FEED THE FUTURE INNOVATION LABORATORY FOR SMALL SCALE IRRIGATION

Mid-Term Report, 2014-2016

Submitted to USAID on Behalf of:
Norman Borlaug Institute for International Agriculture,
The Texas A&M University System (Lead Institution)

International Food Policy Research Institute (IFPRI)

International Livestock Research Institute (ILRI)

International Water Management Institute (IWMI)

North Carolina A&T State University (NCA&T)

Texas A&M AgriLife Research

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Abbreviations:

ABM:	Agent-Based Model
AOR:	Administrative Officer's Representative
APEX:	Agricultural Policy/Environment eXtender
BDZ:	Bahir Dar Zuria
EC:	Ending Cash
FARMSIM:	Farm Scale Nutrition and Economic Simulation Model
FEAST:	Feed Assessment Tool
FGD:	Focus Group Discussion
FtF:	Feed the Future
IDSS:	Integrated Decision Support System
IFPRI:	International Food Policy Research Institute
ILRI:	International Livestock Research Institute
ILSSI:	Innovation Lab for Small-Scale Irrigation
IWMI:	International Water Management Institute
NCA&T:	North Carolina A&T University
NCFI:	Net Cash Farm Income
NPV:	Net Present Value
SNNP:	Southern Nations, Nationalities and Peoples
SPAM:	Spatial Allocation Model
SRI:	System of Rice Intensification
SSI:	Small-Scale Irrigation
SWAT:	Soil and Water Assessment Tool
WEAI:	Women Empowerment in Agriculture Index
WFD:	Wetting Front Detector

I. INTRODUCTION AND SUMMARY

Overview

The Feed the Future Innovation Laboratory for Small Scale Irrigation (ILSSI) is a five-year cooperative agreement between USAID and Texas A&M (key implementing entities at Texas A&M are the Borlaug Institute for International Agriculture and Texas A&M AgriLife Research) to provide a knowledge base for sustainable smallholder irrigation development. ILSII involves research in Ethiopia, Ghana and Tanzania. Texas A&M is the lead institution with partners from the International Water Management Institute (IWMI), International Livestock Research Institute (ILRI), International Food Policy Research Institute (IFPRI) and North Carolina A&T State University (NCA&T). ILSSI key partners closely collaborate with national universities and other partners in all three target countries.

ILSSI is conducting research aimed at increasing food production, improving nutrition, accelerating economic development and contributing to the protection of the environment. The primary components of this cooperative agreement are:

(1) identification of promising small-scale irrigation (SSI) technologies;

(2) assessment of impacts, tradeoffs and synergies of SSI technologies and practices;

(3) understanding of constraints and opportunities for up-scaling and improved access;

(4) capacity development, partnerships and engagement.

The following flowchart (fig. 1) provides a summary view of the five year cooperative agreement flow with the key steps that are being taken to ensure final products that are useful and usable with relevant national capacity to implement.

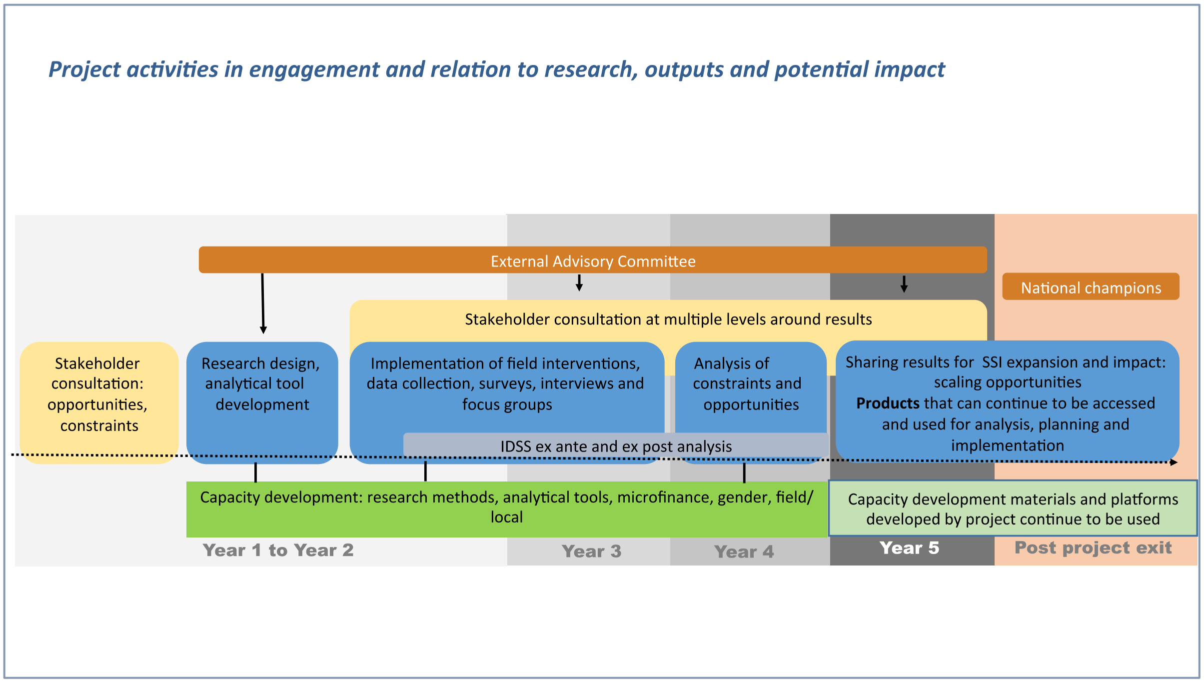

Figure 1: Project activities in engagement and relation to research, outputs and potential impact.

Mid-Term Report Structure

ILSSI has completed three years of the five year cooperative agreement. The fourth year continues field research, end-line surveys, and analyses as well as capacity building in all three target countries. The fifth year will involve completing studies, preparing an overall synthesis of results and an international meeting. With concurrence of the AOR, ILSSI prepared this mid-term report for the use of the upcoming External Review of the project beginning in early 2017.

This report is based on a large number of key reports and publications, which are referenced in this report for more detailed study. These reports are identified on each page of the report where they are referenced and can be consulted through the links provided.

The intent for this organization is to provide all readers with a relevant summary of the status of ILSSI at the end of its third year while providing a convenient link to more detailed information and data as specific interests and needs dictate.

Structure and Function of ILSSI

ILSSI is comprised of multiple components, which are highly interactive and linked in structure and function.

Structure: The following institutions comprise the management/implementation structure of ILSSI:

- **Management Entity (ME)**: The Borlaug Institute for International Agriculture at Texas A&M houses the management entity for the agreement. The ME plans and coordinates interactions between partners and components, and provides a synthesis of overall results.

- **The Integrated Decision Support Team (IDSS):** The IDSS Team at Texas A&M (multiple disciplines within Texas A&M AgriLife Research represented) develops and applies a suite of integrated models that evaluate small-scale irrigation interventions, including their environmental and economic consequences. Through collaboration with IFPRI, the potential, opportunities and constraints are assessed at local, regional and national levels.
- **The International Water Management Institute (IWMI) and the International Livestock Research Institute (ILRI):** IWMI and ILRI are CGIAR centers with multidisciplinary research faculty and staff located in ILSSI relevant countries. Using previous and current engagement with national counterparts, IWMI and ILRI provide leadership in field research, as well as engagement with stakeholders from farm to national level and have specific partnerships with national organizations (usually universities) that they are engaging directly to conduct ILSSI's research in farmer's fields using a research for development approach. They maintain local engagement and training of practitioners or users of ILSSI product. IWMI has been directly involved in recent studies of water management in the ILSSI countries and utilizes this experience and expertise in ILSSI research activities and analysis.
- **The International Food Policy Research Institute (IFPRI):** IFPRI, another CGIAR center, brings global experience to ILSSI in assessing the consequences of research, development, and policy implications on smallholder farms and institutions from farm to national levels. IFPRI brings a high level of expertise with accompanying databases for these assessments at regional and national levels. IFPRI is engaged in household survey collection, as well as upscaling of smallholder irrigation potential.
- **North Carolina A&T University (NCA&T):** NCA&T brings internationally proven conservation agriculture production system and drip irrigation to research on commercial kitchen gardens in the three ILSSI countries. The focus of this research is on female farmers whose products enhance household nutrition and contribute to income.

Functions*:* ILSSI has four major interrelated components to identify opportunities for developing small-scale irrigation: analyses and assessment, field studies, household surveys, and modeling. Drawing upon each of these four components, opportunities for detailed and integrated capacity development are identified and evaluated. The integration of the products of these component studies allows a holistic assessment of the potential, opportunities and constraints of the adoption of small-scale irrigation.

