FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Small-Scale Irrigation Applications for Smallholder Farmers in Tanzania
Ex Ante Analysis of Options

Texas A&M University Integrated Decision Support System Team
USAID Feed the Future Innovation Laboratory for Small-Scale Irrigation

Jean-Claude Bizimana, Neville P. Clarke, Yihun T. Dile, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, Abeyou W. Worqlul

The authors wish to acknowledge the following agencies and individuals who were instrumental in providing data and expert advice for this report: our partners at Sokoine University of Agriculture; Cleophelia Roberts and Carlo Azzarri, both of the International Food Policy Research Institute (IFPRI); and Ben Lukuyu of the International Livestock Research Institute (ILRI).

Small-Scale Irrigation Applications for Smallholder Farmers in Tanzania
Ex Ante Analysis of Options

Introduction

The research reported here is part of the product of the USAID Feed the Future Innovation Laboratory for Small-Scale Irrigation (ILSSI), and summarizes ILSSI's analysis of proposed small-scale irrigation (SSI) interventions at three target sites in Tanzania. ILSSI was formed to undertake research aimed at increasing food production, improving nutrition, accelerating economic development, and contributing to the protection of the environment in Ethiopia, Ghana and Tanzania. We are currently working to generate actionable recommendations for strategic investments in agricultural development in rural Tanzania by integrating: natural resources, agricultural, and socioeconomic data; input from local farm families; local agronomic research and demonstrations; and powerful natural resource, agronomic, and farm-scale economic models. We are also training local government agency personnel and university faculty and students to continue using ILSSI tools and methodologies to inform national decision makers after this five-year project is completed.

ILSSI combines: the on-site agronomic and SSI expertise of the International Water Management Institute (IWMI), the International Livestock Research Institute (ILRI), and North Carolina A&T State University (NCAT); the socioeconomic research capabilities of the International Food Policy Research Institute (IFPRI); and the hydrologic, agronomic, and farm-scale economic modeling experience of Texas A&M University (TAMU). The project requires close interaction with international, national, and local agriculture and rural development professionals; local farm families and community leaders; and university faculty and students engaged in agricultural and rural development research in the target regions. IWMI and ILRI have facilitated close working relations with these stakeholders in support of ILSSI activities.

There are three major components of ILSSI: (1) field studies evaluating selected SSI methods; (2) household surveys to assess and evaluate gender, nutrition, and economic consequences of SSI interventions; and (3) the application of a suite of integrated models to quantitatively estimate the impact of SSI on production, environmental, and economic outcomes. An iterative process of engagement is involved in linking the three components of ILSSI to form a final product.

This report deals with the third ILSSI component, using ILSSI's Integrated Decision Support System (IDSS) to quantitatively estimate the impacts of proposed SSI interventions. The IDSS is comprised of a suite of previously validated, interacting, and spatially explicit agroecosystem models: the Soil and Water Assessment Tool (SWAT); Agricultural Policy Environmental Extender (APEX); and Farm Scale Nutrition and Economic Risk Assessment Model (FARMSIM). The IDSS predicts short and long-term changes in crop and livestock production, farm economies, and environmental services produced by changing land uses, agricultural technologies and policies, climate, and water resources management (including SSI). The three models (and their sister and antecedent decision tools) have been used successfully for more than 25 years to address complex biophysical and economic issues in the United States and around the world, providing decision makers with reliable predictions of the production, environmental, and economic impacts of their actions. A detailed description of the IDSS is found in Appendix 1.

In the ILSSI studies, the IDSS analyses are used to: (1) evaluate results of field studies; (2) produce quantitative stochastic integrated estimates of outcomes and impacts of the interventions; (3) seek optimal combinations of inputs for best use of interventions; (4) assess upstream, downstream, and community-level implications of the interventions; (5) provide input to training and educational materials for use at local and higher administrative levels; (6) scale up the estimates of production, environmental, and economic consequences of the interventions to geographically equivalent areas of the country; and (7) provide policy makers and private sector investors with scaled-up inputs that contribute to decisions on future investments.

Figure 1 shows the shows the results framework involving information and analysis flow of the IDSS: from definition of scenarios for analysis; through interaction of model components to create ex ante and ex post analyses; leading to users and ultimate adoption and application of SSI technologies. An overview of the results of IDSS ex ante analyses of proposed SSI interventions in Tanzania is provided in the following section ("Summary of Results for Tanzania"). More detailed summaries of the proposed SSI interventions and ex ante analyses at each of the three target sites, including actionable recommendations regarding proposed SSI interventions, are included in the subsequent section ("Regional Summaries").

