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

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USAID Feed the Future Innovation Laboratory for Small-Scale Irrigation

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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 four target sites in Ethiopia. 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 Ethiopia 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 Ethiopia is provided in the following section ("Summary of Results for Ethiopia"). More detailed summaries of the proposed SSI interventions and ex ante analyses at each of the four target sites, including actionable recommendations regarding proposed SSI interventions, are included in the subsequent section ("Regional Summaries").

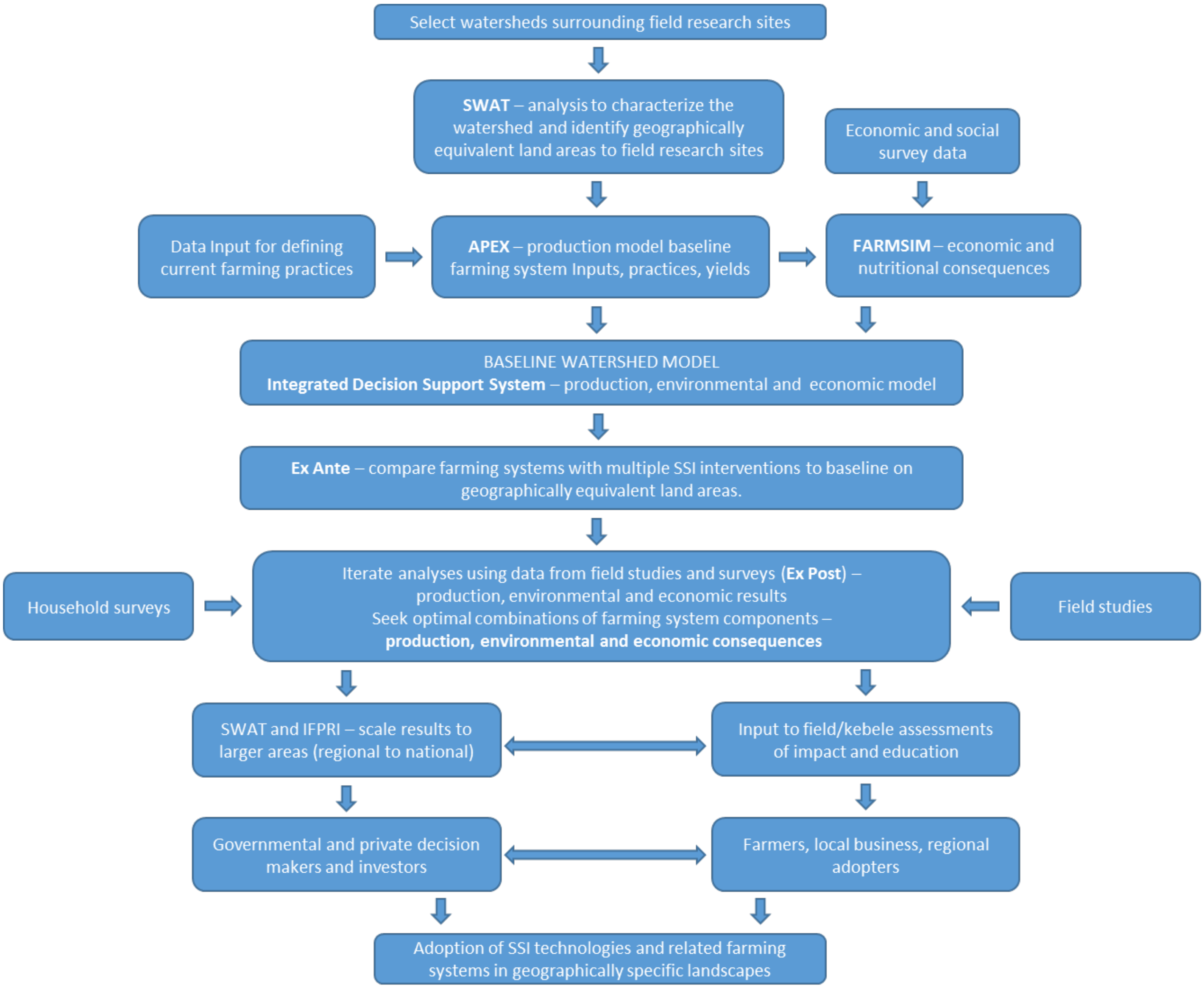
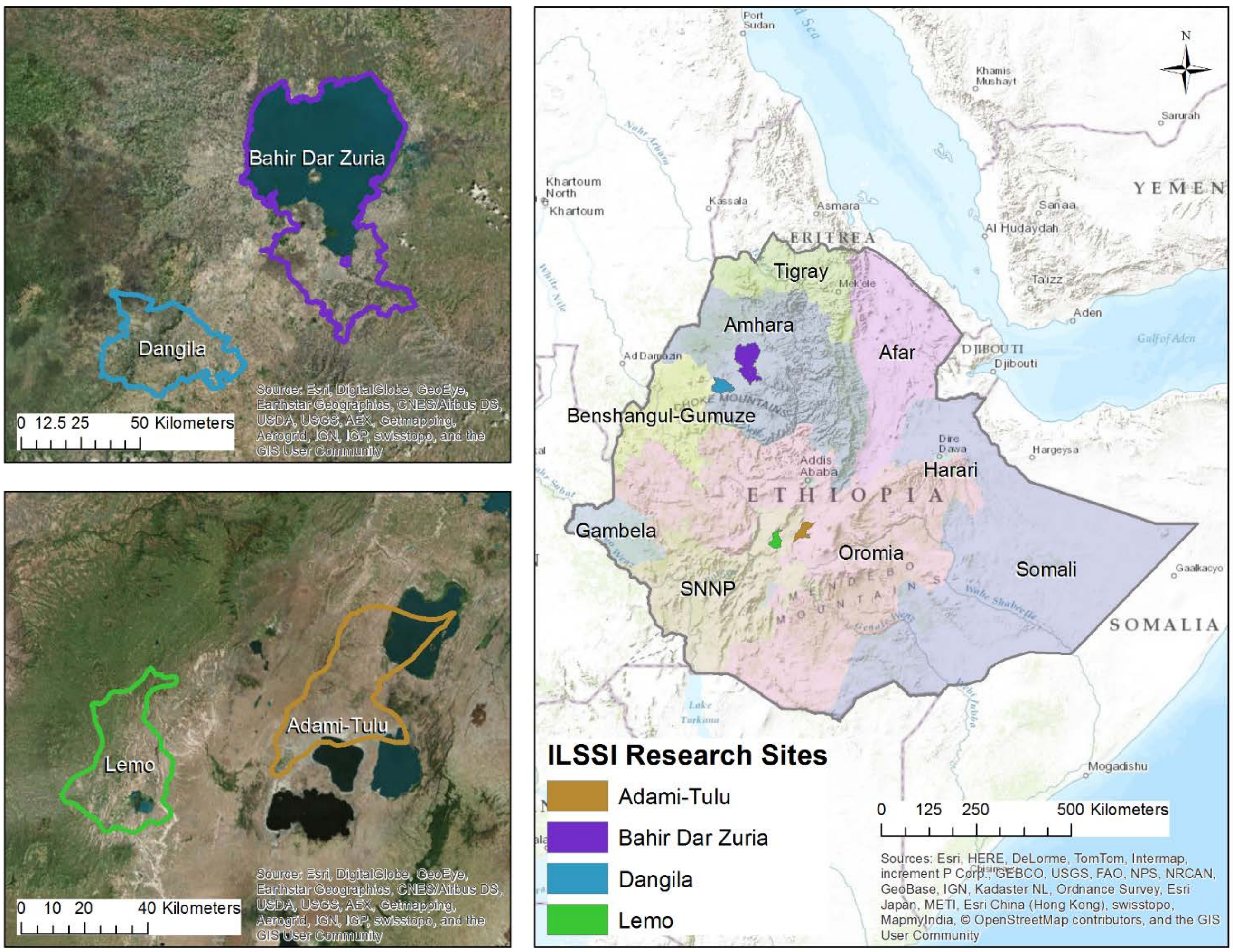