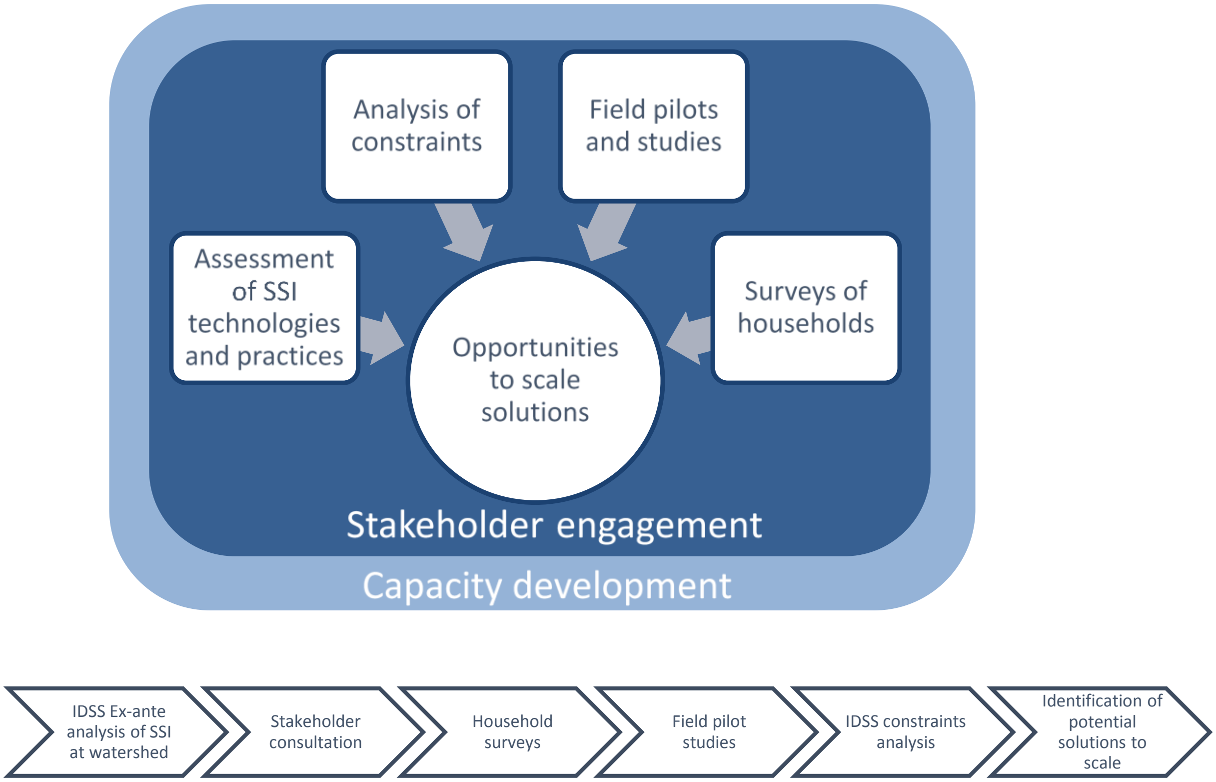

Figure 2: Key Functions of ILSSI

Assessment: An initial analysis of factors influencing the sustainable use of available natural resources, such as ground and surface water, soil, weather history, and estimates of the production and economic consequences of using small-scale irrigation systems was completed. Texas A&M conducted these **ex-ante studies** at watershed level to provide an estimate of the production, environmental, economic and nutritional consequences of small scale irrigation interventions in the study area using the Integrated Decision Support Systems (IDSS**) -** a suite of models comprised of SWAT, FARMSIM and APEX. This initial assessment, based on the best data readily available combined with expert opinions and reviews, shows where, and under which conditions surface and groundwater are available, the amount that can be sustainably used for irrigation, and land areas within the watershed suitable for the application of small scale irrigation technologies. The focus is particularly on the dry season when much of the irrigation would take place. Experts reviewed the product and assessed the consistency with experience and practice. IDSS can be used as a total system or a component part may be used separately to address specific questions.

Initial model results, from the ex-ante analysis estimate potential availability of water and other natural resource inputs to help locate research sites and estimated the consequences of equipment and management practices in advance of field studies. Primary data from field studies and the survey data inform calibration and validation for **IDSS ex-post analysis** and are the basis for developing suitable country, as well as site-specific, scenarios. The results from the scenario analysis contribute to the constraints and gaps analysis, in turn, highlighting opportunities for outscaling and adoption.

Stakeholder consultation and engagement: Stakeholders were engaged at the outset and on a continuing schedule over the life of the project to maintain the research for development approach utilized by ILSSI. Results were provided to stakeholders at the farm-village, regional and national levels and feedback and advice is sought on a continuing basis. Most recently, in June-July 2016, formal stakeholder workshops were conducted to seek inputs on needs and constraints relevant to the more promising small-scale interventions being studied under ILSSI. This consultation is being continued throughout the life of the project.

Field Research: Based on stakeholder consultation at multiple levels and in coordination with local leaders and farmers, a set of small-scale irrigation (SSI) interventions for vegetables, fodder and fruit trees is being piloted and studied in farmers' fields. Supporting quantitative and qualitative studies are carried out based on emerging constraints and issues identified with farmers. Multiple water lifting, distribution systems and farm practices at field level are being evaluated in collaboration with national university partners. The field interventions provide primary biophysical and socio-economic data on small-scale irrigation and the watershed.

Table 1: SSI Interventions by Site

Site	Small-scale irrigation interventions
Ghana	
Bihinaayili, Savelugu, Northern	Drip irrigation technologies, irrigation scheduling, vegetable and fodder testing
Zanlerigu, Nabdam, Upper East	Roof water harvesting, gardens, drip irrigation technologies, irrigation scheduling, vegetable and fodder testing
Dimbasinia, Kassena Nankana East, Upper East	Motor pumps in furrow irrigation, irrigation scheduling, vegetable and fodder testing
Ethiopia	
Dangila and Robit, Amhara	Pulley, Rope and washer pumps, irrigation scheduling, Restrictive layer (groundwater recharge) in Robit only, vegetable and fodder testing
Adami Tulu, Oromia	Motor pumps in furrow irrigation, Rope and washer, irrigation scheduling, vegetable and fodder testing
Lemo, SNNPR	Solar pump, rope and washer, service provider & drip, irrigation scheduling, vegetable and fodder testing
Tanzania	
Rudewa and Mkindo, Morogoro	Motor pump with furrow irrigation, irrigation scheduling, pocket gardens Drip irrigation (Rudewa), vegetable and fodder testing
Babati, Manyara	Fodder

Household surveys: Early in the ILSSI project, in the area surrounding the field study sites, household surveys were completed to provide a baseline for measuring project success and will be performed again later to evaluate the impact of the small scale irrigation interventions. These surveys assess the impact of irrigation on household income, nutrition and factors affecting the access to use of the technology by women and men farmers. Baseline household surveys of farm households have provided data on nutrition, economic status, adoption factors and gender. In years four and five, these surveys will be repeated to see if/how irrigation interventions have had an impact. These surveys are being enriched by a collaborative set of more in-depth surveys that focus on nutritional status of household members before and after the introduction of irrigation interventions sponsored by the FtF Sustainable Intensification Innovation Laboratory (SIIL), as well as by Focus Group Discussions.

Integrated opportunity and constraints analysis and scaling of results to regional and national levels: Smallholder farmers are typically constrained by a range of factors inhibiting SSI opportunities, including factors at different scales, from agro-hydrological and technical to social-institutional. Field and survey studies, along with stakeholder inputs to provide expert opinion and focus, are combined with other sources of local, regional and national data to provide integrated input to the IDSS, which in turn seeks best combinations of strategies, inputs, farming practices as applied to the use of small-scale irrigation interventions. Production, environmental and economic consequences are considered in the integrated product. The IDSS modeling suite is combined with national level models developed by IFPRI to produce an estimate it the results of small-scale irrigation interventions at scales up to the national level. This allows the ILSSI product to be evaluated by decision makers in government and private sector at multiple levels of scale relevant to their decision needs. Research results were used to initiate discussions on constraints in stakeholder workshops held in all three ILSSI countries. These workshops produced prioritized lists of constraints serving as inputs to the subsequent analysis of the impact and their mitigation, which are now underway. This methodology allows for assessment of results at the level of the FtF innovation zones.