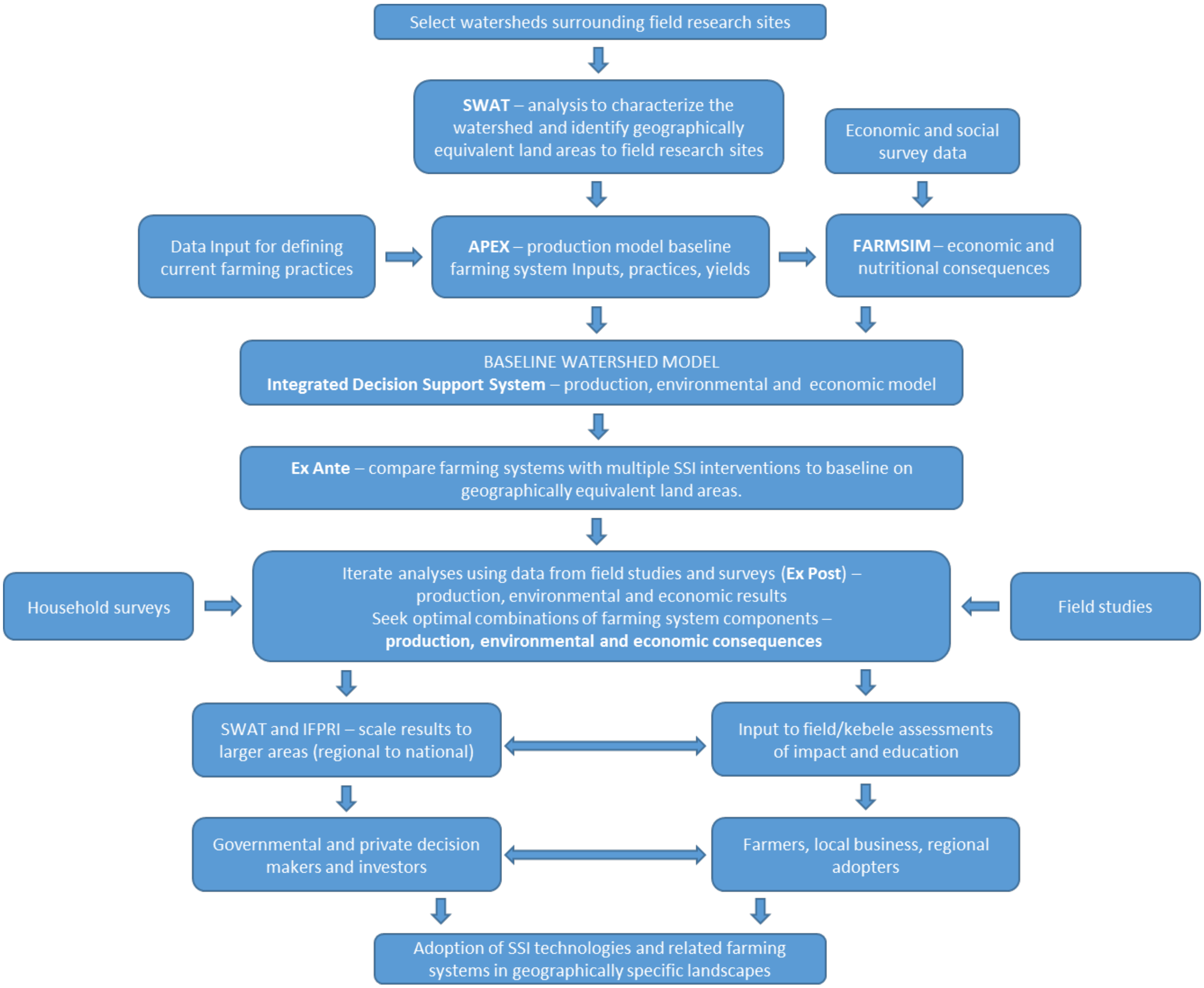
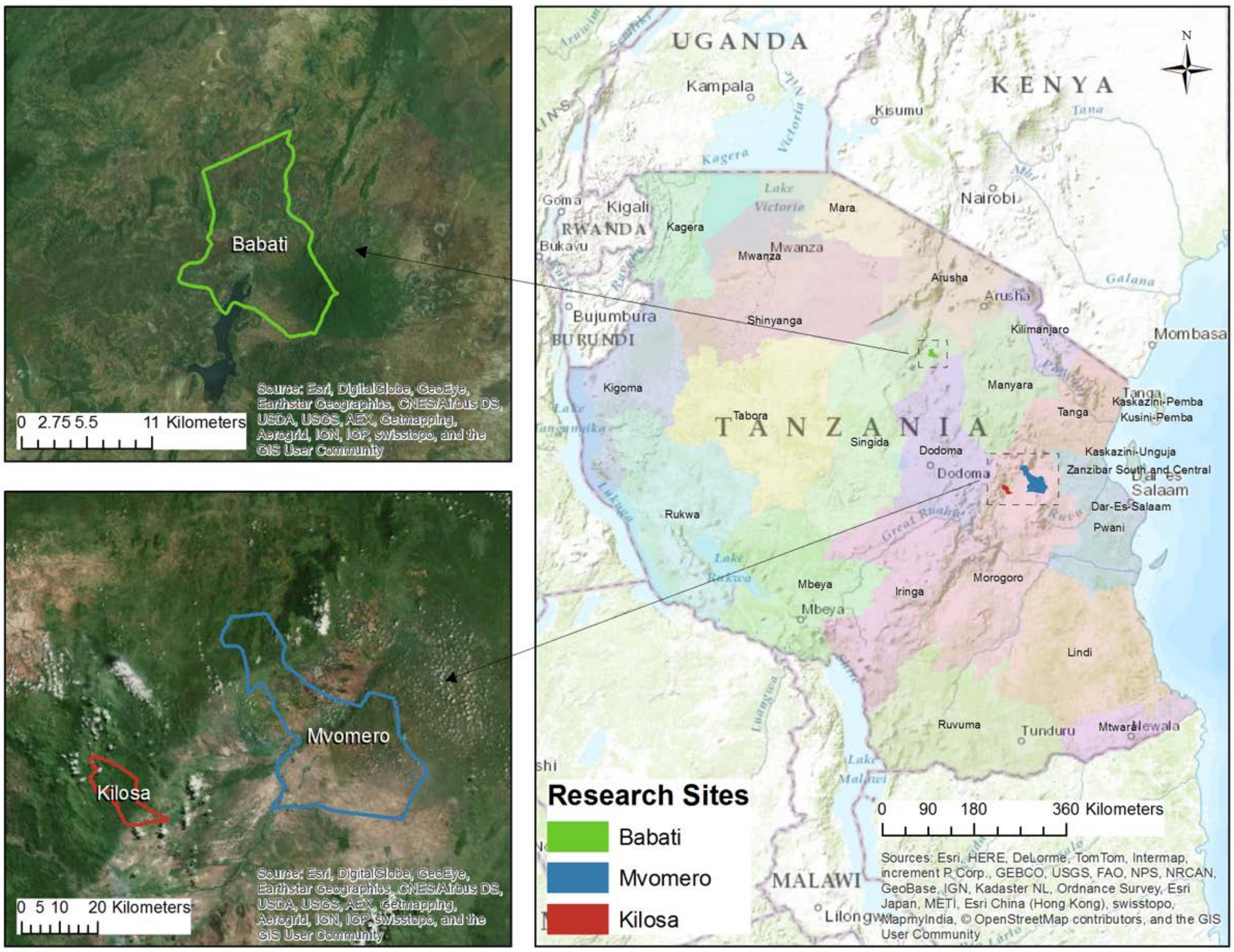