Figure 1. Results framework: information and analysis flow of the IDSS

Summary of Results for Ethiopia

ILSSI analyzed proposed SSI interventions in watersheds located in four different woredas in Ethiopia: Bahir Dar Zuria (BDZ) and Dangila, both in the Amhara region; Adami Tulu, in the Oromia region; and Lemo, in the Southern Nations, Nationalities and Peoples (SNNP) region. Though crops and management practices vary somewhat from region to region, farm-family livelihoods for all of the targeted 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 Ethiopia



In each of the four target sites, ILSSI evaluated maximizing the use of SSI (i.e., implementing SSI on all irrigable soils with slopes of less than 8%) to produce high-value crops during the dry season. All four sites simulated the use of shallow groundwater for SSI, comparing five alternative water-lifting technologies. ILSSI evaluated the impacts of the proposed SSI interventions at each of the four 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 four sites; the amount of irrigation water required for the proposed SSI interventions at each of the four 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, and current versus deep tillage practices in areas with hardpan soils) on crop yields, watershed hydrology, and farm economies, when implemented in conjunction with the proposed SSI interventions; the amount of labor required at each site to raise irrigation water for a small, irrigated field using five proposed water-lifting technologies; and the economic and nutritional benefits to typical farm families of implementing the proposed SSI interventions.

In BDZ, Dangila and Lemo, the IDSS revealed large potential for increased SSI. Simulations indicated that the proposed SSI interventions could be sustained by shallow groundwater recharge without affecting long-term groundwater storage, and would not compromise the environmental health of the watersheds. In Adami Tulu, however, simulations of watershed-scale hydrology indicated that groundwater recharge rates might be inadequate to support extensive SSI. It was noted that higher recharge rates could occur in certain areas within the watershed, such as along stream banks; further studies to identify such areas were recommended. In contrast, surface runoff rates in Adami Tulu were high, suggesting that runoff could be captured in ponds and used as a direct source of water for SSI or to recharge shallow groundwater. Further research into potential sites for small water-harvesting structures, and their associated costs and benefits, was recommended.

Simulations also revealed very high soil erosion rates in the Robit watershed in BDZ, suggesting that neither the current cropping system nor the proposed SSI intervention (in conjunction with the simulated alternate cropping systems) can be sustained without substantial efforts to reduce soil erosion. Further study was recommended to identify alternative cropping systems that could reduce rates of erosion.

Generally, the proposed SSI interventions (especially when combined with increased fertilization rates) increased wet-season grain yields significantly, presumably because crop rotation operations implemented in conjunction with the proposed SSI scenarios resulted in improvements in soil organic matter. As expected, simulations predicted that yields of dry-season crops would be substantial with applied irrigation water.

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. These analyses also compared the costs and benefits of five alternative water-lifting technologies in implementing the proposed SSI interventions: pulley and bucket irrigation, and rope-and-washer pumps operated by hand, animal, gasoline motor, and solar power.

Results of the economic analyses varied from site to site. In all four sites, implementation of the proposed SSI interventions using gasoline-motor or animal-powered pumps 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 all cases, forecasted sales of the irrigated dry-season crop contributed the bulk of NCI (profit) for the five-year planning horizon.

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 four sites. Part of the reason could be that few crops were considered (especially in the vegetable category) in the ex-ante analysis of SSI technologies. 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 evaluation and comparison of alternative farming systems for each of the four sites, including the types of crops grown, recommended management practices, and associated impacts on soil erosion and environmental benefits, are subjects for proposed future study.

ILSSI plans to continue engaging with kebele and woreda 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 four regions in Ethiopia: BDZ, Dangila, Adami Tulu and Lemo. 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.

Dangila

Dangila woreda is located in the Amhara region of Ethiopia. Dangeshta, a rural kebele in the woreda, is located about 80 km south of Bahir Dar. Farm-family livelihoods in the area are derived from cereals produced in the rainy season (most commonly, maize and teff grown in rotation) and irrigated crops grown in the dry season. Groundwater potential and experience in SSI is relatively high; however, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm-family economics, and environmental services.

