very high income effect, whereas subsidizing fertilizer by reducing its price without providing access to irrigation and credit may have a negligible effect.
- (2) The *river pump irrigation scenarios* were modeled because the Ministry of Food and Agriculture in the Upper East Region had a strong interest in examining this option as an alternative to groundwater irrigation. The modeling showed that under current price relations, pumping water out of the river directly is hardly profitable, even if it allows for planting maize outside the usual cropping season. Because of its capital-intensity, this option cannot compete with irrigation from small (or large) reservoirs. This finding underlines the need to overcome the governance challenges of constructing small reservoirs, which were identified under the governance component of the project.

*Chile*: In Chile, two sets of scenarios were modeled, which were of particular interest to the stakeholders: (1) the Ancoa dam project, which started during the project period; and (2) the reform of the subsidy program, which was under discussion during the project period.

- (1) The Ancoa dam project aims to improve irrigation security in the study area by constructing a dam in the Ancoa River. While the project is largely financed by the state, the state charges a fee for the irrigation water that becomes available due to the project, thus shifting a share of the investment cost to the farmers. Before starting construction, the state needed an agreement from farmers equating to a minimum of 50% of total water rights that they are willing to accept this charge. The modeling served to better understand the shadow prices that different types of farms have for water, which translates into their willingness to pay. The simulations showed that under current price relations and technologies, only four out of ten farmers had shadow prices of water that would enable them to pay the required fee. Investments in the efficiency of irrigation, however, would help to go beyond the required 50%. The simulations also showed that farms above 25 ha will experience a much larger increase in their revenue growth rates than farms below that size. This finding indicates that specific efforts are needed to assist smallholders to increase their income, if a further increase in income disparity is to be avoided.
- (2) The *subsidy scenarios* aimed at a better understanding of the impact of the current subsidy regime. The model was able to accurately reproduce the area that benefitted from subsidized irrigation. The model results suggest, however, that most of the farmers, who received a subsidy, would have made the respective investments anyway because they had sufficient economic incentives to do so. The selection procedure for subsidized projects should therefore be modified in order to minimize this crowding-out effect. In particular, it would be beneficial to target the subsidies

more effectively to smallholder farmers, who could not have made the respective investments in improved water use efficiency on their own. The model simulations also showed that farmers who do not have sufficient water rights and benefit from spill-overs and leakages in the irrigation system suffer income losses if investments in improving water use efficiency are made. This finding points to the need to find alternative income sources to this group of farmers.

## Outcomes and impacts

In *Ghana*, the project has three major impact pathways. The White Volta Basin Board, which was established during the research period, is at the center of the first pathway. The application of the Net-Map method assisted the Board in forming strategic partnerships, for example, with the District Assemblies. The second impact pathway is centered around the Ministry of Food and Agriculture, which can use the information generated through the agent-based modeling in designing agricultural programs. Donor agencies and the Ghana Irrigation Development Authority are in the center of the third impact pathway, which focuses on the improvement of small reservoirs. Taken together, the three pathways have a large potential to improve the use of the considerable amounts of funding that government and donors are planning to invest in the northern part of Ghana. Moreover, the project has important messages for other countries in Africa that aim to use small-scale irrigation as a part of their quest for a Green Revolution in Africa.

In the case of *Chile*, the project has four major impact pathways, which involve the following organizations: The National Agricultural Research Institute (INIA), the National Irrigation Commission (CNR), the National Agricultural Development Institute (INDAP), and the umbrella organizations of the water user associations in the region (JdVs). INIA has become the host institution for the MP-MAS computer tools, and the other organizations have started to use MP-MAS to inform their organizational decisions. The expected impact is a more efficient use of the water resources in the region, and a more equitable use of the public funds spent on water resources development. The findings from Chile are also relevant for a range of other countries, especially those that are a similar stage of river basin development and those that aim to follow the “Chilean model.”

## International public goods

Apart from the knowledge generated through the research, the project produced two important international public goods: a refined and field-tested version of the agent-based modeling tool MP-MAS, and the influence-network-mapping tool Net-Map. The software for MP-MAS can be downloaded freely from the Hohenheim University website, together with other relevant information, such as user manuals (<http://mp-mas.uni-hohenheim.de/>). MP-MAS has already been applied in other African and Asian countries. The description of Net-Map is provided on a blog website developed to facilitate access to this tool (<http://netmap.wordpress.com/>). The blog-website provides a wide range of user-friendly information, such as examples of applications, video-clips and a discussion forum. Net-Map has meanwhile been used for at least 25 different projects in African, Asian and Latin American countries.

## Recommendations

The research findings underline the need to expand access to irrigation as a strategy to promote agricultural development and reduce poverty in the semi-arid part of *Ghana*, and in similar regions of Africa. However, government and donor agencies need to tackle the governance challenges involved in the provision of irrigation infrastructure, such as procurement problems that lead to low infrastructure quality. The findings also show that complementary interventions are required to make investments in irrigation effective, especially providing access to credit and promote market development. The research

findings further suggest that a combination of these strategies can be far more effective in increasing fertilizer use than subsidizing the price of fertilizer alone.

For *Chile*, the research findings show that farmers need to increase their irrigation efficiency to be able to benefit from access to water from the Ancoa dam, as they have to contribute to the investment costs of the dam. The findings also indicate that special efforts are needed to create additional income opportunities for smallholders to avoid an increasing income disparity as a consequence of the Ancoa project. Moreover, the research findings underline the need to target irrigation subsidies more specifically to smallholders, as past subsidies mostly went to farmers who had sufficient incentives to make the subsidized investments in any case. Finally, the Chilean case shows that efforts to overcome the collective action problems of water user associations remain necessary, even in a country where these organizations have a long history.

## 1 INTRODUCTION

The management of water basins in an integrated and sustainable way is characterized by three types of complexities: (1) environmental and economic interactions which affect water availability and quality, and concomitantly, household decisions on land and water use, (2) social interactions between stakeholders who are socio-economically and culturally diverse and who often have competing interests and power relations, and (3) a constantly changing macro-environment, which includes political changes, such as decentralization, economic changes, such as change in price relations, and bio-physical changes, such as climate change. The biophysical and economic environment determines the opportunities and constraints faced by different stakeholders in securing their livelihoods, and also determines potential externalities that might arise under alternative water management systems. Social relationships shape how these constraints and externalities are managed, leading to ultimate outcomes in terms of efficiency of water use, equity in access, and sustainability.

In recent years, multi-stakeholder governance structures, such as River Basin Management Boards, have gained increasing importance for the management of water resources. By providing a platform for knowledge exchange and negotiation, such governance structures have a considerable potential for improving water resources management, because they can take the socio-economic complexities of river basins into account. To become more effective in their decision-making, such platforms benefit from access to policy-relevant information about the bio-physical parameters that determine the opportunities and challenges of water resources management. In particular, they benefit from information about the economic, social and environmental impacts of different development and management options. Likewise, policy-makers at the regional and national level, who make ultimate decisions on public investments in water resources development will be able to make more informed decisions if they adequate information on the impact of different investment scenarios. Science-based information is, of course, only one factor that influences decision-making on river basin management. Ultimately, such decisions reflects policy beliefs as well as interests and power structures.

Yet to exploit the full potential of providing knowledge for better decision-making on river basin management, it is essential to use the best available methods to generate information, and generate and disseminate information in a form that is relevant and accessible to the stakeholders involved in decision processes. The "Integrating Governance and Modeling" project pursued this goal by (a) developing decision-support tools for evaluating environmental-economic-social interactions of river basin management, and (b) by testing and promoting the use of these decision-support tools within multi-stakeholder governance structures.

The research under this project was conducted in the White Volta Basin in Ghana and the Maule Basin in Chile. Figure 1-1 displays the study area in Ghana. Administratively, the White Volta Basin falls into the Upper East Region of Ghana which is among the poorest among all ten regions in Ghana. The population density of more than 100 persons / sq.km is higher than the national average of 75 person / sq.km. The region is ethnically very diverse. In terms of agro-ecological conditions, the region is located in the semi-arid tropics of Sub-Saharan Africa and is characterized by a single growing season that lasts from May to October. Agriculture is mostly rainfed, with guinea corn, millet, rice and groundnuts as main crops. Livestock, especially cattle and goats are also important in the research area. There are two large-scale irrigation systems located in the Upper East Region, the Tono and the Vea irrigation schemes with irrigation areas actually served of 1,200 and 1,500 ha, respectively. Irrigation is also practiced under small reservoirs, which have attracted increasing interest by donor agencies in recent years. Small reservoirs in this context refer

to reservoirs that serve to irrigate less than 100 ha. The agent-based simulation model was developed for the Atankwidi+ catchment and adjacent areas, which is also displayed in Figure 1-1. Adequate drinking water supply is a major problem in the Ghana study region (unlike in the Chile case), therefore it was included in the analysis, as well. Just like Ghana, Chile is a unitary (i.e. not a federal) state, which is administratively divided into regions. The research area is located in the 7<sup>th</sup> Region, also referred to as Maule Region. In the study area, a 'typical' sub-basin of the Maule River covering some 600 km<sup>2</sup>, there is a pronounced dualism of market-oriented large-scale holdings with fruit plantations in the valley and subsistence-oriented small-scale holdings on the uplands. Agricultural development during the past decade has been characterized by a substantial expansion in fruit crop production, whereas traditional agricultural production focused on staple food crops, such as wheat, maize, rice and beans.

The Ghana case presents an early stage in institutional and infrastructure development for water resources management. The potential irrigable area in Ghana has been estimated at approximately 350,000 ha; but currently only some 10,000 ha are irrigated. Expanding irrigation is not only essential to use agriculture's potential for reducing poverty. It will also help farmers to cope with the increased rainfall variability, which is likely to increase due to the impact of climate change. In contrast, the Maule Basin represents a mature state in both regards. Chile has a well-established and highly capable institutional set-up for water resources management, whereas Ghana is still in the process of building such institutions, ranging from water user associations to sub-basin boards.

The comparison between the two basins is also interesting from property rights perspective. Chile has been widely considered a role model for market-oriented approach to water resources management. The 1981 Water Law emphasizes private tradable water rights with limited state influence on water use. Likewise, farmers have private property rights in irrigated land. Ghana reformed its water legislation in 1996. While this law also envisages that the state will grant private water rights to users (as in the Chilean system), the implementation is still in an early phase. Hence, water use continues to be governed by different property regimes, which are linked to the prevailing land tenure systems. Customary land rights play an important role in minor irrigation schemes, while major schemes are under state property and managed by state agencies. Partly, water has the characteristics of an open access resource, as well, e.g., in case of pumping water from rivers. Thus, conducting research in both basins creates scope for understanding pathways of river basin development and produce international public goods from which should be of interest for a wide range of countries.

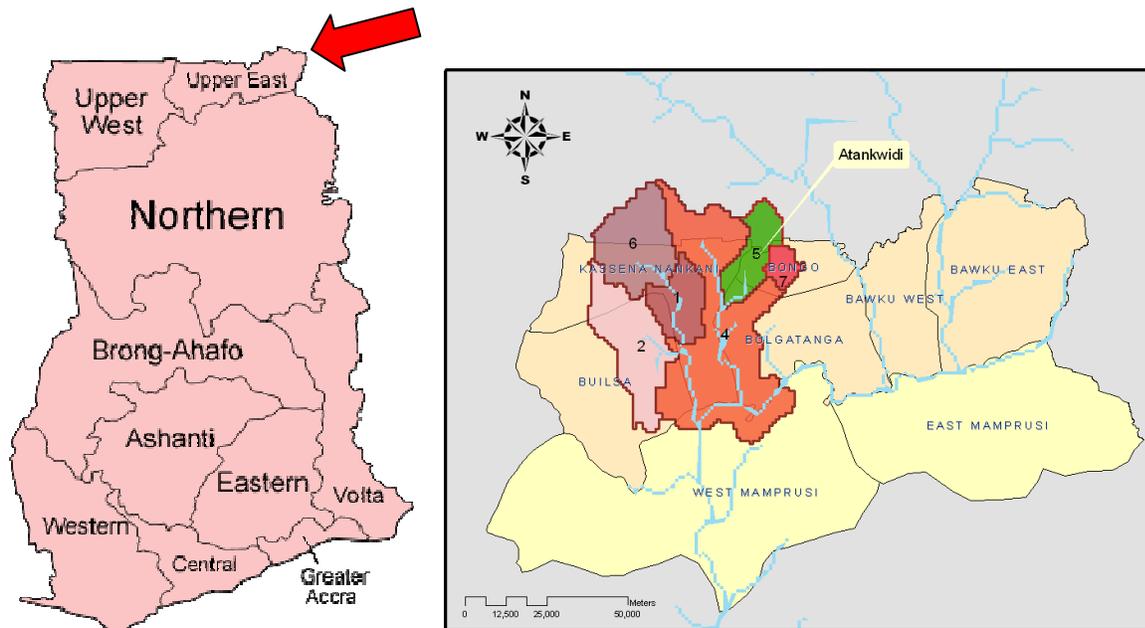


Figure 1-1: Research site in Ghana: Upper East Region (UER) on left side, sub-basin of White Volta River (study area) on right side ( see also Figure A-6 in Appendix C).

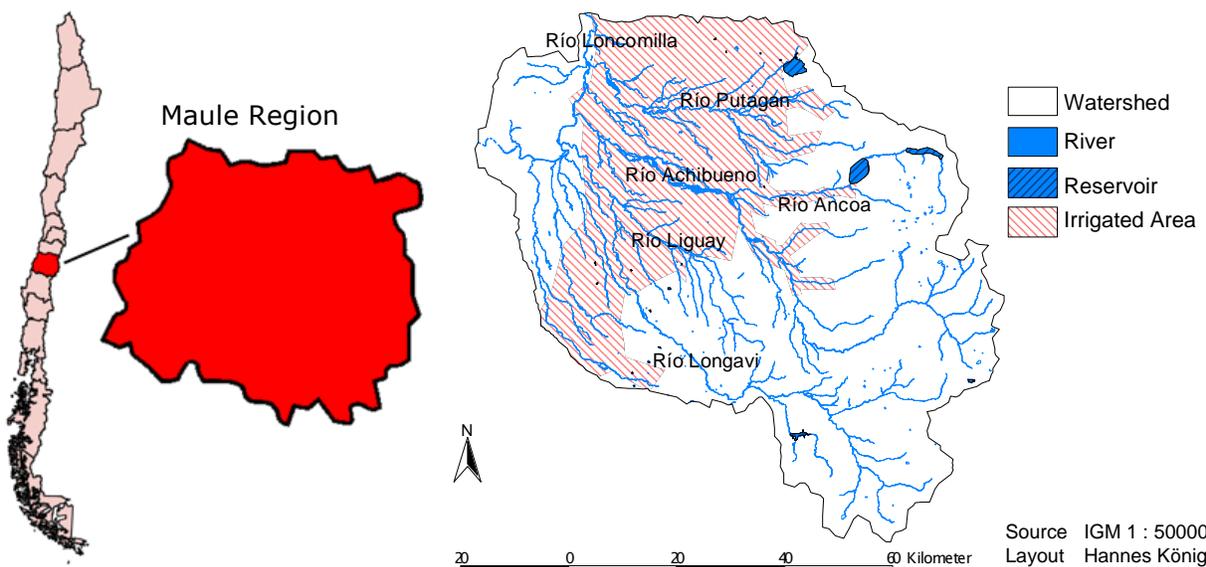


Figure 1-2: Research site in Chile: Maule Region on left side, sub-basin of Maule River (study area) on right side (see also Figure A-9 in Appendix C).

## 2 PROJECT OBJECTIVES AND FINDINGS

The project aimed at contributing to the overall goal of managing land and water resources in river basins in an economically efficient, environmentally sustainable and socially acceptable way by developing integrated simulation models in close collaboration with multiple stakeholders and by promoting their use as decision-tools in multi-stakeholder governance systems. To contribute to this overall goal, the project pursued the following three objectives:

4. Analyzing multi-stakeholder governance structures;
5. Developing decision-support tools for predictive understanding of agent-agent and agent-environment interactions that integrate local and scientific knowledge; and
6. Using of the models as decision-tools for planning processes in multi-governance structures and monitoring their use.

## 3 Objective 1: Analysis of multi-stakeholder governance structures

### 3.1 Methods

As can be seen from Figure A-1 in Appendix C, the analysis of existing governance structures was the first step of the research approach. This analysis served four different purposes. First, a comparative analysis of the governance structures in the two study regions was a research objective in its own right. Second, the analysis informed the project teams about the institutional landscape and the relevant stakeholders, thus forming the basis for the stakeholder interaction that was a main element of the research process. Third, the analysis served as a “baseline” against which ongoing changes in the governance structure, including those induced by the project, can be compared. Forth, the analysis also aimed to contribute to methodological innovations, which were realized in form of the Net-Map tool.

The analysis involved two steps. At the beginning of the project, an initial assessment of governance structures and stakeholder needs was carried out. This assessment was guided by a conceptual framework, which is sketched in the next section. In the second step, in-depth studies were carried out on specific aspects of water resources governance, which were identified as critical in the initial assessment.

#### 3.1.1 Conceptual framework

The conceptual framework draws on concepts of the New Institutional Economics and its application natural resource governance and public administration by the team members in charge of governance (Birner & Wittmer, 2009; Birner & Wittmer, 2004; Birner & Wittmer, 2006). The framework is further described in the Governance Structure Report (Birner, Schiffer, Asante, Gyasi, & McCarthy, 2005). The framework encompasses the following six elements:

- 1) Mapping of the actors involved in water resources management, distinguishing actors from the public sector, the private sector and the third sector (see Table A-1 in Appendix C for a characterization of these three sectors and examples from irrigation management).
- 2) Identifying the types of property rights and (often overlapping) property regimes governing water resources (distinguishing state, private and community-based property regimes and open access);
- 3) Characterizing the ways in which the infrastructure required for water use (irrigation or drinking water use) is (a) provided, (b) financed, and (c) managed;

- 4) Reviewing the regulations, coordination that affect water use;
- 5) Assessing the interactions of the actors involved in water resources management (coordination; conflicts; market and non-market based exchange of water rights);
- 6) Assessing governance structures in terms of their implications for efficiency, equity and environmental sustainability of water use.

### 3.1.2 Empirical data collection

For the in-depth studies on critical issues of governance, two different methods were used: survey-based research; and research using the Net-Map tool, which was developed in this research project.

#### Initial assessment methods

The collection of empirical data for the initial assessment of governance structures and stakeholder needs involved the following steps:

- Review of the relevant literature as well as legal and policy documents for both countries;
- Interviews with representatives of relevant organization in the public, private and third sectors and with experts (approx. 50 interviews in each country);
- Visit to local communities to hold focus group interviews (approx. 20 communities);
- Interactions in stakeholder workshops with the aim to identify their needs and priorities (see Objective 3 for further details);

#### Surveys

Under the project, household and community surveys were conducted in both Ghana and Chile. These surveys served (a) to generate data for the agent-based modeling tool (see Objective 2), and (b) to provide data for analysis of governance issues. The surveys were implemented as follows:

*Ghana household and community survey:* The survey aimed at generating a household data set that is statistically representative for the Upper East Region. In a first step, 31 communities were randomly sampled, and a community-level survey was conducted to obtain information on basic infrastructure, land use, access to roads and markets, demographic characteristics of the community, local service providers and community groups. In communities where Water and Sanitation Committees (WATSANs) existed, representatives of two of these organizations were interviewed, as well, using a separate questionnaire. This resulted in a data set of 61 WATSANs. From the 31 communities, 292 households were randomly sampled. The plan to conduct a survey among Water User Associations (WUAs) could not be realized due to the low number of WUAs in the sampled communities. A WUA survey was subsequently conducted as part of the small reservoir survey described below. The household dataset includes three layers of information: household level, individual level, and plot level. Household level data includes natural resource management practices, inputs purchased, implements and tools owned, main problems existing in the crop production, household assets and access to services. The individual level data includes demographic information for 1,919 household members, such as relation to the household head, gender, age, education and participation in local community groups. The third layer provides crop production information about 560 plots owned by the households.

*Chile household and community survey:* As a first step in data collection, lists of all CdAs were obtained from all relevant Juntas de Vigilancia in the study region. Next, from the list of CdAs, 35 were randomly selected and interviewed. During each CdA interview,

enumerators collected lists of all households holding water rights within the CdA. From these lists 8-12 households were randomly selected and interviewed. During the household interview, enumerators asked a variety of questions regarding contributions decisions and amounts as well as detailed questions about farm production and management. Information at both the household and CdA level are integrated to form a final dataset which contains 318 households falling in 35 CdAS distributed across eight Junta de Vigilancia areas.

In Ghana, the non-functioning of small reservoirs was identified as a major problem. To conduct an in-depth study on this topic, a survey of small reservoirs was carried out as follows:

*Ghana small-reservoir survey:* To conduct this survey, the team first tried to identify all small reservoirs in the Upper East Region, using two data sources:

- Ghana Irrigation Development Authority (GIDA) database of reservoirs and dug-outs from 1996;
- Satellite image interpreted by Jens Liebe (2002) that identified wet spots (small reservoirs and wet spots).

A team member then visited all 126 small reservoirs that could be identified on this basis. At each reservoir, he filled a brief survey questionnaire based on interviews with local knowledgeable people based and on observations (e.g., observing the conditions of the dam walls; observing whether or not cultivation took place). If a Water User Association (WUA) existed for the respective reservoir, a separate survey questionnaire was applied, resulting in a data set of 31 WUAs. He also took photos and GPS measurements of each reservoir. For the analysis, data were compared with available satellite image and Google Maps. A set of available spatial data, such as a soil map, a map of road networks, rainfall data and a digital elevation model were used, as well.

In addition to analyzing the data from this survey, a variant of the Net-Map tool described in the next section was applied as well. In this variant of the method, the emphasis was placed on understanding the different steps in the process of constructing small reservoirs.

### *The Net-Map Tool*

The Net-Map tool was originally developed by Eva Schiffer in Ghana as a diagnostic tool to gain a more structured and in-depth understanding of the multi-stakeholder water governance system of the White Volta Basin and to support the White Volta Basin Board in their strategic decision making (see Schiffer and Waale 2008). Subsequently, the tool was also used as a diagnostic tool to analyze policy processes in Chile.

Net-Map is a participatory research method, which combines elements of stakeholder mapping and ranking techniques with social network analysis. The method is particularly suited to find out how much influence different actors have (or had) on achieving a defined outcome, and what the sources of their influence on that outcome are. Influence is defined in this context based on Max Weber's definition of power, which holds that an actor can induce others to act according to his or her will, even despite potential resistance of those actors. The method can be applied with individual respondents or groups, and it involves the following steps (see <http://netmap.wordpress.com/> for more details):

1. In a first step, the respondents are asked to identify who all the actors are that can influence the respective outcome. Their names are written on "actor cards" (preferably post-it stickers) and distributed on a big empty sheet of paper. One can use different colors for different types of actors (e.g., distinguishing public, private and third sector actors). Actor figurines can be used to represent the actors in addition to their name cards, even though the method can also be applied without

those. If actors are expected to have different interests with regard to the outcome in question, one can also mark down their interest orientation on the paper (e.g., in favor or against a particular reform).

2. In a second step, the respondents are asked to describe different types of relations between the actors. The types of relations have to be identified previously by the researcher on the basis of the research question. Examples of relations include flows of funds, flows of information and authority relations.
3. As a third step, the respondents are asked to rank the influence of the actors, either on a pre-defined scale (say 1-8), or a scale that the respondents choose. In this case, the rankings can be normalized to the same scale during the analysis. The "clue" of the Net-Map method is the visualization of this scale through checkers game pieces, which are stacked on top of each other, thus building "influence towers." These towers (see Appendix D) represent the influence of the actors, leading to a three-dimensional map.
4. In a fourth step, the map is used as a basis for discussion with the respondents. In particular, the map can be used to discuss the sources of influence of the different actors, features of the network structure between the actors, and entry points for changes in the system.
5. The data derived from the mapping exercise can be analyzed in different ways. The data about the network structure can be used for social network analysis, using computer software programs such as VisuaLyzer, or Ucinet. The height of the "influence towers" can be analyzed separately or in combination with the network data. If data on the same topic are collected from different actors, it is also possible to combine the individual maps for the purpose of analysis.

As further discussed below, Net-Map is one of the major public goods produced by the project. IFPRI's Communication Division played an important role in transforming the tool into a "product" that is easily accessible by interested users. Experience has shown that the tool can be used not only for research purposes, but also in support of organizational development. In 2008, Eva Schiffer won the CGIAR Young Promising Scientist Award for developing Net-Map.

## **3.2 Results for Ghana**

### **3.2.1 Results of the initial assessment**

#### Legal framework

Until the 1990s, the management of the Ghana's water resources was fragmented among various institutions with no clear policy for coordination. Irrigation has not played a major role in the country (as less than 1% of the agricultural area is irrigated). A set of legal studies on Water Resources Management (WARM), however, called for the establishment of a coherent policy framework to guide the future development of water resources. These studies were supported by major donors (CIDA, DANIDA, DFID, GTZ, UNDP and the World Bank.) In 1996, an act was passed, which established a Water Resources Commission (WRC). The Water Resource Commission Act declares all water resources to be state property, by vesting the property and control of the water resources in the President, on behalf and in trust of the people of Ghana. The act assigns the responsibility to regulate and manage the use of water and to co-ordinate all policies regarding water resources management to the WRC. The regulatory functions rest specifically with the mandate of WRC to register and regulate water use rights. This mandate refers to the use of water for

commercial purposes; the use of water for domestic purposes does not need to be registered under the Water Resources Commission Act.

### Institutional landscape

Figure 3-1 describes the institutional landscape for water resources management in Ghana. Unlike in the case of Chile, domestic water supply is included here, as well (As indicated above, the Ghana study included drinking water due to its importance). As indicated above, the Water Resources Commission (WRD) plays a central role for water resources management in Ghana. The commission started its operations in 1998. The act stipulates that the members of the WRC are representatives of all government agencies that are involved in water resources management, a member appointed by the national House of chiefs, and two additional members, one of which should be a woman. Apart from the women's representative, WRC decided to invite a representative of the environmental NGOs to serve on the Board.

The Water Resources Commission Act does not specify a decentralized governance structure, but it allows for the formation of sub-commissions as seen necessary. The WRC uses this as the legal basis for the development of Basin Boards that are supposed to implement the functions of the WRC at a lower level. Due to the nature of the matter at stake, it was decided that these decentralized Boards should not be tied to administrative boundaries but integrate water governance on a River Basin level. The first pilot Basin Board was developed in the Densu River Basin. In this area, water pollution problems are the major challenge. As a second pilot project, the Commission chose the upper White Volta Basin. Here the importance of a coordinating actor was emphasized because of cross-boundary water issues, as the White Volta Basin stretches into Burkina Faso and – to a smaller portion – into Togo.

As can be seen in Figure 3-1, a range of further government agencies are involved in water resources management, as well. These include agencies with a "development orientation", such as the Ghana Irrigation Development Authority (GIDA) and those with an "environmental protection orientation", such as the Environmental Protection Agency.

Due to the decentralization process in Ghana, which started in the late 1980s, the District Assemblies plays a role in water resources management, as well.<sup>1</sup> They consist of a council of elected and appointed District Assembly Members, the district administration (which is also referred to as District Assembly) and a District Chief Executive, who is appointed by the President.

Water and Sanitation Teams formed by District Assembly staff are responsible for facilitating access to drinking water, with oversight from the Community Water and Sanitation Agency (located at the regional level). At the village level, drinking water facilities, such as boreholes, are supposed to be managed by village-level Water and Sanitation Committees (WATSANs), which are also supposed to contribute 5-10% of the establishment cost of the facilities.

In collaboration with the Departments of Food and Agriculture and GIDA, the District Assemblies are also in charge of small-scale irrigation infrastructure, in particular, small reservoirs. There is a policy to form Water User Associations (WUAs), which are supposed to manage and maintain the small reservoirs.

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<sup>1</sup> Ghana is divided into ten administrative regions, which are subdivided into 138 metropolitan, municipal and district assemblies.