Figure 1. Results framework: information and analysis flow of the IDSS

Summary of Results for Tanzania

ILSSI analyzed proposed SSI interventions in watersheds located in three different watersheds/districts in the United Republic of Tanzania: Mkindo watershed, in the Mvomero district of the Morogoro region; Rudewa watershed, in the Kilosa district of the Morogoro region; and Babati watershed, in the Babati district of the Manyara region. Though crops and management practices vary somewhat from region to region, farm-family livelihoods for all of the target sites are derived from cereals produced in the rainy season and, in some cases, irrigated crops grown in the dry season.

ILSSI Research Sites in Tanzania



In each of the three target sites, ILSSI proposed implementing SSI, using diverted river water, to maximize cultivation of high-value vegetable and fodder crops in the dry season and productivity of the rice crop. ILSSI evaluated the impacts of the proposed SSI interventions at each of the three target sites by simulating and comparing current and alternative farming systems specific to each site.

For each site, all three ILSSI component models were used in an interactive and integrated fashion. SWAT was used to simulate watershed-scale hydrology and soil erosion to examine the effects of the proposed SSI interventions. APEX was used to analyze the impacts of the proposed SSI interventions on crop yields and soil erosion at the field scale. FARMSIM was used to determine the effects of the proposed SSI interventions on farm family livelihoods and nutrition. Stakeholders have been engaged throughout the project through: interactions with ILSSI in-country staff; surveys of farm-family resources, practices and needs; and informal training and short courses for in-country university faculty, students, and government officials.

Simulations with the integrated and interactive IDSS models allowed us to evaluate: the land appropriate for SSI of dry-season crops at each of the three sites; the amount of irrigation water required for the proposed SSI interventions at each of the three sites; the complete hydrology of each watershed (e.g, groundwater recharge and runoff rates) with and without the proposed SSI interventions; soil erosion rates associated with current cropping systems and the proposed SSI interventions; the impacts of various farming practices (e.g., current versus recommended fertilization rates) on crop yields, watershed hydrology, and farm economies, when implemented in conjunction with the proposed SSI interventions; and the economic and nutritional benefits to typical farm families of implementing the proposed SSI interventions.

Simulations indicated that there is ample water available for the proposed SSI interventions in Mvomero and Babati, and that the proposed SSI interventions are sustainable and would not compromise the environmental health of their respective watersheds. In Kilosa, low flows were significantly affected by the withdrawal of irrigation water from rivers (though peak flows were not affected). This suggests that the proposed SSI interventions in Kilosa may not compromise the overall water balance significantly; however, ecosystems that depend on low flows may be affected, and some alternative, surface-water storage or groundwater extraction may be needed to supply human and livestock drinking water during periods of extreme low flows.

At all three of the target sites, suitable fields far from rivers receive less irrigation water than those close to rivers; accordingly, the proposed SSI interventions will require development of advanced surface water diversion and transfer technologies and/or wells to sufficiently irrigate fields located far from the rivers.