In Dangila, ILSSI proposed maximizing SSI of high-value, dry-season crops, using shallow groundwater and one of five alternative water-lifting technologies. ILSSI evaluated the proposed SSI interventions by simulating and comparing two alternative farming systems:

1. a crop rotation of maize and teff grown in alternating wet seasons, applying fertilizer at rates currently used by farmers in the region; and
2. a crop rotation consisting of wet-season grains (maize or teff), fertilized at government-recommended rates, plus an irrigated, dry-season double crop (onion) on all irrigable land (i.e., all areas with slopes less than 8%—856 ha, or approximately 17% of the watershed area), using shallow groundwater.

Simulations indicated that there is a large potential for increased SSI in Dangila. A complete hydrologic analysis of the area's 5150-ha watershed calculated that the average annual volumetric groundwater recharge was over 26 million m^3, and simulations indicated that the proposed SSI interventions would use less than 20% of the annual shallow groundwater recharge. Excessive irrigation from shallow groundwater can deplete aquifers that contribute to stream flow, potentially reducing those flows; however, simulations indicated that the proposed SSI interventions would reduce stream flow by only 8%, and should not compromise downstream flows. This suggests that the proposed SSI interventions can be sustained by the shallow groundwater recharge without affecting long-term groundwater storage, and would not compromise the environmental health of the watershed.

The proposed SSI interventions (especially when combined with increased fertilization rates) increased wet-season grain yields significantly, presumably because crop rotation operations implemented in conjunction with the proposed SSI scenarios resulted in improvements in soil organic matter. As expected, simulations predicted that onion yields would increase with applied irrigation water of up to 391-392 mm.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping system) on farm-family economics. These analyses compared the costs and benefits of five alternative water-lifting technologies: pulley-and-bucket irrigation, and rope-and-washer pumps operated by hand, animal, gasoline motor, and solar power. Of the alternative technologies examined, none of the water lifting technologies met the irrigation water requirements for the proposed SSI interventions in Dangeshta kebele (i.e., for all 856 ha of irrigable land in the kebele). However, implementation of the proposed SSI interventions using motor pumps produced by far the highest NPV, NCI, and EC reserves of the six scenarios simulated (including the baseline, non-irrigated scenario). In each of the alternative scenarios, the increase in farm revenue was due almost entirely to the sale of surplus irrigated onion. Where motor or solar pumps were used, the forecasted sales of irrigated onions contributed, on average, 46% of the total crops receipts and 100% of the net cash (profit) for the five-year planning horizon.

The main barrier to SSI with motor or solar pumps is the initial investment in the technology. The initial investment costs of an animal-powered pump or hand-operated pump are much lower; however, the NPV results strongly suggest that an investment in motor pumps would pay large dividends in increased income and wealth. Moreover, individual farmers might benefit by spreading entry costs over more irrigated area, perhaps by having two or three farmers share a motor pump. Accordingly, in Dangila, ILSSI recommends implementing the proposed SSI interventions using motor pumps.

Despite improvements in farm family economics resulting from the proposed SSI interventions, nutritional deficiencies persisted under the simulated, improved cropping system. 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 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 study.

Bahir Dar Zuria

This report 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 in Bahir Dar Zuria (BDZ) woreda, in the Amhara region of Ethiopia. Farm family livelihoods in the area are derived from cereals produced in the rainy season and irrigated crops grown in the dry season. Groundwater potential and experience in SSI is relatively high; however, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm family economics, and environmental services.

In BDZ, ILSSI proposed maximizing SSI of high-value, dry-season crops, using shallow groundwater and one of five alternative water-lifting technologies. ILSSI evaluated the proposed SSI interventions by simulating and comparing four alternative farming systems:

1. current farm management practices and fertilizer rates with rotations of maize, finger millet, and teff grown in the wet season;
2. in addition to the current wet season crops (scenario 1), using shallow groundwater to grow an irrigated, dry season double crop (onion) on all irrigable land (i.e., areas with slopes less than 8%);
3. increasing fertilizer application in farming system 1 (i.e., without irrigated, dry-season onion) to government recommended rates; and
4. increasing fertilizer application in farming system 2 (i.e., with irrigated, dry-season onion) to government recommended rates.