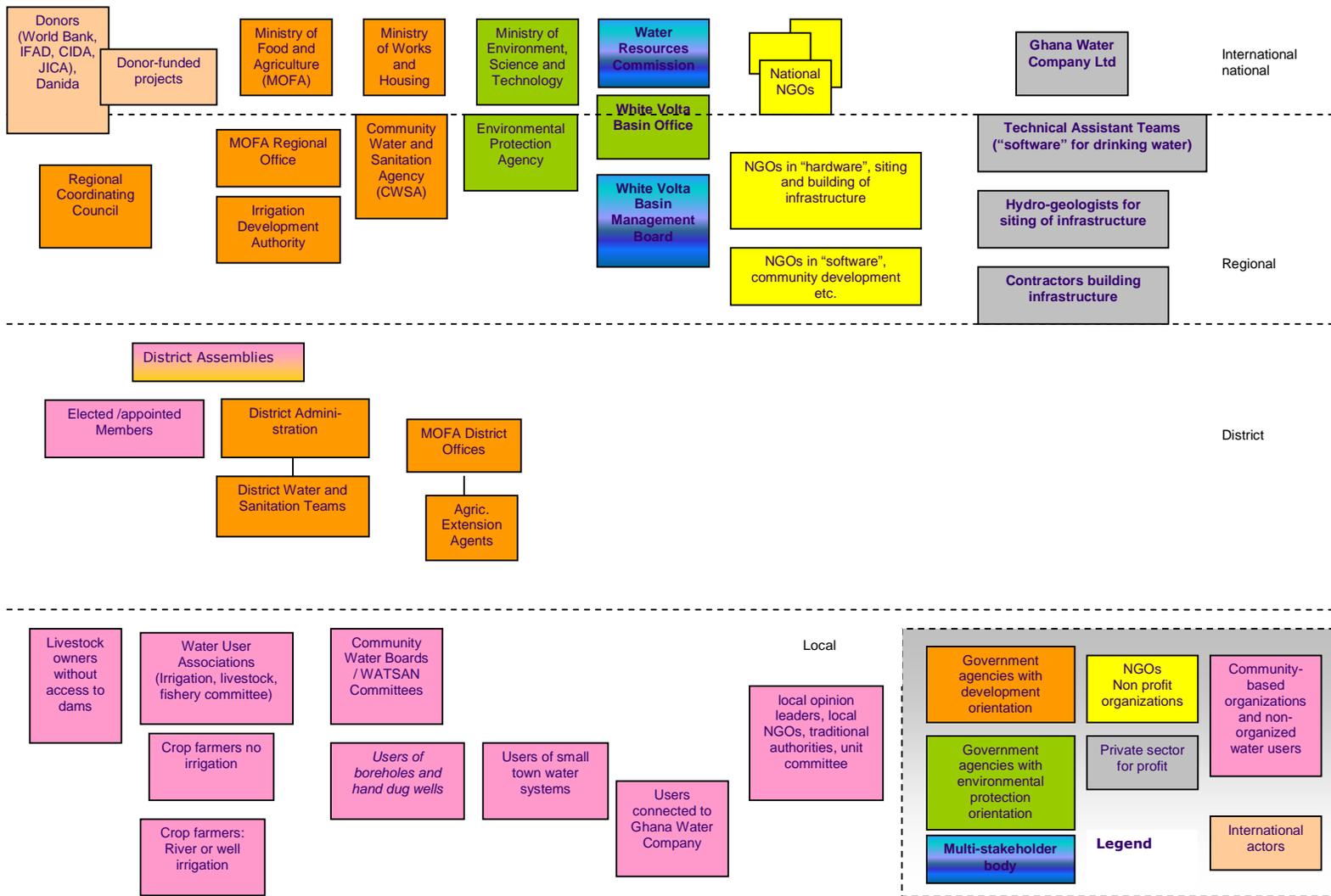


Figure 3-1: Governance structures in Ghana  
Source: Authors

There are two large-scale irrigation schemes in the research area, the Tono and Vea irrigation schemes. They are managed by the Irrigation Company of the Upper Region (ICOUR), a state-owned company. Land in these schemes is state property (given by the respective chiefs to the state), and they are managed by state agencies. Farmers can lease land in these schemes on a yearly basis. In 2000, ICOUR started to promote WUAs. At the time of the initial assessment in 2004, 54 WUAs had been formed.

They are supposed to form village committees and collaborate with ICOUR, for example, with regard to land leasing. ICOUR is expected to cover all its costs of irrigation management through water levies. The levies, which vary by crop, are decided annually in a meeting that is attended by the representatives of the village committees, the Regional Coordinating Council, the chiefs and the District Assembly representatives.

Non-governmental organizations (NGOs) play various roles in water resources management. They are involved in the construction of bore holes for drinking water, either with their own funding or under contract arrangements with the District Assemblies, and they also facilitate communities in the formation of Water and Sanitation Committees or Water User Associations. Private companies play a role as contractors, both for the construction of drinking water facilities and small reservoirs.

### Governance and policy issues

This section describes the main governance and policy issues that were identified through the assessment of governance structures and the stakeholder needs assessment (see Objective 3 for more details on the stakeholder workshops).

#### Access to safe drinking water

In spite of government and donor efforts to expand the provision of safe drinking water facilities, access to drinking water remains an important problem in the region. Access is particularly difficult during the dry season, when boreholes and wells dry up, or provide little water, leading to long waiting times. All but one of the 20 communities visited for the initial assessments reported frequent physical fights among the women fetching water, usually triggered by someone jumping the line. Such fights often lead to serious injuries, which can be seen as an indicator of the level of desperation that exists regarding water supply. The interviewed stakeholders highlighted the heavy demands on women's time for fetching water to be a major problem. WATSANs were only partly successful in resolving these kind of problems.

#### Non- functioning of small reservoirs

According to the assessment, small reservoirs have high priority for communities, not only as a source of irrigation water, but also as a domestic water source during the dry season, a water source for livestock, and an opportunity for fishing. Communities that did not have access to small reservoirs considered access a high priority. However, most of the communities that had access to small reservoirs were discontent with their functioning. Communities with access to new reservoirs typically report problems with the quality of construction. Communities with older reservoirs frequently demand the desiltation of tanks. The stakeholder interviews also revealed that there were serious disagreements with the irrigation administration as to how and when desiltation should be carried out. Problems with the construction and maintenance of reservoirs seriously limit their use for irrigation. In fact, only 7 out of the 16 communities visited for the initial assessment that had a dam did in fact cultivate the designated irrigation area. This problem is further discussed in Section 3.2.2 ).

#### Underutilization of the irrigation potential in large-scale schemes

The irrigation potential in the large-scale irrigation schemes is not fully used either. Tono, one of the two large reservoirs in the study area, was constructed between 1975 and 1985 and has a potential irrigable area of 3,800 ha, of which 1500 ha were used at the time of the initial assessment. Vea was constructed in 1965, and has a potential irrigable area of 2,000 ha, of which 1200 ha is typically used. Due to conflicts between

drinking water and water for irrigation, especially in dry years, this area is often further reduced, as priority is given to drinking water. In 2004, only 300 ha of land were cultivated in that scheme. Farmers also complain about the level of the fees they have to pay for irrigation, agronomic problems and marketing problems. Agronomic problems, such as pests in tomato, reportedly also arise from the land lease system. Farmers often do not know the previous crop systems on the land they are leasing, which obviously makes crop fertilization and crop rotation difficult to manage.

#### Lack of livelihood opportunities and the role of off-farm employment

The needs assessment also revealed that a general lack of livelihood opportunities is seen as a major problem in the Upper East Region, especially since agricultural income sources are limited by constraints that individual households can hardly solve, such as access to credit and marketing facilities, or lack of irrigation facilities. From the household perspective, off-farm activities, both in agriculture (i.e. on other farms) or outside agriculture, are seen as one possible source of livelihoods. Young adults often migrate for off-farm employment, which has frequently been highlighted as a major problem in the focus group interviews conducted during the initial assessment.

### 3.2.2 Results of the in-depth studies

Based on the initial assessment of governance structures and stakeholder needs, the team decided to conduct in-depth studies on three topics:

- As in other countries, donor agencies in Ghana have placed strong emphasis on community- and group-based approaches to governance reform, which aim at improving water resources management. Both WATSANs and WUAs are examples. Research was conducted to better understand (a) how these organizations work in practice, (b) to what extent they compete for the household's time, thus possibly affecting labor availability for farm or off-farm activities, and (c) whether they have an effect on natural resource management practices.
- Since the Ghanaian government and donor agencies have shown increasing interest in supporting small reservoirs (as an alternative to investing in the improvement or expansion of large-scale irrigation schemes), research was conducted to understand why existing reservoirs are not used to the full extent for irrigation. Since the small reservoir survey revealed that major problems lie in the construction process, additional research was conducted to analyze the governance challenges involved in the construction process.
- The White Volta Basin Board, which constitutes the major multi-stakeholder governance body in the research area, was in the process of establishment during the research period. The Board was also a major partner of the research project. Therefore, it was decided to conduct in-depth research on the strategies that the Board could use to best achieve its goals.

#### Group-based governance reforms

##### How do groups work in practice? The case of Water and Sanitation Committees

WATSANs, as indicated above, play a central role in implementing a "demand-driven" community-based approach to the management of drinking water supply in Ghana. This analysis points to a mixed success with this strategy in the Upper East Region. Communities took the first step in demanding a drinking water facility to be constructed or rehabilitated in only half of the surveyed cases. However, they contributed resources to the construction/rehabilitation in 70% of the cases, and they are fairly effective in collecting monthly fees for the maintenance of the facilities. In half of the cases, these fees are decided in consensus in community meetings with the WATSAN committees. The involvement of the WATSANs in infrastructure construction is rather limited. In only one third of the cases, WATSANs were able to express an opinion on the choice of the contractors. Meetings to evaluate the work of the contractor were held in 70% of the cases, but 80% of the WATSAN representatives participating in such meetings indicated

that they were not used to discuss problems in the construction process. The results also indicated that accountability between community members and the WATSAN Executive Committee is created through other mechanisms than those foreseen in the design of this reform strategy. The chairperson was selected through competitive elections in only 18% of the cases, and in 40% of the cases, the chairperson has been in charge for more than 9 years. It appears that chairpersons remain in place on a consensus basis as long as the community is satisfied with their services. Since the number of WATSANs was too limited to conduct an econometric analysis, the data were later collected for this project were combined with a new data set collected by IFPRI and ISSER in 2008, which used a similar questionnaires regarding drinking water supply. This analysis, which was still in progress at the time of submitting this report, aims at identifying the factors that are associated with the existence of WATSANs in a community, and with the functioning and the effectiveness of WATSANs.

*Do groups compete for scarce on-farm and off-farm labor time?*

A second type of analysis conducted with a view to assess the prospects of group-based governance reforms used the household data collected for the project to analyze the relations between male and female household member's decisions to engage in community-groups and in off-farm activities and the possible implications of these decisions for crop yields (McCarthy and Sun, 2009). This analysis covered all types of community-based groups, including micro-credit groups. A household decision model was developed, according to which households maximize expected utility of on-farm and off-farm returns, subject to a number of household constraints. The model includes an agricultural production function that distinguishes between the labor input of male and female household members. This analysis led to the following results: Households that participate in groups and have higher crop yields are those located in communities with better soil characteristics and better infrastructure and those that are wealthier, better educated, and not severely labor constrained. Female participation in off-farm labor markets increases at higher levels of labor availability, but participation in women's groups' only increases as labor scarcity is relaxed at lower levels. Yet, the factors determining group participation are complex, since female-headed households with higher dependency ratios are also more likely to participate, which indicates that this type of household perceive benefits in group membership in spite of labor constraints. Female participation in off-farm income appears to be complementary to on-farm crop returns. Unlike the decision of women, the decision of men to work off-farm is dependent on the underlying productivity of the land, as captured by the negative impact of soil quality, and potentially land security, on this decision.

*Are groups associated with change in natural resource management practices?*

The third analysis conducted under this theme addressed the question as to whether the number of groups that exist in a community, as an indicator of collective action is associated with the adoption of sustainable natural resource management practices, considering that practices are important for the protection water catchments (Andam and McCarthy, 2009). A regression analysis of the survey data showed that the number of groups is in fact positively associated with the construction of natural resource management structures that benefit from collective action, such as terraces, stone bunds, ditches, and fences. The regression analysis also showed that access to agricultural extension was not significantly associated with the adoption of such practices, whereas use of the radio as main source of agricultural information was. Expectedly, no significant association could be observed between number of community groups and natural resource practices that households can adopt individually, such as use of crop residues, fodder or manure.

*Governance challenges of constructing small-scale reservoirs*

Small reservoirs have attracted increasing interest in recent years as an alternative to large-scale irrigation, not only in Ghana, but also in other African countries. Hence, the experience of the research region has important lessons to offer. Figure A-2 shows a

map of the small reservoirs that were captured in the survey. Figure 3-2 shows the number of small reservoirs that were constructed in different time periods, and indicates to what extent they were used for irrigation. The figure distinguishes reservoirs that were used for irrigation in the area designed for this purpose, and reservoirs, where irrigation took place in the catchment or reservoir area, which is an undesirable practice.

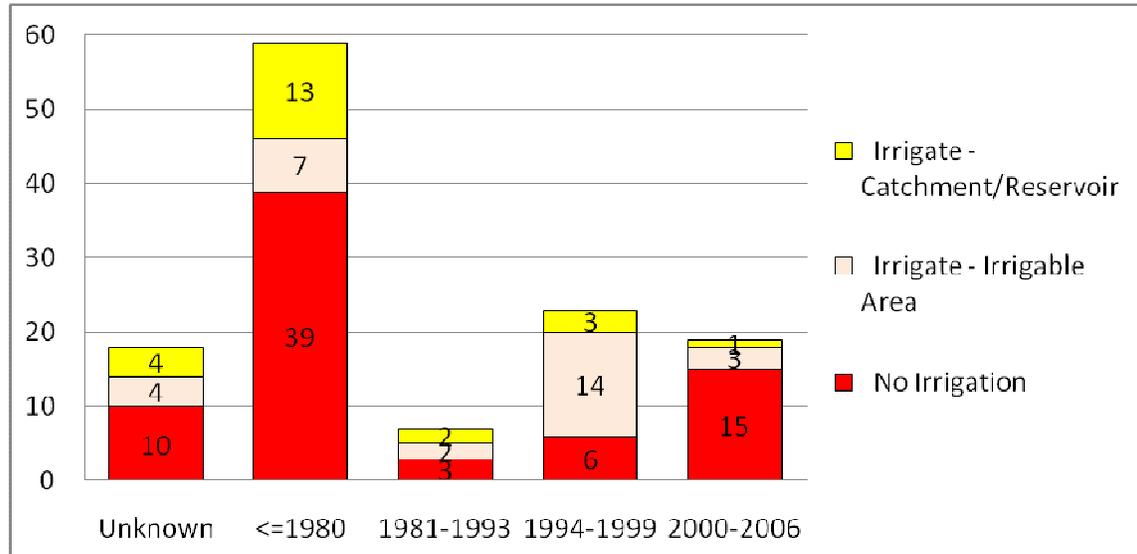


Figure 3-2: Number of small reservoirs and their use, by time period

Source: Authors

The figure shows that a disturbingly high number of reservoirs that were constructed or rehabilitated in the period between 2000 and 2006 (15 out of 19) were not used for irrigation. The majority of the elder reservoirs (constructed or rehabilitated before 1980) were not used for irrigation either. An econometric analysis was conducted using spatial information (see methods section above). This analysis (McCarthy et al., 2009) showed that irrigation in the designed area is significantly higher in locations with better quality construction, with greater water availability and with better soil quality. More isolated areas also more likely to choose this type of irrigation. Irrigation in the catchment/reservoir area is more likely to occur in locations with higher population density.

An econometric analysis was also conducted to identify the factors associated with maintenance and protection activities. This analysis showed that dams constructed with concrete spillways (as an indicator of quality of construction) were more likely to have stable dam walls, to have trees or grasses planted in the catchment, and have more collective activities overall. Greater soil quality was also associated with more collective activities, whereas the degree of isolation of the dam site and population pressures had no statistically significant impact on any of these variables.

The survey data also revealed major construction problems for the reservoirs constructed between 2000 and 2006. In particular, canals were often not built or not finalized years after the construction had started, or reservoirs did not fill to a level that would allow for irrigation. In view of these problems, further research was conducted to better understand the governance challenges of the construction process (Birner, 2008). The Net-Map method (see above) was applied for this purpose, both with a focus group and with key informants. The results are displayed in Figure 3-3, which combines the information gathered from different sources. As further described in the respective paper, the analysis identified two major problems in the construction of these reservoirs: First, as is typical for infrastructure investments, there are considerable risks for the "diversion of funds" in the contracting process. According to key informant information, a

share of the resources dedicated for construction works is used to finance political parties, both directly and through contractors who finance election campaigns. There are also incentives to make “informal payments” to supervisors that can undermine the quality control system.

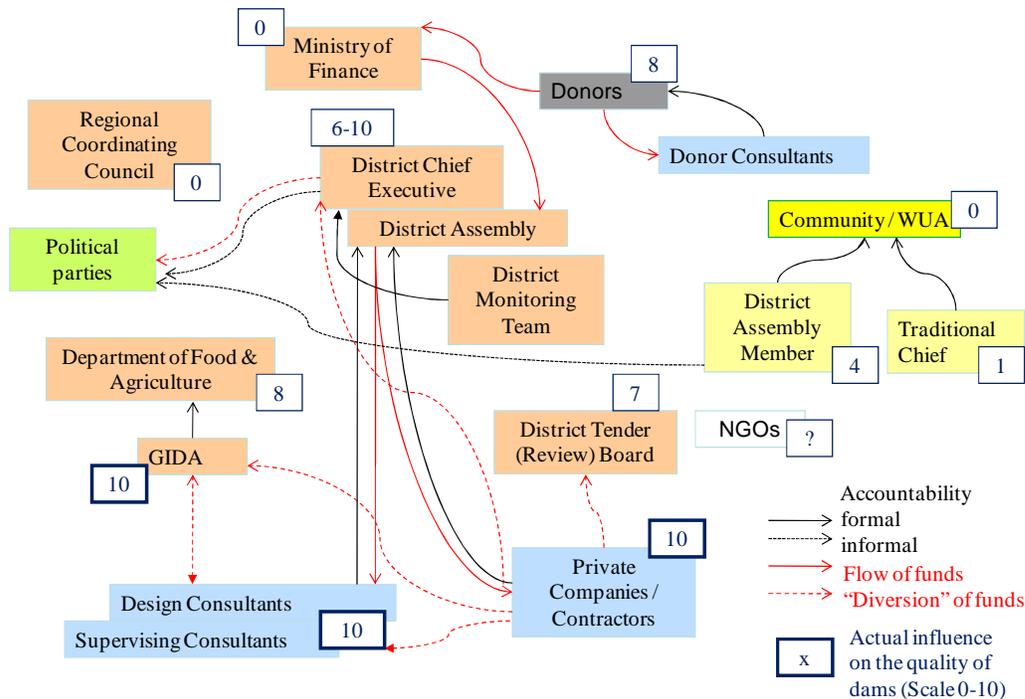


Figure 3-3: Construction of small reservoirs  
Source: Authors

Strategies to deal with this problem could focus on the Water User Associations in charge of the dams, since they have the largest ultimate stake in the quality of infrastructure provision. However, as the influence-mapping showed, their actual influence of quality of infrastructure provision is negligible. In particular, WUA representatives cannot prevent that final payments are made to contractors even if the quality of the construction is below standard. This situation prevails even though communities are supposed to contribute resources, usually in terms of labor, to the construction of small reservoirs. In practice, contractors often proceed without the community’s labor contribution as they find it difficult to organize that contribution. The District Assembly Members, as elected representatives have some more influence than the WUAs, but still, their influence is not sufficient to pursue the communities’ interests vis-à-vis the rather powerful irrigation administration and the private contractors. Possible strategies to resolve these problems, which were also discussed at the final stakeholder workshop, include the following: making the signature of a WUA representative a requirement before final payments are made to contractors; increasing the publicity about problems in infrastructure construction by involving the local press; strengthening the role of the District Assembly Members vis-à-vis the irrigation bureaucracy; involving NGOs to mobilize communities; increase monitoring by central rather than local agencies; and train contractors to improve their technical capacity in small reservoir construction.

### Functioning of the Basin Board

As indicated above, the White Volta Basin Board is the major multi-stakeholder governance structure in the research region. The Net-Map tool was used to analyze the strategies that the Board could use to increase its effectiveness, and to advise the Board members in this regard. The following approach was used: In a first step, the Board

members were interviewed individually about their vision of the Board's major goals. Second, individual Net-Maps were drawn based on interviews with individual Board members. In a third step, the individual networks were combined to develop a common network vision (cognitive social structure, see Krackhardt 1987). These were subjected to quantitative social network analysis to determine different centrality measures for the different kinds of networks (money, command, advice and information). In bi- and multivariate analysis we tested hypotheses concerning the connection between influence of actors and their position in the various governance networks. Figures A-3 to A-5 in Appendix C presents the network maps of the actors involved, displaying networks of command, funding and advice, respectively. Figure 3-4 displays the influence level of different actors, as identified by the respondents.

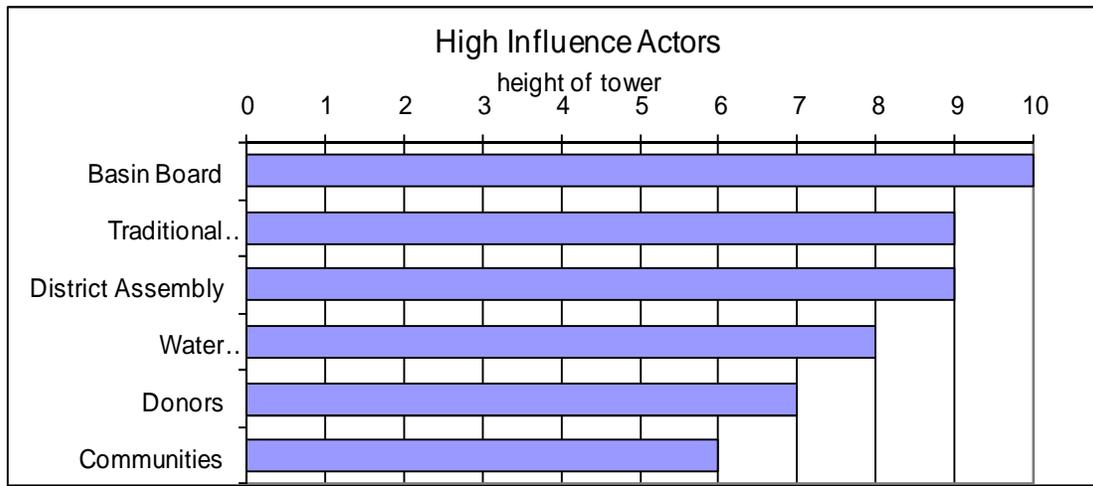


Figure 3-4: Influence levels of different actors

Source: Authors

This analysis supported the hypothesis that influence of actors was linked to their position in the information and advice networks. However, the analysis did not indicate that a significant connection exists between influence and the position in the command or funding network (see Schiffer, Hartwich and Monge, forthcoming). The study suggests that significant effects of social networking are at play beyond the formal lines of command and funding, as stakeholders in watershed-management make decisions. Stakeholders are seen as more influential if they participate more prominently in information exchange and provide more advice to others. The findings suggest that there are relevant network effects that determine the influence stakeholders have in water-resource-management decisions. The findings indicate that program leaders, analysts and policy makers in watershed management may need to take these informal networks into account more prominently as they influence decision making processes and the attainment of development and resource-management goals.

In the discussion of the Board members about what makes actors influential, they discovered that the six actors with the highest influence tower all fulfilled crucial and very distinct roles that no other actor could easily take over. The Basin Board as was seen as having core responsibility for formulating and achieving its own goals. However, it needed the support of the donors for funding, the Water Resources Commission (WRC) as national level policy making and supervisory body, the District Assemblies as the core implementers on the ground, the traditional authorities who had the strongest leadership position and sanctioning power on the village level, and finally the communities, whose cooperation would make or break any community-based intervention.

### 3.3 Results for Chile

#### 3.3.1 Results of the initial assessment

##### Legal framework

The governance of Chile's water sector is governed by the 1981 National Water Law, which focused primarily on improving the economic efficiency of irrigation (see Chile Governance Structure Report for a more detailed account of the evolution of Chile's water legislation). The law declares water a public property, to which the state can grant private right rights, which are independent of land rights. Once such water rights are granted, they enjoy the full constitutional protection of private property, which prevents any state influence on water user (except for cases of officially declared droughts). Original water use rights were allocated free of charge, for an unlimited period, and without any limit on the quantity demanded, to those who requested them. In case demand exceeded water availability, rights were auctioned. While the law encouraged investments and improved water efficiency, the allocation of water rights without any limits gave rise to the accumulation of water rights for hoarding and speculation.

The Water Code Reform, which was passed in 2005 after 12 years of debate, sought to reconcile the advantages of strong private water use rights with sustainability concerns and the protection of the public interest in the public good characteristics of water. The reform included inter alia the following innovations: (i) New water rights can only be issued after due consideration of environmental impact. (ii) Use rights on certain water resources can be excluded from privatization. (iii) Demand for water use rights need to be justified in terms of needs – unused water rights are covered by a fee. (iv) Stakeholder involvement in public water and river basin management is facilitated by strengthening the legal status of water user organizations. As further explained below, the operational management of irrigation has largely been devolved to water user associations and their umbrella organizations, which constitute "third sector" organizations according to the framework applied here (see Table A-1 in Appendix C).

Even though Chile is internationally recognized for its market-based approach to water resources management, the state continues to play a far-reaching role in subsidizing private investments in irrigation infrastructure. The legal framework for the subsidies is provided by Irrigation Law N° 18.450 (Ley de Fomento al Riego), which has been in effect since 1985. User organizations or individual users can present projects and can receive up to 75% of the investment costs as subsidy. Initially, smallholders had very limited access to these funds due to a crowding out effect. A change of the law in 1999 requires that the number of smallholders that receive funds equals the number of commercial holdings. A strategic alliance between the National Irrigation Commission and the Instituto Nacional de Desarrollo Agropecuario (INDAP) also helped smallholders to increase their access to this funding source. In 2006, the total budget under this law exceeded the equivalent of 40 million US\$<sup>2</sup>. Since May 2008 an amendment to the Law allows farmers who only rent the farmland to apply, as well. Since December 2007 an amendment to the National Water Law (Código de Aguas) exempts applicants to the program of Irrigation Law 18.450 from the need to have the water rights associated with their land titles officially registered. This change allowed large groups of small-scale water users to access this funding source, as well.<sup>3</sup>

<sup>2</sup> Gobierno de Chile, Ministerio de Hacienda,  
[http://qeminis.dipres.cl/virlib/docs/Gestion/2006/doc22-344-2007910\\_doc22-344-2006717\\_EPS130601072006\\_00015.pdf](http://qeminis.dipres.cl/virlib/docs/Gestion/2006/doc22-344-2007910_doc22-344-2006717_EPS130601072006_00015.pdf)

<sup>3</sup> [http://www.ramonfarias.cl/article.php3?id\\_article=956](http://www.ramonfarias.cl/article.php3?id_article=956)

### Institutional landscape

Figure 3-2 presents the institutional landscape for irrigation in the research region. The central state organization in charge of irrigation is the Comisión Nacional de Riego (National Commission for Irrigation, CNR), which is linked to the Department of Agriculture and coordinates all irrigation-related activities. In the research region, the Comisión Regional de Riego (Regional Commission for Irrigation, CRR) is the central agency in charge. As shown in Figure 3-2, a range of other state organizations are also involved in water resources management, such as the Dirección General de Aguas (DGA), which is in charge of registering water rights, monitoring stream flow, and mediating disputes about water rights. More details about these organizations can be derived from the Chile Governance Structure Report (Wittmer et al., 2005). For small-holder farmers, the Instituto Nacional de Desarrollo Agro-Pecuario (National Institute for Agriculture and Livestock Development, INDAP) is particularly important, as it manages public support programs that are targeted to smallholders.

INDAP operates the program for small-farmers. According to information collected during the initial assessment, approximately 70 % of the INDAP funds are used for individual farmers, and 30 % for farmers' groups. The farmers receive 80 % in form of a grant, and 20 % in form of a loan. Interesting, there was an internal rule, according to which the word „subsidy“ had to be avoided for these grants and the word „incentive“ was used instead. Around 20 % of the funds provided by INDAP are administered through PRODESAL, which attends only to people identified as poor in the CASEN survey, a type of living standard survey conducted every two years.

As mentioned above, irrigation management has largely been devolved to water user associations in Chile, and the above-mentioned state agencies play largely a facilitating and regulatory role. The highest level of water user associations in Chile is the Federación de Canalistas de Chile (Federation of Canal Users), an umbrella of all higher level water users associations such as Juntas de Vigilancia (Watch Committees), which manage river basins (there are three in the 7<sup>th</sup> Region, the research area), and Asociaciones de Canalistas (Associations of Canal Users), which manage irrigation schemes (five in the 7<sup>th</sup> Region). The lowest levels of organization are the Comunidades de Agua (CDAs, Water Communities). They are responsible for water distribution to users' plots, the maintenance of secondary and tertiary irrigation channels, and the collection of fees. The latest water code reform also made them responsible for ground water management.