Simulations of flow, sediment, and crop yields at each of the sites showed that the application of additional fertilizer would increase crop yields substantially and, at the Mvomero and Babati sites, would also decrease the soil loss from erosion. The implementation of multiple cropping systems also affected simulated crop yields and sediment losses, though results varied from site to site. Simulations also showed that SRI rice production would result in higher crop water productivity compared to traditional rain-fed rice. These results suggest that, as concluded in prior studies, SRI rice is the best alternative in places like Tanzania and many parts of Africa where there is suitable land for agricultural production but limited access to water (Worqlul et al. 2015). Simulations also indicated the sensitivity of SRI rice yields to drying and wetting periods.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping systems) on farm family economics. Results of the economic analyses varied from site to site. In Mvomero, implementation of the SRI method of rice cultivation and multiple cropping of fertilized maize with irrigated vegetables only (not fodder) produced the highest net present value (NPV), net cash farm income (NCI), and ending cash (EC) reserves of the alternative scenarios simulated (including the baseline, non-irrigated scenarios). In Kilosa and Babati, cash income increased as the irrigated area increased.

The most preferred scenario in terms of income generation was the one that allocated the largest area of irrigable cropland to vegetables, fodder and SRI rice.

Despite improvements in farm family economics resulting from the proposed SSI interventions, some nutritional deficiencies persisted under the simulated, improved cropping system in each of the three sites. We would also, therefore, propose expanding the types of crops irrigated in the dry season to increase family nutrition and NCI, but only if such crops can be irrigated without causing excessive soil erosion or reduction in environmental benefits. The relatively modest percentages of cropland in each of the three districts also limits the expansion of SSI and cultivation of additional crops at the target sites.

The results of our analysis raise a number of issues to be resolved in future modeling and field research. These include the need to identify: (1) the potential for use of shallow groundwater from SSI in areas too distant for use of surface water; (2) appropriate fertilizer amounts for more intensive cropping systems involving production of irrigated vegetable, fodder, and grain crops in the dry season; and (3) appropriate management of fertilizer and harvest practices for irrigated fodder production. The evaluation and comparison of alternative farming systems, including the types of crops grown, recommended management practices, and associated impacts on soil erosion and environmental benefits, are subjects for proposed future simulation and field research.

ILSSI plans to continue engaging with local leaders, university faculty and students, and government officials, to test the results of ex ante analyses and examine other SSI and farming system alternatives suggested by local farmers and other agricultural experts. We anticipate and recommend that in-country research on the applicability of SSI be informed by and respond to the ex ante analyses summarized above and discussed in further detail below. The ILSSI modeling team stands ready to complement field and simulation studies conducted by in-country collaborators, continually improving our ability to accurately represent the production, environmental, and economic effects of SSI and related agricultural practices.

Regional Summaries:
Interpretive Summaries of Ex Ante Analyses of Regional SSI Interventions

ILSSI completed ex ante analyses of the consequences of SSI interventions in three districts in Tanzania: Mvomero, Kilosa, and Babati. Detailed reports of these ex ante analyses are prepared as stand-alone documents and are attached to this report. The following are interpretive summaries of these more comprehensive reports.

Mvomero

The Mvomero district is located in the Morogoro region, and includes the rural village of Mkindo and the Mkindo watershed. The annual crops yields produced in the district are far below global average yields. Farm-family livelihoods in the area are derived from main cereal crops (most commonly rain-fed rice and maize) produced in the rainy season. Vegetables such as tomato and cabbage are produced as well, and cultivation of these crops could be expanded with the implementation of SSI in the dry season; however, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm-family economics, and environmental services.

In Mvomero, ILSSI proposed implementing SSI, using diverted river water, to maximize cultivation of high-value vegetable and fodder crops in the dry season and productivity of the rice crop. ILSSI evaluated the proposed SSI interventions by simulating and comparing five alternative farming systems:

i. continuous cropping of traditional grains (rain-fed rice and maize) grown during the main rainy season, using current (minimal) fertilizer rates and current (minimal) irrigation;
ii. multiple cropping of rainy-season grain crops (rain-fed rice and maize) with several irrigated, dry-season crops, using current (minimal) fertilizer rates;
iii. multiple cropping of rainy-season maize, fertilized at higher rates, with several irrigated, dry-season crops;
iv. cultivation of a perennial fodder crop (e.g., Napier grass) on pasture land; and
v. continuous cropping of an irrigated rice crop using the System of Rice Intensification (SRI) method of cultivation.

For purposes of the simulations, APEX and FARMSIM chose tomato, cabbage and fodder (oats/vetch) as representative irrigated dry-season crops, based on input from local experts. Additional crops will be modeled in ex post studies that reflect field studies and broader applications.

Simulations indicated that there is ample water available for the proposed SSI interventions in the Mkindo watershed. Agricultural land comprises a relatively small percentage (just 24.86%) of total land in the watershed. Accordingly, the total annual volume of irrigation water withdrawn in the watershed would be less than 5.9 million m^3, or just 14% of the annual stream flow leaving the watershed. Moreover, simulations indicated that proposed SSI interventions would reduce average monthly stream flow by only 3%, and that peak and low flows would not be affected by the withdrawal of irrigation water from rivers. This suggests that the proposed SSI interventions are sustainable, and would not compromise the environmental health of the watershed; however, because suitable fields far from rivers receive less irrigation water than those close to rivers, the proposed SSI interventions will require development of advanced surface water diversion and transfer technologies and/or wells to sufficiently irrigate fields located far from the rivers.