The study also examined the effects of deep tillage on the region's hardpan soils in conjunction with the proposed SSI intervention, and the effects of different irrigation amounts on the dry-season crop. Onion was chosen as representative dry-season crop for purposes of the simulations, 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 a large potential for increased SSI in BDZ. A complete hydrologic analysis of the area's 1506-ha watershed calculated that the average annual volumetric groundwater recharge was over 4 million m^3. Simulations indicated that the proposed SSI interventions would use approximately 40% of the annual shallow groundwater recharge. Additionally, simulations indicated that the proposed SSI interventions would reduce average monthly stream flow by 6%, and should not compromise downstream flows. This suggests that the proposed SSI interventions can be sustained by the shallow groundwater recharge without affecting long-term groundwater storage, and would not compromise the environmental health of the watershed.

The proposed SSI interventions (especially when combined with increased fertilization rates) increased wet-season grain yields significantly, presumably because crop rotation operations implemented in conjunction with the proposed SSI scenarios resulted in improvements in soil organic matter. As expected, the proposed SSI interventions also resulted in significant onion yields, which were shown to increase with applied irrigation water of up to 140 mm (the irrigation depth required to reduce plant stress levels to 0%).

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping system) on farm family economics in Robit kebele. These simulations compared the costs and benefits of five alternative water-lifting technologies: pulley-and-bucket irrigation, and rope-and-washer pumps operated by hand, animal, gasoline motor, and solar power. Additionally, these simulations analyzed the effects of deep tillage (as opposed to current, shallow tillage practices) to break up hardpan soils. In all, eleven scenarios (including the baseline, non-irrigated scenario) were simulated.

Of the technologies examined, only the gasoline pump met the irrigation water requirements for the proposed SSI interventions (i.e., for all 787 ha of irrigable land in the kebele). Implementation of the proposed SSI interventions using animal-powered or motor pump produced the highest NPV, NCI, and EC reserves of the eleven scenarios simulated. The benefits were greatest when these technologies were combined with deep tillage to increase rooting depth and reduce drought stress in the grain crops. In each of the alternative scenarios, the increase in farm revenue was due almost entirely to the sale of surplus irrigated onion. Where an animal-powered or motor pump was used in combination with deep tillage practices, the forecasted sales of irrigated onions contributed, on average, 87% of the total crops receipts and 100% of the net cash (profit) for the five-year planning horizon.

A motor pump can irrigate an area three times larger than that covered by an animal-powered pump. The main barrier to SSI with motor or solar pumps is the up-front investment in the technology; the initial investment costs of an animal-powered pump are much lower. Individual farmers might benefit by spreading entry costs over more irrigated area, perhaps by having two or three farmers share a pump.

Despite improvements in farm family economics resulting from the proposed SSI interventions, nutritional deficiencies persisted under the simulated, improved cropping system. 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.

Notably, the simulated soil erosion rates were very high in BDZ, suggesting that the current and alternative cropping systems simulated in this study cannot be sustained without substantial efforts to reduce soil erosion. Every effort should be made to identify and implement cropping systems that reduce the rates of soil erosion. 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 study.

Adami Tulu

This report 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 in Adami Tulu, a Feed-the-Future woreda in the Oromia region of Ethiopia. Farm-family livelihoods in the area are derived from mixed-subsistence farming, including cultivation of a main crop of cereals in the rainy season. Some families also produce irrigated vegetables in the dry season. SSI interventions can aid in the effective use of limited natural resources; however, groundwater potential in the area is modest. Moreover, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm-family economics, and environmental services.

In Adami Tulu, ILSSI proposed maximizing SSI of high-value, dry-season crops, using shallow groundwater and one of five alternative water-lifting technologies. ILSSI evaluated the proposed SSI interventions by simulating and comparing two alternative farming systems:

1. a crop rotation of maize, teff, and wheat, grown in alternating wet seasons, applying fertilizer at rates currently used by farmers in the region; and
2. a crop rotation consisting of wet-season maize, teff, or wheat, fertilized at government-recommended rates, plus an irrigated, dry-season double crop (onion) grown on all irrigable land (i.e., all areas with slopes less than 8%), using shallow groundwater.