As indicated in Figure 3-4, a range of private-sector actors are important in Chile's water sector governance, as well. To compete for the grants through which the state provides subsidies, irrigators hire consultancies that prepare the plans for infrastructure investment. The companies that are contracted to carry out construction works are from the private sector, as well. In principle, private companies can engage in public-private partnerships for large-scale investments in reservoirs, too. The government that took office in 2006, however, abandoned this option for the planned construction of the Ancoa reservoir which is located in the research region. Water users have to contribute to the financing of new large-scale irrigation projects by paying an annual fee for irrigation water received from those projects.

Hydro-power plants are also an important player in Chile's water sector, as the country's electricity generation relies mainly on hydropower and natural gas. Currently 86% of power generation is privatized, but 14% comes from Colbún, the main company remaining in the state sector. Colbún generates hydropower from two dams located in the 7<sup>th</sup> Region, in which the research area is located. Concerns about the security of supply of natural gas from Argentina have increased the pressure to consider new hydropower projects.

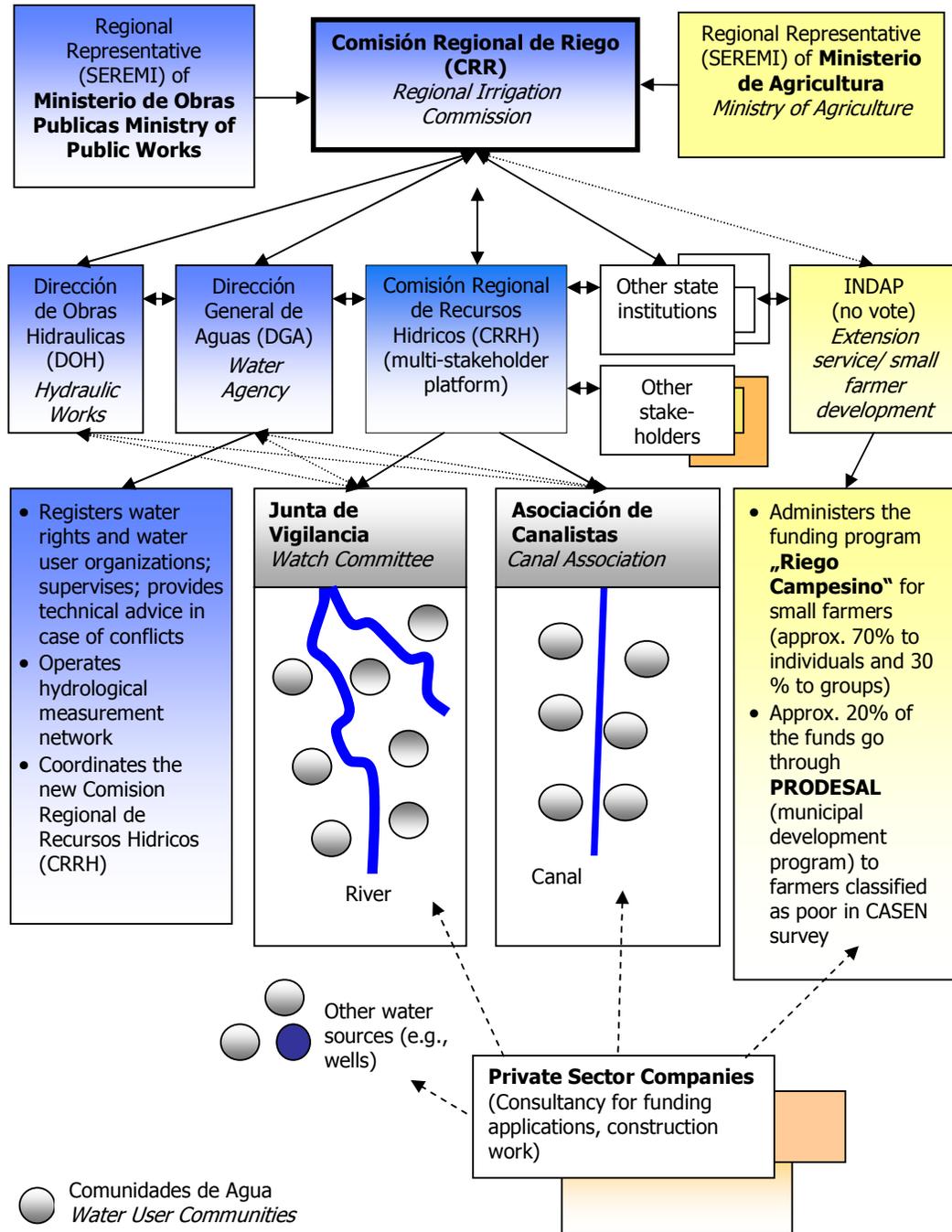


Figure 3-5: Governance structures in Chile

Source: Authors

### Governance and policy issues

This section describes the main governance and policy issues that were identified through the assessment of governance structures and the stakeholder needs assessment (see Objective 3 for more details on the stakeholder workshops).

#### High variation in capacity and functioning of water user associations

According to information collected for the governance structure assessment, there are 370 Comunidades de Agua in the 7<sup>th</sup> region. 166 were registered in 2005, 8 were in the process of registration, and 196 were not registered. According to key informant interviews conducted during the assessment, many Comunidades de Agua do not function very well. Sometimes, they do not even hold an annual meeting. Reportedly, it is often the water users at the end of the canal, who are more active in these organizations, because otherwise they do not get any water at all. Three different discourses could be observed during the interviews with the leaders of the Asociaciones de Canalistas and the Juntas de Vigilancia.

- (1) An „entrepreneurial integrated development" discourse: Examples are the Canal Association Maule Sur and the Junta de Vigilancia Rio Longaví. The representatives stressed that they want to develop a variety of projects not only with regard to irrigation, but also with regard to crop production, tourism, electricity, etc.
- (2) A „efficiency-oriented irrigation service" discourse: This discourse was prominent in case of the Canal Association Digua. The representatives emphasized that they concentrate on providing irrigation in the most efficient way, rather than diversifying their activities. The members are considered as clients, to whom they want to provide a highly professional service. A subdivision of the organization in Comunidades de Agua is seen as inefficient. This canal organization was the only one among the visited, in which a trade of water rights among members (in form of renting rights) was indeed functioning.
- (3) A „poor farmers" discourse: This discourse was observed in case of the Junta de Vigilancia Rio Achibueno. The representatives stressed that the low income level of the members (most of whom got their land through the land reform) does not allow the organization to hire a professional which could develop projects and apply for funds for the Junta de Vigilancia. The funds generated from the members are just sufficient to hire professionals on a temporary basis who make sure that the water of the river is distributed according to the rights held by the Comunidades de Agua.

The discourses are certainly an expression of rather far-reaching differences in the economic resource base and the managerial capacity of the different Canal Associations and Juntas de Vigilancia of the region. Interestingly, in the discourse of all interviewed organization leaders, small farmers were portrayed as traditional and often portrayed as “ignorant.”

#### Need for improvement of irrigation infrastructure

According to the stakeholder needs assessment, the main problem in the area is the need to improve irrigation infrastructure to increase the availability of irrigation water and, importantly, to reduce the risk of water shortages in low-rainfall years. There is potential for improvement both by modernizing the existing infrastructure to increase water use efficiency and by constructing new infrastructure for retaining additional water quantities. In this regard, three main policy issues were identified:

- *The future of the subsidy regime:* As indicated above, the state subsidizes private investments in irrigation to a considerable extent. The policy debate on this issue focuses on the question as to what extent smallholders are able to access these subsidies, and as to whether a continuation of the subsidy would be justified under welfare and efficiency considerations. Policy-relevant research on this topic was very timely during the project period, as a decision

had to be made on whether and in what form to expand the subsidy program under Irrigation Law No. 18.450 until the year 2010.

- *Distributional impacts of canal improvement:* In the irrigation systems in the research area, small-holder farmers who do not have water rights, or who have insufficient water rights, benefit considerably from inefficiencies in water use as they use spill-over water, or water resources that become available due to seepage in canals. Hence, investments that focus on improving water use efficiency in some parts of the system may have negative distributional effects in other parts of the system. However, the magnitude of these effects was not clear, which made it difficult to identify appropriate research interventions.
- *Financial and distributional aspects of the Ancoa dam project:* The construction of a dam in the Ancoa River has been a long-standing policy issue in the research region, since this investment would considerably improve water use security in the area. At the beginning of the research project, the policy discussion focused on the option of a public-private partnership to make this large-scale investment possible. As indicated above, this option was discontinued after the change of government in 2006. Yet, the question remained as to how the benefits of this investment would be distributed, and as to whether it would be profitable from the farmers' point of view to pay their share of the investment in form of fees.

#### Conflicts between farmers and hydropower plants regarding timing of water release

The most important surface water use besides agriculture in the 7th Region of Chile is hydropower generation. Conflicts between hydropower generation and irrigation mainly concern the timing of water release. Representatives of Comunidades de Agua, who were interviewed for the governance structure assessment, stressed that they had difficulties to win court cases against the hydropower companies as those are able to hire the better lawyers. The opinions on this subject also seem to differ. Representatives of the water resources administration stressed that the hydropower industry typically respects the irrigators' water use rights.

#### Water quality

According to stakeholder interviews, another issue of increasing importance is water quality. The main concerns are poorly purified sewage water and contamination with agro-chemicals. These issues are important also in the implementation of the "Good Agricultural Practice" (GAP) quality standards for high-value crops that became prerequisite for exports to EU and US markets from 2002 onwards.

### 3.3.2 Results of the in-depth studies

Based on the governance structure and stakeholder needs assessment, two topics were selected for further in-depth research. First, in view of the wide variation in the capacity and functioning CdAs and their umbrella organizations, it was decided to conduct further research on the factors associated with their performance. Second, in view of the policy debate on the reform of the irrigation law, a case study on this topic was conducted. Other questions of interest, such as the cost-effectiveness of the Ancoa dam, were analyzed using the agent-based model (see Objective 2).

#### Functioning of Water User Associations

Water user organizations have to solve the classic problem of collective action. The theoretical models used in the literature are typically based on cooperative or non-cooperative game theory, and concentrate on the single decision on how much of the non-excludable good, in this case, water, to provide. The analysis conducted under the project took into account that water is but one input into the crop production. Therefore, a two-person, two-input non-cooperative model of farmers' decisions to provide a public good and purchase private inputs was developed (McCarthy and Essam, 2009). The model takes into account heterogeneity among users in terms of productivity (by

assuming that one player in the two-person game is more productive than the other) and in terms of location (by assuming that tail-enders have a greater marginal incentives to invest in canal maintenance).

Using the household and community survey data (see above), Heckman two-step estimator results were produced regarding a household's decision on whether to contribute labor and funds to the water user association. This analysis showed that households that are members of CdAs that do not belong to Juntas de Vigilancia and that own few agricultural assets are more likely to participate. Of the households contributing labor, agricultural assets and the amount of land owned strongly influence the number of labor hours provided. Land differences have little to no statistically significant effect on any of the contribution decisions. At the community level, the size of the CdA negatively affects the probability that a household will contribute labor or both money and labor. CdA size also tends to reduce the amount of labor contributed. However, there is no effect on monetary participation. The connections of a CdA president moderately affect monetary participation and contributions, and strongly influence the amount of labor and money contributed. Interestingly, membership in Juntas de Vigilancia was found to reduce participation and contribution amounts across all categories. A unique feature of the analysis was that it also examined the relation between contributions to CdAs and farm revenues. In line with expectations, households with greater managerial capacity and older and more educated household members earn more revenues on average. At the community level, households located in larger CdAs with a well-connected CdA president have higher farm revenues. But, in CdAs where members have vast land differences, revenues are reduced as group heterogeneity appears to impose a cost on community members in terms of lower farm revenues. Finally, interventions were simulated that maximize the social connections of a CdA president (e.g., by connecting CdA presidents across groups) while at the same time ameliorating the negative incentives to contribute money based on heterogeneity in landholdings. Under such a scenario, monetary contributions increase by 9% and farm revenues increase by 11%. This finding underlies the value of investing in a better functioning of the CdAs.

#### *Policy process of reforming Chile's irrigation law*

To understand the policy process of reforming Chile's irrigation law (Law N° 18.450, see above), the Net-Map method was applied. Respondents included representatives of different types of organizations at regional and national level Table 3-1. The following links between actors were identified: "ordenar" (lines of command), "consejo" (giving advice), "información" (information) and "presión política" (exerting political pressure, lobbying).

The mapping revealed that no substantial conflicts of interests existed between the actors involved in the process. This is, of course, not surprising for subsidy policy, since those who might oppose the subsidy (the taxpayers) are not organized as an interest group. However, one might expect some level of disagreement between the regional and national policy levels and between different water types of water users concerning the structural design of the program. The annual allocation of capped funds and the distribution according to geographical region and beneficiary group bear a potential for conflicts of interest between competing regions, water user organizations and between small and medium versus large users. In fact the produced by the members of the CNR emphasizes the weight peasant organizations and agricultural lobbies exert at national level, suggesting that there are indeed high stakes involved in the reform process; however, even their map does not indicate any lines of serious conflict.

A plausible hypothesis to explain this lack of conflict is that, in fact, the irrigation subsidies program is financially so well equipped that all demands can be met, lowering the impetus of distributive struggles over money. This hypothesis is supported by a rising overall budget for the subsidy program, facilitated by a comfortable financial situation of the Chilean government in general, thanks to the continuously high national

earnings from copper exports. To further explore this question, the agent-based model (Objective 2) was used to simulate the effect of different levels of subsidies.

With regard to further stakeholders one might have expected that non-agricultural water users, namely from the energy and paper industry would play a prominent role on the net maps, seeking to influence the irrigation law on issues where their own water interests are being affected. Though these actors have been mentioned in two maps, their position was characterized as supportive of the program extension. This may indicate that these users did not consider subsidy reform to be a strategic avenue to pursue their interests.

*Table 3-1: Influence of different actors on outcome of legal reform*

Author of net-map	Water user organizations	CNR (National Commission for Irrigation)	CRR (Regional Commission for Irrigation)	National level politicians	Council of Ministers	National level lobby organizations	Regional level politicians
CNR	<b>5</b>	<b>5</b>	4	4	<b>5</b>	0-4	1
JdV Ancoa	1	2	-	4	3	1	-
JdV Achibueno	4	3	-	4 (Congress)	5	0	-
JdV Maule	2	<b>5</b>	1	4	4	0 (companies)	-
JdV Longavi	<b>5</b>	1	0	1	<b>6</b> (Treasury)	0	-
SAG Maule	3	3	0	<b>5</b>	0-4	0-3	0-2
INDAP Maule	1	1	0	3	-	-	0
Average	3.0	2.9	0.7	<b>3.6</b>	<b>3.6</b>	0.4	0.3

Source: Authors

The above synthesis of weights attributed to different actors reveals several noteworthy particularities concerning the ways how actors at different levels depict their respective images of the influence networks which determine the law reform process:

- All maps agree on the dominant role of the national level politicians in this process. This is an expected result, considering that the law is passed at the national level. All maps depict both, the political arena and the government (Consejo de Ministros), as equally influential for the law reform. The maps also agree on the little weight regional politicians have in this process. This reflects the centralist political and administrative structure of the country and it goes along with the general perception that Chilean politics takes place in the capital. This is also reflected by the low influence level attributed to the Regional Commissions for Irrigations (CRRs) as compared to the National Commission. This is somewhat surprising since one might have expected the CRR to be the main lobbyist for the region.
- The CNR map, drawn from a national level perspective, differs substantially from the regional level maps in two regards: (i) they are the only ones interviewed that consider the CRRs are in fact influential on the law reform and (ii) national level stakeholders and lobbyists are also attributed significant weights. This implies that regional actors have limited awareness of the lobbying that is taking place at the national level.
- The four representatives of regional water user organizations differ in their view of their own weight as actors in the process (weights 1-5). This allows for two alternative interpretations: either their influence is de facto highly diverse depending on their varying capacities. Alternatively, their experiences with and

understanding of the process and the interplay of the various actors might differ, independently of their de facto influence. Importantly, the CNR members consider water user organizations as very influential overall.

In sum, the law reform process appears to be essentially driven by the Consejo de Ministros, the CNR as principal coordinating agent of regional councils and national level politicians. As interest groups the regional water user organizations have a strong voice in the national policy process, supported by several national level lobbying organizations, such as the Sociedad Nacional de Agricultura. Interestingly, environmental NGOs do not seem to play any role at all in this process.

### **3.4 Comparative discussion and conclusions**

Table 3-2 summarizes the findings of the analysis of the governance structures for both countries. Expectedly, water sector governance in the two research areas differs considerably, reflecting the different stages of water resources development in the basins, and the different stages of economic development of the two countries. In Ghana, the potential for water resource use is highly underutilized, and the legal and institutional framework for their management is in an early stage of development. Chile, by contrast, has a legal and institutional framework for water resources management that is widely considered to be one of the most “advanced” in the world, thus making the country a model for others to follow. In fact, the assessment shows that in several regards, the Ghanaian water sector reform of 1996 follows the major design elements of the Chilean system. In particular, the reform foresees an assignment of water rights, and it created an organization (the Water Resources Commission) in charge of assigning and registering these rights. Moreover, Ghana adopted the strategy of creating Water User Associations and transferring management tasks to them.

Thus far, the analysis can be seen as consistent with conventional wisdom regarding water resources management in these two countries. However, the research conducted under this project also revealed important insights that go beyond this conventional wisdom:

- The Chilean model is widely associated with the notion of a market-oriented approach to water resources management, an approach that has been widely discussed in the literature by both proponents and critics (see Bauer, 2004 for a review). In view of the limited role that water markets have come to play in Chile even 20 years after the original reform, the “Chilean model” appears rather interesting for *other* features than the market-orientation, which carry interesting lessons for other countries, such as Ghana:
  - Chile is rather remarkable regarding the extent to which it has in fact devolved the management of irrigation to water user associations and their umbrella organizations – which are “third sector” rather than private sector organizations in the framework used here (Table A-1 in Appendix C). The research indicated that the management of the umbrella organizations (Juntas de Vigilancia and Asociaciones the Canalistas) has become increasingly professionalized in recent years.

Table 3-2: Comparison of governance structures in Ghana and Chile

<b>Dimensions of Governance</b>	<b>Ghana</b>	<b>Chile</b>
<b>Property rights / regimes</b>		
Property rights/regimes for water resources	By law, water is public property, but state can grant individuals & organizations use rights against fee; small-scale farmers exempted from fee	By law, water is public property, but state grants full private water rights that can be traded; original assignment of water rights was free.
Property rights/regimes for land for agricultural land	Customary land tenure; private use rights; large-scale irrigation under state property	Full private property rights with land titles
<b>Irrigation infrastructure</b>		
<i>Financing of infrastructure</i>		
• Reservoirs and main canals	State and donor agencies	State; public-private partnerships as option; contribution from irrigators
• Irrigation infrastructure at farm / farmers' group level (e.g., field canals)	State and donor agencies	Farmers with substantial subsidies from the state
<i>Provision of infrastructure</i>		
Government agency in charge of infrastructure provision	Ghana Irrigation Development Authority	Dirección de Obras Hidráulicas
<i>Management of irrigation</i>		
Organization in charge of operation		
• Large-scale schemes	State irrigation agencies	Umbrella organizations of water user organizations
• Minor schemes, secondary/tertiary canals	Water user associations	Water user associations
Government agencies in charge of coordination, regulation and facilitation	National Water Resources Commission and its River Basin Offices District Assemblies	Dirección de Agua Comisión de Riego (national and regional level)
Multi-stakeholder coordination bodies	River Basin Boards, e.g. White Volta Basin Board	Comisión Regional de Recursos Hídricos
<b>Interactions between water users</b>		
Trade in water rights	No trade in water rights as of now; lease of land in major irrigation schemes	Trade in water rights possible, but limited in practice
Conflicts	Conflicts regarding irrigated land arising from overlapping property regimes	Conflicts between irrigators and hydro-power providers about timing of water release
<b>Assessment of governance structures</b>		
Efficiency	Underutilization of schemes due to low quality of infrastructure and maintenance problems	Inefficiencies in water use due to need for rehabilitation of infrastructure
Equity	Number of beneficiaries of small reservoirs limited; inequitable access to large-scale schemes	Farmers without (sufficient) water rights benefit from spill-overs
Environmental sustainability	Potential for irrigation largely underutilized	Increasing concerns about environmental sustainability of water use

Source: Authors

These organizations hire professional staff and adopt advanced management practices, which greatly increase their capacity not only to manage their water resources, but also to negotiate with the irrigation administration and to be politically active. At the level of the Comunidades de Agua, however, the typical collective action problems remain an important obstacle, even in a county with a system that is as advanced as that of Chile. As the research summarized above shows, interventions that improve capacity at the level of the CdAs have a considerable potential to improve revenue collection and—through better water management—farm revenues, as well.

- The public sector has remained to be an important player in Chile’s water system in two major ways:
  - First, even though Chile’s water resources and irrigation administration plays mainly a facilitating, regulating and coordinating role, this administration has a remarkably high capacity in terms of technical expertise. In terms of Fukuyama, Chile reduced the scope, but not the strength of the state in the water sector (Fukuyama, 2004). The message for other countries is that the need to invest in a highly capable and effective irrigation administration does not disappear when using the “Chilean approach.”
  - Second, contrary to Chile’s “neo-liberal” image, the state continues to invest substantial financial resources into water resources development. As reported above, the targeting of these resources has only very gradually become more targeted towards smallholder farmers over the years. This was only possible through targeted programs *and* a capable public agency with the special mandate to support smallholder farmers (INDAP). What can also be learned from the Chilean approach to subsidizing infrastructure investment is the consistent use of private incentives to overcome the quality problems in publicly financed infrastructure that Ghana is plagued with: Farmers have to pay a share of both the small-scale and the large-scale investments in irrigation infrastructure. In case of small-scale investments, they or their organizations also have to manage those. Infrastructure quality is also supported by high technical capacity in the public and private sectors, and probably by a functioning liability system (an aspect that might be of interest for further research).
- Ghana is widely recognized in Africa as one of the countries with relatively good governance, as measured, for example, by the World Bank indicators (Kaufmann, Kraay, & Mastruzzi, 2008). Yet, the research revealed that the irrigation administration is confronted with major governance challenges in making small-scale reservoirs work. The strategy of involving Water User Associations to resolve such problems was found not to be working very well. Efforts to increase the technical capacity of the irrigation administration also seemed limited. While donor agencies displayed growing interest in funding small reservoirs, there was apparently inadequate recognition of the governance challenges that need to be resolved to make this strategy work (One would expect that a situation where only 3 out of 19 recently constructed small reservoirs work would alert donor agencies and the government). In view of the challenges of making small reservoirs work, it seems also justified to reconsider the strategy to invest in large-scale reservoirs. Further research would be justified to compare the economic profitability of both options, taking into account that specific governance challenges that either options is confronted with.

## 4 Objective 2: Developing decision-support tools

During the course of the project, various decision support tools were developed in close collaboration with stakeholders in Ghana and Chile. Tools included whole-farm programming models, specific user maps from GIS, water-balance models, hydrology simulation models, and agent-based simulation models. The Net-Map tool described in the previous section also contributed to Objective 2, as it was found to be useful not only for diagnostic purposes, also to support decision-processes within organizations. For reasons of scope, this section concentrates on the “Mathematical Programming Based Multi-agent system (MP-MAS)”, which played a central role in this project and which combines different other models mentioned above.

Mathematical Programming Based Multi-agent system (MP-MAS) is a multi-agent model of land use and land cover change developed at Hohenheim University, based on the work of Berger 2001, Schreinemachers *et al.* 2007 and Berger *et al.* 2007. This model couples a cellular component that represents a landscape with an agent-based component that represents human decision making (Parker *et al.* 2003). The methods for parameterization and validation of the agent-based simulation model have been described in detail in Berger and Schreinemachers (2006), Robinson *et al.* (2007), Berger *et al.* (2007) and Schreinemachers *et al.* (2007). The following sections present how these methods were applied in Ghana and Chile and what insights could be derived from simulation experiments (scenario analyses). In both countries, the agent-based model was calibrated and tested together with stakeholders, during the course of workshops and interactive modeling sessions (see Objective 3 below for further details). In Chile, a group of advanced model users—mostly technical staff from water user associations—was formed and received intensive training. Special software versions were made available for analysis of water shadow prices, farm investment and reservoir management.

### 4.1 Ghana

#### 4.1.1 Methods

##### *Study region and landscape model*

As indicated in the introduction, the Upper East Region (UER) of Ghana was selected as study area for agent-based modeling. The region has a population of 919,253 and a total land area of 8842 Sq.km (GSS 2000). Administratively, the region is divided into eight districts. Based on simulation output from the hydrology model WASIM-ETH (see more details on this software below in the Chile section), a sub-catchment of the White Volta basin in UER was delineated. This catchment, named Atankwidi+, was used as the landscape for the multi-agent simulation in this project; WASIM-ETH delivered the input data for river flow and precipitation. The catchment comprises four districts of UER in Ghana: Bongo, Builsa, Kasena Nankana and Bolgatanga. Table 4-1 shows some basic statistics for the four districts.

*Table 4-1: Basic statistics of districts in Atankwidi+ catchment*

	Bongo	Builsa	Bolgatanga	Kasena Nankana
Total Population	77,885	75,375	228,815	149,491
Households [Number]	13,348	15,537	39,655	267,57
Average household size [Number]	5.8	4.9	5.8	5.6
Population density [Person/sq.km]	204	90	105	111

Area of the district in the catchment [%]	48	40	31	80
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Source: Ghana Statistical Service (2000)

The spatial information was merged from different sources for the region and the White Volta basin (e.g. GLOWA Volta, Water Resource Commission of Ghana). Using the ArcGIS software, farming land in the Atankwidi+ catchment was netted out by purging it of forests, roads, rocky unsuitable lands, areas under water, etc. The locations of small reservoirs and 2 large irrigation schemes in region, namely Tono and Vea, were plotted on the map. The exact spatial boundaries for the irrigation command areas of small and large reservoirs were not available. Based on secondary information, the irrigable land area was therefore hand-drawn for each dam site in the catchment; this area represents the irrigable land available for cultivation for the farmers. The remaining farming land constitutes the rainfed land. The landscape created consisted of uniform grid sized cells; a grid cell represents a piece of landscape (0.25 ha) that can be used for agricultural production. Figure A-6 in Appendix C provides a detailed map of the Atankwidi+ area.

### Agents and farm plots

#### Location of agents and farm plots

Since there was no spatial information available (latitude/longitude) of each household in the Atankwidi+ catchment area, a spatial randomization procedure was used to generate the location of agents and their farm plots. Using the survey data collected in all districts of the Upper East Region in 2005 (see above), the sample was divided into four clusters based on the number of agricultural plots operated by each household. The number of plots was used to cluster the sample because this was the one variable most strongly correlated with other important variables such as household size, number of livestock and agricultural implements (assets). For each cluster, information about distribution of rainfed land, irrigated land, and distance of farming plots from farmstead was estimated from the survey data. Then using this information, the farmsteads and farming plots were randomly allocated to the agents in the landscape.

#### Agent population

The socioeconomic layers contain information about the agents' resource distribution and their membership to the network threshold groups. The survey data collected in the region has 292 sample households, which was a relatively small fraction when compared to the actual population in region. Following Berger and Schreinemachers (2006), a Monte Carlo technique was used to generate a random agent population from our survey data. Cumulative distribution functions for the resources were calculated for each cluster of sample observations. Each agent was allocated quantities of up to 78 different resources using this random procedure. The resources included 68 different categories of household members (34 age and 2 sex groups), 6 types of livestock (goat buck, goat doe, cows, bulls and sheep ewe and sheep ram), female head, liquidity, form of expectation, and innovativeness. In the Upper East, households have a large number of livestock, so a maximum of 20 piecewise linear segmentation was used to implement the empirical distribution functions. Figure 4-1 compares the population pyramid calculated for the survey population with the pyramid for the agent population. The pyramids more or less look similar in their distribution of members under different age category. The random generator hence created a realistic demographic structure.

### Agent decision model

#### Mixed integer linear programming (MILP)

Agent decision-making is modeled using mathematical programming (MP)<sup>4</sup>. The MP approach assumed each household to maximize the expected household income, which consists of cash income from sales (crop and livestock products) and off-farm labor, in-kind income from self-consumption of crop and livestock products, under constraints such as different types of available land, labor, capital, irrigation water, and food consumption requirements (i.e. land use is endogenous in our model). Due to the presence of market imperfections in the Upper East Region, cash income and in-kind home consumption objectives are included separately in the model objective function<sup>5</sup>. Therefore, the production and consumption decision of the agents are non-separable. This means that consumption decisions need to be taken into account when optimizing production decisions.