Simulations of flow, sediment, and crop yields in the alternative scenarios showed that the application of additional fertilizer would increase crop yields substantially and decrease the soil loss from erosion. The implementation of multiple cropping systems also affected simulated crop yields and sediment losses. Proper understanding and use of multiple cropping combinations could increase crop yields and improve soil health, but some combinations would probably decrease productivity if fertilization rates were inadequate. For the fertilizer application scenarios simulated in this study, multiple cropping of maize with tomato increased the nitrogen stress days for both crops and significantly reduced simulated yields of both crops, suggesting that increased fertilization amounts should be considered for multiple cropping of maize with tomato. In contrast, multiple cropping of maize with fodder significantly increased simulated maize yields and did not significantly affect fodder yields. Simulations also showed that SRI rice production would result in higher crop water productivity compared to traditional rain-fed rice. These results suggest that, as concluded by Worqlul et al. (2015), SRI rice is the best alternative in places like Tanzania and many parts of Africa where there is suitable land for agricultural production but limited access to water. Simulations also indicated the sensitivity of SRI rice yields to drying and wetting periods.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping systems) on farm-family economics in Mkindo village. The scenarios that produced by far the highest NPV, NCI, and EC reserves were those that implemented continuous cropping of SRI rice (in combination with multiple cropping of fertilized maize with either irrigated vegetables and fodder, or with irrigated vegetables only). The most preferred scenario in terms of income generation was the one that implemented SRI rice and multiple cropping of fertilized maize with irrigated vegetables only. In contrast, the scenario that included multiple cropping of rain-fed rice (rather than continuously cropped SRI rice) with irrigated vegetables and fodder did not differ greatly from the baseline, non-irrigated scenario.

Despite improvements in farm-family economics resulting from the proposed SSI interventions, nutritional deficiencies persisted (especially in vitamin A) under the simulated, improved cropping systems. We would also, therefore, propose expanding the types of crops irrigated in the dry season to increase family nutrition and net cash income, but only if such crops can be irrigated without causing excessive soil erosion or reduction in environmental benefits. The relatively modest percentage of cropland in the area (just 24.86% of the total watershed area) also limits the expansion of SSI and cultivation of additional crops in the Mkindo watershed.

The results of our analysis raise a number of issues to be resolved in future modeling and field research. These include the need to identify: (1) the potential for use of shallow groundwater from SSI in areas too distant for use of surface water; (2) appropriate fertilizer amounts for more intensive cropping systems involving production of irrigated vegetable, fodder, and grain crops in the dry season; and (3) appropriate management of fertilizer and harvest practices for irrigated fodder production. The evaluation and comparison of alternative farming systems, including the types of crops grown, recommended management practices, and associated impacts on soil erosion and environmental benefits, are subjects for proposed future simulation and field research.

Kilosa

The Kilosa district is located in the Morogoro region of the United Republic of Tanzania. The Rudewa watershed and the rural village of Rudewa-Mbuyuni are located within the Kilosa district. The annual crops yields produced in the district are far below the global average yields. Farm-family livelihoods are derived from main cereal crops (most commonly rain-fed rice and maize) produced in the rainy season. Vegetables such as tomato and cabbage are produced as well, and cultivation of these crops could be expanded with the implementation of SSI in the dry season; however, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm-family economics, and environmental services.

In Kilosa, ILSSI proposed implementing SSI, using diverted river water, to maximize cultivation of high-value vegetable and fodder crops in the dry season and productivity of the rice crop. ILSSI evaluated the proposed SSI interventions by simulating and comparing five alternative farming systems:

i. continuous cropping of traditional grains (rain-fed rice and maize) grown during the main rainy season, using current (minimal) fertilizer rates and current (minimal) irrigation;
ii. multiple cropping of rainy-season grain crops (rain-fed rice and maize) with several irrigated dry-season crops, using current (minimal) fertilizer rates;

iii. multiple cropping of rainy-season maize (fertilized at higher rates), with several irrigated dry-season crops;
iv. cultivation of a perennial crop (e.g., Napier grass) on pasture land; and
v. continuous cropping of SRI rice.

For purposes of the simulations, APEX and FARMSIM chose tomato, cabbage and fodder (oats/vetch) as representative, irrigated dry-season crops, based on input from local experts. Additional crops will be modeled in ex post studies that reflect field studies and broader applications.

Simulations indicated that there is ample water available for the proposed SSI interventions in the Rudewa watershed. Cropland comprises a very small percentage (just 1.46%) of total land in the watershed; even when combined with irrigable pasture land, the area to be irrigated would comprise just 1.74% of total land in the watershed. Accordingly, the total annual volume of irrigation water withdrawn in the watershed would be less than 960,000 m^3, or just 0.14% of the annual stream flow leaving the watershed. Moreover, simulations indicated that proposed SSI interventions would reduce average monthly stream flow by only 0.69%. Low flows were significantly affected by the withdrawal of irrigation water from rivers, but peak flows were not affected. This suggests that the proposed SSI interventions may not compromise the overall water balance significantly; however, the low flows may be reduced and ecosystems that depend on the low flows may be affected. Some alternative surface water storage or groundwater extraction may be needed to supply human and livestock drinking water during periods of extreme low flows. Moreover, because suitable fields far from rivers receive less irrigation water than those close to rivers, the proposed SSI interventions will require development of advanced surface water diversion and transfer technologies and/or wells to sufficiently irrigate fields located far from the rivers.