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Capacity development: Capacity development is continuous throughout the ILSSI project. At farm level, ILSSI provides training and learning support to farmers and local stakeholders, such as extension agents and microfinance cooperatives. ILSSI also collaborates with national university partners, involving students in field research, engagement with farmers, collecting relevant data, and obtaining feedback from farmers on technologies and practices. Students and faculty design theses problems and analyze field data relevant to ILSSI objectives. At the research and planning level, ILSSI trains stakeholders in universities and institutions in the design and utilization of household survey instruments and IDSS. Additionally, graduate students and faculty are involved in field studies, mentored in research methods, and trained to use IDSS. Based on the capacity developed in each country and databases created, stakeholders will be enabled to use IDSS to address specific development scenarios or questions related to individual elements of the natural resource environment and the production system after the project.

II. RESEARCH PROCESS AND INTEGRATION: DATA AND METHODS

This section of the Mid-Term Report describes key methods, tools and data generated under ILSSI. Results from these instruments are presented in Section III.

A. Research in farmers' fields

Research at farmer field level focuses on understanding the biophysical and socio-economic opportunities and constraints of water lifting and water management technologies across various agro-ecological zones. The field research was designed to respond to knowledge gaps identified during stakeholder consultation workshops held at the onset of the project in 2014[1] [2] [3], as well as previous studies on technologies in the project countries.[4] The research includes piloting technologies and practices with farmers, and collecting and analyzing data from the field, household, watershed and markets to understand potential and boundaries for scaling. The research design focuses on understanding how water is used and can be more effectively and efficiently used (per input labor, income, land), understanding fertilizer uptake, and comparing water lifting technologies in terms of labor, gender, etc.[5] [6] [7] In addition, intervention packages test various forms of finance for SSI technologies and include regular training and support for agronomy and agricultural water management practices. Appendix 1 provides a summary table of field level interventions for each site and country.

Site selection, as well as identification of participating farmers, followed a transparent process according to set criteria related to water access, availability, willingness to irrigate and take up credit for a specific technology.[58] Farmers joined the research activities voluntarily, with a targeted 50-percent participation of women.

ILSSI engages with farmers regularly in the field and seasonally at farmer forums. Farmers were trained to keep records of their farming and irrigation practices related to the study. Research is supported by national research institutes' students and staff who collect scientific data from the fields and the farmer field books at each site.

Prior to the implementation of field level pilots, an Environmental Monitoring and Mitigation Plan (EMMP) was established for each site to ensure sustainable implementation of the technologies and compliance with country-specific environmental practice.[9] [10] [11] Local partners and the farmers in the intervention communities were informed about potential environmental issues and provided their agreement to comply with practices identified to reduce potentially negative impacts.

ILSSI collects data using standardized sheets to ensure homogeneity across sites and countries to enable cross-site and cross-temporal analysis.[12] Biophysical and socio-economic data collection are summarized

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[1] Stakeholder consultation proceedings Ethiopia
[2] Stakeholder consultation proceedings Tanzania
[3] Stakeholder consultation proceedings Ghana
[4] Ag Water Solutions
[5] Research Design Ghana
[6] Research Design Ethiopia
[7] Research Design Tanzania
[8] Description of the process of consent of farmer participation
[9] Experimental Design Mitigation & Monitoring Plan - Tanzania
[10] Experimental Design Mitigation & Monitoring Plan - Ghana
[11] Experimental Design Mitigation & Monitoring Plan - Ethiopia
[12] Field Book For Collection of Agronomic Practices

in Appendix 2. Data on the irrigated field pilots and watershed monitoring are stored in excel databases and submitted to the IWMI data-portal after quality control to be shared with ILSSI project partners and made available as public goods.

While water quality was not part of the initial ILSSI proposal, the project has added various water quality tests for different sites, based on key issues often emerging in the intensification process of smallholder agriculture and uptake of SSI. In addition to nutrients, salinity, and heavy metals, water is tested in Ghana for E Coli contamination that might affect health and therefore, nutrient absorption, and in Ethiopia for specific pesticide contamination. Water quality testing, residual concentration in soil and occurrence in plant tissue of irrigated crops using water resources, as such, is on-going in the field intervention watersheds to understand the potential environmental impact of current practices and the risk for intensification of irrigated vegetable and fodder production and also the potential impact of expanded irrigation on health and nutrition.

B. Field-based monitoring and assessment

i. Household surveys

IFPRI has conducted baseline household surveys in Ethiopia, Ghana, and Tanzania for ILSSI intervention villages, as well as other farmers in the vicinity of the ILSSI intervention sites.[13] [14] The Ghana and Tanzania questionnaires follow the same format as the Ethiopia questionnaire, but have minor response code changes.

ILSSI is using the Women's Empowerment in Agriculture Index (WEAI) to measure the relationship between women's empowerment and irrigation and how women's empowerment influences nutrition outcomes. The WEAI is a survey-based tool, asked of both the main male and female decision makers in a household, used to determine inclusion of women in domains important to the agricultural sector. It takes approximately 40 minutes to complete.[15]

As a response to an emerging knowledge gap, IWMI and national partners in Ethiopia developed an additional research protocol[16] [17] in 2015 to address specific questions on profit, finance and credit for irrigation, and market prices. The survey was implemented in 2016. The data from that survey supplements what is collected at field and household level to assess and project potential profitability comparing different technologies and crops. The microfinance data, in particular, enables analysis of credit access, capacity, risk and perceptions, and contributes toward assessing the extent to which access to credit to finance investments in irrigation influences adoption of technologies by smallholder farmers. The data also contributed to the formulation of a model to measure risk uncertainty, which would support the private sector in decision-making for small-scale irrigation investments. Market price information during the irrigation season is also collected bi-weekly.

ii. Focus Group Discussions (FGDs)

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[13] Sampling Strategies of ILSSI Baseline Surveys and Key Modules
[14] ILSSI/IFPRI Study on Irrigation, Gender, and Nutrition: Ethiopia Household Questionnaire
[15] Women's Empowerment in Agriculture Index Questionnaire
[16] Interview instruments for microfinance research protocol
[17] Survey on socio -economic and credit service for small scale irrigation (SSI) - Household questionnaire

ILSSI utilized focus group discussions (FGDs) with communities at the sites of field interventions as well as control sites in Ethiopia, Ghana, and Tanzania. The aim was to deepen engagement with communities and augment survey-based and biophysically-oriented research.

Two sets of focus group protocols were implemented between 2014 and 2016: one focusing on irrigated fodder potential, and the other on linkages between gender and irrigation technology adoption, use and benefits.

ILRI implemented focus groups in project sites in Ethiopia to better understand the level of demand for fodder, the types of fodder available and preferred, the livestock for which fodder would be most appropriate, as well as perceived market potential for irrigated fodder.[18]

IWMI and IFPRI collaborated on the second set of FGDs to qualitatively assess gendered issues around small-scale irrigation[19] [20] with linkage to the WEAI.[21] [22] The focus group guidance questions sought to assess gendered, intra-household preferences for water technologies and how technologies respond to existing needs, roles, and responsibilities, as well as to understand the distribution of benefits from adoption of SSI technologies at the household level.

iii. Livestock surveys

Farmer feed, forage demand, and forage preferences were obtained through a structured interactive process involving researchers, development agents and farmers and facilitated, documented and evaluated by the application of the Feed Assessment Tool (FEAST) developed by ILRI [23] [24], which was applied in Ethiopia, Tanzania, and Ghana [25] [26] [27] [28] [29]. The design of the irrigated forage trials in the three countries were based on, and derived from, FEAST results and syntheses.

The potential impact of planted and irrigate forages on livelihoods was estimated by selected livestock productivity trials but more widely by application of bio-energetic relationships routinely used in livestock nutrition. These relationships were developed from forage yields, forage fodder quality as estimated in the ILRI livestock nutritional laboratory, animal live weight and its maintenance requirement and efficiency factors of feed conversion into meat and milk.