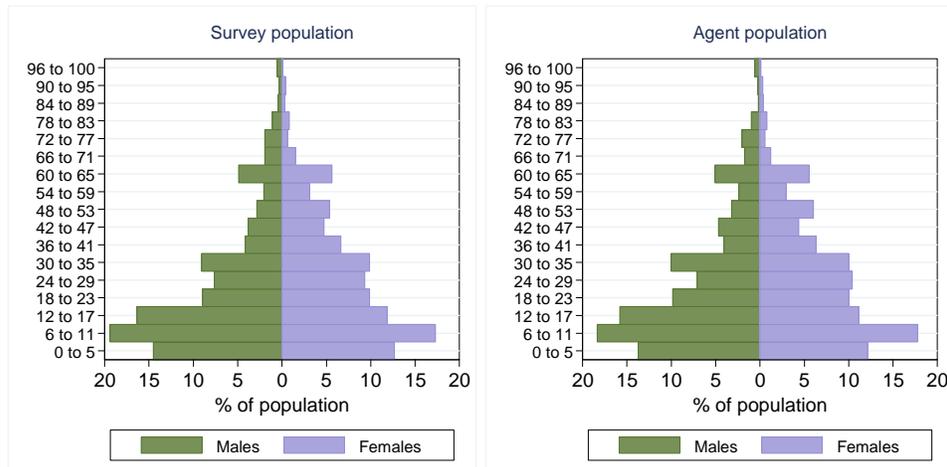


Figure 4-1: Population pyramid comparing survey estimate with agent population  
Source: Authors

#### Three-stage non-separable decision process

Based on Berger (2001) and Schreinemachers *et al.* (2007), the project team developed a multi-period three-stage non-separable MP by including investment, production and consumption decisions. For each year in the simulation, three MILP matrices were solved for each agent, simulating investment, production and consumption respectively. Each stage involves the optimization of a MP matrix and parts of the solution vectors are transferred between sequential stages. The matrices differ in internal matrix coefficients (e.g., yields and consumption function coefficients), objective function coefficients (e.g., prices), right-hand-side values (e.g., assets, resource endowments, and liquid means), and in the number of included constraints. Investment and production decisions are based on expected yields and prices. After the input decisions are made in the production model, the bio-physical model (FAO56) simulates crop yields based on the water deficit. Expected yields of each crop are then replaced by simulated actual yields in the consumption stage matrix and the final income obtained by the agents are allocated between savings and consumption depends on food energy requirement. Even though the model runs at an annual time period, it includes monthly land, labor, and water constraints to capture multiple cropping, peak labor needs and monthly variations in the irrigation water supply. The non-linear response of the crop yields to different combinations of inputs (like labor and fertilizers) was captured using a piecewise linear segmentation.

<sup>4</sup> The livestock production in the model can only take integer values so the type of mathematical program used is a mixed integer linear program (MILP).

<sup>5</sup> When markets are imperfect, the resource allocation that optimizes the level of income does not necessarily optimize consumption (Sadoulet and de Janvry 1995).

To capture the food consumption and poverty level in the Upper East Region, the consumption part in the model includes a detailed budgeting system that allocates the income from farm and off-farm activities to savings, non-food expenditure (using a modified Working-Leser model), and eight categories of food products (using a Linear Approximation of the Almost Ideal Demand System (LA/AIDS)). The Ghana Living Standard Survey (GLSS) IV data was used to estimate the saving, expenditure and demand equations for the food categories, and these parameters are included in the MP-MAS model. The expenditure values on each food categories were converted into adult equivalent energy units and used to estimate the consumption and poverty level for each household agent.

#### Simulating crop yields using the CROPWAT model

The crop yields were modeled following the FAO56 approach (Clarke *et al.* 1998, Smith 1992). The crop-water requirement ( $CWR$ ) for crop  $c$  in month  $m$  is the product of a crop coefficient ( $Kc$ ), the potential evapotranspiration ( $ETO$ ), and the planted area ( $Area$ ):

$$CWR_{cm} = Kc_{cm} * ETO_m * Area_{cm}$$

The  $CWR$  could either be met through irrigation ( $IRR$ ) or rainfall, which was converted into effective rainfall ( $ER$ ) to capture the share of rainfall actually available to the crop, depending on its growth stage. The amount of water actually supplied ( $CWS$ ) was then as follows:

$$CWS_{cm} = ER_{cm} + IRR_{cm}$$

For lack of detailed irrigation response data from the study region, the quotient of crop water supplied and the crop water requirement were simply averaged over all months with non-zero crop water requirements:

$$Kr_c = (1/m * \sum(CWS_{cm} / CWR_{cm}) \quad | \quad CWR_{cm} > 0)$$

The crop growth model assumed that the crop yield was lost if the average  $Kr$  fell below 0.5, while for  $Kr$  values greater than or equal to 0.5 the  $Kr$  value was multiplied by the crop yield potential ( $YPOT$ ) to simulate the actual crop yield ( $Y_c$ ):

$$Y_c = \begin{cases} Kr_c * YPOT_c & \text{if } Kr_c \geq 0.5 \\ 0 & \text{if } Kr_c < 0.5 \end{cases}$$

The main source of irrigation water in the Upper East Region is surface water and rainfall which were simulated with the distributed hydrology model WASIM-ETH. The two irrigation projects (Tono and Veia), 88 small reservoirs and river water pumping at the White Volta River are the source of surface water supply. The available irrigation water in each irrigation site (inflow) is then shared among the model agents based on their amounts of irrigable land in that particular irrigation site.

#### Innovation diffusion

The only type of agent-agent interactions in the model used in Ghana is networks of innovation diffusion. Due to lack of time, other agent-agent interactions such as labor-sharing arrangements, safety nets and collective action could not be included at this stage of research. Based on Berger (2001), innovation diffusion was modeled by using individual network thresholds. The agents in each period compares the adoption level in the network with its own threshold; if the first exceeds the second then the innovation becomes accessible to the agent and enters the MILP. The network adoption rate increases when the innovation is adopted by the agents.

#### Model validation

The MP-MAS model was validated by conducting regression analyses between observed land use values with predicted values from running the baseline scenario (McCarl and

Apland, 1986). The baseline reflects the current situation and assumes the current trends in demography, diffusion of innovations, prices and rainfall. A regression line was fitted through the origin for the observed and predicted land use of main seven crops expressed in percentage to total area of these crops (Figure 4-2). The comparison was done at various levels of aggregation (see appendix E). At household level the model fit coefficient is on average 0.8, a satisfactory value. The goodness-of-fit is higher, however, at the cluster level (values between 0.96 and 1.02), which indicates that the MP-MAS results should be preferably interpreted at the cluster level.

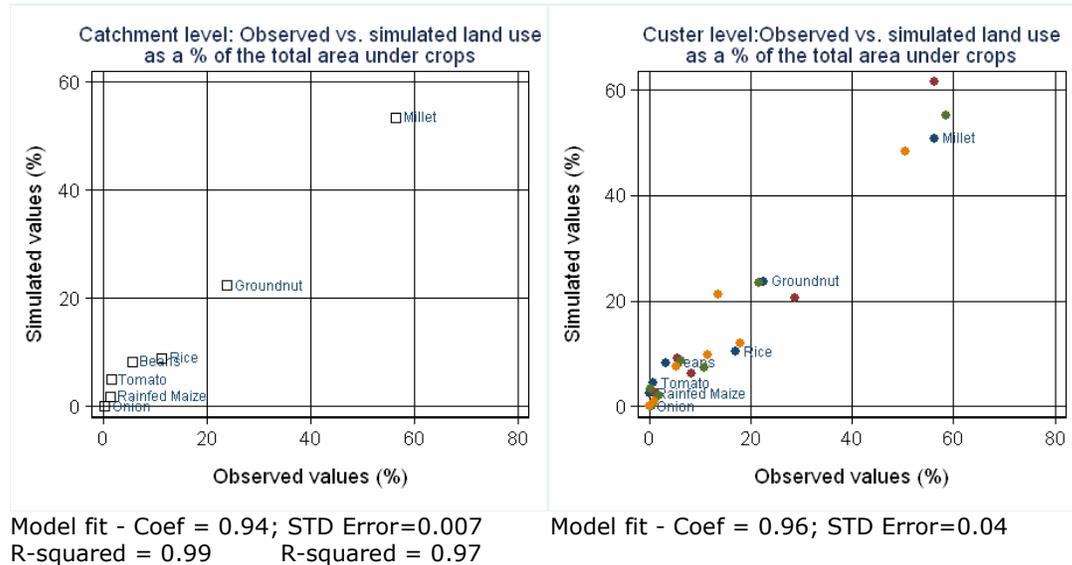


Figure 4-2: Validation of land-use with linear regression fit  
Source: Authors

### Scenario design and outcome indicators

The household data analysis and econometric studies conducted in the Upper East Region produced the following results (see also Objective 1):

- The potential irrigation areas in the major two irrigation projects and also in the small reservoir sites are not fully used by the farming communities in the area.
- Irrigation farming is cash demanding and most farm households are cash constrained mainly due to absence or limited access to farm credit.
- Having obtained access to credit results in an increased participation of farm household in irrigation farming and also increases the use of mineral fertilizers.
- Econometric analysis (Yilma et al., 2008) revealed that in the absence of credit markets the household members migrate during the irrigation season to finance irrigation farming operations in the Upper East Region.

Based on these results and the model use cases discussed with the stakeholders, the following scenarios (Table 4-2) were simulated with MP-MAS to analyze the distributional effects of different policy options on household income and poverty level:

Indicators such as land use, household income and poverty distribution were used as outcome indicators to analyze the simulation results. The farm households in the study area were post-stratified according to their access to irrigation facilities into three categories: rainfed farms, "large reservoir farms", indicating household with irrigation in the Veia and Tono irrigation schemes and "small reservoir farms", indicating household using small reservoirs. This classification was used to capture the impacts of different scenarios on households that use different types of irrigation facilities or, respectively, do not have access to irrigation. Households that pump water out of river ("river pumping

farms”) were introduced as an additional category to model the effect of this type of irrigation.

#### 4.1.2 Results

The baseline model results reflect current land use patterns that are dominated by staple crops (millet and beans) with limited cash requirements and rather low productivity. The irrigation area is not fully cultivated, only 30-40% is under tomato, irrigated rice and onion. Livestock is used as a buffer for smoothening food consumption demands, and food security is decreasing on average over the simulation horizon.

*Table 4-2: Scenario definition*

No.	Scenario	Description
1	Baseline	The baseline reflects the current situation. It assumes absence of formal credit market, limited access to off-farm employment, average normal year rainfall and constant prices for inputs and outputs.
2	+ access to credit	The farm credit is now available for the farm households at 25% interest rate, which they have to repay within the same cropping year.
3	+ more off-farm employment	The off-farm employment opportunity is increased by 20% from the baseline level.
4	+ credit and off-farm	Corresponds to Baseline + access to credit + increased off-farm employment.
5	lower fertilizer price	The fertilizer price is reduced by 20% from current price (baseline).
6	as 5 + access to credit	In addition to reduced fertilizer price, the farm households are given access to credit.

Source: Authors

#### Modeling access to credit scenarios

To relax the capital constraints, all households in the model are given access to farm credit. Figure 4 shows that access to credit would enable households to change their land use from subsistence rainfed farming to high value crop irrigation farming. Even with 25% of interest rate, the model suggests that households apply for farm credit and expand their area under irrigation farming. The simulation results show that access to credit would likely increase the average household income and food energy consumption (Table 4-3). The application of mineral fertilizer (in kg per ha) could also triple with the access to credit which would help to improve the sustainability of agricultural land use in the region.

*Table 4-3: Impacts of different scenarios*

Scenario	Income (GH. Cedi)	Food Energy Cons. (BJ/Capita)	Avg. Fertilizer (Kg/ha)
Baseline	826.8	2.82	16.5
+ Increased off farm	873.3	2.98	17.2
+ Access to credit	1,282.2	4.11	53.4
+ Both	1,331.0	4.26	54.8
+ Fertilizer price (-20%)	832.1	2.84	16.9
+ Credit (in addition)	1,289.5	4.14	58.0

Note: Average values over 10 year simulation period.

Source: Authors

The impacts of credit on welfare of the different farm types are analyzed and presented in

Table 4-4. The simulation results show that access to credit could increase the income of the irrigation farm households (small reservoir and large reservoir farms) by 56% and 82 %, respectively, over the baseline income level, while the income of the rainfed farm households would increase only by 22 %. The results indicate that farm households who have physical access to irrigation land would be benefiting more by availing credit than subsistence rainfed farmers. It can be concluded from this policy scenario that providing access to credit without expansion of irrigation facilities in the region would not give the intended result of improving the livelihood of poor subsistence rainfed farmers.

Table 4-4: Impact of credit on different farm types

Farm type	Average Income per HH (GH. Cedi)		Change
	Baseline	Access to Credit	
Rainfed farm	620.94	760.42	0.22
Large reservoir farm	1109.55	2019.21	0.82
Small reservoir farm	1123.34	1757.25	0.56

Note: Average

values over 10 year simulation period

Source: Authors

The kernel density distributions of poverty for different scenarios are given in Figure 4-3. Access to credit would probably reduce poverty substantially, as most of the poor households could cross the poverty line (3.259 BJ/capita/year). The distribution graph also shows that the poorest agents would not benefit from access to credit, as the tail of the distribution has not changed. This is mainly because the poorest agents are those without physical access to irrigation land and availing credit for rainfed farming is not so profitable. So the poverty status of the poorest agents would probably not change even under favorable policy interventions.

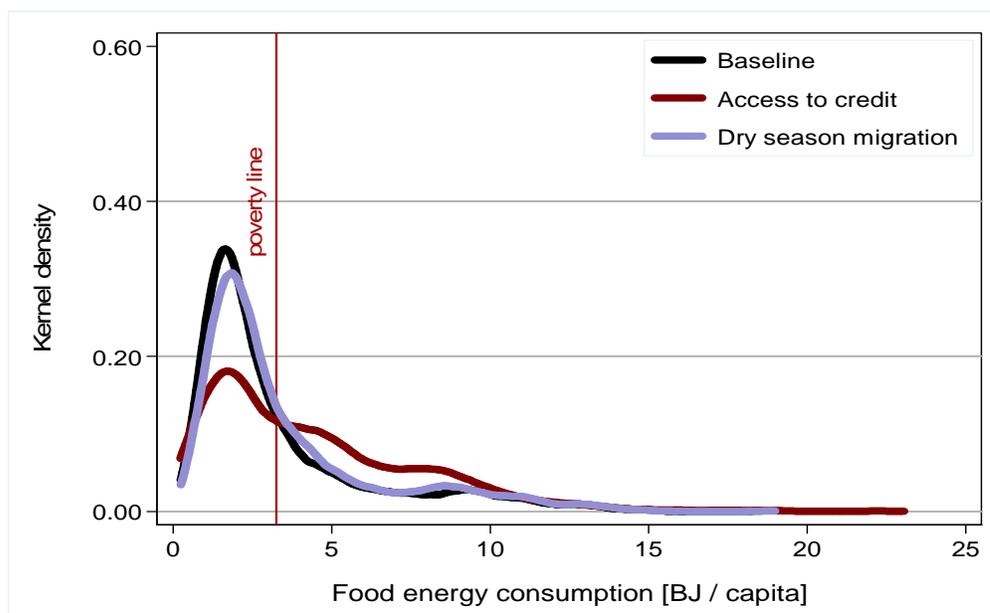


Figure 4-3: Kernel density graph showing the change in poverty distribution

Source: Authors

### Modeling river pumping scenarios: 3<sup>rd</sup> crop irrigated maize

Most of the large and small scale irrigation schemes are concentrated in the northern part of the Upper East Region. In the southern part households are mostly engaged in rainfed farming only. In an effort to increase the area under irrigation farming—as a development strategy to reduce poverty—, the regional Ministry of Food and Agriculture (MoFA) introduced the cultivation of irrigated maize in the dry season by pumping river water using diesel pumps. This innovation was assessed using the multi-agent model to determine whether this new irrigation technology would benefit the farming communities under the current socio-economic conditions, and also to test which policy options would increase the area under river pump irrigation.

Three scenarios were analyzed: The first scenario is the baseline and represents the current situation in which the households do not have access to river pump irrigation. The second scenario assumes that all agents have access to credit and that poor households are preferentially given access to river pump irrigation. In the third scenario, in addition to credit, the model assumes that the maize output price and maize yield increase by 20% and pumping costs decline by 20%.

The simulation results show that access to credit would increase the income of the river pumping farm agents by 28 % (Table 4-5). Due to high pumping costs and unfavorable market prices, the 3<sup>rd</sup> crop irrigated maize is not profitable for the households, so the adoption of the technology under the current situation is very low. The results also suggest that even under scenario II, the income of the river pumping farm agents would increase by only 38 % when compared to the baseline income (Table 4-5). At the time of constructing the model, the current fuel cost was not low enough, and the market price of maize was not high enough to bring the desired result of increasing the area under 3<sup>rd</sup> crop irrigated maize.

Table 4-5: Impact of 3<sup>rd</sup> crop irrigation maize by river pumping

Farm Type	Average Income per household (GH. Cedi)				
	Baseline	Scenario 1	Change (%)	Scenario 2	Change (%)
Rainfed farm	576.2	663.3	0.15	665.8	0.16
Small reservoir farm	697.6	960.9	0.38	967.7	0.39
River pumping farm	481.2	615.1	0.28	662.3	0.38

Note: Average value over 10 year simulation period. *Scenario 1*: access to credit and *Scenario 2*: Reduced pumping cost (-20%); Increased maize yield (+20%); Increased maize price (+20%) + Access to credit

Source: Authors

#### 4.1.3 Discussion

The simulation developed here provided an ex ante assessment of policy options discussed among policy makers and stakeholders in Ghana. Especially for the introduction of 3<sup>rd</sup> crop irrigation maize simulation results helped to identify possible diffusion paths for this innovation. Policy makers were, in particular, interested in likely impacts on poverty distribution and food security. These aspects can only be sufficiently captured by disaggregated simulation models such as MP-MAS that are specified at the agent level and can be used for “out-of-range” scenarios.

Two dynamics in the model drive the simulated diffusion of innovations: capital accumulation and thresholds. Each agent individually allocates its productive assets to accumulate capital, irrespective of the decisions of other agents. Network thresholds are based on a partitioned logit function estimated from a static model and the behavior of

other agents only affects the decision space of an individual agent if the more risk-taking innovator groups have not completed their adoption of the innovation. Once a personal threshold value has been reached, then the behavior of other agents no longer constrains the own adoption behavior. Some readers might argue that this limited degree of agent interdependence disqualifies this approach from being a “true” agent-based model. The modeling approach in this study is indeed a hybrid between traditional farm-based models, micro-simulation, and agent-based models. To exploit the advantages of our agent-based approach further, more interactions—for instance, as shown in Berger (2001) and Berger et al. (2007)—will be included in future versions of this application to Ghana. Such interactions can, for example, include the assignment of agricultural lands, the negotiation about local water rights, and informal labor markets. For the current assessment of irrigation options, we judged that not including these aspects is an acceptable simplification of reality.

Some model limitations have to be mentioned here. Unfortunately, no household panel data was available for the study area. Therefore, the model dynamics, especially the buffering role of livestock in household food consumption, had to be calibrated rather ad hoc. More simulation experiments are currently undertaken to test more thoroughly the robustness of results. At the time of completing the project, market price risks could not be considered adequately. High market risks will certainly affect the profitability of credit and therefore dampen the highly favorable impacts on household income found in this study. We are investigating this aspect by incorporating risk in our model and expect to have more detailed results soon.

#### 4.1.4 Conclusions

In this project, a dynamic bio-economic multi-agent model was developed and used to analyze various policy instruments that can improve the income from farming and thereby reduce rural poverty in the Upper East Region of Ghana. The household survey analyses and econometric studies conducted in the region revealed that most farm households are cash constrained, since existing programs to improve access to credit were not found to be accessible by the majority of the farm households. On the “business-as-usual” path, the simulation results suggest that the cash constrained farm households would not have enough incentives to extend the capital-intensive irrigation farming practices currently promoted in the region in the form of pumping water out of the river. The results also indicate that under this condition, food security in the region would further deteriorate.

By providing farm households access to credit, the simulation experiments show considerable positive effects on both household income and poverty distribution. However, one must keep in mind that so far market and price risks have not been fully accounted for. Simulation results also suggest that access to credit would promote much higher levels of fertilizer application, an important finding for the policy current debate about fertilizer use in Africa. In addition, the model results also show that access to irrigation is essential for lifting the poor out of poverty, as neither providing credit nor improving access to fertilizer alone would have a comparable poverty reduction effect.

The results underline the need to rethink the policy focus in Northern Ghana: more instruments should be tested for provision of credit and increased public investment in order to improve the physical access of irrigation land for poor farm households. The findings also underline the urgency of the need to resolve the governance problems identified above, which have restricted access to irrigation in the region.

## **4.2 Chile**

### *4.2.1 Methods*

#### Study region

As indicated in the introduction, the Chilean study region is located in the Maule Region, located in the central part of the country. The modeled area comprises more or less the total of the arable soils of the municipalities of Linares and Longaví as well as a small part of Colbún (see Figure 1-2). The three municipalities of Linares, Longaví and Colbún have a total population of 129.019 heads, according to the 2002 General Census.

Table 4-6: Population in project region

Municipality	Population	Rural Population
Linares	83.249	15.025
Colbún	17.619	12.467
Longaví	28.161	21.955

Source: INE (2008)

As a natural barrier to the clouds coming from the Pacific, the Andes receive high amounts of precipitation, especially during winter time. The snow serves as a natural reservoir, which fills the riverbeds that run from the mountains to the Pacific Ocean, when melting in spring and summer. Reservoirs allow a better control of the water flow and its extension into the summer months as well as the generation of electricity.

The main rivers of the study area are the Longaví, Achibueno, Ancoa, Putagán and Rari, all tributaries of the Loncomilla. The area receives an important amount of irrigation water from the Melado River via the Melado tunnel. Agricultural development over the modeling period 1996-2007 is characterized by a strong expansion of fruit production from about 9.7% to 22% of the cropped area in the three municipalities. Major fruit crops are apples, raspberries, kiwis, and pears. Lately blueberry cultivation experienced a strong surge. Traditionally, production focused on wheat, maize, rice, beans, potatoes and sugar beets as well as vegetable cultivation.

#### Model structure

##### Agent-based model (MP-MAS)

The specification of MP-MAS is comparable to the one used in Ghana. The main differences are that (i) livestock production is modeled at the level of the herd, not the individual animal as in the Ghanaian context, and that (ii) consumption decisions are modeled separately from the production and investment decisions using a simple cash consumption function. These simplifications are justified for Chile because (i) livestock does not play a dominant role for buffering liquidity and food consumption needs and (ii) the majority of farms considered in the Chilean study area are directed at market production and not at subsistence farming.

The inclusion of return flows and spillovers in the hydrological model, however, introduces a second level of interactions between farmers as the amount of water available to each farmer depends on the irrigation practices of the other users.

##### Hydrology model (WASIM-ETH)

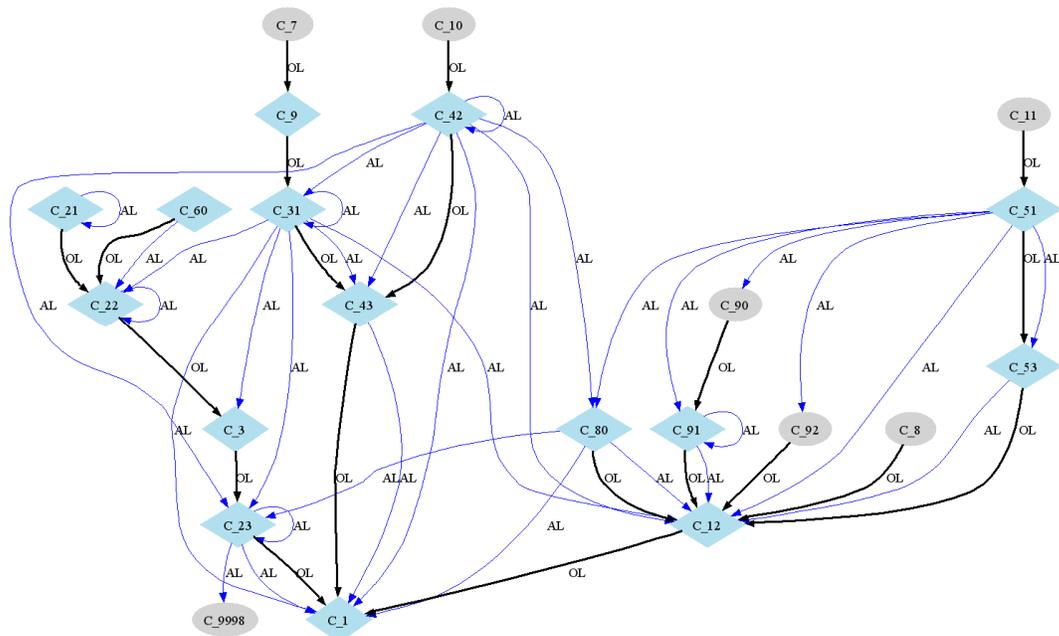
For the hydrological modeling, the physically-based distributed model WaSiM-ETH version 2 (Schulla and Jasper, 2006) was used, which simulates the water in the ground by means of Richard's Equation. To be able to calculate the potential evapotranspiration, according to Penman-Monteith, the model has an irrigation module that simulates the application of water according to the crop requirements and it also has tools to simulate water flows between catchments, external inflows and crop use, considering the availability of water.

The spatial resolution selected for simulation in Chile was 2000x2000 m<sup>2</sup> and the temporal resolution was daily. The pre-processing for the application of the hydrological model included the normalization of the spatial data. We used TANALYS provided by Schulla and Jasper (2006) and the 90x90 m<sup>2</sup> Digital Elevation Model of NASA, calculating secondary grids as slope, aspect, flow direction, flow accumulation and river network. For the modeling with WaSiM-ETH, the study area was divided in 21 catchments, defined systematically from important points in the rivers, corresponding to flow stations, water

intake points and external inflows. The study area is part of a larger river basin, not considered in its totality. For this reason, a special head catchment was generated that is not part of the model catchment but collects the inflows from the larger basin. Two smaller head catchments were treated as external because they are located in high altitude zones of the Andes with insufficient data.

In addition to spatial maps and hydrology time series, WASIM-ETH requires specification of varied parameters related to land use, soil type and irrigation. Land use, soil type and irrigation were parameterized by means of tables that describe each grid cell with a set of parameters defined in the control file. The estimation of the potential evapotranspiration for each land use type by means of the Penman-Monteith equation used knowledge of local experts about the seasonal behavior of parameters such as the stomatic resistance (RS) and the Leaf Index Area (LAI). It was assumed that the agricultural zone corresponds to a representative reference crop (annual crop). The other land uses were parameterized according to the recommendations of the model authors (Schulla and Jasper, 2006).

Two important aspects were modeled in relation to the irrigation. On the one hand, the irrigation module allowed for the application of a water sheet according to the irrigation schedule externally calculated and parameterized in the "irrigation table" in the control file of WASIM-ETH. On the other hand, the irrigation water distribution was modeled according to actual water use rights. The water was assigned to each grid cell according to the potential evapotranspiration (ET<sub>o</sub>). An excess of water was applied to simulate the efficiency of the application of the irrigation water (E<sub>a</sub>), assumed to be 30%. The model simulated the total volume in the nodes that were distributed to the different catchments proportionally to the water rights. Figure 4-4 shows the water flows.



Note: The chart indicates the water flow origin (intake) and destination (where irrigation water is applied, according to the water rights). Catchments are depicted as an ellipse (headwater) or as a rhombus. AL corresponds to artificial water transfers (canals) and OL refers to the natural water courses.

Figure 4-4: Water flows in simulation model

Source: Authors

Since catchments give and receive water from other nodes, an iterative process was developed until the transferred daily volumes generated in successive runs of the model

(2 or 3 times) converged. More details on the calibration and validation of the hydrological can be found in appendix F.

### Data processing

#### Model landscape

The model landscape or environment with which agents interact consists of the soils, the hydrological sectors and the location of the agents therein. The soil layer of the model is based on CIREN soil maps and contains only the arable soils of the area. Hydrological sectors are the same as in EDIC-CEDEC (1992). Meteorological and fluvimetric data were obtained from DOH/SMI (2004) and EDIC-CEDEC (1992). The hydrological system of the study area is modeled using Berger (2001)'s adaptation of a local expert model. This model was re-calibrated using the distributed hydrological model WASiM-ETH (cf. Uribe et al. 2009).