Simulations of flow, sediment, and crop yields in the alternative scenarios showed that the application of additional fertilizer would increase crop yields substantially. The implementation of multiple cropping systems also affected simulated crop yields. Proper understanding and use of multiple cropping combinations could increase crop yields and improve soil health, but some combinations if under-fertilized would probably decrease productivity. For the fertilizer application scenarios simulated in this study, simulations indicated a significant increase in rice yield for each of the multiple cropping scenarios, with the highest rice yield resulting from multiple cropping of rice with fodder. Multiple cropping of maize with fodder significantly increased simulated maize yield, whereas multiple cropping of maize with cabbage decreased simulated maize yield slightly. Tomato and fodder yields decreased significantly when simulated as multiple crops with rain-fed rice and maize. Cabbage yields also decreased slightly in both multiple cropping scenarios. These reductions in simulated yields generally reflected increases in nitrogen stress to the affected crops, and suggest the need for further exploration of appropriate fertilization amounts for these particular multiple cropping combinations.

Simulations showed that SRI rice production would result in higher crop water productivity compared to traditional rain-fed rice. These results suggest that, as concluded by Worqlul et al. (2015), SRI rice is the best alternative in places like Tanzania and many parts of Africa where there is suitable land for agricultural production but limited access to water. Simulations also indicated the sensitivity of SRI rice yields to drying and wetting periods.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping systems) on farm-family economics in

Rudewa-Mbuyuni village. The scenarios that produced by far the highest NPV, NCI, and EC reserves were those that implemented continuous cropping of SRI rice (in combination with multiple cropping of fertilized maize with irrigated vegetables and fodder). Cash income increased as the irrigated area increased. The most preferred scenario in terms of income generation was the one that allocated the largest area of irrigable cropland to vegetables, fodder and SRI rice.

Despite improvements in farm-family economics resulting from the proposed SSI interventions, nutritional deficiencies (in vitamin A particularly) persisted under the simulated, improved cropping systems. We would also, therefore, propose expanding the types of crops irrigated in the dry season to increase family nutrition and net cash income, but only if such crops can be irrigated without causing excessive soil erosion or reduction in environmental benefits such as stream flows in the dry season. The extremely modest percentages of cropland and irrigable pasture land in the area (together, just 1.74% of total land in the watershed) also limit the expansion of SSI and cultivation of additional crops in the Rudewa watershed.

Our analysis raised a number of issues to be resolved in future modeling and field research. These include the need to identify: (1) the potential for use of shallow groundwater from SSI in areas too distant for use of surface water; (2) appropriate fertilizer amounts for more intensive cropping systems involving production of irrigated vegetable, fodder, and grain crops in the dry season; and (3) appropriate management of fertilizer and harvest practices for irrigated fodder production. The evaluation and comparison of alternative farming systems, including the types of crops grown, recommended management practices, and associated impacts on soil erosion and environmental benefits, are subjects for proposed future simulation and field research.

Babati

The Babati district is located in the Manyara region of the United Republic of Tanzania. The Babati watershed and the rural village of Matufa are located within the Babati district. The annual crops yields produced in the district are far below global average yields. Farm-family livelihoods are derived from main cereal crops (most commonly rain-fed rice and maize) produced in the rainy season. Vegetables such as tomato and cabbage are produced as well, and cultivation of these crops could be expanded with the implementation of SSI in the dry season; however, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm-family economics, and environmental services.

In Babati, ILSSI proposed implementing SSI, using diverted river water, to maximize cultivation of high-value vegetable and fodder crops in the dry season and productivity of the rice crop. ILSSI evaluated the proposed SSI interventions by simulating and comparing five alternative farming systems:

i. continuous cropping of traditional grains (maize and rain-fed rice) grown during the main rainy season, using current (minimal) fertilizer rates and current (minimal) irrigation;
ii. multiple cropping of rainy-season grain crops (rain-fed rice and maize) with several irrigated dry-season crops, using current (minimal) fertilizer rates;
iii. multiple cropping of rainy-season maize (fertilized at higher rates) with several irrigated dry-season crops;
iv. cultivation of a perennial crop (e.g., Napier grass) on pasture land; and
v. continuous cropping of SRI rice.

For purposes of the simulations, APEX and FARMSIM chose tomato, cabbage and fodder (oats/vetch) as representative dry-season crops, based on input from local experts. Additional crops will be modeled in ex post studies that reflect field studies and broader applications.