Livestock water productivities were estimated by associating water input for irrigated fodder with meat or milk production from it and from the economic return to meat or milk.

iv. Watershed level instrumentation and data collection

[18] Focus group discussion with participants of irrigated fodder
[19] Instructions for Implementation of FGDs in Ethiopia, Ghana and Tanzania
[20] ILSSI approach to gender as a cross cutting issue
[21] Women's Empowerment in Agriculture Index - Resource Center
[22] Gender - Focus group discussion guidance
[23] Feed Assessment Tool
[24] Cross regional comparison of FEAST results in Ethiopia, Tanzania and Ghana
[25] Assessment of Livestock Production and Feed Resources at Robit Bata, Bahir Dar Zuria, Ethiopia
[26] Assessment of existing and potential feed resources for livestock production in the Northern Ghana
[27] Report of Feed Assessment for Rudewa Village - Kilosa District
[28] Report of Feast Assessment in Babati District Manyara Region
[29] Assessment of livestock Production and Feed Resources at Kerekicho

The field data/empirical data collection at the watershed scale focuses on understanding key hydrological processes (e.g. groundwater recharge, surface water availability) and to gather information on water availability in all watersheds. A summary table of instrumentation and data collected for watershed level analysis can be found in Appendix 3. This research serves to understand and quantify the various water resources available at the watershed scale. Additionally, sediment fluxes and quality is assessed in some watersheds: Robit, Dangila, Lemo, Rudewa, Mkindo, and Bihinaayili. The data is used by SWAT and APEX to analyze environmental boundaries for expansion of irrigated area and/or intensification of irrigation on existing land area. Most intervention farms in the different sites fall within the Robit watershed in Ethiopia and the sub-basins of the White Volta in Ghana. The size of the watersheds ranges between 7 and 50 km^2 in the various countries. Information on soil, land use and other maps available for the selected watersheds has been collected from national institutions and/or previous IWMI projects. As with the field level pilot interventions, data is collected from the watershed by IWMI researchers, as well as students and staff of national research institutions.

Moreover, in response to stakeholder requests, ILSSI will carry out water abstraction surveys at the watershed level to identify the amount of water used for livestock, domestic use and irrigation in both the dry and rainy seasons.

C. Integrated Modeling: from interventions to national level

The Integrated Decision Support System (IDSS) is a suite of proven, interacting, and spatially explicit agroecosystem models: the Soil and Water Assessment Tool[30] (SWAT); the Agricultural Policy/Environment eXtender[31] (APEX); and the Farm Scale Nutrition and Economic Simulation Model[32] (FARMSIM). Together, these models predict short and long-term changes in production of crops for people and livestock, farm economies, and environmental services produced by changing land uses, agricultural technologies and policies, climate, and water resources management.

The flow of information and analysis to and from the IDSS is iterative in nature. Data obtained from literature and local experts, as well as from field research and applicable field-based monitoring (e.g., household surveys), discussed above, were input into the IDSS component models and used to generate "baseline" models of the current farming systems at each ILSSI study site and to identify proposed SSI interventions for evaluation at each site.

The IDSS team then conducted ex-ante analyses of each study site, comparing the current farming system at each site to alternative farming systems that included the proposed SSI interventions. In the ex-ante analyses, SWAT was used to simulate watershed-scale hydrology and soil erosion at the sites to examine the effects of 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; and FARMSIM was used to determine the effects of the proposed SSI interventions on farm family livelihoods and nutrition. The completed ex-ante analyses provided ILSSI with an assessment of the feasibility of SSI at each site and the relative merits of the proposed SSI interventions; they also identified constraints or limitations for the use of these systems, and issues (or "gaps") requiring further research. The data and methods used in the ex-ante analyses are described in greater detail in national and regional reports.[33] [34] [35]

[30] SWAT-Soil and Water Assessment Tool.
[31] APEX: A new tool for predicting the effects of climate and CO2 changes on erosion and water quality.
[32] Evaluation of new farming technologies in Ethiopia using the Integrated Decision Support System
[33] Ex Ante Analyses - Small-Scale Irrigation Applications for Smallholder Farmers in Ethiopia

Following completion of the IDSS ex-ante analyses, ILSSI solicited stakeholder input on the gaps and constraints identified in the ex ante analyses at a series of stakeholder meetings.[36] At these meetings, stakeholders produced a collaboratively prioritized short list of constraints specific to each country, based on their knowledge and experience and institutional interests and priorities. ILSSI has begun analyzing these prioritized lists of constraints, with the goal of producing context-specific proposals for mitigation. Additional details on the data and methodology of these assessments can be found in ILSSI's report on the completed gaps and constraints analysis for SSI systems in the Robit watershed.[37]

Throughout the project, ILSSI has continued field research and monitoring activities as described in Sections II.B-D. Collected data from more recent local field studies and surveys may reinforce or, for various reasons (such as the site-specific nature of field studies versus the broader scope of the IDSS simulations) conflict with modeled results. As part of the iterative modeling process, the results of subsequent field studies and monitoring activities (including stakeholder input on gaps and constraints) will be incorporated into ex post analyses of the proposed SSI interventions, to refine previous results and ultimately identify the optimal SSI farming system for each site.

After completing analyses of proposed SSI interventions at the study sites, ILSSI assesses the potential for expanding SSI in the project countries, as well as the impacts of large-scale implementation of SSI on biophysical factors (e.g., crop yields), environmental sustainability, and economic and family welfare in the project countries. The assessment of SSI adoption decisions at the national scale is complex. For example, while crop prices may be treated as constants in cost-benefit analyses at the local level, they must be treated as variable when evaluating SSI investments at the national scale. Moreover, SSI development is, by its nature, generally a decentralized process involving multiple individual decisions at the farm level. Decision makers, while independent, may nevertheless influence each other.

The upscaling framework developed by the ILSSI partners, illustrated in Figure 3 and detailed in a summary report available for review,[38] integrates several modeling tools and biophysical and socioeconomic data to address such complexities. In the pre-suitability analysis, selected environmental criteria (e.g., climate, terrain, population) are weighted to score land suitability for irrigation development. The land suitability scores are used to establish the suitability domain for SSI, an initial estimate of the geographic areas in which irrigation adoption could occur. Reports detailing the methodology for assessing irrigation potential and land suitability, as applied in Ethiopia, are available for review.[39] [40]

The team then introduces economic and water balance considerations into the simulation to determine the likely scale and pattern of SSI development across the nation using an agent-based model (ABM) for simulating irrigation expansion. The ABM defines farmers as autonomous agents to explicitly evaluate multiple farm-level irrigation technology adoption decisions—a realistic representation of the decentralized dynamics of SSI development.

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[34] Ex Ante Analyses - Small-Scale Irrigation Applications for Smallholder Farmers in Tanzania
[35] Ex Ante Analyses - Small-Scale Irrigation Applications for Smallholder Farmers in Ghana
[36] Stakeholder Consultation Workshop Report: Ethiopia, Ghana, Tanzania
[37] An example of gaps and constraints analysis for small scale irrigation systems in the Robit watershed
[38] scale up of biophysical and environmental analysis of proposed sci interventions summary of-aims timelines methodology and progress
[39] Assessing irrigation potential and land suitability in Ethiopia
[40] Assessing potential land suitability for surface irrigation using groundwater in Ethiopia

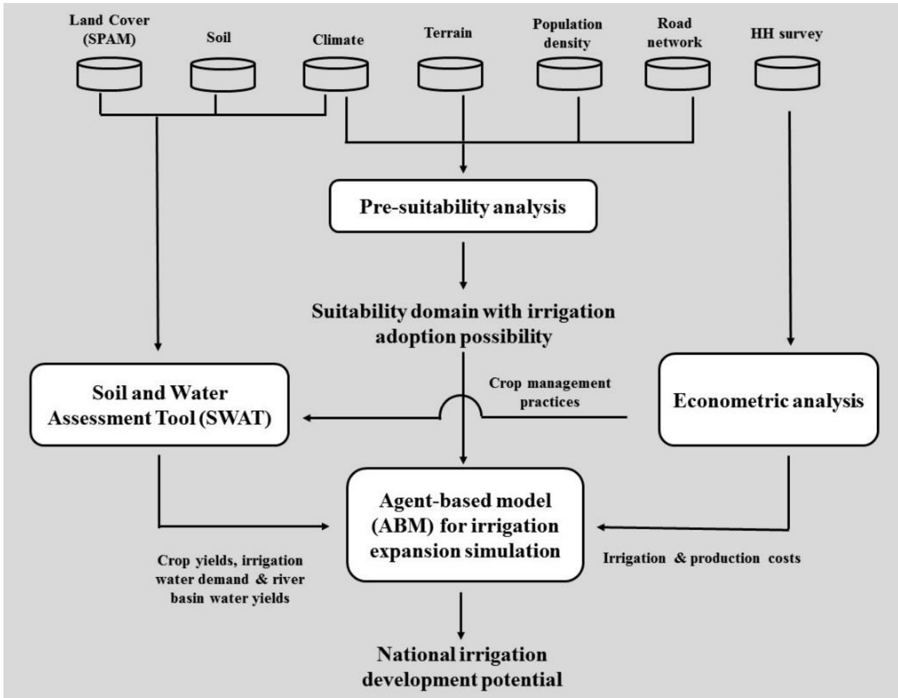

Figure 3. Methodological framework for assessment of national SSI development potential

D. Cross country comparisons and conclusions

When the study is completed, stakeholders will have access to a comparison of the utility of multiple SSI systems across the three ILSSI countries as well as to quantitative estimates of the constraints on the use of these systems and strategies for mitigation. The modeling capacity and databases will allow stakeholders to use one or more or the entire suite of IDSS models to address specific scenarios or questions. The ability to concurrently assess the production, economic, and environmental consequences of the interventions under consideration will provide a new, integrated capacity for analysis to inform strategies and specific applications.