#### Agent Population

Information on the agricultural population of the study area was available through plot ownership maps obtained from the local real estate registries, the water rights registers of the local water users associations, the Agricultural Censuses of 1997 and 2007 and the farm survey conducted by the IGM Research Project.

The agent population for the model was created based on the plot ownership map, by taking each separate holding as one agent. Water rights and soil endowments could be linked to the agents by spatial overlay of the respective maps. The distribution of all other endowments (machinery, perennial crop plantations, farm contracts, family labor) was estimated from the 1997 Agricultural Census. Census and model population were each subdivided into 16 clusters (four geographical subareas and four farm size classes based on ODEPA classifications). For each of these clusters a cumulative distribution function was estimated and then the Monte-Carlo-Technique (Berger and Schreinemachers 2006) was used in a similar fashion as in the Ghanaian model.

#### Farm model and agronomic data

Basic agronomic data was taken from EDIC-CEDEC (1992), who provide production data of 1992, and DOH/SMI (2004), who provide data observed in 2003. Plant water demands were calculated using the FAO56 model adjusted by local experts in Chile. Market prices of outputs have, as far as possible, been taken from the ODEPA database, transformed into local farm-gate prices by considering transportation and marketing costs. Investment costs for advanced irrigation technologies were estimated from the database of projects funded under the Irrigation Law N° 18,450 (see above), which CNR facilitated to the project. The dataset was complemented by individual information from local experts (e.g. machinery and infrastructure cost, new crops, innovation diffusion).

The farm model draws on the one build for the area by Berger (2001), but has been widely extended and updated. It covers 21 different crops at four different technology levels combined with several irrigation technologies. The farm decision model was validated at the micro-level using an interactive modeling approach. The decision problem was solved for individual farms, which formed part of the surveyed sample, the results were discussed with the farmers and the model was subsequently adapted. The integrated model was then validated at the basin scale by comparing outcomes to land use data obtained from the agricultural censuses of 1997 and 2007.

### Adapted model versions

For different applications within the framework of the research project different specially adapted model versions were developed for various use cases (see below):

1. The *full area multi-purpose model* was used by the research team for policy assessment of the use cases at basin scale, consisting of the integrated modeling framework (MPMAS, FAO56 and the hydrological model WASiM-ETH) parameterized for the full study area.

2. The *single farm model* contains only the farm investment and production decision problems for one farm and is used for interactive validation and the calculation and discussion of water shadow prices with stakeholders.
3. In the *Exogenous Land Use* model, the farm decision problem is replaced by exogenously given land use data at sector level. Originally thought to calibrate the hydrological model, it was extended and adapted for the area of influence of the Bullileo reservoir as well as the area of influence of the Ancoa Dam Project at the request of stakeholders. It provides a straightforward tool to assess the operational schemes of the reservoirs given certain land uses and fluviometric data with respect to irrigation security. A simplified user front end was developed for this purpose.
4. The *full-area model coupled with WaSiM-ETH* uses tdt-Technology for a dynamic coupling of the distributed hydrological model WaSiM-ETH with the full area multi-purpose model enhancing the quality of hydrological analysis.

The software, manual and input datasets are available for download from the following website: <http://mp-mas.uni-hohenheim.de>

#### 4.2.2 Results

In the Chilean context, the scenarios to be modeled were referred to as “use cases” of the model. They were identified on the basis of the governance structure assessment and the interaction with the stakeholders (see Objectives 1 and 3).

##### Use Case 1: The Ancoa Dam Project

As discussed above, the Ancoa dam project aims to address the historically low level of irrigation security in part of the study area by the construction of a dam in the Ancoa River, which can capture and hold water during the winter season, and distribute it through the summer irrigation season. While the project will be largely financed by the state, it also charges a net sum from farmers over the life of the investment. For the dam project to go ahead, the state needed an agreement from farmers equating to a minimum of 50% of total water rights within the region, that they are willing to accept this charge. The benefits farmers expect from the improved water security vary considerably between farms, as factors other than water may be more severe constraints at farm level.

The modeling framework was used to estimate the distribution of benefits among farmers and based on that to predict their willingness to sign the agreement. Using the single farm version of the model in an interactive modeling approach, shadow prices for irrigation water were calculated for ten survey farms and discussed with stakeholders. As shown below only four out of ten farms have water shadow prices higher than the average subsidized price at an assumed effective water allocation of 60% of their nominal water rights. Allowing for investments into several advanced irrigation technologies increases the shadow price for most farms and in this case half of the surveyed farms would be willing to pay for secure water at the given price.

Then the full area model was used to scale up the results and estimate the distribution of water shadow prices over the farming population of the study area based on the asset distribution functions estimated from the household survey. Figure A-8 in Appendix C shows the cumulative distribution function over the study area. As the project proceeded and the construction works for the dam started, the modeling framework served as a basis for the water users associations to discuss strategies how to prepare for the start of operation of the reservoir. The full area integrated model was used to simulate future scenarios 2008-2018 with and without the dam project, and with the dam project combined with an unlimited subsidy for advanced irrigation technologies. Average yearly income growth rates (Table 4-8) show that while the economic effect (not considering the charge) is generally positive, but also indicate that the income difference between

farm size classes will grow considerably over time. This divide is exacerbated by the dam project and even more so in combination with the subsidy.

*Table 4-7 Shadow price for 60% and 100% water allocation with and without investment, versus the subsidized price for secure water rights*

Farm	Default scenario		Investment scenario		Average Subsidized Price Secure Water
	60%	100%	60%	100%	
1	0.8	0.5	0	0	6.5
2	0.7	0.4	3.9	0	11.4
3	22.4	0.7	14.9	0.8	11.4
4	17.6	12.9	17.6	12.9	13.2
5	7.7	7.5	13.9	13.9	13.2
6	0.7	0.7	0.7	0.7	22.8
7	0.9	0.7	5.9	0.7	6.5
8	0.9	0.7	6.2	0	11.4
9	13.6	0	13.8	0	13.2
10	5.9	2.6	7.8	7.8	4.3

Note: Prices are measured in \$Pesos/m<sup>3</sup>.

Source: Authors

*Table 4-8 Average yearly income growth rates 2008-2018*

Scenario	Farm Size Class			
	< 5 ha	5-25 ha	25-60 ha	> 60 ha
without Ancoa	0.17%	1.65%	3.80%	5.91%
with Ancoa	0.33%	2.16%	3.93%	7.94%
Ancoa/CNR	0.38%	2.76%	9.58%	14.44%

Source: Authors

### Use Case 2: Irrigation subsidy reform

As discussed above, the Irrigation Law N° 18.450, "Promotion of the Private Investment in Irrigation and Drainage Infrastructure", in effect since 1985, provides funding to the improvement of minor irrigation infrastructure and of irrigation at the field level. It is administered by the National Commission of Irrigation (CNR), which defines each year programs and the amount of funding for certain regions and specific target groups.

The integrated modeling framework was used to assess the effectiveness of the subsidy program in modernizing the irrigation technology on the one hand, and to analyze its equity impact on the other. Equity and distributional impact are not only relevant from a welfare perspective. Farms are also interconnected through the hydrological system and produce or depend on return flows of other farmers' irrigation water. Increasing irrigation efficiency at one point in the system might lead to lower water availability elsewhere. Again small and traditional farms seem more vulnerable, as many are more dependent on return flows.

The full area specification of the model is used to simulate the development from 1996 to 2016 under four different policy scenarios:

1. The *Traditional Scenario* assumes that no investments into advanced irrigation technologies are possible.
2. The *With Scenario* is the baseline: advanced irrigation technologies are available and subsidized for selected farmers (selection captures the actual selection criteria of CNR)

3. The *Without Scenario* assumes that advanced irrigation technologies are available, but there is no subsidy.
4. The *Ad Libitum Scenario* assumes that there is a subsidy for advanced irrigation technologies for all farmers amounting to 60% of the investment cost without a limit for the public budget.

A comparison of the With and Without Scenarios generally reveals little difference in the actual area extent of irrigation technology use. Figure 4-2 indicates that the expansion of drip irrigation (one important type of investment subsidized under the law) does not differ much between the two scenarios. However, a comparison of census data with the CNR project database reveals that about 44% of the area increase of localized irrigation between 1996-2006 has been subsidized under Irrigation Law 18,450. This fact is adequately reproduced by the model. Importantly, the results show that most of the farmers, who received a subsidy for localized irrigation technologies, would have invested anyway. Most of the investments into localized irrigation technologies are associated to perennial crops (apple, kiwi, blueberries) with high gross margins, which make investment very profitable.

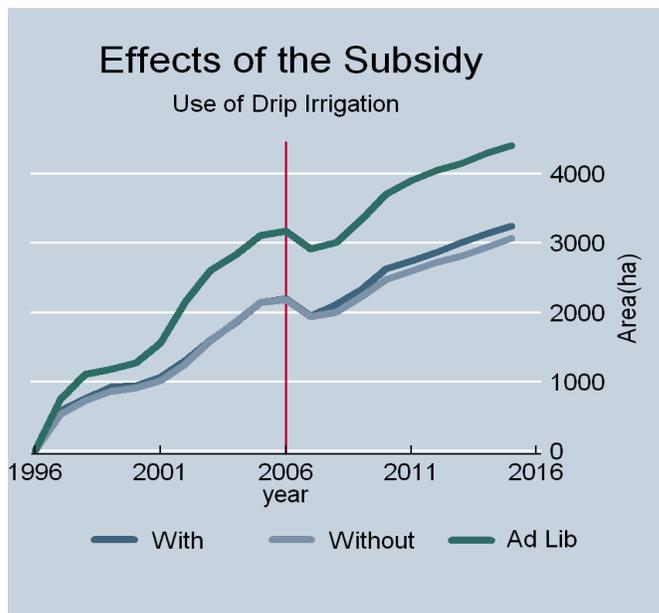


Figure 4-5 Effects of the subsidy on the extent of drip irrigation use

On the other hand, the Ad Libitum Scenario shows that there is a potential to increase the use of localized irrigation if subsidies were not limited by budget constraints. According to the project database, most actual subsidies were awarded to medium-sized (25-60 ha) farms in the area. A stronger shift towards smaller farms might increase the area effect, but further research is needed to confirm this.

With respect to the distribution of benefits, Figure A-9 in Appendix C shows the spatial distribution of gains and losses in per-ha-on-farm-income 2002 in the Ad libitum Scenario compared to the Without Scenario. Mainly larger farms belong to the winners and show considerable on-farm income gains. Losses are rather dispersed over many farms. There is no clear spatial pattern; winners and losers can be direct neighbors. The model suggests for many farms a high reliance on off-farm labor, which might help to compensate small losses due to lower water availability. However, as the labor market was not explicitly modeled here and no data on farm incomes or their composition was available, this still requires further research for confirmation.

Besides support for modernizing on-field irrigation, the irrigation law also provides funding for meso-scale irrigation infrastructure, which can be obtained by water user associations, e.g., to mend leaking canals. Though data on projects funded under this scheme exists, very little is known about the actual impact, as knowledge about meso-scale processes and interactions as well as canal conditions is scarce. The full area multi-purpose model was used to test several improvements of canal efficiency based on different expert hypothesis on meso-scale processes of water losses, reuse and potential redistribution among farmers due to leaking infrastructure, loose enforcement of nominal water rights and abandoning of water in wet years. Due to the lack of measurement data, results could not be validated, but should be seen as a first approach to serve as a basis for discussion and help to focus future research.

Dependence on spillovers (waters owned, but abandoned by other farmers), canal leakage, reuse and sometimes illegal appropriation is not uncommon among smaller and economically weaker farmers. The impact of an improvement of canal efficiency differs with the degree of dependence. For farmers, who usually produce spillovers (Group A), the benefits from canal efficiency are only relevant during very dry years. For farmers that own sufficient water rights during 'typical' years, but suffer from deficit even during moderate droughts, canal improvement has largest benefits (Group B). For agents that lack sufficient water rights, especially for those that over-proportionally benefit from surplus water (Group C), the impact of canal improvements is more complex and depends on the assumptions on meso-level processes: If canal improvements cause the overall availability of 'free' water to increase, they profit (e.g. if canal leakage leads to real losses and improvements leads to more secure water supply for Group A farmers, who then produce more spillovers), otherwise they lose (e.g. because canal leakage is not completely lost, but reusable).

Given the distribution of water rights in the area, modeling results suggest that the commercially most relevant stratum of farmers (> 60 ha) tends to profit from improved canal efficiency. Smaller farmers might be able to compensate losses through higher off-farm employment, which again points to the importance for a future inclusion the labor market into the model.

#### 4.2.3 Discussion

Since a version of the MP-MAS had already been developed for the research region prior to the project, the potential of this modeling approach could be more fully used in the Chile case than was possible in the Ghana case (see Section 4.1.3). In particular the potential of the MP-MAS approach to model the hydrological interactions between different types of farms proved to be essential to answer questions that were of high policy relevance during the research period, both with regard to the Ancoa project, and with regard to the subsidy reform. In both cases, the modeling approach was able to throw light on important distributional questions, which are often neglected in the policy debate due to the lack of evidence. The MP-MAS application showed that the Ancoa dam project will not substantially increase the rather slow income growth rates of farms below 25ha, whereas the combination of the Ancoa dam and the subsidy program would more than double the income growth rates of the farms above 25 ha, thus leading to an increasing income disparity between small and large farms. The application of the decision-support tool also showed that for a substantial share of the water users, it will only be economic to pay the fees required to get access to the additional water resources provided by the Ancoa dam water if investments are made to improve their water use efficiency.

The MP-MAS simulations also revealed that in the past, the subsidy program had mostly benefitted farms that would have had sufficient economic incentives to pursue the subsidized investments without the respective subsidy. The selection procedure currently used by CNR grades the projects by weighting irrigation efficiency improvements and

land suitability classes. Apparently, this procedure mostly leads to a subsidization of projects that are profitable from a private perspective also without subsidy. To reach beyond this group of projects, considerably higher funding levels would be required under the current selection mechanism. As further simulation results showed, continuing the current funding system aggravates the divide between smallholder and commercial farms. This finding calls for additional efforts to improve the targeting of the subsidies to households who had previously been excluded from the program. The recent change in the modalities of the subsidy program in 2007 — which enabled farmers who do not have registered water rights to access the funds —, can be seen as an important step in this direction.

The use of the MP-MAS model also made it possible to throw light on the question as to whether there are “losers” associated with the improvement of the efficiency of water use by rehabilitating the canal infrastructure. The modeling approach made it possible to quantify the effects of such investments on different type of farm households, and also to identify the spatial location of the “winners” and “losers” of this intervention.

#### **4.2.4 Conclusions**

The application of the MP-MAS model to the two use cases that have been identified together with the stakeholders in the research region imply that specific attention needs to be paid to the distributional impact of both the Ancoa project and the subsidy reform. In fact, both policy interventions have rather problematic distributional implications, which need to be addressed to avoid a further increase in income disparity between large-scale and small-scale farmers, and between farmers that have water rights and those that can only benefit from spill-over and leakages. The results suggest that it may not be justifiable to finance canal improvements with funds that are reserved for poverty alleviation. Instead, while use of general economic development funds for this purpose is justifiable, poverty alleviation funds should be used to mitigate negative impact on farmers that already have lower income levels and do not benefit proportionally from these policy interventions, or even suffer income losses as a consequence.

## **5 Objective 3: Using the models as decision tools**

### **5.1 Methods**

#### **5.1.1 General approach**

The third main objective of the project was to assess the use of the decision tools in practice and, based on this assessment, to identify appropriate strategies for enhancing the model impacts on decision-making processes. Computer-based decision tools have been proposed in recent years as an effective means to disentangle the complexities and uncertainties related to the management of natural resources. Especially agent-based simulation has been suggested as a promising approach to involve stakeholders in the definition and solution of resource use problems. Because of their interactive and participatory feature, agent-based simulation might integrate various sources of knowledge and help to reach consensus on the implementation of problem solutions.

Sterk et al. (2009) propose several ideotypical arrangements for using models as decision tools at the science-policy interface. “Knowledge broker” is the arrangement relevant for the decision tools developed and tested in this project. Compared to traditional arrangements with a clear distinction between the science and policy domains, “knowledge broker” means that scientists developing the models directly engage with interest groups (resource users) and devote much effort in merging and transferring the scientific knowledge generated by their models. The model focus is on “social learning”, i.e. scientists, resource users, extensionists, government officials and other stakeholders jointly increase their knowledge base about the land system in question, exchange their views and personal interests and may then finally negotiate

possible solutions. Policy-makers typically take part in this collaborative learning endeavor but are not steering the process and do not have control over the objectives and results.

An important prerequisite for a useful decision support tool in a “knowledge broker” arrangement is to earn the trust of different stakeholders in the model and its simulation results. In this project, a *collaborative research and learning framework* (Box 5-1) guided the joint development of the model with those interested in using it. The joint development had three objectives: (1) to improve the quality of information used to set up and parameterize the model, (2) to ensure that the relevant questions and criteria can be addressed with the model as well as to identify relevant and feasible policy options and (3) to provide decision makers with access to the model which ideally includes training them to use it.

The following sections describe the country-specific implementation of the collaborative research and learning framework. Although the fundamental nature of the planning problems is the same in both countries — problems are “unstructured” in the sense that objectives are not clearly defined and standard technical solutions cannot be easily applied —, countries differ in the “stage of basin development” and the technical capacity that is locally available. The focus here is placed on the key tools developed and applied in this project, agent-based simulation and influence-network-mapping. Information on all other decision tools can be derived from the project website.

**Box 5-1: Steps in the collaborative research and learning framework**

Step 1: First round contacts, introductions

Inform stakeholders, contribute to understanding governance structures

Step 2: Demonstrations of the model

Elicit feedback on problems, needs and potential solutions and evaluation criteria (use-cases, scenarios); may involve another workshop

Step 3: Organizing feed-back, esp. regarding front-end

More workshops and evaluation of workshops, may also involve smaller working groups/interviews

Step 4: Practical use of the model by stakeholders

Identification of people who to train, training - training version of the model

Step 5: Monitoring/evaluating the use of models by stakeholders

Establishing the use potential of the model

Source: Authors

### 5.1.2 Application in Ghana

In Ghana, the stakeholders were involved in developing both the Net-Map tool and the agent-based modeling for improved decision making in water governance. They helped to define the most relevant use-cases and provided data for the modeling. In the process of developing and fine-tuning the model, the regular stakeholder meetings served as a sounding board to make sure that model assumptions were in line with the actual conditions on the ground. An added benefit of these meetings was that the stakeholders were involved in an ongoing dialog process with each other and the researchers, which facilitated inter-sectoral learning and collaboration.

Unfortunately, Step 4 and Step 5 of the framework (Box 5-1) could only be implemented to a limited extent in Ghana. One reason was that the post-doc modeling position at the Hohenheim University could only be filled with some delay and subsequently was again not filled for approximately one year due to change in staff. The specific qualification requirements for this position made it difficult to find appropriate candidates. Another reason was that the close collaboration with the GLOWA Volta project and with IFU-IMK

for the hydrology modeling did not materialize as was intended in the original proposal, again caused by change in staff.

Nevertheless, two short *training courses* and *regular model feedback meetings* were held in Ghana. Final simulation results were communicated to regional and national level stakeholders in two conferences at the end of the project.

### 5.1.3 Application in Chile

Four advanced user workshops were conducted with the purpose to adapt and fine-tune modeling to information needs of stakeholders and to train end users how to calibrate and run the model. Two cases of particular interest were jointly selected, described and analyzed with stakeholders: (i) Ancoa Dam and associated conflicts, and (ii) reform and application of the Irrigation Law 18.450. Modeling results informed discussions with emphasis on these two model use-cases.

- In December 2006, the first workshop for advanced users “Modelación Aplicada como Herramienta para la Gestión de Recursos Hídricos” (Applied modeling as tool for the management of water resources”), was carried out at the University of Talca. The main objective of this workshop was to present advances on multi-agent and hydrologic modeling achieved by the project and to set up a group of interested users of the model for future training. A total of 20 professionals from various private and public institutions attended.
- In March 2007, the second workshop for advanced users was conducted. Twelve participants attended the workshop; lectures and discussion focused on i) advances in hydrologic modeling, ii) interactive modeling, iii) first use-case with CNR. In addition, there was practical training with software applications.
- In December 2007, the third workshop for advanced users counted with a total of 8 advanced users. Training and discussions focused on i) interactive modeling with farmers, ii) preliminary results of CNR use-case modeling, iii) Ancoa use-case modeling. Again exercises in data processing and software application were conducted, for which a preliminary version of MP-MAS software was introduced.
- The last workshop took place at the Junta de Vigilancia del Rio Ancoa in Linares in December 2008. Training on MP-MAS software was provided to 5 advanced users who attended this workshop. Attendees received instructions to run the model and copies of the model were installed on their personal computers.

Workshops were evaluated with regard to use and appropriateness of the model. For the final evaluation (see below) project participants were interviewed, including those who had decided to withdraw their active involvement in training and consultation at previous project stages.

## 5.2 Results

### 5.2.1 Results for Ghana

In Ghana, the Net-Map tool was used extensively in addition to the agent-based modeling tool in support of decision-support processes. Therefore, this section describes the results for both tools.

#### Agent-based modeling tool

During the time of the implementation of the research project, the national policy debate focused increasingly on the question as to how agricultural development and poverty reduction could be stimulated in the three Northern regions of the country, which include the Upper East Region. The results of the Living Standard Measurement Surveys indicated that poverty had remained depressingly high in Northern part of the country, while it had substantially declined elsewhere in the country. Prior to the 2008 elections, policy-makers also placed increasing attention to this region, as this region could not be

neglected by either of the two competing major parties. It was decided to set up a Fund for the development of the region. Moreover, a fertilizer voucher scheme was implemented in 2008, as well. Yet, there was a considerable lack of knowledge on the opportunities and challenges of different strategies that could be pursued in the region and on the possible synergies between them. In this context, the approach of the project to develop the scenarios to be modeled in close stakeholder interaction proved very timely, since it allowed the project team to provide knowledge on those options that were favored by the stakeholders from the region itself, using empirical data collected in the region. Having worked for several years “on the ground”, the project was one of the few providers of empirical knowledge when the region finally started to attract strong attention on the national policy agenda.

The stakeholder interactions showed that the regional office of the Ministry of Food and Agriculture (MoFA) placed particularly strong hopes in the option to pump water directly from the river for irrigation, as trials had shown that this would make it possible to grow a third season crop of maize. To assist MoFA in the evaluation of this option, project scientists collected technical and price data in the field and developed basic planning tools such as gross margin and sensitivity analyses. The model results for this innovation were not too favorable in terms of profitability at the farm level, which had a certain sobering effect on the stakeholder side, but they were still well received. Likewise, the project pursued a close collaboration with MoFA and the Ghana Irrigation Development Authority in assessing the opportunities and challenges of the small reservoirs.

The regular model feedback meetings organized by the project team in Bolgatanga, proved to be a useful avenue to feed research results into current policy debates, especially as the project team also invited other researchers working in the region to present their results. Moreover, it turned out that these meetings served as a forum to promote dialogue among the representatives of different departments, especially those responsible for agriculture and environmental protection, which allowed them to develop a more concerted approach.

When the policy-related simulation results were presented at the final national level conference in December 2008, stakeholders showed particular interest in the model findings, especially in the findings regarding the functioning of small reservoirs, the role of credit, and the linkages between irrigation, credit and fertilizer use. After a lively discussion, participants agreed that these topics required further consideration. As mentioned above, the project was completed before all options of the model could be exploited in collaboration with the stakeholders. In particular, Steps 4 and 5 of the collaborative research and learning framework (Box 5-1) remain to be undertaken in Ghana, and would best be pursued in the scope of a follow-up project. As further discussed below, IFPRI’s Ghana Strategy Support Program can also serve as an important entry point for further feeding the results produced by the project in the ongoing policy debates.

### [Net-Map tool](#)

The development and use of the Net-Map method with the White Volta Basin Board proved to play a significant role for the organizational development of the board and for the increase of the “social capital” of its members. At the beginning of the project, the institution of the Basin Board was approved but still awaiting its implementation. Thus the Post-Doc employed by the project for the governance component of the project was present when the Basin Officer set up office in Bolgatanga, invited potential membership organizations and started the process of forming the board. The membership was rather diverse in terms of content expertise, position in the governance system and process understanding. In the first round of introductory interviews, it became apparent that board members had widely differing ideas of the purpose of the board and their own role in it. The continuous presence of the Post-Doc in the field allowed the project to interact

with the board members and other stakeholders on a regular basis and to help them use Net-Map for a network learning process.

The general reaction of board members both to the individual and the group mapping exercises was considerable excitement about the learning experience and improved understanding of the networks they are supposed to be interacting with. This proved to be particularly beneficial for a governance body with high diversity and high expectations, but—as it turned out—rather low formal enforcement capacity. The discussions about the network allowed the board members to exchange knowledge and increase the social capital of the board as a whole by becoming aware of all linkages that individual board members used. It helped them understand who their core partners are and why and develop strategies for interacting with those and the other network members.

While in most research activities the learning effect of research partners can only be expected when the results are presented, Net-Map allows participants to learn during the process of data collection. The common network map showed a broader diversity of actors than most individual maps. This indicates that most board members were only aware of and linked to their own kind of actors (e.g., government representatives drew mainly governmental networks; district representatives included more local actors than regional representatives). Through engaging in the network mapping exercise together, they became aware of their own “blind spots” and developed a more inclusive and balanced idea of the governance network they interact with. For example, very few individual interviewees mentioned the private sector or faith-based organizations as important actors. However, when discussing the common network vision, they realized that many water related activities (planning and building water infrastructure, training water users, marketing agricultural inputs) are carried out by the private sector that thus becomes relevant actor to be concerned with. Similarly, when realizing that most of the goals of the Basin Board cannot be imposed and that policing compliance is also difficult for the board, the group engaged in a discussion of developing strategies for the involvement of those actors who can change public opinions and actions, thus pointing to the importance of working together with the traditional authorities, the media and religious leaders. At the presentation of the results to a broader stakeholder forum in Bolgatanga (beyond board members), a number of participants expressed their wish to be included more prominently in the network and initiated a dialogue about various ways of involving non-member stakeholders.

### 5.2.2 Results for Chile

One key objective of the user workshops and their subsequent evaluation was to explore conditions for effectively applying the decision support tools and feeding results into ongoing planning processes. During the last model user workshop, participants stressed the importance of the models in bringing “hard” facts on the table, i.e., water rights, shadow prices, costs and benefits of investments, and in clarifying the interactions between water users, especially when using return flows. Technical staff of the water user associations requested interactive models for special planning purposes, e.g., to adjust the operational curve of reservoirs to the changing water requirements of new crops. The project team made an effort to respond to these requests and designed special software to be run by staff of the water user association.

Based on the final evaluation of model users in December 2008, several lessons could be drawn:

- While involvement of multiple stakeholders tends to enhance input quality and subsequent uptake of the decision support, it became clear that in accordance with their institutional roles, users differed significantly in scope and depth of interest with

regard to running model applications, e.g., for scenario building and analysis. Consequently some users opted to not continue respective training activities.

- Stakeholders reflected on the project's process that the uptake and impact of the decision support tool would have been much stronger in case the modeling software had been completed during an earlier stage of the project. At the same time, stakeholders admitted that the quality of input data was occasionally poor and that the project team had to make time-consuming efforts to consolidate the data collected by various organizations.
- To those users with a strong motivation to apply the modeling software, a more frequent interaction with project staff with stronger focus on capacity building and more practical training with the software would have been appreciated.
- As a key requisite to establish durable working relations with intended project users, it was important to maintain contact, both with the targeted personnel (e.g. in the government agencies) and also with their superiors who had to endorse this involvement and make it possible in practical terms as well.

In general, stakeholder involvement and support in Chile has been strong and sustainable. Over the 4 years of the project, 3 out of 4 water user associations continued to send their technical staff to all model training sessions. This can be seen as an encouraging quality assessment, considering that water user associations in Chile are not state-run organizations, but are directed and funded by farmers who typically have a highly developed sense for opportunity costs of time and money.

Stakeholder support has continued after project completion in December 2008. Recently, a follow-up project has been submitted for funding by INIA, the national research organization hosting the MP-MAS software and datasets in Chile. In this project to be funded by the Chilean government, INIA together with the CNR and the Juntas de Vigilancia, plan to fine-tune the various components of the MP-MAS software for further use in infrastructure and investment planning.