Onion was chosen as representative dry-season crop for purposes of the simulations, based on input from local experts. Additional crops will be modeled in ex post studies that reflect field studies and broader applications.

Simulations of watershed-scale hydrology suggested that recharge of the shallow aquifer may be inadequate to support a large amount of SSI in Adami Tulu. The average annual shallow groundwater recharge under baseline conditions was less than 21 mm across the 3070-ha watershed, and the average, area-weighted, annual irrigation required by the proposed SSI interventions was almost 89 mm. Since groundwater withdrawals would far outpace average groundwater recharge, we can conclude that the proposed SSI interventions may not be sustained by the shallow groundwater recharge without affecting long-term groundwater storage. It must be noted that some soils in the watershed may generate less runoff and greater recharge of the shallow aquifer, and recharge may occur via stream banks during the wet season. If such areas occur within the watershed, they could be used for SSI; however, this study was not detailed enough to identify such areas.

In contrast to the modest groundwater recharge rates, mean annual surface runoff across the watershed was estimated to be more than 250 mm, far exceeding the almost 89 mm of irrigation water required for the proposed SSI interventions. Therefore, surface runoff might be captured in ponds and used either directly or to recharge shallow groundwater. Analyses of potential sites and likely costs and benefits of irrigating from small water-harvesting structures were beyond the scope of this study but could be addressed in future research.

Should they prove sustainable, the proposed SSI interventions (especially when combined with increased fertilization rates) were shown to increase wet-season grain yields. As expected, the proposed SSI interventions also resulted in significant onion yields, which were shown to increase with applied irrigation water of up to 150 mm (the irrigation depth required to reduce plant stress levels to 0%).

For purposes of analyzing the economic effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping system) in Bochesa, a kebele in Adami Tulu woreda, we assumed that locations could be identified with sufficient recharge of shallow groundwater to support such interventions. These analyses also compared the costs and benefits of five alternative water-lifting technologies: pulley-and-bucket irrigation, and rope-and-washer pumps operated by hand, animal, gasoline motor, and solar power. Of the alternate technologies examined, only motor pumps met the irrigation water requirements for the proposed SSI interventions in Bochesa (i.e., for all 531 ha of irrigable land in the kebele). Implementation of the proposed SSI interventions using motor pumps produced the highest NPV, NCI, and EC reserves of the six scenarios simulated (including the baseline, non-irrigated scenario); the scenario utilizing animal-powered-pump irrigation was the second-best-performing scenario. Alternative scenarios involving hand-operated and solar pumps were the third-best-performing scenarios, with both showing a similar level of performance. In each of the alternative scenarios, the increase in farm revenue was due almost entirely to the sale of surplus irrigated onion. Where motor pumps were used, the forecasted sales of irrigated onions contributed, on average, 96% of the total crops receipts and 100% of the net cash (profit) for the five-year planning horizon.

Assuming that future studies identify locations with sufficient recharge of shallow groundwater to support the proposed SSI interventions, the irrigation water requirements for these interventions could be met with motor pumps. Note that simulations showed that investments in both motor- and animal-powered-pump irrigation will generate profits for the farmer. Motor pumps can cover three times the area of animal-powered pumps, but with much higher entry and capital costs. Individual farmers might benefit by spreading entry costs over more irrigated area, perhaps by having two or three farmers share a motor or solar pump. Finally, despite its low pumping capacity and high capital cost, the solar-pump system may be a more promising option for the future due to its low operating, maintenance, and environmental costs.

Despite improvements in farm-family economics resulting from the proposed SSI interventions, nutritional deficiencies persisted under the simulated, improved cropping system. We would also, therefore, propose expanding the area and types of crops irrigated in the dry season to increase family nutrition and net cash income, but only if the additional area and crops can be irrigated without depleting the shallow aquifer, causing environmental degradation, or reducing environmental benefits provided by the land. Additional analyses would be needed to (1) identify local areas within the watershed with adequate groundwater recharge to support SSI, and (2) evaluate the hydrologic and economic feasibility of constructing small dams to capture runoff for use for SSI. 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 also subjects for proposed future study.