III. SUMMARY OF RESULTS

A. Summary of research on Small-Scale Irrigation by country: evidence from the field

The field interventions proceeded in Ethiopia for two irrigation seasons (2014, 2015) and one irrigation season in Ghana and Tanzania (2015). Interventions for the first three years showed that the transition between rainy and dry season crops poses challenges to farmers; it requires new practices in the management of water resources and irrigation scheduling, management and maintenance of technology, and decisions for on-farm irrigation roles with labor constraints. As such, some pilot farmers experienced losses in the first season of field interventions. ILSSI worked with farmers across the countries to improve production in the upcoming dry season. This sub-section outlines preliminary results from past seasons based on data available.

Results of field studies have in some instances (e.g., with regard to shallow groundwater availability in certain areas) differed from modeling simulation results (discussed in Section III.C.), and in some instances reinforced these results or provided additional data for analysis (e.g., with regard to farmer preferences for certain water-lifting technologies). Field data will be incorporated into "ex post" modeling simulations, to refine previous modeling results and ultimately identify the optimal SSI farming system for each site.

1. Availability of water resources:

Water availability and suitability, particularly in the context of climate change, is a critical requirement for expanding SSI. There is extensive interest in shallow groundwater (i.e., 0 – 25 m) for irrigation development, but there has been a lack of high resolution information for shallow groundwater potential across most of sub-Saharan Africa. In response to stakeholder demand in Ethiopia and Ghana, studies are being carried out to understand and quantify groundwater recharge at ILSSI sites in order to better analyze the potential for sustainable intensification using shallow groundwater with SSI. In Tanzania, the focus for SSI development is on the sustainable use of surface water in the Wami-Ruvu Basin.

Field data collected in Ethiopia (2014-2015) suggest potential for SSI expansion with shallow groundwater is limited by recharge levels under current rainfall and land use conditions. The availability of shallow groundwater has strong spatio-temporal variability across watersheds[1] [2] [3] [4] Estimated crop water requirements, recharge rates, and therefore groundwater availability, suggest that the groundwater resources alone might be insufficient in many upper watershed locations but might meet crop requirements at foot slopes. Modeling results for certain study sites (discussed in Section III.C. and F.) vary, possibly because the model simulations consider a larger area than the field trials. Field data will be incorporated into ex post analyses to refine modeling results. These local observations are complimentary to the larger study modeling water availability at the country level, which is reported in a following chapter of this report.

In Ghana, field studies indicate that the underlying aquifer in the Upper East Region of Ghana (two of the project watersheds, Navrongo and Zanlerigu) stores around 1290 mm, but currently only 0.02% is used for irrigation. At the same time, all ILSSI sites are proximate to reservoirs with shallow groundwater downstream (< 3 m). An initial trend analysis using data from 1981 to 2014, showed increasing rainfall in all three watersheds under the study, but also increasing variability during the rainfall season. While shallow groundwater utilization show potential for SSI expansion, the effect of reservoirs on shallow groundwater recharge is being assessed in the project to further understand availability for SSI over the medium to long term.[5] Modeling results for the Ghana sites (discussed in Section III.C.) have revealed both potential for and several constraints on increased SSI. Field data will be used to refine modeling results.

The two watersheds in Tanzania (Mkindo and Rudewa) have been instrumented and data collection is ongoing to assess suitability and availability of surface water for SSI.

2. Water lifting and water management

Ethiopia: Initial research results from field piloting show promise for some SSI technologies to improve production and incomes, but with a strong variation between farmers on results from use of technologies,

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[1] Field level pilot interventions in small-scale irrigation and agricultural water management

[2] Rainfall Run Off Process in the Upper Blue Nile Basin: The Case of the Dangishta Watershed

[3] Insights and Opportunities from New Field Studies with small scale irrigation in Tanzania, Ghana and Ethiopia

[4] Determining groundwater potential for small scale irrigation in the Ethiopian Highlands (Journal paper: draft)

[5] Agro-climatic and hydrological characterization of the selected watersheds of northern Ghana.

as well as their perception and preference. During the first year of implementation, the ILSSI project assessed, among other things, the performance of manual water lifting technologies and irrigation scheduling methods under groundwater irrigation on crop and water productivity of vegetables and fodder varieties, as a way to demonstrate and provide evidence of use of small-scale irrigation appropriate technologies and practices to increase agricultural production and improve livelihoods of smallholder farmers. Two key factors identified from the first year are labor and groundwater sustainability.

In summary[6], performance of manual water lifting technologies tested depended on well depth, water availability, and frequency of maintenance and repair issues. Rope and washer pumps had more frequent maintenance and repair issues in some sites plus the flow rate of the rope and washer pumps generally decreased with increasing well depth. These factors affected the amount of water lifted by the rope and washer pumps, thus affecting yield production and water productivities. For pulley with storage tank systems, a gradual increase in flow rate was observed with increase in well depth. No issues were reported in any sites with the pulley systems. The amount of water applied using these manual lifting technologies generally decreased with increasing irrigated plot area due to increasing labor, time, and water requirements needed to irrigate a bigger plot adequately. Soil moisture level or amount monitoring helped guide especially farmers new to irrigation on when to irrigate and how much water to apply. Timely water applications improved yield and water productivity of the various crops in the various sites, and also limited water losses.

There is an overall increased labor required for manual lifting devices[7]. Furthermore, the technical efficiency of male and female irrigators for different crops showed that where the irrigation period and number of irrigation applications needed during the season increased (e.g. tomato), female farmers had a lower technical efficiency [a.] compared to male irrigators; male irrigators experienced only minimal differences in technical efficiency across the various crops. The constraints of labor are further shown in the field interventions, as some farmers using manual lifting requested different technologies or have withdrawn from the project. In addition, an Africa RISING survey[8] in shared field sites with ILSSI showed that the majority of farmers prefer a solar pump installed near the household for multiple uses. This reduces labor time required for water collection for multiple uses. In sum, the potential for a technology to simultaneously reduce labor for on-farm irrigation and for domestic water lifting may increase the likelihood for sustained adoption.

Field results on the profitability of various water-lifting technologies generally confirm simulated results in the IDSS ex ante analyses, discussed in Section III.C, which showed that manual water-lifting technologies (such as pulley irrigation and hand-operated rope-and-washer pumps) were less profitable than other tested technologies. Farm-scale economic modeling indicated that, at all four sites, implementation of the proposed SSI interventions using gasoline motor or animal-powered pumps would produce the highest net present value (NPV), net cash farm income (NCFI), and ending cash (EC) reserves of all the scenarios simulated.[9] Data gathered in the field studies will be used to refine modeling results in IDSS ex post analyses.

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[6] Testing appropriate smallholder irrigation technologies for increased and sustainable agricultural production in Ethiopia.

[7] Field level pilot interventions in small-scale irrigation and agricultural water management

[a.] The technical efficiency measured is the actual production of what the farmer produced compared to what he/she could potentially produce given a specific set of inputs.

[8] Gender and water technologies (2016).

[9] Ex Ante Analyses - Small-Scale Irrigation Applications for Smallholder Farmers in Ethiopia

In addition to labor constraints, another critical factor is ensuring sustainable use of shallow groundwater. Groundwater resources are limited and need to be used efficiently on the field to ensure increased production alongside sustainable intensification. Therefore, ILSSI introduced the Wetting Front Detector (WFD) in the field interventions as a tool for farmers to manage irrigation scheduling. WFD show farmers when to increase water consumption to be most effective. Trials of irrigation scheduling tools suggest that this can increase on-field water use by 30 % at critical growth stages using the WFD, but also double crop yield, resulting in more yield for water used. Farmer decisions on irrigation frequency and amount appears correlated with labor availability; farmers that lack mechanized water lifting under-irrigate and farmers with mechanized water lifting over-irrigate because it saves them time to simply flood fields. At the same time, irrigation scheduling trials showed that improved production can also deplete soil nutrient balances, so improved irrigation scheduling should be accompanied by recommendations to farmers on nutrient management to both ensure soil health and support higher yield levels.