### **5.3 Comparative discussion**

The different experiences in Ghana and Chile confirm the importance of focusing on methods, research questions and strategies that are adapted to the local context and local needs. In a system with established and resourceful institutions and organizations as in Chile, which looks back on a long history of commercial irrigated agriculture, a different approach was needed than in Ghana, where the partner institutions were in a crucial phase of institutional development, and irrigation still played a minor role in largely subsistence-oriented smallholder farming system. The most burning questions in both systems were different and the research project adapted its approach to this. In Ghana, the project responded to the opportunity to support the institutional development of a newly instituted organization and to feed inputs into the setting-up, visioning and organizational structuring of the basin board. This window of opportunity meant that the project was able to produce and communicate the findings, especially those from the governance research, at a point in time when the situation was in flux and the conditions for their up-take were very favorable. In Chile, on the other hand, the public, private and third-sector organizations concerned with water governance in the research area were well developed and consolidated so that the major pressing questions in this setting centered around economic and hydrological issues, to support fair and equitable distribution of water, and to allow for realistic ex ante assessments. Here, the technical staff of the various water user associations and the irrigation administration was highly enthusiastic about the computer-based tools provided by the project, and took own initiatives to expand the use of these tools beyond the scope of this project.

The use of the computer-based tools, however, could not be monitored to the extent originally intended in the project proposal. Although stakeholders provided extensive datasets collected at their organizations, pruning and consolidating these datasets

proved to be highly demanding in terms of time and personnel. Moreover, the project experienced delay in model development due to change in staff, especially in Ghana. Stakeholders received training and gained experience with the computer models during the course of the project but ready-to-use versions of the software were available only at the final workshops. Monitoring the actual model use will therefore be continued in follow-up projects in both countries. Monitoring activities will cover the following model use cases:

- In Ghana, the use of the computer models will be assessed in terms of changes in (i) irrigation planning of MoFA and other government agencies in UER; (ii) actions and practices of the White Volta Basin Board; (iii) funding of donors for specific irrigation projects in the Upper East Region.
- In Chile, actual model use will be monitored for changes in (i) operational curves of Ancoa and Bullileo reservoirs and water distribution to irrigation sectors in the study area; (ii) investment planning of the Juntas de Vigilancia for building new irrigation infrastructure; (iii) implementation of irrigation subsidy programs of CNR, especially regarding the selection procedure of subsidized projects.

## 5.4 Conclusions

As argued by Berger et al. (2006), one key advantage of agent-based modeling is the one-to-one correspondence of real-world and computational agents, which facilitates participatory simulation and model-enhanced learning (e.g. Becu et al., 2008). Using agent-based land use models effectively—so that model users receive early warnings, share their system understanding and improve the outcomes of their land-use decisions (Hazell et al., 2001)—poses a number of challenges that have not been fully resolved yet<sup>6</sup>. Based on the practical experience in this project, this section reflects on the following critical issues: (i) participatory techniques for model validation; (ii) building trust in model results; (iii) using MP-MAS for agricultural extension; and (iv) development of teaching and training programs.

### 5.4.1 Participatory techniques for model validation

According to the project experience in Ghana and Chile, the agent-based software MP-MAS proved to have a clear advantage over other integrated modeling approaches that project team members had applied before, for example, aggregate regional land use models (van de Giesen et al., 2006). Single-agent models for representative farm households can be constructed and validated jointly with stakeholders in interactive model validation rounds. The team first collected farm-specific data on factor endowments such as labor, land and water, and processed these data for a standalone version of MP-MAS. Using Excel workbooks, the team calibrated each single-agent model to replicate current land use decisions and performed sensitivity tests together with stakeholders. Through “what-if” scenarios, for example, on “how do you adjust your land use if you receive less irrigation water”, the team could elucidate additional constraints that the farmers actually faced and that were originally not included in the model. The single-agent models were then gradually improved until sufficient model fit for each of the representative farm households was reached. In a second step, the full agent model for the study area was calibrated and validated, using the Monte Carlo approach as described in Berger and Schreinemachers (2006). The project experience shows that the use of standardized questionnaires is an efficient way of collecting basic agent data on agricultural land-use. The alternative of stakeholder group interviews, as used by other scholars (see Robinson et al., 2007) turned out to be more time-consuming.

### 5.4.2 Building trust in model results

The interactive modeling rounds for parameter testing and model validation can help to build trust in the simulation results of MP-MAS. Since farmers and water managers are directly involved in compiling the model database and performing the sensitivity

<sup>6</sup> See for example von Paassen (2004) who reports mixed success for applications of Linear Programming models in developing countries.

analyses, they become familiar with the model and its interfaces. Results from special model computations, for example, of individual water shadow prices, can be compared with local data and experience. This helps to create confidence in the model if the results are plausible. Typically, testing and calibrating of MP-MAS requires more than one modeling round and might demand additional time if unforeseen constraints need to be included. The insight from applying MAS models with many feedback rounds is that stakeholders and potential model users are prone to losing interest if these rounds consume much of their time. The interactive modeling rounds should therefore generate information that is perceived as immediately useful by stakeholders. In case of market-oriented farm household such information typically involves estimates of crop yields, farm profitability, and household income; in case of water managers it involves minimum river flows, average water uptake and water use efficiency per irrigation section.

#### *5.4.3 Using MP-MAS for agricultural extension*

Mathematical Programming is one of the planning methods taught in farm management schools and is used in agricultural extension. Standard farm decision problems such as partial budgeting, investment and income analysis can be directly addressed by the tools incorporated in MP-MAS, making use of the database that has to be built up for the model application. The project experience shows that staff in farm extension programs can therefore be convinced with relative ease to use the single-farm features of MP-MAS. The practical challenge, however, is the maintenance and adaptation of the MP-MAS input files, which requires some minimum knowledge in database management and MP. To address this challenge, the use of the ubiquitous software MS-Excel for input/output operations proved to be useful. Moreover, in Chile it was feasible to form a group of advanced model users that were trained in using MP-MAS.

#### *5.4.4 Development of teaching and training programs*

MP-MAS requires, as all other software programs, teaching and training. The team started developing specific programs targeted at various potential user groups, ranging from introductory demonstrations in a few days to a series of workshop sessions held over one year. At Hohenheim University, Germany, the team members offer consecutive courses on "Farm-System Modeling" and "Land-Use Economics" at MSc level and "Advanced Techniques for Land-Use Modeling" at PhD level. The inclusion of agent-based modeling in the curriculum of the Master Study Programs "Agricultural Economics" and "Agricultural Sciences in the Tropics and Subtropics" at the University of Hohenheim has added young scientists to the model developer group and increased the number of empirical research applications as part of dissertation projects.

## 6 OUTCOMES AND IMPACTS

### Summary Description of the Project's Main Impact Pathways

#### Ghana

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
(1) White Volta Basin Board	The Board is more strategic in identifying and leveraging the partnerships needed to pursue the goals of the Board.	Increased awareness of the different networks that the members have; increased awareness of the need to leverage different types of partners due to limited formal enforcement capacity	Use of the Net-Map method; Having a post-doc stationed in the Basin Office for two years; Frequent organization of stakeholder feedback meetings	Long-term benefits from more effective functioning of the Board expected; difficult to quantify as the Board pursues multiple goals
(2) Ministry of Food and Agriculture (MoFA) and donor agencies	Pursue a broader range of options for improving agricultural incomes in the region;	Increased awareness of the challenges involved in the option to pursue river pump irrigation under current price relations	Use of economic analyses and subsequently the MP-MAS model to simulate the effects of different strategies to increase agricultural incomes	Potentially large effect due to increased funding (Northern Rural Growth Program alone has more than US\$100 million; findings can guide investment choices
(3) Donor agencies, Ghana Irrigation Development Authority and MoFA	Take measures to improve the quality of constructing small reservoirs so that they can indeed be used for irrigation	Increased awareness of the governance challenges involved in making small reservoirs work	Conducting small reservoir survey (once problem was diagnosed); analyzing governance challenges using Net-Map	Large leverage effect possible since donor agencies plan to invest tens of millions of US\$ in small reservoirs

## Summary Description of the Project's Main Impact Pathways

### Chile

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
(1) Instituto de Investigaciones Agropecuarias (INIA)	Formed national consortium for computer-based decision support and applied for large-scale funding	Increased knowledge and technical capacity for conducting computer-based system analysis	Offering opportunity for staff to join Hohenheim group; intensive training in using coupled agent-based and hydrology models	1 scientist joined Hohenheim group for 1 year, completed doctoral thesis using coupled model, and now leads the new consortium that applied for funding
(2) Comisión Nacional de Riego (CNR)	Considers agent-based modeling as tool to improve integrated assessment of irrigation policy options	Increased insights in using computer-based decision tools	Advanced user training for software developed in project	Approached INIA to form consortium and apply for public funding to fine-tune software
(3) Instituto Nacional de Desarrollo Agropecuario (INDAP)	Staff feels more competent regarding consulting capacity	Enhanced overall understanding of the functioning of the region's landuse related hydrology	Advanced user training for software developed in project	Difficult to quantify, regional program leader participated in advanced model user training
(4) Juntas de Vigilancia de los ríos Longaví, Ancoa, Achibueno, Putagán (JdV)	Consider agent-based modeling as tool to improve water management	Increased skills in using computer-based decision tools	Advanced user training for software developed in project	Technical staff in 3 out of 4 JdV completed advanced user training; 2 out of 4 JdV installed software on personal computers; all signed MoU for follow-up project submitted for funding

*Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?*

For the case of *Ghana*, all three major impact pathways have the potential to be adopted. The Basin Board has already adopted the changes listed above, and due to the intensive interaction with the regional office of MoFA, changes in the awareness and knowledge about different strategies to increase farmers' income have already occurred. The adoption the third impact pathway (improving the quality of constructing is less secure, since there are obviously vested interests that benefit from the current "leakages" in the system. Efforts may have to concentrate on ensuring that the quality of construction is good enough to ensure that the small reservoirs can indeed be used for irrigation, rather than trying to avoid all possible leakages that can occur. According to the information available to the project team, only one of the donor agencies involved in financing small reservoir has used its own monitoring and evaluation system to detect quality problems and act accordingly. In the case of all three impact pathways, the main beneficiaries are the smallholder farmers in the region, which benefit from improved income opportunities. In the longer run, farmers in comparable regions of Africa may benefit, as well, from the knowledge generated by the project.

In the case of *Chile*, the project has already achieved substantial impact:

- The project's current and future impact centers around (i) the substantially enhanced information base and (ii) the capacity of regional and national level *government agencies*, built during the project, to make use of this information for water management, extension, regulation and related infrastructure development. Improved understanding of the complex system connections has been identified as a major step forward – project participants emphasized that concrete outcomes of such improved understanding may appear in unexpected ways and even in years to come in the context of their work requirements, Chilean water policy innovation and in future regional development projects.
- In addition, capacity building of the *water user organizations (JdV)* to apply the modeling software will allow significant improvements in their respective internal water management tasks; importantly, software application will also substantially enhance the capacity of the JdVs to pursue and defend their members' interests in the context of negotiations with powerful external actors as e.g. hydro-power interest groups in the case of the Ancoa Dam.
- Furthermore, modeling exercises were considered a very valuable 'space for discussion' between *members of different agencies and organizations*. Computer exercises served to build a common understanding of systemic properties among various actors. Members of the national level CNR noted that this common understanding helped boost horizontal and also cross-level inter-agency exchange and collaboration.
- Finally, the modeling software and training activities allow for a more differentiated consideration of water policies, water use and infrastructure: model applications powerfully illustrate consequences of *alternative policy and investment options*, thereby contributing to a more informed public debate and more careful water related decision making.

*What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.*

In the case of *Ghana*, some analyses are still ongoing, and the respective papers still have to be published. Moreover, since the project had most of its stakeholder interactions in the research region itself, substantial efforts are still necessary to disseminate research results at the national level. These strategies will be pursued under IFPRI's Ghana Strategy Support Program (GSSP), which has secured funding, a long-term commitment to support policy-making through research, and excellent networks with policy-makers at the national level. Informed by the results of this project, GSSP has already included irrigation development into its current work plan.

In the case of *Chile*, maintaining the database/software for practical use and more end-user training is required in order to make the projects achievements sustainable. Accordingly, INIA has formed a national consortium and applied for funding for a follow-up project; Hohenheim scientists will support this new project through consultancy services (final decision regarding approval of funding from INNOVA Chile is expected for fall 2009).

*Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors. Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?) Why were they unexpected? How was the project able to take advantage of them?*

For the case of *Ghana*, the third impact pathway was unexpected, since it was only discovered during the research process that a considerable number of the small reservoirs, including of the recently constructed ones, were not used for irrigation. The project was able to take advantage of this impact pathway by securing additional funding to conduct a stocktaking survey and additional in-depth research on the governance challenges of constructing small reservoirs.

Fortunately, the project in *Chile* could gain the interest and support of INIA who is now hosting and maintaining the MP-MAS software and database (first impact pathway). This was unexpected because INIA was not part of the original project set-up; the two Chilean scientists responsible for the GIS and hydrology modeling components left the project on very short notice. Thanks to additional funding from Hohenheim, one key scientist from INIA stayed with the Hohenheim group in Germany for one year and started a doctoral studies project using the software developed in this project. Without INIA the project would have faced severe problems in completing its activities and especially in linking up with actors in the second and fourth pathway.

Even though the Net-Map tool is not in itself an impact pathway, it is worth noting that the development of this tool was partly unexpected as well, since it was not foreseen in the project proposal. The team, however, took into account that Eva Schiffer had developed a predecessor tool of Net-Map when hiring her as Post-Doc for the project.

*What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?*

Prior to the project, prototype versions of the MP-MAS model already existed and the team was familiar with both research regions. However, the project team underestimated the efforts in terms of time and resources that were required to get the MP-MAS software to a stage where it could be used for simulation with stakeholders, especially since datasets from project counterparts turned out to be far less accurate than expected. Hence, a longer project period would have been beneficial to fully implement all steps of the collaborative research and learning framework in both countries.

Moreover, substantial amounts of funding for data compilation, data management and launch of website had to be covered by co-funding from Hohenheim University. The team should also have been more risk-averse in the project proposal and not have built on the optimistic assumption of being able to share key data and modeling tasks with others. As the expected close cooperation with GLOWA Volta and IFU-IMK could not be realized due to change in staff, the hydrology component of the project was particularly under-resourced.

The project did not experience challenges regarding stakeholder involvement, since a close interaction with stakeholders and policy-makers from project inception onwards was an integral part of the project. In the case of Ghana, the project could have placed more emphasis in interacting from the beginning not only with regional stakeholders, but also with national stakeholders, and especially with the donor community.

## **7 INTERNATIONAL PUBLIC GOODS**

### **7.1 Multi-agent modeling (MP-MAS)**

Agent-based simulation models have shown much promise for stakeholder interaction in natural resource management, especially in combination with role-playing games and other qualitative research approaches. But no practical experience existed so far with using agent-based simulation as a “quantitative” interactive tool, and this project is the first that coupled cutting-edge simulation software such as MP-MAS (agent-based model) and WASIM-ETH (process-based hydrology model). The project has therefore achieved a breakthrough in using agent-based simulation as part of Policy Relevant Monitoring Systems (PRMS, see Hazell et al., 2001) that are informative, intelligent and interactive.

MP-MAS is a freeware software developed by Thomas Berger and his team in Hohenheim and can be downloaded from <http://mp-mas.uni-hohenheim.de/>. Both Windows and Unix versions are available. MP-MAS has been applied in integrative research projects in the following countries:

- Germany
- Uganda
- Ghana
- Chile
- Thailand
- Vietnam

### **7.2 Influence network mapping (Net-Map)**

The development of the Net-Map method also yielded impact far beyond the scale of one research project. It can basically be used to better understand any situation where multiple actors with formal and informal networks follow common or conflicting goals. Net-Map has a number of characteristics that make it especially user-friendly and that have contributed to a wide spreading of the tool. Net-Map is

- Easy to learn and apply;
- appeals to the researcher and implementer;
- allows for quantitative and qualitative analysis, and
- focuses on questions that are of general concern as people attempt to achieve goals in social settings.

Eva Schiffer has also undertaken special efforts to publicize the tool beyond the traditional research channels. She publicizes Net-Map through her weblog (<http://netmap.wordpress.com>). Since its launch in November 2007, there have been almost 25,000 visits to the Net-Map weblog. The blog serves as knowledge hub with manual, slide shows, introductory pod-cast and video, numerous case studies and regularly up-dated discussions.

So far, the team is aware of at least 25 different projects and initiatives using Net-Map in Africa, Europe and Asia, including projects involving the World Bank, FAO, IFAD, Red Cross, IFPRI, Inter-American Development Bank, ICARDA, African Peer Review Program, InWent, ILRI and various universities in the developed and developing world. The method development was inspired by a CPWF workshop on PIPA and the critical innovations of Net-Map (especially the influence towers) were integrated in the PIPA approach. Appendix D provides a list of initiatives that use Net-Map.

## **8 PARTNERSHIP ACHIEVEMENTS**

### **8.1 Ghana**

- *White Volta Basin Board*: The project developed a particularly close relationship with the Basin Board, which proved to be mutually beneficial in many ways. The Basin Board was an important host institution for the project, facilitating its access to the region and to the stakeholders involved. At the same time, the Basin Board benefitted from the research feed-back provided by the project and the application of Net-Map, as has been explained above.
- *Ministry of Food and Agriculture (MoFA)*: A close collaboration was established with the regional office of the MoFA, which played an essential role for the development of the scenarios to be modeled. Through this intensive interaction, policy planning by MoFA could directly benefit from the insights of the modeling approach.
- *National research institutes*: The project played an important role in strengthening existing partnerships with national research institutes, especially ISSER and WRI. IFPRI has already realized an important follow-up project with ISSER, which involved substantial data collection. The project built upon the achievements of the Challenge Program project.
- *International research community*: Participation in the Challenge Program has also led to a more intensive exchange of ideas with other researchers. The projects in the Volta basin varied greatly from each other in terms of thematic and regional focus, so there were some with which we had a greater overlap and exchange than others, especially beneficial were the interactions with the Small Reservoirs Project and the Cross Boundary Water Governance Project (including mutual logistical support and combined research feedback to stakeholders). The Akosombo Workshop, which was the first one to bring all projects together, introduced applied a network mapping approach, which was a crucial inspiration for the development of the Net-Map tool,

one of the unexpected high impact results of the project. Exchange with fellow Challenge Program researchers was especially valuable for those colleagues who were located further away from the centers of international research and generally had less chances for exchange with fellow researchers.

## 8.2 Chile

In Chile, the major partnership achievements are the following:

- *Instituto de Investigaciones Agropecuarias (INIA)*: The national agricultural research institute (INIA) became interested and involved in model development during the course of the project. INIA staff joined the Hohenheim group for almost one year for training and finally completed a doctoral studies project about hydrology modeling. INIA is now hosting the agent-based model developed here and maintains the model database after project completion. Recently, INIA has formed a Chilean consortium for computer-based decision support and applied for funding for a follow-up project on agent-based modeling.
- *National Irrigation Commission (CNR)*: CNR expressed that it can make effective use of the model for approximating impacts of their various policy options in the region. Impact assessments could be made much more spatially explicit as compared to previous expert judgment – the model’s validity became convincingly clear in an ex-post analysis of impacts of the reformed irrigation law. After completion of the project, CNR has approached INIA to form a consortium to fine-tune the models developed here for assessment of its irrigation policy programs.
- *INDAP*: Interviews with INDAP, the national extension service for small-holder agriculture, revealed that the project had significantly enhanced INDAP’s overall understanding of the functioning of the region’s landuse related hydrology, embedded in the wider social-ecological system. INDAP felt this had improved their consulting capacity, even without having completed the training for use of the software developed here.
- *Juntas de Vigilancia*: Members of two JdV (out of four in the study area) emphasized that modeling results corresponded specifically to their information needs. Specific software has been requested from the project team in order to improve the operational curve of reservoirs run by the technical staff. The project’s training course enabled two JdV to apply the modeling software and to calculate shadow prices for irrigation water. This allows the JdV to assess current irrigation efficiency and to localize and qualify additional water demand in their areas – indispensable for decisions on infrastructure maintenance and enlargement.
- *Water Users and their Associations*: The reception of the project has always been warm, probably owing to a sequence of previous research projects in the region. Water users approached the project team to assist in organizing a regional irrigation organization intended to better represent their particular water use interests at national level. While this regional level organization has not yet materialized due to internal conflicts of interests, water users not directly involved in model training have continued to observe the project activities closely. Farmer representatives congratulated the project team for its achievements during the final plenary session of the project conference in December 2008 and expressed their openness for continuing computer-based analysis and decision support.

## 9 RECOMMENDATIONS

This section presents major recommendations for research and policy for Ghana and Chile, followed by a set of recommendations that can be derived from the comparison of the two countries.

### 9.1 Ghana

#### 9.1.1 Recommendations for policy

##### Expansion of irrigation

The project findings clearly indicate that the expansion of irrigation is key to poverty reduction in the semi-arid parts of the country. As indicated above, the model results show that the returns to other investments in improving productivity, especially the promotion of fertilizer use, is most effective if households have access to irrigation.

The option of pumping water directly out of the river proved not to be financially attractive. In view of the governance challenges of making small reservoirs work, it also seems appropriate to reconsider the balance of investing in small versus large reservoirs. The findings suggest that “small is not always beautiful,” but further economic studies have to be conducted to compare the two options (which was not the focus of this study). The governance challenges of constructing and managing small-scale versus large-scale facilities should explicitly be taken into account when making policy decisions on these investment options.

The project did not specifically examine into the use of groundwater for irrigation purposes, as hydrological studies on this topic were still underway at the time when this project was implemented. This option is considered by the Water Resources Commission. Observations made during stakeholder interactions indicate that a careful analysis of groundwater availability needs to precede any development in this respect, especially because of a potential competition with drinking water supply. Large-scale commercial companies are very interested in using groundwater, whereas NGOs seem highly critical of considering this option even for smallholders. It would be desirable to avoid a situation where—in case that this using groundwater for irrigation indeed proves environmentally viable—large-scale companies get access to this option whereas smallholders are deprived of it.

##### Use existing infrastructure more effectively

The findings of the project also suggest that efforts should be undertaken to use the already existing irrigation infrastructure—both large-scale and small-scale—more effectively. It might be useful to learn from other cases, such as the Office du Niger irrigation project in Mali, which benefitted considerably from giving farmers private rights to land. Similarly, in case of small-scale reservoirs, it might be interesting to learn from Burkina Faso, where these reservoirs seem to work much better. In any case, donor agencies need to resolve the governance problems of constructing and managing small reservoirs before investing in new ones. As discussed above, potential strategies include strengthening the role of water user associations vis-à-vis the contractors; increasing the publicity about problems in infrastructure construction by involving the local press; strengthening the role of the District Assembly Members vis-à-vis the irrigation bureaucracy; involving NGOs to mobilize communities; increase monitoring by central in addition to than local agencies; and train contractors to improve their technical capacity in small reservoir construction and foster competition among them. Some donor agencies could also be more rigorous in using their own monitoring and evaluation systems to detect problems before investing in new reservoirs.

### *Expand access to credit*

The simulation results clearly indicate that improving access to agricultural credit plays a key role in improving farm incomes. Yet, one has to take into account that there have been numerous efforts to improve access to credit in the research region, including approaches that involve farmer-based organizations and rely on group liability. These approaches have not proved sustainable, partly due to well-known problems of low pay-back rates and political interference. However, anecdotal experience during the research period indicated that expectations of higher prices—which happened when a tomato factory declared it would start operations in the Upper East region—can lead to a considerable supply-response without any particular credit program. (Ultimately, the factory did not start its operations as planned, which led to a price collapse and considerable losses on part of the farmers). This case indicates that credit constraints may be a symptom of underlying problems, especially low profitability of current production and marketing systems. Using a value chain perspective might be useful, which aims not only at providing credit, but at the same time addressing all steps of the value chain, from seed supply to agro-processing, to increase the profitability of agricultural enterprises. In view of the pervasive role that risk plays in the research area, it might also be useful to experiment with weather-based insurance systems to remove one of the important constraints that cause market failure in credit supply.

### *9.1.2 Recommendations for research*

#### *Expand capacity for economic analysis*

The project experience indicates that the research region would benefit from a strengthening of the capacity to conduct economic analysis of farm enterprise development. Even the use of comparatively simple tools, such as gross margin analysis, would help decision-makers to better distinguish viable from non-viable options to increase agricultural incomes. Strengthening the collaboration between the Ministry of Food and Agriculture and the universities would be useful, for example, by involving more B.Sc. and M.Sc. students in analyzing development options in the rather neglected northern part of the country.

#### *Identify host for agent-based model*

Unlike in the case of Chile, it was not possible during the duration of this project to identify a host institution for the MP-MAS model and database. Yet, it became clear that the use of the model could play an important role in providing evidence-based information that could feed into the integrated water resources management planning activities that the Water Resources Commission is responsible for. Likewise, the model could be used to inform donor agencies about different investment options in irrigation and agriculture. Considering the increasing interest of donor agencies and the government to invest in the Northern part of the country, such information is urgently needed. For example, under the Northern Rural Growth Program alone it is planned to invest more than US\$ 100 Million in the Northern part of the country. The capacity to simulate alternative investment options for such large amounts of funds could result in considerable pay-offs. Hence, it would be useful to identify an institution with the technical capacity to run and maintain the MP-MAS model and database. Donor agencies may also be willing to invest in improving the technical capacity of the host institution in operating MP-MAS.

#### *Factors that influence the profitability of irrigation*

The project also suggests that it would be useful to carry out additional research on factors that influence the profitability of different irrigation investments. These factors include the role of risk, distinguishing production and market risk; the role of farmer-based organizations; and the role of alternative strategies for market development. The case of the tomato factory mentioned above might serve as an interesting case study

about the opportunities and challenges of market development in the region, and its implications for credit availability.

## **9.2 Chile**

### *9.2.1 Recommendations for policy*

#### *Continue irrigation support but strengthen local capacity*

Simulation results indicate that government support for irrigation development contributed to achieving higher incomes and higher levels of water-use efficiency at the farm level and can do so in future policy programs as a “second-best solution”. But simulation results also showed that the government needs to pay more attention to reaching smallholder farmers when reforming public programs for small and large-scale irrigation investments. Smallholders with insufficient water rights who benefit from unused water resources and spill-overs in the system may not only fail to benefit, but even lose income sources as a consequence of irrigation investments, thus underlining the needs to identify income-generating alternatives for them. Especially for large-scale investments, project findings point to the importance of strengthening the technical capacity of water user associations and of supporting their capability for collective action. In the absence of well-functioning physical infrastructure at the lowest levels of the water distribution system, building institutional infrastructure through collective action remains one key point for reaching both higher productivity and fairness in water allocation. It is encouraging that CNR has recently set up a pilot study in the research area in order to increase local capacity and collective action of low level user associations within the Ancoa dam project.

#### *Continue improving policy planning and evaluation*

In Chile, the application of advanced computer models helped the water user associations and the irrigation administration better understand how the benefits from investing in the small and large-scale infrastructure will be distributed among stakeholders. During the last decades, project planning has been largely out-sourced to private consultants with the consequence that data and methods used for evaluation have been kept in private property. Interviews with public sector officials, however, revealed that more in-house capacity should be built up to enhance the planning and evaluation of government programs. Higher in-house capacity will allow better supervision of consultancy studies and improve model documentation and data management. Officials expressed their interest in extending the policy evaluation criteria by more economic and social indicators, such as distribution of benefits among farmers, risk assessments, and likely occurrences of social hardships. In order to achieve a broader and more balanced assessment of policy programs, we recommend establishing science-policy networks that go beyond the current irrigation engineering focus and include socio-economic nodes as well. Since collective action and innovation at the lowest levels of the water distribution system play an important role, stakeholders of these levels should be much stronger involved in planning and evaluation procedures. For testing these new procedures with better stakeholder involvement, we suggest more pilot studies with “knowledge broker” arrangements, in which scientists, engineers, stakeholders and government officials may engage in collaborative learning using a computer-based platform.

#### *Implement regional adaptation plans for climate change*

In December 2008, the president of Chile announced the national adaptation plan to climate change that considers as action points for agriculture to increase the irrigation area and the storage capacity of reservoirs. Project findings clearly show that both action points require thoughtful implementation at the regional level, using a balanced planning and evaluation approach. Due to high levels of irrigation return flows in some regions, measures to increase the irrigation area typically imply that some water users receive

more and others less water than before. These “dry-water savings”, which are well known in the engineering literature but difficult to quantify in practice, have to be taken into account when designing policy interventions. The simulation models used in this project have the capacity to assess water savings at the catchment level, and we suggest using these and other computer-based tools for implementing regional adaptation measures to climate change. As the project has also shown, extending the storage capacity of reservoirs requires parallel efforts to strengthen the capacity for collective action and innovation at the lowest levels of the water distribution system. Otherwise, more water will not necessarily translate into higher productivity but rather into more conflicts and water misuse.