Lemo

This report 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 in Lemo woreda, in the Southern Nations, Nationalities and Peoples (SNNP) region of Ethiopia. Farm-family livelihoods in the area are based on mixed crop and livestock production, with most farmers cultivating main crops of cereals and vegetables during the rainy season. During the dry season, most farmers use water from hand-dug, shallow wells for household use and to water livestock, with a few farmers irrigating tiny plots of land. Groundwater potential is relatively high; however, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm-family economics, and environmental services.

In Lemo, ILSSI proposed maximizing SSI of high-value, dry-season crops, using shallow groundwater and one of five alternative water-lifting technologies. ILSSI evaluated the proposed SSI interventions by simulating and comparing two alternative farming systems:

1. crop rotations of maize, teff and wheat, grown in the wet season, applying fertilizer at rates currently used by farmers in the region; and
2. crop rotations consisting of wet-season maize, teff, or wheat, fertilized at government-recommended rates, plus irrigated, dry-season double crops on all irrigable land (i.e., all areas with slopes less than 8%), using shallow groundwater.

Onion and fodder (oats/vetch) were chosen as representative dry-season crops for purposes of the simulations, 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 great potential for increased SSI of dry-season crops in Lemo. A complete hydrologic analysis of the area's watershed (with a catchment area of 500 ha) calculated that the average annual volumetric groundwater recharge was over 1.5 million m^3, and that the proposed SSI interventions would use less than 10% of the annual shallow groundwater recharge. Excessive irrigation from shallow groundwater can deplete aquifers that contribute to stream flow, potentially reducing those flows; however, simulations indicated that the proposed SSI interventions would reduce average monthly stream flow by only 5.6% and should not compromise downstream flows. This suggests that the proposed SSI interventions can be sustained by the shallow groundwater recharge without affecting long-term groundwater storage, and would not compromise the environmental health of the watershed.

As expected, simulations of the onion crop predicted that yields would increase substantially as applied irrigation water was increased up to 455 mm (the irrigation depth required to reduce plant stress levels to 0%). Similar results would be expected with respect to other dry-season crops, including fodder.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping system) on farm-family economics in Upper Gana. These analyses compared the costs and benefits of five alternative water-lifting technologies: pulley-and-bucket irrigation, and rope-and-washer pumps operated by hand, animal, gasoline motor, and solar power. Of the alternate technologies examined, none of the technologies met the irrigation water requirements for the proposed SSI interventions (i.e., for all 540 ha of irrigable land in the kebele). Implementation of the proposed SSI interventions using gasoline motor pumps produced by far the highest NPV, NCI, and EC reserves of the six alternative scenarios simulated (including the baseline, non-irrigated scenario). The second-best-performing scenario implemented animal-powered pump irrigation, and the worst of the six scenarios simulated (including the baseline, non-irrigated scenario) was the scenario that implemented irrigation with pulley and bucket. In each of the alternative scenarios, the increase in farm revenue was due almost entirely to the sale of surplus irrigated fodder and onion. Where gasoline motor pumps were used, the forecasted sales of irrigated fodder and onion contributed, on average, 62% and 17%, respectively, of total crops receipts, and 83% and 17%, respectively, of the net cash (profit) for the five-year planning horizon.

Although gasoline-motor pumps could not irrigate all 540 ha of irrigable land in the kebele at 0% water stress, they had twice the coverage animal-powered pumps (the next-best alternative), though with much higher operational and capital costs. Individual farmers might benefit by spreading entry costs over more irrigated area, perhaps by having two or three farmers share a pump. Simulation results showed that irrigation with both gasoline motor pumps and animal-powered pumps will generate profit and income for the farmer. The lower operating, maintenance, and environmental costs of solar pumps (as opposed to gasoline-motor pumps) might also make them an attractive long-term option.