In Ethiopian trials on irrigated fodder[10], crop coefficients were established for Desho, Napier and oats and vetch mixture, three fodder species that are currently being irrigated. The characterization of the crop coefficients will aid in improved crop water requirement estimations for the species across Ethiopia. The scheduling of fodder species (Desho and oats and vetch) resulted in an increase in vetch and Desho grass, but not in oats.

Data gathered in the field studies on the yields of various crops with implementation of WFDs and irrigation scheduling will be used to refine modeling results in IDSS ex post analyses.

Despite variation between farmers, irrigation does offer potential for improved income and improved household consumption, based on an economic analysis of 233 rainfed and 166 irrigating farmers in the project areas[11]. Input, production and labor costs per hectare are significantly higher in irrigated agriculture as compared to rainfed agriculture (Figure 4), but annual income (both agriculture and non-agricultural) and consumption/expenditure of irrigators is significantly higher than that of non-irrigators (Figure 5). Likewise, the contribution of agriculture to annual income of irrigation users is higher than that of non-irrigation users.

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[10] Testing appropriate smallholder irrigation technologies for increased and sustainable agricultural production in Ethiopia.

[11] Comparative analysis of the poverty impact of access to smallholder irrigation technologies: Ethiopia

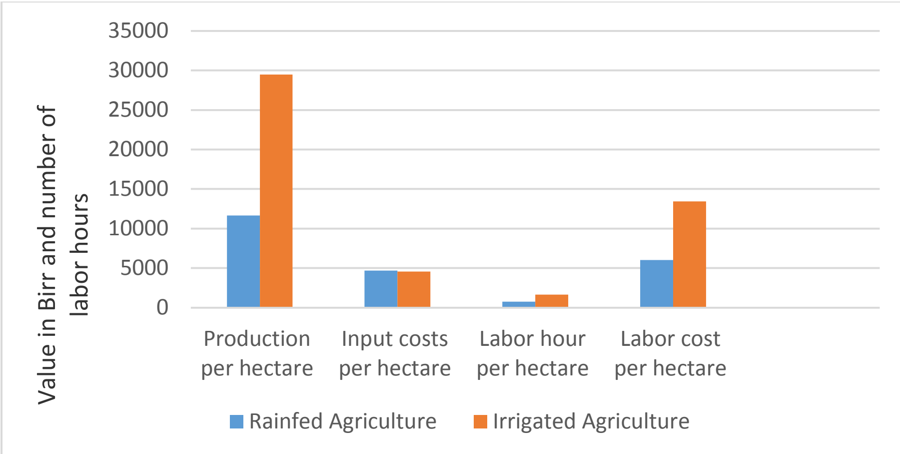

Figure 4: Mean comparison of production and input use per hectare of irrigated and rainfed land

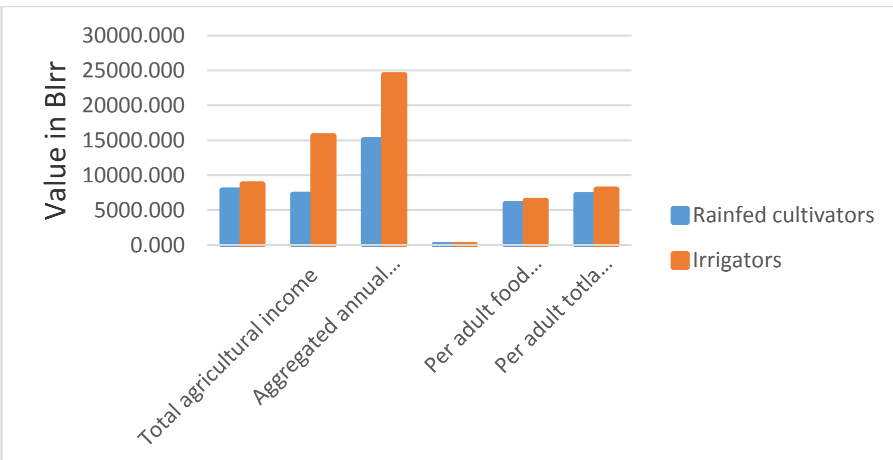

Figure 5. Mean comparison of income and consumption of Irrigators and rainfed only households

Field data on the effects of SSI on production and economic outcomes generally confirm simulated results in the IDSS ex ante analyses, discussed in Section III.C, which showed that SSI (especially when combined with increased fertilization rates) increased yields of both the irrigated dry-season crops and the rainy-season grains significantly, and that implementation of SSI (particularly when using gasoline motor or animal-powered pumps) was more profitable than the non-irrigated scenario.[12] Field calculations and IDSS simulations of yields and profits vary, as the model simulations consider a larger area than the field trials and also considered additional water-lifting technologies. Field data will be incorporated into ex post analyses to refine modeling results.

Ghana: In the first irrigation season, male and female farmers preferred motorized pumps (petrol or diesel) to reduce labor time and physical effort required. ILSSI piloted two types of drip irrigation with water lifting and varied water sources: one designed by the University for Development Studies (UDS) that can be locally sourced and assembled but had never been piloted with farmers, and the other an

[12] Ex Ante Analyses - Small-Scale Irrigation Applications for Smallholder Farmers in Ethiopia

imported kit. First season results provided preliminary suggestions.[13] First, between the drip systems tested, the UDS design is more robust and easier to use than the imported drip system, though may be more labor intensive, and thus increase on-farm costs. More generally, adoption of drip systems may depend on labor availability. Preliminary results showed that farmers with perceived ample water availability and mechanized water lifting technologies tend to by-pass on-field application systems because flooding fields reduced labor required. In areas with lower water availability, farmers tended to under water, because they needed to extend the water that had been stored in order to reduce labor required to collect water for domestic purposes. Therefore, underwater and overwatering, which negatively affected yields, appears to relate to labor and water availability.

A cost-benefit analysis conducted for one site assessed labor requirements and profitability with preliminary results showing that labor accounts for most of the cost of irrigation and capital investment in motorized water lifting technologies (i.e. petrol pumps) only minimal. A comparison across crops and both 'traditional' watering [a] and petrol pump irrigation suggested that some commonly irrigated crops may not be optimal for profitability, e.g. the profit/cost ratio increased more significantly for corchorus than for onion under irrigation.[14] In addition, women farmers report that growing vegetables enables them to save money and time, as they are customarily responsible for purchasing the 'relish' (i.e. vegetables) to add to meals.

Table 2: Cost-benefit analysis of irrigation field trial in Bihinaayili

Crop and system	*Total cost (US$)*	*Yield (kg/ha)*	*Total revenue (US$/ha)*	*Break-even yield (Kg/ha)*	*Gross margin (US$/ha)*
Onion (traditional)	788	1,439	1,226	924	438
Onion (improved)	810	1,543	1,315	951	504
Corchorus (traditional)	446	6,738	2,660	1,131	2,214
Corchorus (improved)	453	9,421	3,719	1,147	3,266

Data collected in the field trials (e.g., data on the labor requirements, costs, and yields associated with varying water-lifting technologies and crops at each of the field sites) will be incorporated into IDSS ex post analyses to refine the modeling results discussed in Section III.C.

Tanzania: A first cost-benefit study for irrigated African eggplant, tomato, and maize using motorized pumps was conducted in ILSSI sites, showing profitability for all crops but with variation. The evaluation of the first season of irrigation showed some farmers adopted motor pumps for small scale irrigation, but

[13] Technical and socio-economic consideration for dry season small-scale irrigation in northern Ghana.
[a] In this case, traditional means use of buckets and/or watering cans and manual lifting and carrying from a water pond or reservoir.
[14] Assessment of the profitability of dry season irrigation technologies for smallholder farmers in Northern Ghana

others preferred to continue to use buckets and not adopt new water lifting technologies. Non-adoption of mechanized water lifting was not anticipated, and research is on-going to understand the reasons why farmers do not adopt mechanized technologies available. In addition, homestead gardens introduced to female farmers showed profitability and they increased pocket bag production in the subsequent season. Women reported that they reduced their trips to the market for buying vegetables. Finally, Water User Associations have been formed in two study case sites to facilitate sustainable water resource management at both community and watershed level'[s]

3. Water quality:

Water quality has emerged as an important issue with intensification of smallholder agriculture and uptake of SSI. ILSSI tests existing water sources that are being used by farmers in the field pilot sites, as well as other points in the watershed.