Simulations indicated that there is ample water available for proposed SSI interventions in the Babati watershed. Cropland comprises a relatively small percentage (just 21.86%) of total land in the watershed. Accordingly, the total annual volume of irrigation water withdrawn in the watershed would be 835,950 m^3, or just 2.1% of the annual stream flow leaving the watershed. Moreover, simulations indicated that proposed SSI interventions would reduce average monthly stream flow by only 1.1%, and that peak and low flows would not be affected by the withdrawal of irrigation water from rivers. This suggests that the proposed SSI interventions are sustainable, and would not compromise the environmental health of the watershed; however, because suitable fields far from rivers receive less irrigation water than those close to rivers, the proposed SSI interventions will require development of advanced surface water diversion and transfer technologies and/or wells to sufficiently irrigate fields located far from the rivers.

Simulations of flow, sediment, and crop yields in the alternative scenarios showed that the application of additional fertilizer would increase crop yields substantially and decrease the soil loss from erosion. The implementation of multiple cropping systems also affected simulated crop yields. Proper understanding and use of multiple cropping combinations could increase crop yields and improve soil health, but some combinations would probably decrease productivity if fertilization rates were inadequate. For the fertilizer application scenarios simulated in this study, multiple cropping of maize and rain-fed rice with fodder increased simulated maize and rice yieldsIn contrast, multiple cropping of maize with tomato reduced simulated maize yields. Similarly, tomato and fodder yields decreased significantly when simulated as multiple crops with rain-fed rice and maize, and cabbage yields also decreased in both multiple cropping scenarios. These reductions in crop yields resulted from increased nitrogen stress levels to the crops, and suggest a need for increased fertilization rates for these particular multiple cropping combinations.

Simulations also showed that SRI rice production resulted in higher crop water productivity compared to traditional rain-fed rice. These results suggest that, as concluded by Worqlul et al. (2015), SRI rice is the best alternative in places like Tanzania and many parts of Africa where there is suitable land for agricultural production but limited access to water. Simulations also indicated the sensitivity of SRI rice yields to drying and wetting periods.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping systems) on farm-family economics in Matufa village. The scenarios that produced by far the highest NPV, NCI, and EC reserves were those that implemented continuous cropping of SRI rice (in combination with multiple cropping of fertilized maize with irrigated vegetables and fodder). Cash income increased as the irrigated area increased. The most preferred scenario in terms of income generation was the one that allocated the largest area of irrigable cropland to vegetables, fodder and SRI rice.

Despite improvements in farm-family economics resulting from the proposed SSI interventions, nutritional deficiencies (in vitamin A particularly) persisted under the simulated, improved cropping systems. We would also, therefore, propose expanding the types of crops irrigated in the dry season to increase family nutrition and net cash income, but only if such crops can be irrigated without causing excessive soil erosion or reduction in environmental benefits. The relatively modest percentage of cropland in the area (just 21.86% of the total watershed area) also limits the expansion of SSI and cultivation of additional crops in the Babati watershed.

The results presented above raise a number of issues to be resolved in future modeling and field research. These include the need to identify: (1) the potential for use of shallow groundwater from SSI in areas too distant for use of surface water; (2) appropriate fertilizer amounts for more intensive cropping systems involving production of irrigated vegetable, fodder, and grain crops in the dry season; and (3) appropriate management of fertilizer and harvest practices for irrigated fodder production. The evaluation and comparison of alternative farming systems, including the types of crops grown, recommended management practices, and associated impacts on soil erosion and environmental benefits, are subjects for proposed future simulation and field research.

Appendix 1

WHAT IS AN "INTEGRATED" DECISION SUPPORT SYSTEM?

Agricultural ecosystems are complex. At the farm level, their performance is influenced by a myriad of biophysical and socioeconomic factors, including: weather, soil properties, land forms, land uses, crop and livestock management practices, farm sizes and financial resources, farmer experience and labor availability, farmer financial and equipment resources, farm family needs, input and output prices, and availability of credit. At larger scales, such as watersheds and regional political subdivisions, the larger environmental and socioeconomic effects of agriculture on natural resources, environmental services, community wellbeing, and local/regional markets may become significant. The complex and interactive effects of these factors on farm productivity and economics, as well as local ecosystem services, make agricultural decision making difficult --- both for farm families and policy makers.

In recognition of these complexities, the Integrated Decision Support System (IDSS) has been created to "integrate" the interactions of crop and livestock production, environmental conditions, and farm family economics into the decision making process. IDSS analyses are meant to address farm-level as well as watershed and larger-scale impacts. Thus, decision makers with access to IDSS analyses will have a more complete understanding of the likely effects of their decisions on food production, natural resources, environmental services, and economics --- both at the farm and larger scales.

IDSS Tools.
The IDSS (http://IDSS.tamu.edu) includes a suite of spatially explicit simulation models that include: SWAT- Soil and Water Assessment Tool (http://swat.tamu.edu), APEX-Agricultural Policy Environmental eXtender (http://epicapex.tamu.edu), and FARMSIM-Farm Income and Nutrition Simulator (http://afpc.tamu.edu). The complete IDSS package also includes a wide variety of biophysical and socioeconomic databases characterizing the biophysical, economic, and management factors affecting the agroecosystem. A series of graphical and statistical tools are also provided to IDSS users to help them analyze and visualize both the inputs and outputs of analyses.

These IDSS models have been extensively used across the U.S. and in international settings to analyze the performance of many diverse agroecosystems at the farm, watershed, and larger scales. Collectively they provide an integrated approach linking production, economic, and environmental consequences of agricultural systems, new technology, and farm policy, for decision makers at multiple temporal and spatial scales.