Despite improvements in farm-family economics resulting from the proposed SSI interventions, nutritional deficiencies persisted under the simulated, improved cropping system. 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 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 study.

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.

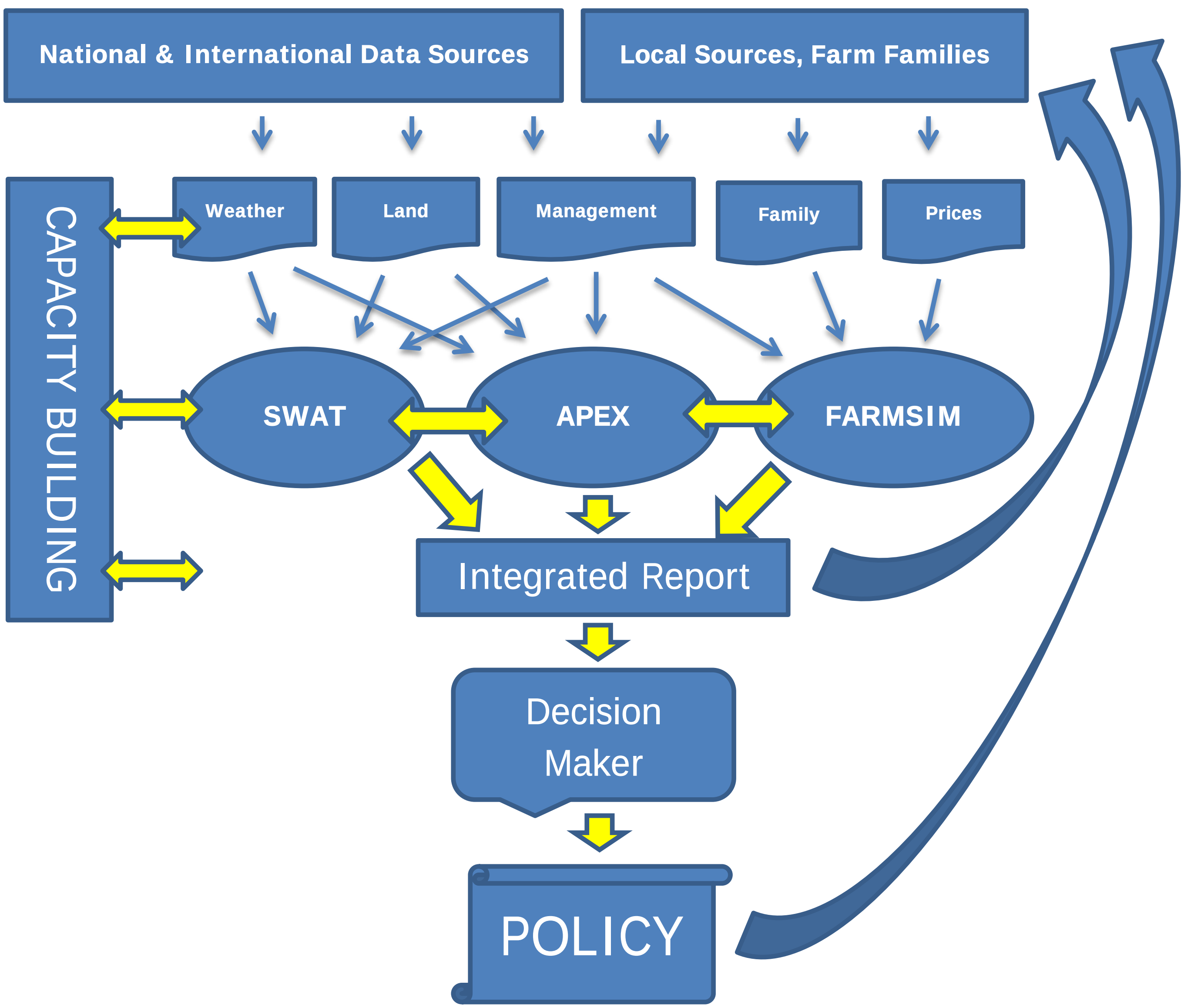


Figure 1. Information flows within the IDSS.