### *9.2.2 Recommendations for research*

#### *Build research consortium*

Our experience in this project was that, although many datasets have been collected in the water sector and many partial models have been applied, overall quality and consistency of data across organizations is rather poor. Improving both data management and model base can be best achieved within a larger water system research consortium. This new consortium could join forces to increase the technical capacity of actors involved and especially increase the capacity for “knowledge broker” arrangements that could foster the use of computer-based decision and planning tools. To achieve this, the consortium will have to fine-tune the software and tools available, develop new courses for training and extension, and maintain strategic links to regional stakeholders. The very recent initiative of INIA to build such a consortium with national funding is the first step in this direction. One important gap we noticed when using our computer tools with farmers is the lack of specific information and advice for farm management in the region. Essential inputs for the farming sector, such as standardized farm accountancy data, assessment of irrigation techniques, gross margin and market chain analyses are largely missing. We suggest considering the establishment of “business centers” as spin-offs from research organizations that could offer this information as consultancy services to the private and public sector. These centers should closely interact with the applied production-related research on irrigation, precision agriculture and fruit processing currently undertaken at the various national research organizations, for example INIA.

#### *Provide timely policy analysis*

The project was fortunate in terms of timing because it could address pressing policy issues such as the possible extension of the irrigation subsidy law and the construction of the Ancoa dam. Providing timely policy analysis, however, requires constant investment in the scientific basis of the modeling platform plus synchronization of the model development cycle with the agenda of policy planning and evaluation. This again can be best achieved by a larger water research consortium with tight communication links to the national and regional policy domains. We are confident that the recent initiative of INIA of building a national consortium in close collaboration with CNR will be a successful in this respect.

#### *Assess regional adaptation strategies*

Key informant interviews and discussions at the computer training workshops revealed that actors are concerned about climate change impacts but largely lack knowledge of meteorological trends and possible land use adaptation strategies. We clearly see here great demand for computer-based system studies, making an attempt to assess regional impacts and strategies regarding climate change. The following research topics should urgently be addressed in Chile: (1) assess climate change impacts at regional level by coupling land use models with land surface-atmosphere models; (2) evaluate other risks and uncertainties in agro-value chains as well as risks/uncertainties associated with ecosystem services; (3) explore the scope for collective action in water resources

management at the lowest levels of organization; (4) research the use and governance of groundwater resources and of water quality, both related to good agricultural practices and export agriculture; (5) explore mitigation strategies in agriculture and forestry such as carbon sequestration and bio-energy crops.

### 9.3 Recommendations derived from a comparative perspective

The project also allows for a set of recommendations that can be derived from the comparison between Chile and Ghana. In view of its market-oriented approach, Chile is widely considered as a model for other countries, and Ghana has in fact followed a “Chilean-type” approach, especially by creating the legal and institutional framework for assigning water rights and for devolving management authority to water user associations. Yet, as has been argued above, the Chilean model has important *other* lessons to offer, which have received less attention in the literature and policy debate (see Section 3.4):

- *Investment in technical expertise:* The Chilean case indicates that even though the public sector plays “only” a coordinating, facilitating and regulating role, investment in the technical expertise and the managerial capacity of the irrigation administration continues to play a critical role in achieving an effective management of water resources. The case also shows that a far-reaching devolution of management authority to water user associations requires investments in the professionalization of umbrella water user organizations to enable them to pursue their tasks effectively. The Chilean case shows that it is the water users themselves who need to make these investments so as to avoid “state capture” or bureaucratization of these third-sector organizations.
- *Role of collective action:* The Chilean case shows that even in a country with a very long history of irrigation and an advanced legal and institutional framework, the typical collective action problems of water user associations remain relevant. The research indicates that strategies to overcome these collective action problems, especially among organizations with heterogeneous membership, can have a substantial pay-off in terms of raising revenues for irrigation maintenance and increased farm incomes. The Chilean case also shows that even 20 years after the introduction of private tradable water rights, a substantial share of water users have still not registered their rights. Therefore, one needs to be careful not to overload water user organizations with new functions. For example, the recent legal change that made the Chilean water user associations responsible for groundwater management seems quite problematic in this respect.
- *Strategies to promote infrastructure development:* Chile presents a case where there is substantial state involvement in the financing irrigation infrastructure. On the positive side, the Chilean subsidy regime is based on strong incentives, which—together with a high state capacity—lead to high quality of infrastructure investment. On the negative side, the Chilean system has rather problematic distributional implications, and it does not seem to be very effective in stimulating investments that would not have occurred otherwise. Other countries may wish to learn from both the positive and the negative aspects of this system. A subsidy program that requires water user association to compete for a public grants also creates strong incentives for private sector irrigation consultants and firms (who prepare the proposals for the land owners) to develop technical expertise and capacity. However, to what extent such a system can be repeated in a weak public sector environment is an open question. The Chilean experience indicates that countries need to pay special attention to monitor and address negative distributional consequences of subsidy programs based on competitive grants. Reserving a share of the subsidies explicitly for small-scale farmers and assisting

them to use it is an appropriate avenue. Still, it took Chile more than a decade to increase the access of smallholder farmers to irrigation subsidies to 50%.

By comparing two river basins—one in a very early and one in a very advanced stage of river basin development—the project has shown that there are no “silver bullets” for managing water resources. Policy-makers and stakeholders are well advised to balance their efforts to invest in functioning markets, an effective and capable state, and vibrant smallholder organizations, when promoting water resources development. Last, but not least, the project shows that a continuous quest for better analytical tools remains an important task for international agricultural research in its mission to contribute to a more efficient, sustainable and equitable use of the world’s increasingly scarce water resources.

## **10 PUBLICATIONS**

### **10.1 Journal articles**

- Berger, T., and P. Schreinemachers. 2006. Creating agents and landscapes for multi-agent systems from random samples. *Ecology and Society* 11 (2), art. no. 19.
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Schiffer, Eva, Hartwich, Frank and Mario Mongue: Who has Influence in Multi-Stakeholder Governance Systems? Using Net-Map to Analyze Watershed Management in Northern Ghana; submitted April 2009

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**Appendix A: Abstracts of key publications****On integrated governance and modeling**

Berger, T., R. Birner, J. Díaz, N. McCarthy, H. Wittmer. 2007. Capturing the Complexity of Water Uses and Water Users within a Multi-Agent Framework. *Water Resources Management* 21: 129-148.

The management of water resources in an integrated and sustainable way is usually complex given that the scale of management implied by hydrological characteristics often subsumes many layers of social, political and economic institutions. Even at the sub-basin level, multiple users may include local small-scale farmers, large-scale commercial farmers, hydro-electric power companies, other industrial users, municipal water users, and those using water resources for leisure and/or tourism. Adding to the complexity of multiple water users are the various uses to which water resources are allocated, including irrigation, potable water, power generation, industrial production, environmental amenities, and recreation. Early attempts to capture this complexity by applying game-theoretic models have focused on identifying the single game structure most adequate to characterize a particular real world situation. But, including heterogeneity amongst users as well as different uses often means that any one problem might be characterized by a number of different game structures, depending on the value of parameters characterizing the players' payoff matrices. This means that empirical data is necessary to determine which payoff matrices obtain in practice, and the sensitivity of these matrices to changes in exogenous variables. Because outcomes from current water management decisions depend, at least in part, on individual incentives captured by the payoff matrices, policy interventions can be designed to change parameters that alter these payoff matrices. Also, understanding the impacts of different parameter values will aid us in understanding breakdowns in traditional management systems due to external changes, and to identify mechanisms for facilitating local-level institutional responses to such changes. A promising way of incorporating both the complexity of water uses and water users is to combine game-theoretic approaches with computer simulations. Recent advances in computing power and data availability make it now possible to build empirically parameterized models in which heterogeneous agents interact with each other and their environment (multi-agent systems). Using the example of water resource management in four micro-watersheds of the Maule River in Chile, we illustrate the type of policy-relevant information that can be generated. Our model represents different types of users with heterogeneous landholdings, exit opportunities, technologies, access to credit, and time preferences, and allows for interactions between the use of the common-pool resource and privately owned resources. Policy scenarios may include external assistance (transfer payments), changes in the number of players (population movement), land and water markets, and infrastructure development.

Yilma, T., E. Berg, and T. Berger. 2008. The agricultural technology-market linkage under Liberalisation in Ghana: Evidence from micro data. *Journal of African Economies*, 17 (1): 62-84.

Combinations of factors, including inappropriate economic policies, have contributed to the poor economic performance of sub-Saharan Africa (SSA). The impacts of some corrective policy measures, both on the macro economy and on the rural economy, are not very clear because they have led to unintended consequences, such as increasing poverty and inequality. This paper examines the effect of the removal of subsidized agricultural credit for irrigation farmers in Ghana, a country of pioneering reforms in SSA. A theoretical model of this scenario is constructed, in which it is shown that under multiple-market imperfections farmers resort to alternative income sources to finance irrigation. Particularly in the presence of off-farm alternatives, multiple-market

imperfections can induce both on-and off-farm income generating activities during the same season. This model is subsequently tested and validated with household data collected from northern Ghana. The empirical analysis shows that there is a strong complementarity between irrigation farming and off-farm employment, two activities that depend heavily on labor endowment. The observed complementarity suggests that in weak credit markets irrigation farmers generate liquidity from off-farm activities, which could lead to a demand for larger family size in the long run.

### **On MP-MAS**

Berger, T., and P. Schreinemachers. 2006. Creating agents and landscapes for multi-agent systems from random samples. *Ecology and Society* 11 (2), art. no. 19.

An important goal of modeling human-environment interactions is to provide scientific information to policymakers and stakeholders in order to better support their planning and decision-making processes. Modern technologies in the fields of GIS and data processing, together with an increasing amount of accessible information, have the potential to meet the varying information needs of policymakers and stakeholders. Multi-agent modeling holds the promise of providing an enhanced collaborative framework in which planners, modelers, and stakeholders may learn and interact. The fulfillment of this promise, however, depends on the empirical parameterization of multi-agent models. Although multi-agent models have been widely applied in experimental and hypothetical settings, only few studies have strong linkages to empirical data and the literature on methods of empirical parameterization is still limited. This paper presents a straightforward approach to parameterize multi-agent models in applied development research. The parameterization employs a common sampling frame to randomly select observation units for both biophysical measurements and socioeconomic surveys. The biophysical measurements (here: soil properties) are then extrapolated over the landscape using multiple regressions and a digital elevation model. The socioeconomic surveys are used to estimate probability functions for key characteristics of human actors, which are then assigned to the model agents with Monte-Carlo techniques. This approach generates a landscape and agent populations that are robust and statistically consistent with empirical observations.

Schreinemachers, P., and T. Berger. 2006. Land-use decisions in developing countries and their representation in multi-agent systems. *Journal of Land Use Science* 1: 29–44.

Recent research on land-use/cover change (LUCC) has put more emphasis on the importance of understanding the decision-making of human actors, especially in developing countries. The quest is now for a new generation of LUCC models with a decision-making component. This paper deals with the question of how to realistically represent decision-making in land use models. Two main agent decision architectures are compared. Heuristic agents take sequential decisions following a pre-defined decision tree, while optimizing agents take simultaneous decisions by solving a mathematical programming model. Optimizing behavior is often discarded as being unrealistic. Yet the paper shows that optimizing agents do have important advantages for empirical land-use modeling and that multi-agent systems (MAS) offer an ideal framework for using the strengths of both agent decision architectures. The use of optimization models is advanced with a novel three-stage decision model of investment, production, and consumption to represent uncertainty in models of land-use decision-making.

Robinson, D., D. Brown, D. Parker, et al. 2007. Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science* 2: 31–55.

The use of agent-based models (ABMs) for investigating land-use science questions has been increasing dramatically over the last decade. Modelers have moved from 'proofs of existence' toy models to case-specific, multi-scaled, multi-actor, and data-intensive models of land-use and land-cover change. An international workshop, titled 'Multi-Agent Modeling and Collaborative Planning—Method2Method Workshop', was held in Bonn in 2005 in order to bring together researchers using different data collection approaches to informing agent-based models. Participants identified a typology of five approaches to empirically inform ABMs for land use science: sample surveys, participant observation, field and laboratory experiments, companion modeling, and GIS and remotely sensed data. This paper reviews these five approaches to informing ABMs, provides a corresponding case study describing the model usage of these approaches, the types of data each approach produces, the types of questions those data can answer, and an evaluation of the strengths and weaknesses of those data for use in an ABM.

### On WASIM-ETH

Uribe, H., T. Arnold, J. Arumí, T. Berger, and D. Rivera. 2009. Modificación del modelo WaSiM-ETH para mejorar su aplicación en áreas regadas. *Ingeniería Hidráulica en México*, vol. XXIV (2): 23-36.

Los modelos distribuidos físicamente basados, han sido ampliamente usados para el análisis hidrológico; sin embargo, sólo algunos incorporan el riego en el balance hídrico. El modelo "Water Balance Simulation Model (WaSiM-ETH)" incluye módulos de riego, evapotranspiración (ET) y distribución de agua, lo que permite su uso en cuencas con riego. Sin embargo, su aplicabilidad puede ser limitada por la carencia de datos para emplear la ecuación de Penman-Monteith (P-M). Para superar este inconveniente, los autores modificaron WaSiM-ETH, agregando el módulo "reference\_crop" que estima la evapotranspiración potencial (ETP) a partir de la ET de un cultivo de referencia (ET<sub>ref</sub>) y de los coeficientes de cultivo (K<sub>c</sub>). El modelo WaSiM-ETH modificado fue calibrado y validado para el Sistema de Riego Linares (SRL), en la Zona Central de Chile. Los módulos "reference\_crop" y de riego fueron evaluados verificando su correcto funcionamiento. Los resultados indicaron que WaSiM-ETH modificado incorporó correctamente el consumo de agua y el riego de diferentes cultivos en la simulación hidrológica. En cuencas grandes el modelo funcionó correctamente, mientras en cuencas pequeñas, donde los trasvases de agua de riego pueden ser incluso mayores que el caudal natural, el modelo presentó problemas debido a la carencia de información de flujo en canales y porque la distribución de los recursos hídricos no ocurre exactamente conforme a los derechos de agua, condición supuesta para la modelación. Los resultados permitieron concluir que es posible aplicar el modelo WaSiM-ETH modificado en cuencas regadas, constituyendo una herramienta para simular escenarios útiles para la toma de decisiones.

### On Net-Map

Schiffer, E., and J. Peakes. 2009. An innovative approach to building stronger coalitions: the Net-Map Toolbox. *Development in Practice*, Volume 19 Issue: 103.

A common challenge faces development organizations, from the highest policy-making circles to local, grassroots organizations: how to work with other groups to build stronger partnerships and achieve consensus on goals? This article describes the Net-Map Toolbox, a new tool which builds and expands upon existing social-networking approaches. The article highlights the experience of using the Toolbox with the White Volta Basin Board in Ghana, a multi-stakeholder organization responsible for overseeing

local water resources. The authors discuss how the Net-Map Toolbox can assist members of development-oriented organizations to better understand and interact with each other in situations where many different actors can influence the outcome.

Schiffer, Eva, Hartwich, Frank and Mario Mongue: Who has Influence in Multi-Stakeholder Governance Systems? Using Net-Map to Analyze Watershed Management in Northern Ghana; submitted as IFPRI Discussion Paper, April 2009

Multi-stakeholder governance structures, such as management boards involving members of the public sector, civil society and the private sector, have emerged as an important approach in development. They are used in various fields, ranging from the management of natural resources to the provision of public services. To make such governance structures work, it is essential to gain a better understanding of the influence that different stakeholders have and the factors that determine their influence. This paper uses Net-Map, an innovative participatory method, to analyze how formal and informal networks influence multi-stakeholder governance, using the case of the White Volta River Basin Board in Northern Ghana as an example. The Net-Map method makes it possible to visualize both the network relations between actor as well as the perceived influence of various actors on development outcomes. In this study, Net-Map was applied to representatives of the member organizations of a multi-stakeholder governance board of the White Volta River Basin. The interviewees first mapped the type and strength of relationships they maintain with other stakeholders with respect to information exchange, command relations, funding and advice. In a second step, the interviewees rated the influence that specific stakeholders have in decision making and on the achievement of development and resource management goals. Based on the network maps, social network indicators were constructed, and the relationship between these indicators and the perceived influence of different actors was analyzed using different regression techniques. The study suggests that significant effects of social networking at play beyond the formal lines of command and funding, as stakeholders in watershed-management make decisions. Stakeholders are seen as more influential if they participate more prominently in information exchange and provide more advice to others. The findings suggest that there are relevant network effects that determine the influence stakeholders have in water-resource-management decisions. The findings indicate that program leaders, analysts and policy makers in watershed management may need to take these informal networks into account more prominently as they influence decision making processes and the attainment of development and resource-management goals.

### **On governance structures**

McCarthy, N. and Y. Sun. 2009. Participation by Men and Women in Off-Farm Activities - An Empirical Analysis in Rural Northern Ghana. IFPRI Discussion Paper 852.

Using survey data from the Upper East region of Ghana collected in 2005, the paper evaluates the household- and community-level factors influencing women's and men's decisions to participate in off-farm activities, either in the off-farm labor market or in local community groups, and the relationship with on-farm crop returns. Results indicate that crop returns are not affected by increased labor availability over a certain labor-land ratio. Female participation in off-farm labor markets increases at higher levels of labor availability, but participation in women's groups' only increases as labor scarcity is relaxed at lower levels. Alternatively, male participation in off-farm work increases over all levels of labor availability. Results also indicate that male labor is relatively more productive on-farm versus off-farm than female labor, and, though education increases the likelihood that both women and men will work off-farm (with no impact on crop revenues), the impact is greater for women. Finally, participation in off-farm work does not appear to be driven by the need to reduce exposure to risk or to manage risk ex post; wealthier households located in wealthier communities are more likely to

participate in off-farm work. Evidence for participation in groups and risk is more complicated; wealthier households in wealthier communities are also more likely to participate, but so too are female-headed households with higher dependency ratios.

McCarthy, Nancy and Tim Essam: Impact of Water User Associations on Agricultural Productivity in Chile; submitted as IFPRI Discussion Paper, November 2008.

This paper uses combined household and community level data, collected from the Maule Region (VII) of Chile, to evaluate factors affecting the decision to participate in yearly irrigation maintenance activities, and the influence of current behavior on farm revenues. Empirical results suggest that water user association characteristics explain much of the variation in participation decisions, contribution amounts, variable input purchases, and subsequent farm revenues.

**Appendix B: Glossary of terms**

**Governance** is "... the exercise of economic, political, and administrative authority to manage a country's affairs at all levels. It comprises mechanisms, processes, and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations, and mediate their differences" (UNDP, 1997).

**Institutions** are the humanly devised constraints that structure human interaction. They are made up of formal constraints (rules, laws, constitutions), informal constraints (norms of behavior, conventions and self-imposed codes of conduct), and their enforcement characteristics (North, 1990, 1991).

**Organizations** are characterized by membership and roles assigned to the members. Like institutions, organizations may be formal or customary. Water user organizations are an example.

**Sectors:** For the analysis of governance structures, it is useful to distinguish three sectors: the public sector, the private sector, and a "third sector." The latter sector can also be referred to as a collective action sector, and it includes different types of organizations in civil society (see Table A-1 in Appendix C).

**Levels:** According to the political-administrative system, one can consider the following levels: the level of individuals, followed by the household and firm level, the community level, different tiers of local government, the regional level, the national level, and the international level. These levels intersect with the levels one can define according to water use and water management criteria: the level of the individual water users, the household level, the community of individuals or households using a joint infrastructure – or subsystem thereof - for drinking water or irrigation, sub-basins of rivers and finally river basins, which may also be internationally shared.

**Stakeholders** are all individuals and organizations that have an interest – or a stake – in the use and management of water resources.

**Actors** are all persons and organizations who are involved in the management of water resources.

**Agents** represent actors in simulation models, i.e. they are computer code that mimics the actual behavior, especially the decision-making process, of persons and organizations. In our agent-based model, agents typically represent farm-households (resource users) and water user organizations (infrastructure providers).

**Appendix C: Additional figures and tables**

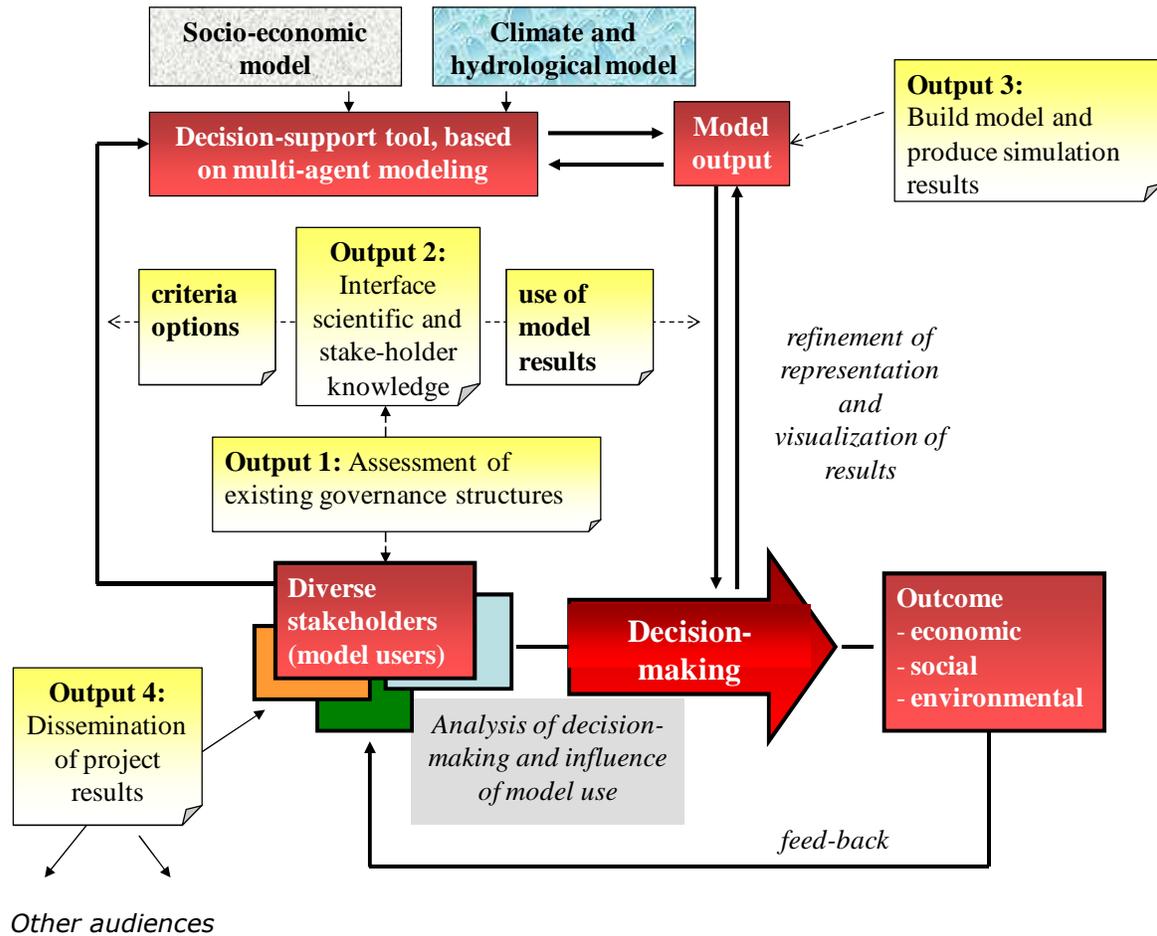


Figure A - 1: Concept diagram of the project

Source: Authors

Table A - 1: Types of Organizations in the Public, Private and Third Sector

Public sector		Third (Collective action sector)			Private sector	
		Grassroots Organizations		NGOs		
Government	Public administration	Membership organizations	Co-operatives	Service organizations	Private businesses	Farm households
<i>Orientation of organizations</i>						
political	bureaucratic	self-help (common interests)	self-help (resource pooling)	charitable (non-profit)	profit making	Family support (social and economic)
<i>Goals and Interests</i>						
Public interest Reelection	Public interest Department expansion	Multiple goals (profit and non-profit)	Service to members	Public interest NGO expansion	Private interest Corporate social responsibility?	Multiple goals (profit and non-profit)
<i>Accountability</i>						
Voters and constituents Lobby groups	Policy-makers (Lobby groups)	Members	Members	Donors/ Employees	Shareholders Customers/ Employees/ Stakeholders?	Family household members
Downwards	Upwards/ within	Downwards	Downwards	Downwards/ within	Downwards/ Within (upwards)	Downwards/ within
<i>Examples from Irrigation Management</i>						
Minister of Agriculture	Irrigation bureaucracy	Water User Associations (WUAs)	Farmer's cooperatives	NGOs that support WUAs	Contractors for irrigation infrastructure	Households using irrigation

Source: Modified from Uphoff (1993:613) with input from Ruth Meinen-Dick and Kai Wegerich

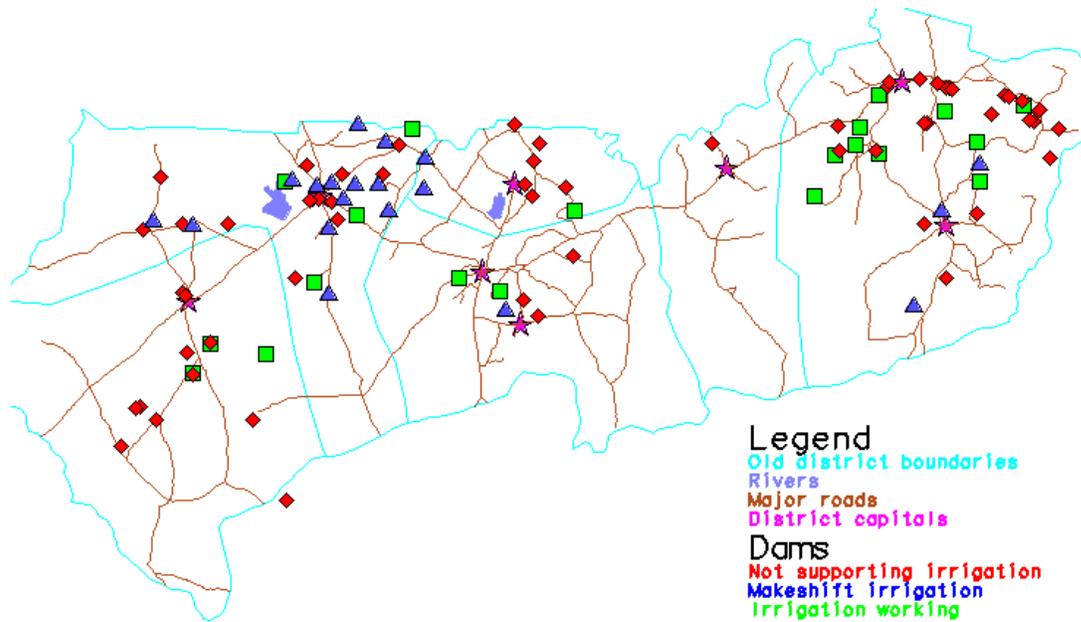


Figure A - 2: Small reservoirs in the Upper East Region covered in the survey

Source: Authors

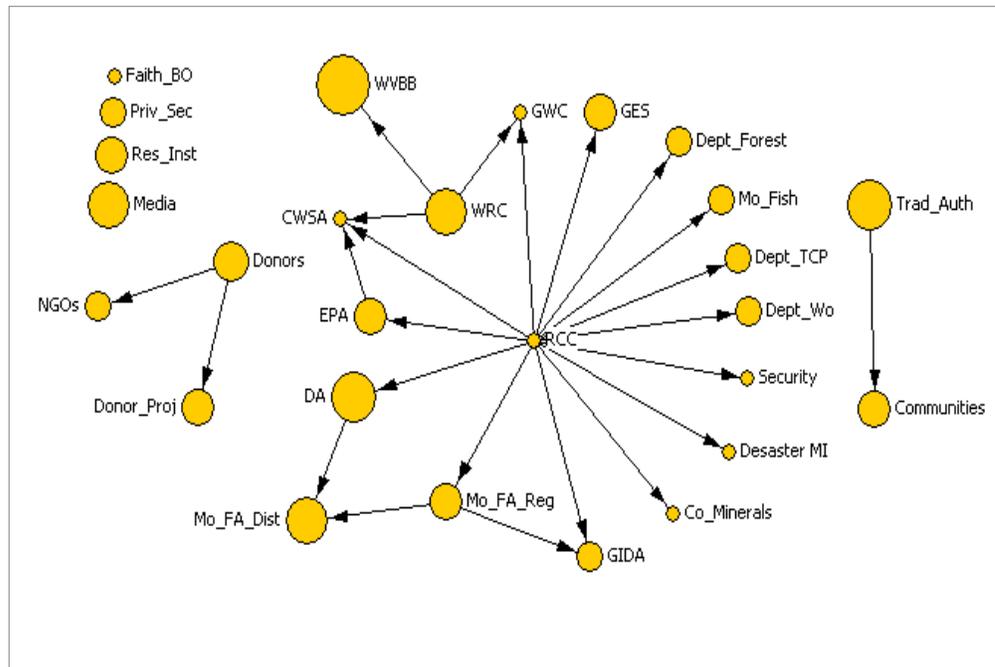


Figure A - 3: Command network influencing the achievement of the basin board's goals