The biophysical databases used by the IDSS are largely available worldwide in the form of geographic information systems (GIS) and other natural resources databases. The crop management and economic inputs are largely obtained locally from agricultural experts familiar with local management practices and farm family and market surveys.

IDSS developers and users are well aware of the complexities of modeling complex agroecosystems. As a result, capacity building is an important goal of the ILSSI project. Short courses designed to increase the analytical and decision skills of IDSS users are offered to university students and agricultural professionals in all three ILSSI countries on a regular basis.

The IDSS team includes scientists with deep professional understanding of African ecosystems to provide guidance to African users.

Finally, the IDSS "team" includes representatives of international agricultural research organizations (IWMI and ILRI) and faculty at several African universities. These colleagues maintain close working relationships with government agencies, non-governmental development organizations, and local farmer and community groups. As part of the ILSSI project, they conduct field research on issues related to small-scale irrigation and provide these data to the IDSS modeling team for use in model calibration and verification. This linkage is critical not only to obtain information about current agricultural practices, but also to conduct real-world evaluations and demonstrations of new small-scale irrigation technologies. Figure 1 shows the major components and information flows with the IDSS.

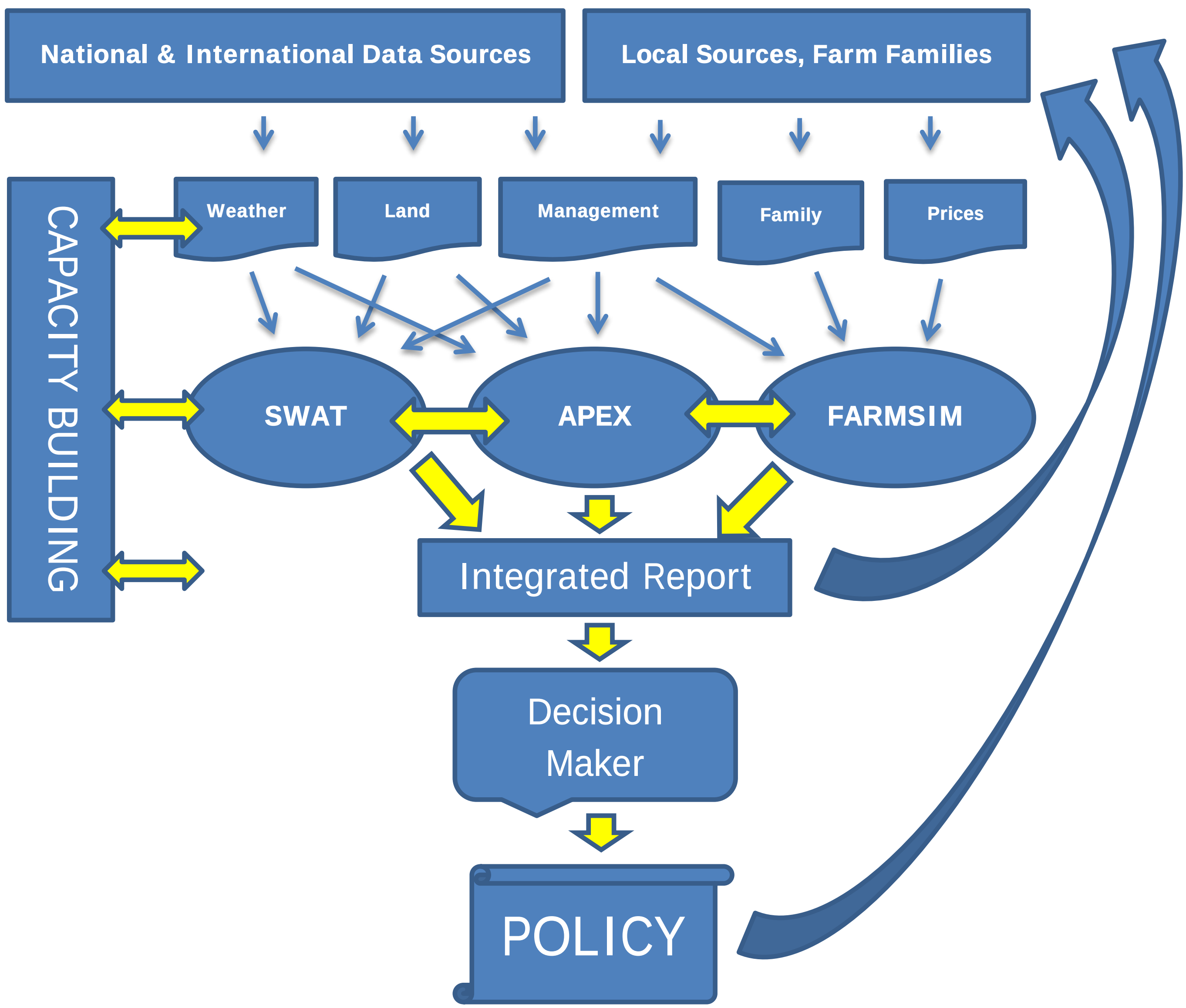


Figure 1. Information flows within the IDSS.