Ethiopia: ILSSI tests irrigation water sources for specific pesticide contamination to understand the potential environmental impact of current practices. Testing of residual concentration in soil and occurrence in plant tissue of irrigated crops is on-going. In the Rift Valley, ILSSI is monitoring groundwater is to assess seasonal changes and groundwater suitability for crop production related to soil fertility and salinity.[15]

Ghana: ILSSI tests irrigation water sources for nutrients, salinity, and heavy metals, as well as E Coli contamination that might affect health and therefore, nutrient absorption. The data for the watersheds showed that water from existing wells, reservoirs and rivers is of good quality for irrigation and could be used for expanding small- and medium scale irrigation in the selected catchments. However, nearby areas had elevated levels of Fe, justifying the need for monitoring water quality and identifying remediation measures. Water quality related to domestic purposes is less suitable, as E Coli is present in most of the water sources. Though not the result of intensification or increased irrigation, many water sources are used for both irrigation and domestic purposes, and contamination could counter gains that otherwise would be achieved for health and nutrition through SSI.

4. Microfinance and credit for SSI technologies

Stakeholders at multiple consultations have stated that a fundamental barrier for SSI at household farm level is the capability of individual or groups of farmers to provide for initial investment costs for the SSI technology. ILSSI is now exploring different repayment schemes across sites as an emerging research issue toward identifying high potential micro finance solutions for SSI. In Ethiopia, ILSSI worked with local cooperatives mandated for microfinance lending to provide the water lifting technologies on credit. Cooperatives in Ethiopia generally do not have repayment terms favorable to SSI technology lending and capacity of the cooperatives for management of small loans is low. In addition, farmer capacity for saving and repayment for SSI technologies was also assessed by the project as low, requiring a series of trainings to cooperatives and farmers on lending, saving and repayment.[16] However, repayment rates appear to be as low after the second season[17] [18] and requires more in-depth study. In a different arrangement in Ghana, tanks and pumps were purchased by the project and farmers agreed to repayment beginning in season one. Payment based on production volume began on motorized pumps in the one area that was not affected by

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[15] Agricultural Water Management under Small Holder Irrigated Farms and its Impact on Soil fertility and Nutrient Management

[16] ILSSI Report: Financial Literacy Trainings

[17] ILSSI Ethiopia: Technology Loan repayment in Amhara region - Ethiopia

[18] Issues with irrigation technologies and credit arrangements - in Jawe and Upper Ghana

extreme weather events. The Tanzania pilot was developed by farmer groups in the two sites and differs substantially from the credit arrangements in Ethiopia and Ghana. Farmer groups charge for pump use at rates variable by location and group or non-group membership.[c.] ILSSI continues to monitor the various credit arrangements across the sites to identify good practices that could increase access to and improve repayment for small loans for SSI technologies.

5. *Irrigated fodder*

Allocation of irrigated land can be seasonal with vegetables or crops in the same planting year, and perennial that is forage is established to last for several years. Forages can be classified as those that primarily provide energy (grasses) and those that provide significant amount of protein in addition to energy (legumes). Combinations of annual and perennial grasses and legumes were investigated in all three countries. Data collected in the field trials (e.g., data on the labor costs and yields of the different forage crops at each of the field sites) will be incorporated into IDSS ex post analyses to refine the modeling results discussed in Section III.C.

Ethiopia: In Ethiopia the project chose a mixture of oats and vetch for annual cropping and Napier and Desho for the second cropping pattern. To increase management forage options and increase forage yield, multi-cut oat and vetch trials were implemented in the third year. Both forage yield and forage quality data were obtained to calculate meat and milk yield using well- established bio-energetic relations. Thus irrigated one-cut oat-vetch cropping on 100 m^2 of would result in either 47.2 kg of meat or 280 kg of milk. In the 3rd year of the project multi-cut oat and vetch management resulted in significantly increased yield and time period during which the mixture is available. Allocating the same area i.e. 100 m^2 to Desho would result in 24.5 kg of meat and 163 kg of milk, respectively. The yield of first-cut Napier was very low (2.2 tons per ha) resulting in an estimated 5.4 kg of meat and 32 kg of milk. This was set up to allow calculations of milk and meat production with additional information, for example Napier and Desho yield from following harvests. For example, new yield comparisons of single and multi-cut oat and vetch mixture show that multi (i.e. 3) cut would increase milk and meat production by a factor of 2.3 and widen the time window of fodder management from one harvest after 85 days to harvest after 40, 85 and 120 days. Water requirement was also calculated.

Preliminary cost benefit analysis for irrigated forages, based on findings from work in Ethiopia in Lemo with oats and vetch forage mixes fed to small ruminants, suggested irrigated forage as a cash crop can be attractive to small holders, particularly women. Analysis [19] [20] [21] [22]was conducted at farm level evaluating three different farmer categories, as per the table below, which provides details of mean estimated costs. Labor costs are the most important (about 70% of total costs) and will likely determine overall profitability and decision to adopt irrigated fodder. The high labor costs for irrigated forage households ultimately resulted in an overall disappointing benefit - cost ratio; households practicing rainfed agriculture fared best.

[c.] Project members paying 5,000 Tshs/day (~USD 2.25) and 10,000 Tshs/day (~ USD 4.50) (Rudewa) or 20,000 Tshs/day (~ USD 9.00) (Mkindo) for non-group members. The youth group in Rudewa decided not to rent out their pump.

[19] ILSSl: Semi – Annual Report October 1st 2014 – March 31, 2015

[20] Field Level Pilot Interventions in Small Scale: Fodder Cultivation

[21] Rain fed Fodder Production Northern and Upper East Regions of Ghana

[22] Irrigated Fodder Production in Northern Ghana

Table 3: Impact of livestock related labor costs on benefits form irrigated fodder: Ethiopia

Type of costs (in Ethiopian Birr, ETB)	Irrigating fodder households		Non-project irrigating households		Pure Rain-fed households	
	Mean (n=12)	Std. Dev.	Mean (n=15)	Std. Dev.	Mean (n=15)	Std. Dev.
Total crop labor cost	15132.98	9619.72	11424.72	6904.07	7647.78	5829.19
Total cost labor livestock	29916.25	55348.17	14993.33	16253.42	12141.78	8583.45
Mean Benefit Cost Ratio	0.60		0.86		0.95	

Ghana: In Ghana three forage grasses (Chloris gayana, Brachiaria ruziziensis and Sorghum almum) and one forage legume (Lablab purpureus) were cultivated on a 100 m^2 plot divided into two for 50 m^2 each for grass and legume. The twelve farmers pooled the fodder produced to fatten ten young rams for about 2 months with average initial weight of 14.11±3.50 kg. The fodder produced was offered ad libitum. The average weight gains of rams amounted to about 25 gram per ram and day, and were not superior to weight gain from traditional pasture and grazing.

Tanzania: In Tanzania Napier emerged as the most preferred forage option resulting in the further testing of five different cultivars of Napier Cultivar dependent variations in dry biomass yield were statistically, and livestock nutritionally, highly significant ranging from 6.2 (SD=0.6) to 16.6 (SD=1.3). Fodder quality of Napier was estimated by leaf to stem ratio, which varied cultivar dependent from 0.9 to 0.4. Leaf to stem ration was insignificantly (P=0.42) inversely (r = - 0.46) associated with biomass yield.

6. Commercial home gardens

NCA&T is conducting research on conservation agriculture and drip irrigation[23] with a focus on commercializing home gardens. This intervention involves minimum tillage, ground cover for no-till and established farming practices for horticultural crops. Women farmers participate in these studies in the three ILSSI countries. Field data have been collected in Ethiopia over three years and in Ghana and Tanzania for two years. A water lifting device has been developed and tested with good acceptance by women farmers. NCA&T research compares the use of drip irrigation with and without conservation agriculture. The results of these field studies are being analyzed using the APEX model, which is a component of the IDSS.

B. Summary of surveys and field based monitoring and assessment by country

i. Irrigation-Nutrition Linkages

In 2015, ILSSI published a review [24]on the existing evidence concerning the role of irrigation in improving nutrition and health outcomes. Most of the studies examined showed a positive effect of irrigation interventions on food security. The review concluded, however, that existing evidence was insufficient to draw broad conclusions because nutrition is yet to be considered an explicit objective of

[23] NCA&T Mid-Term Report Results on Commercial Home Gardens
[24] Improving irrigation access to combat food insecurity and undernutrition: A review

irrigation development. Nutrition-sensitive irrigation programs are needed to help realize the full potential of irrigation interventions and avoid adverse impacts on human health and nutrition.