Source: Authors

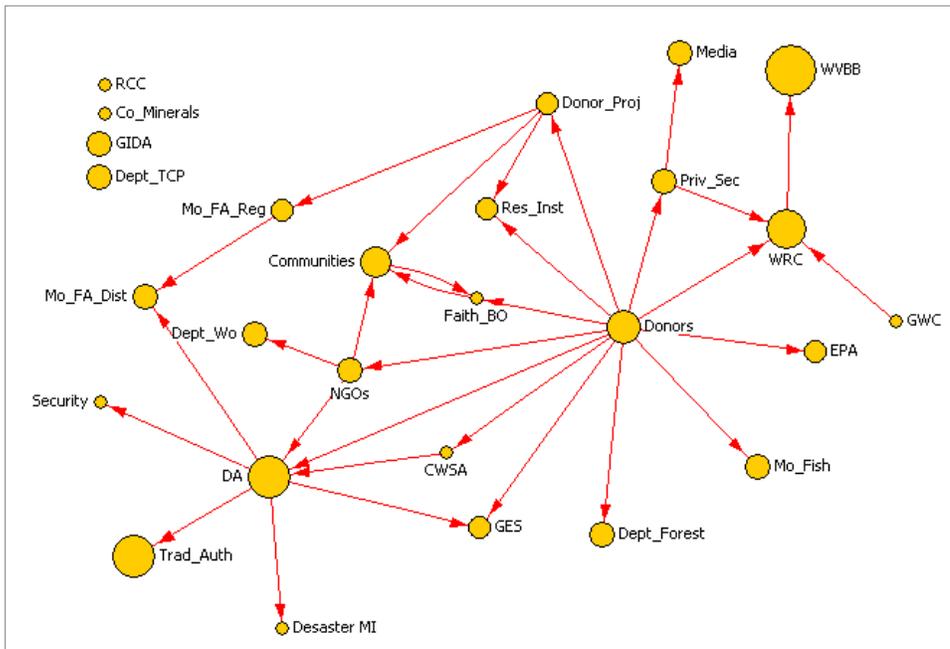


Figure A - 4: Funding network influencing the achievement of the basin board's goals

Source: Authors

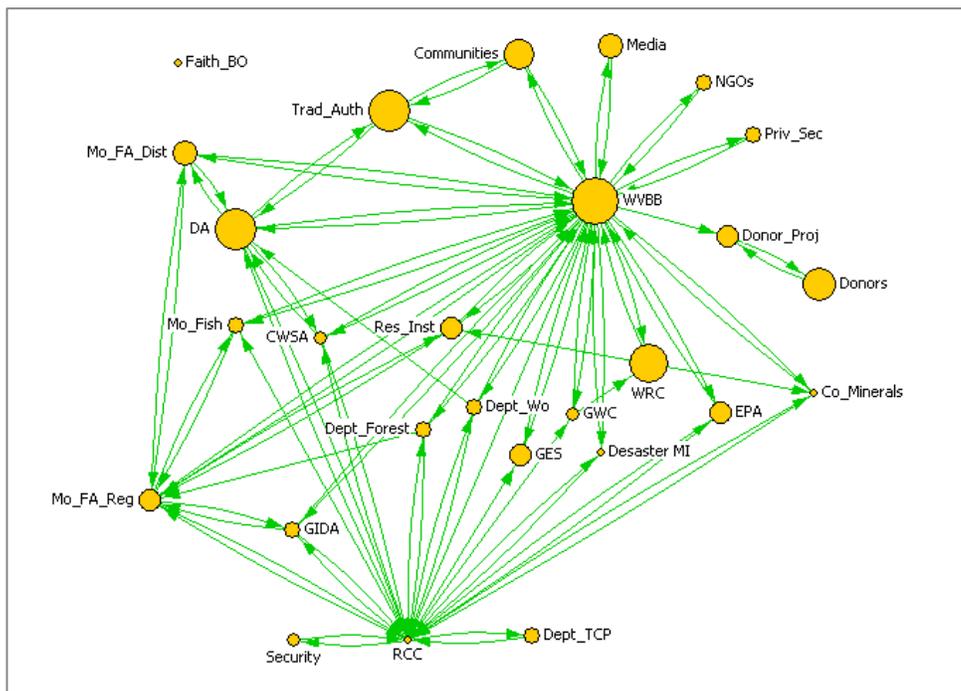


Figure A - 5: Advice network influencing the achievement of the basin board's goals

Source: Authors

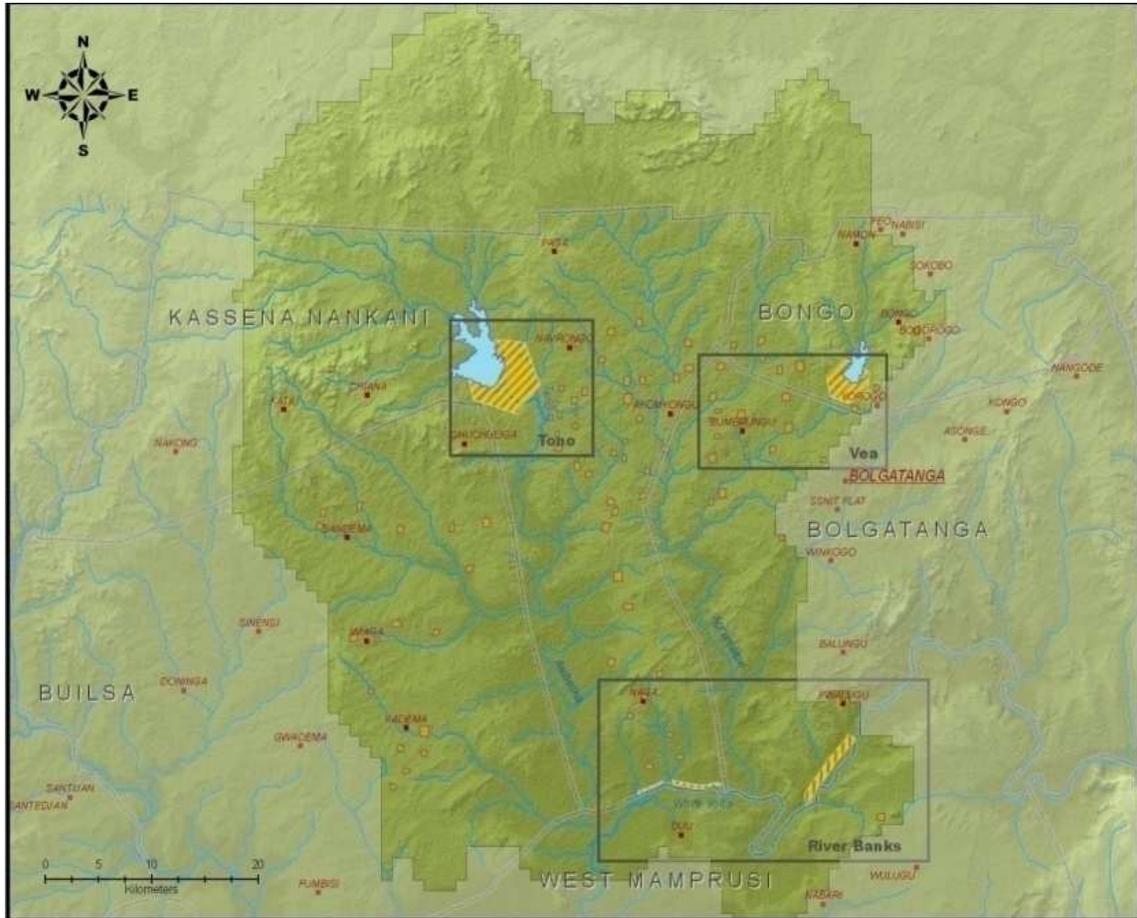


Figure A - 6: Atankwidi+ catchment in the White Volta basin of Ghana

Source: Authors

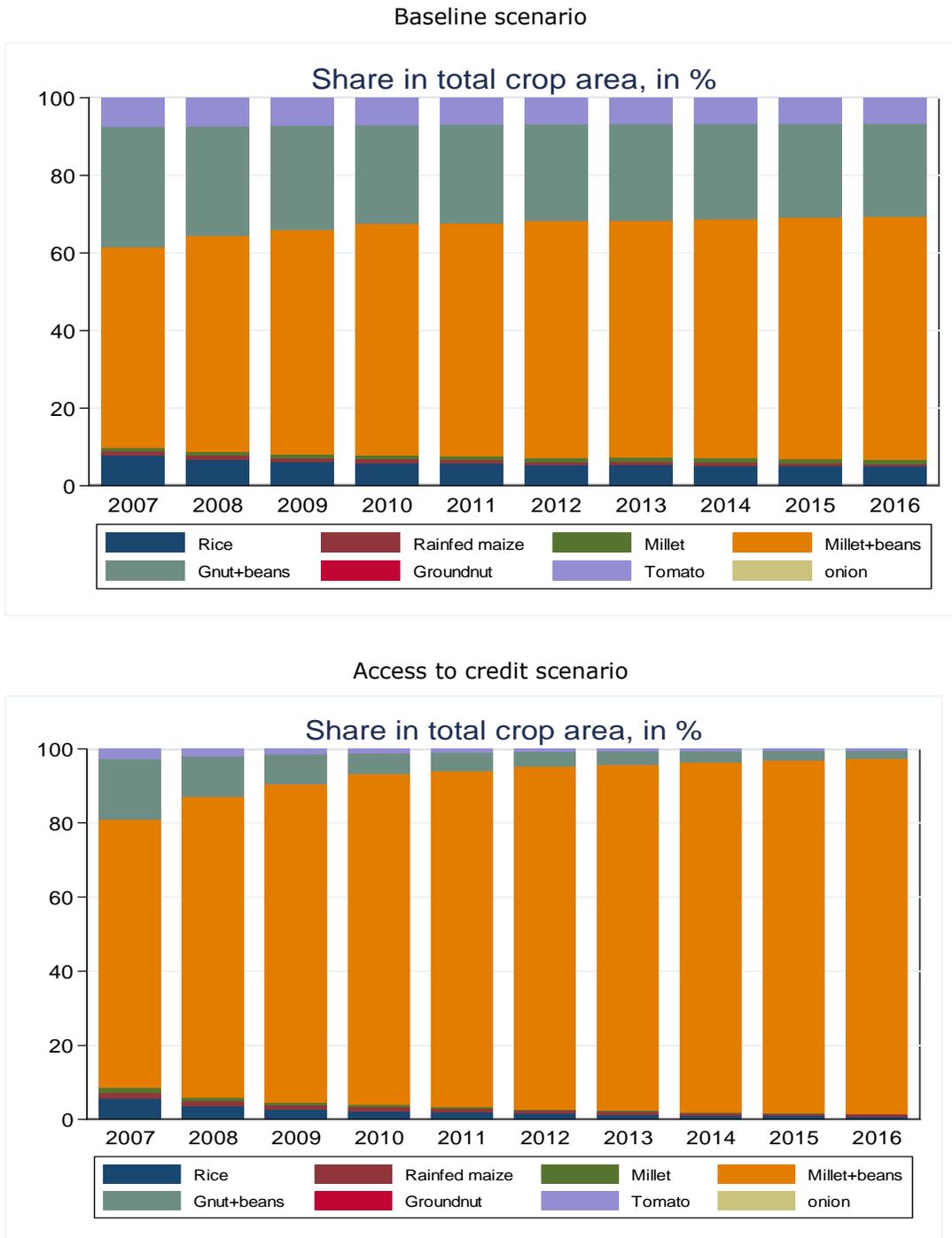


Figure A - 7: Simulated land use pattern in credit scenario

Source: Authors

**CDF Study Region Shadow Price at Various Water Allocations**

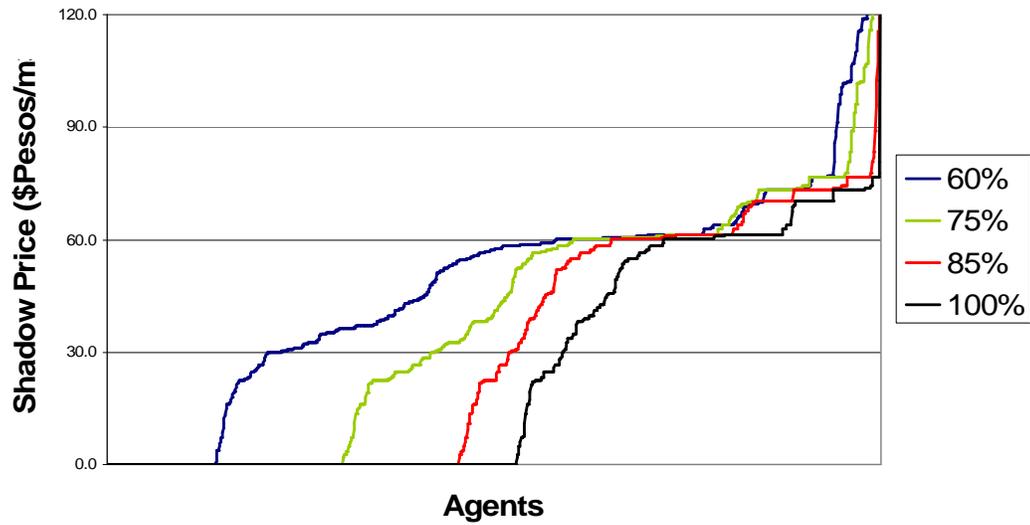


Figure A - 8: Distribution of the water shadow price over the farming population of the study area

Source: Authors

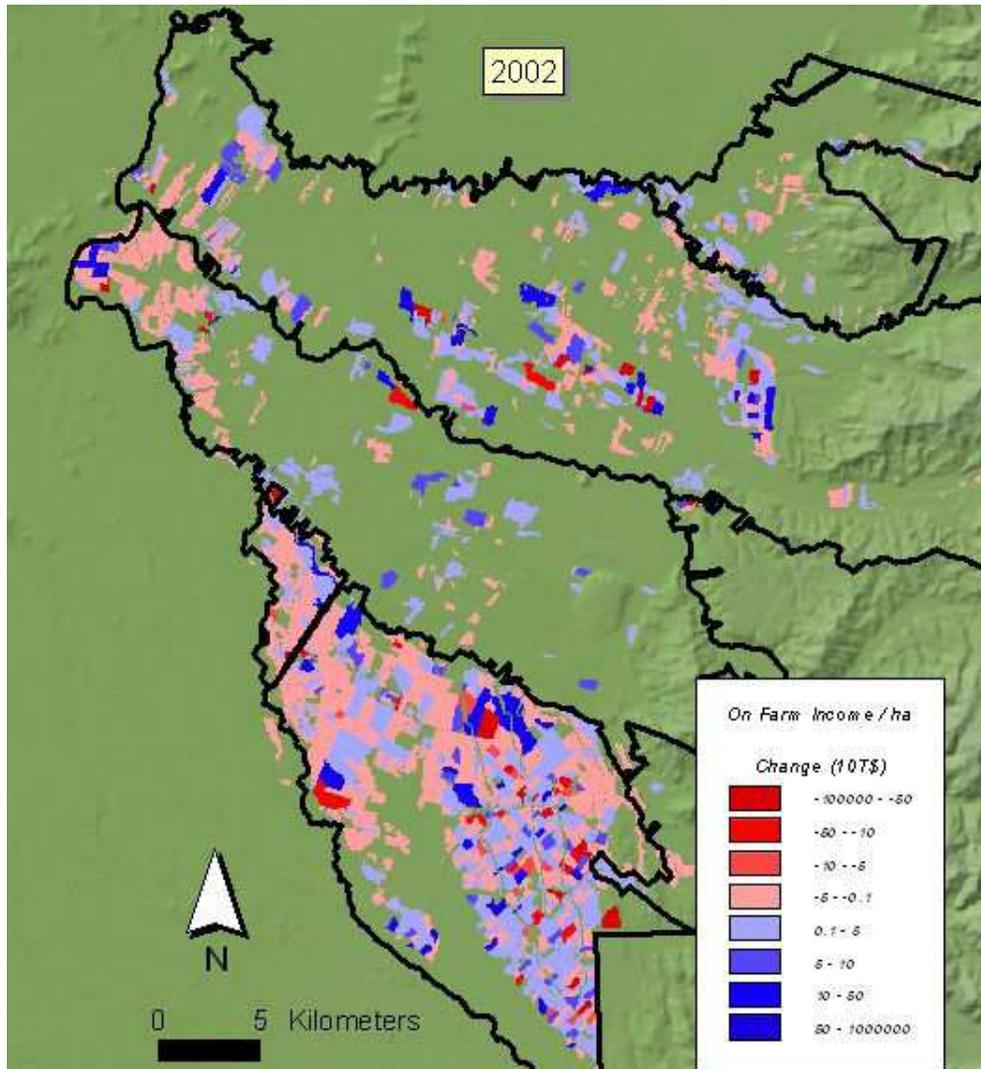
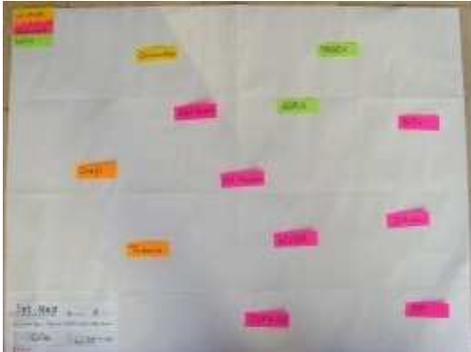


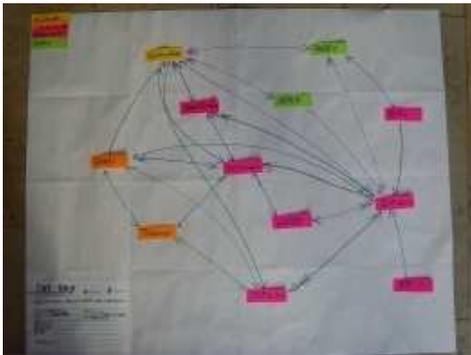
Figure A - 9: Spatial distribution of gains and losses in per-ha-on-farm-income 2002 in 10,000 CHP with an unlimited subsidy compared to no subsidy

Source: Authors

**Appendix D: Illustration of Net-Map**



Picture 1: Identification of actors  
Source: <http://netmap.wordpress.com/about/>



Step 2: Identification of linkages between actors  
Source: <http://netmap.wordpress.com/about/>



Step 3: Assigning "influence towers" to the actors  
Source: <http://netmap.wordpress.com/about/>

**Appendix D: List of Net-Map projects**

One of the significant impacts of this projects is that with Net-Map it developed a participatory method for increased understanding of Influence Networks that has been applied in numerous projects by researchers and implementers around the world, both within and beyond the CGIAR and beyond the water sector alone. As it is impossible to track the spreading of an idea through an open international system, the list below is by no means complete but gives a first impression of the range of projects that Net-Map has been used in or is currently used in around the world.

Care 1: Understanding the role of women in local governance in India

Country: India

Partner/User: IFPRI

Case 2: Research of Fisheries Management in Small Reservoirs in Ghana

Country: Ghana

Partners/Users: University of Bonn

Case 3: Water User Associations at Small Reservoirs Rehabilitated by IFAD

Country: Ghana

Partners/Users: IFAD, IFPRI, University of Bonn

Case 4: Choosing members for District Oversight Committees in the African Peer Review Mechanism Process (APRM)

Country: Ghana

Partners/Users: APRM Secretariat Ghana, Hans Seidel Foundation Ghana

Case 5: Innovation Benchmarks and Indicators - The Ethiopian Maize and Poultry Sectors

Country: Ethiopia

Partners/Users: IFPRI

Case 6: Can Decentralization and Community Based Development Reduce Corruption in Natural Resource Management? (IFPRI)

Countries: Ghana, Indonesia

Partners/Users: IFPRI

Case 7: Food Safety in the Dairy Supply Chain in Uzbekistan (IFPRI, World Bank)

Country: Uzbekistan

Partners/Users: IFPRI, World Bank

Case 8: Supporting Networks for HIV/AIDS and Nutrition Research

Countries: Malawi, Kenya, Uganda, Zambia

Partners/Users: IFPRI, national research institutions in the respective countries

Case 9: Understanding and Supporting Cross-boundary mountain governance in the Hindu Kush Region

Countries: Nepal, Tadschikistan, China-Tibet and China-Xinjiang?

Partners/Users: ASA, InWent, teamconsult

Case 10: Fostering integrated project implementation on the community level

Country: Ghana

Partner/User: Red Cross Ghana, regional office Upper East Region

Case 11: Understanding charcoal production and marketing networks for the development of sustainable alternatives

Country: Ghana

Partner/User: Nature Conservation Research Center (NCRC), Ghana

Case 12: Net-Map as PRA tool to improve implementation of village level irrigation schemes

Country: Mali

Partner/User: IFAD

Case 13: Improving the use of ITCs in the Education System of Burundi

Country: Burundi

Partner/User: Paolo Brunello

Case 14: FAO – CGIAR Knowledge Management Workshops: Improved network understanding for knowledge management practitioners

Countries: Worldwide

Partner/User: FAO, CGIAR KM-ICT

Case 15: Understanding your own community of practice

Country: Portugal

Partner/User: KM4Dev

Case 16: Understanding and improving communication for pro-poor risk reduction of avian influenza

Countries: Ghana, Ethiopia, Kenya, Nigeria

Partner/User: IFPRI, ILRI, FAO etc.

Case 17: Policy making and implementation in Nigeria: The example of the fertilizer policy

Country: Nigeria

Partner/User: IFPRI, Nigeria Strategy Support Program

Case 18: Evaluating the impact of World Bank interventions on agricultural productivity

Countries: China, India

Partners/Users: World Bank, IFPRI

Case 19: Process Mapping of public investment in rural India

Country: India

Partners/Users: IFPRI

Case 20: ICTKM Farmers Conference in Syria

Country: Syria

Partners/Users: ICARDA

Case 21: Institutional potentials and constraints in for the introduction of genetically modified cotton in Uganda

Country: Uganda

Partners/Users: IFPRI/PBS

Case 22: Social Safety Net Program in Bolivia – Status quo and potential for interventions for the Inter-American Development Bank

Country: Bolivia

Partners/Users: Inter-American Development Bank

Case 23: Understanding Urban Poverty in South America and the Caribbean

Countries: Bolivia, Jamaica, Chile, Nicaragua

Partner/User: Inter-American Development Bank

Case 24: Understanding institutional potentials and limitations of the FADAMA II agricultural development project and its pro-poor orientation

Country: Nigeria

Partner/User: IFPRI, FADAMA

Case 25: Collaborative story writing for education on network challenges enterprises are faced with

Country: France

Partner/User: Conseiller en Intelligence Collective

### Appendix E: Validation of MP-MAS (Example Ghana)

Following Berger and Schreinemachers (2006), multi-agent models must be validated by comparing observed and modeled land uses (here: crops) at various levels of aggregation, from the catchment level to the household level.

Household data from the project's random sample in two districts, Builsa and Kassena-Nanakni, were taken to measure the goodness-of-fit of the MP-MAS model. Households were divided into four clusters based on the number of rainfed and irrigation plots. To get one more level of aggregation between the cluster and household level, the households were grouped into 28 groups based on their size of land holdings. Finally to compare the surveyed 92 households in the two districts with the an equal number of model agents, 92 model agents were randomly selected based on cluster weight.

The goodness-of-fit was measured by regressing the modeled land uses on the observed land uses. Coefficients close to unity indicate a good model fit. At each level of aggregation, regression lines were fit only if more than two crops were grown, which reduced the number of observations at the lowest level of aggregation.

Table A - 2: Goodness-of-fit at different levels of aggregation

No	Level of aggregation	Coeff.	Std Error	Sign.	R <sup>2</sup>	Df*	No. agents(N)
1	Catchment	0.95	0.01	0.00	0.99	6	1
2	District	1.00	0.04	0.00	0.99	5	2
	Builsa	1.03	0.03	0.00	0.99	4	1
	Kassena-Nanakni	0.98	0.04	0.00	0.98	6	1
3	Cluster level	0.96	0.05	0.00	0.98	6	4
	Cluster_1	0.91	0.03	0.00	0.98	6	1
	Cluster_2	1.02	0.09	0.00	0.97	5	1
	Cluster_3	0.96	0.02	0.00	0.99	6	1
	Cluster_4	0.96	0.05	0.00	0.97	6	1
4	Group level	0.85	0.16	0.03	0.84	5	24
5	Household level	0.80	0.43	0.20	0.55	3	72

Note: \* Df is the average degree of freedom in each regression model, which corresponds to the average number of crops grown

Source: Authors

**Appendix F: Validation of WASIM-ETH (Example Chile)**

The calibration of the parameters of the WaSiM-ETH Model, Version 2, was done according to the recommendations by Schulla and Jasper (2006). The following parameters had to be calibrated: (a) the interflow drainage density ( $d_r$ ), (b) the recession constant ( $k_{rec}$ ) for the saturated hydraulic conductivity  $K_s$ , and (c) the scaling factor for base flow ( $Q_0$ ). The calibration was carried out for the period 1995-1998, in qualitative form (graphical) and in quantitative form on the Loncomilla gauging station located at the catchment outlet.

The validation was carried out for the years 1999-2001 (see figure below). The quantitative evaluation considered the statistical criteria: (a) Coefficient of efficiency of Nash-Sutcliffe (N-S) (Nash et al., 1970) and (b) Coefficient of Correlation of Pearson ( $R^2$ ). In order to generate the conditions of initial soil humidity, the model was run for the previous year. For the calibration, the values of N-S and Coefficients of  $R^2$  correlation were 0.89 and 0.90, respectively. For the period of validation, the values of N-S and Coefficients of  $R^2$  correlation were 0.90 and 0.90, which can be considered as good values.

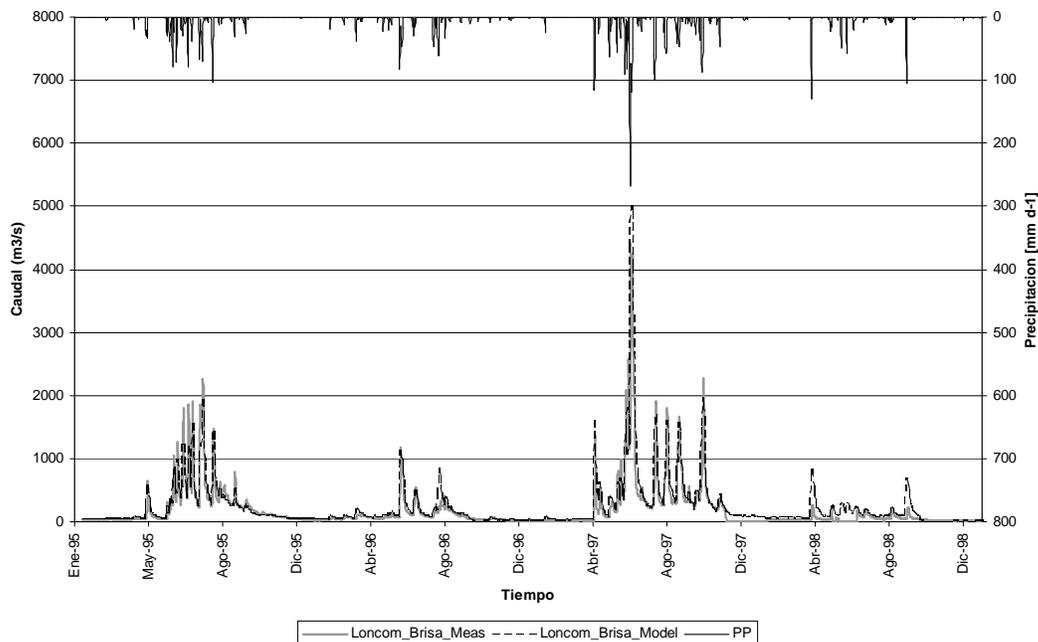


Figure A - 10: Comparison of flows modeled and measured at the catchment outlet (Loncomilla-Las Brisas).

Source: Authors