Similarly, IDSS modeling in the ex ante analyses (discussed in Section III.C., below) showed that, despite some positive nutritional effects, some nutritional deficiencies persisted under the improved, irrigated cropping systems—possibly because the ex-ante analyses only considered a few candidate crops.[25] [26] [27] Additional crops and their impacts on nutrition will be modeled in IDSS ex post simulations.

Preliminary results from econometric analysis of the ILSSI data in Ethiopia and Tanzania show that irrigation significantly improves both household income and the diversity of crops that farmers produce. Increasing household income, in turn, leads to higher dietary diversity, while the relationship between production diversity and dietary diversity is not statistically significant. Thus, irrigation in the study areas is likely to influence nutritional outcomes though an income pathway, rather than the direct production diversity pathway. This is consistent with the literature, which has shown that when production diversity is already high, the association between production diversity and dietary diversity is insignificant or could even turn negative, because of foregone income benefits from specialization [d.].

ii Irrigation-Women's empowerment Linkages

Preliminary WEAI results show that the relationship between women's empowerment and irrigation is not straightforward. Results are inconsistent across the three countries with irrigators in Tanzania and Ghana associated with higher empowerment scores and irrigators in Ethiopia associated with lower empowerment scores (Table 4).

Table 4: Preliminary WEAI results in Ethiopia, Ghana, and Tanzania

WEAI	Irrigators	Gender Parity Index	Non-irrigators	Gender Parity Index	Contributors to disempowerment
Ethiopia	0.82	0.9	0.85	0.91	•Group membership •Leisure time •Speaking in public •Credit access •Control over use of income
Ghana	0.82	0.86	0.8	0.87	•Credit access •Workload •Group membership •Control over use of income
Tanzania	0.88	0.96	0.86	0.92	•Group membership •Credit access •Leisure time •Speaking in public •Autonomy in production

Source: ILSSI baseline data

[25] Ex -ante analyses of small scale interventions - Ethiopia
[26] Ex -ante analyses of small scale interventions - Tanzania
[27] Ex -ante analyses of small scale interventions - Ghana
[d.] The draft paper can be provided upon request

In Ethiopia, irrigators have slightly lower empowerment scores than non-irrigators, 0.82 compared to 0.85, respectively (see Table 5 for detailed results for Ethiopia). In addition, more women from households without irrigation are considered empowered (58 percent) than those from irrigating households (48 percent). The opposite is true for men, where slightly more men from irrigating households can be considered empowered (86 percent) compared to men from non-irrigating households (84 percent). Similarly, the gender parity gap (the share of women who do not achieve the same level of empowerment as their husbands) is higher for irrigators than non-irrigators—51 percent of women from irrigating households do not achieve gender parity while only 40 percent of women from non-irrigating households do not achieve gender parity. However, the average empowerment gap among men and women from households where women are disempowered is larger for non-irrigating households.

The main contributors to women's disempowerment in Ethiopia, in order of importance, are: inability to participate in groups, lack of leisure time, inability to speak in public, lack of access to credit, and lack of control over income. Therefore, it is possible that irrigation exacerbates the problems contributing to women's disempowerment, for example by increasing the amount of time they spend in agricultural production and their overall time burden while also decreasing their control over income earned through the sale of irrigated crops. Qualitative research also suggests that women's inability to participate meaningfully in groups, particularly water user associations, also limits their knowledge about how water resources are managed as well as their ability to influence decisions over water use and allocations (in community schemes). At the same time, it is often women that provide labor for irrigation.

Table 5: Detailed WEAI results by irrigation status for Ethiopia

	Irrigators		Non-irrigators	
Indexes	Women	Men	Women	Men
Disempowered Headcount (H)	0.52	0.14	0.42	0.16
Average Inadequacy Score (A)	0.36	0.30	0.36	0.30
Disempowerment Index (M0)	0.19	0.04	0.15	0.05
5DE Index (1-M0)	0.81	0.96	0.85	0.95
No. of observations	230.00	221.00	178.00	156.00
% of Data used	92.37	92.40	0.96	93.41
% of women with no gender parity (H_{GPI})	0.51		0.40	
Average Empowerment Gap (I_{GPI})	0.20		0.22	
GPI	0.90		0.91	
No. of women in dual households	204.00		151.00	
% of Data Used	0.87		0.92	
WEAI	0.82		0.85	

Source: ILSSI baseline data

Detailed results on the WEAI for Ghana and Tanzania can be found in the descriptive WEAI-irrigation paper [e.].

These preliminary results highlight the complexity of the relationship between irrigation interventions (and development interventions more broadly) and women's empowerment. In some instances irrigation

[e.] The draft paper can be provided upon request is associated with higher levels of women's empowerment (as in Ghana and Tanzania) while in others it is not (i.e. in Ethiopia). As the assessment of the contributors to disempowerment shows, the relative importance of the factors hindering women's empowerment depend on the context. The WEAI provides a useful tool to diagnose these factors and point project implementers towards the barriers to women's empowerment. Targeted approaches will be needed to improve the status of women in agricultural households across the developing world. More in depth research on the relationship between irrigation, women's empowerment and nutrition outcomes is ongoing to shed light on potential entry points for improving the status of women and their children.

iii. Exploration of rural and urban fodder markets to assess opportunities for forages as cash crop

Ethiopia: In Ethiopia in fall 2015, ILSSI surveyed rural fodder markets that could serve as nearby markets for ILSSI project sites (Debre Tabor and Bahir Dar in the Amhara region; Alaba in the Southern Nation, Nationalities and People Region). The surveys looked at market players, types of feed, fodder and forage traded, seasonal fluctuations in supply and prices, volumes traded, farm gate and retail prices and general basic agricultural information. Important findings for ILSSI were: 1) women were major actor in the transaction and sale of forages, 2) green forages that ILSSI propagated such as Napier and Desho were important species in fodder market, i.e. a market for these forages as cash crops potentially exists, 3) relationships between forage prices and forage fodder quality (which was determined in the ILRI laboratory). The results, including estimated of transport costs, were used for a small ex-ante assessment of potential for forage as a cash crop (see below). Urban and peri urban fodder market in and around Addis Ababa were surveyed in summer 2016 to get a more complete picture about the feed, forage and fodder value chain. In contrast to rural markets, green forages (with a high water content) were absent and markets were dominated by grass hay and straw from teff, wheat and barley. Farm gate prices were about 1/3 of the retail prices. Data from rural and urban markets are currently used for the backward establishment of the economics of feed/forage/fodder value chains. ILSSI partners are collaborating to conceptualize a tool to facilitate decisions within this feed and fodder value chain.

Preliminary findings suggest that forage as cash crop production for rural markets achieves at least 50% of the income that would be achieved by using the forages to fatten animal on farm or to produce milk. As pointed out in above calculations on conversion of oats and vetches, Napier and Desho into meat and milk we assumed that feed maintenance cost is born by alternative on farm feed resource. If this is not the case and, for example, oats and vetches have to bear also the cost of maintenance milk production from 100 m^2 by about 50%. Forage as-a-cash-crop approach could therefore become attractive and competitive. Considering the high labor costs associated with the latter enterprises (see below) forage as a cash crop be a more attractive option, particularly when based on improved management options such as multi-cut oat vetch systems and intercropping of Desho and Napier with forage and grain legumes.

C. Summary of SSI interventions tested and modeled by country

The IDSS team completed ex-ante analyses of proposed SSI interventions in Ethiopia, Tanzania, and Ghana in the fourth quarter of year two, the first quarter of year three, and the second quarter of year three, respectively.[28] [29] [30]These analyses identified major opportunities for the introduction of SSI, and the relative merits of numerous SSI interventions; however, they also identified constraints to the use of these

[28] Ex -ante analyses of small scale irrigation interventions - Tanzania

[29] Ex -ante analyses of small scale interventions - Ghana

[30] Ex -ante analyses of small scale irrigation interventions - Ethiopia

systems, suggested possible ways to mitigate these constraints, and identified numerous issues (or "gaps") requiring further research.

Ethiopia. ILSSI analyzed proposed SSI interventions in watersheds in 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. National and regional reports on the IDSS ex-ante analyses are available.[31] [32] [33] [34]At each of the four target sites, ILSSI evaluated the probable consequences of 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. For all four sites, ILSSI simulated the use of shallow groundwater for SSI, comparing five alternative water-lifting technologies. Both current and alternative farming systems specific to each site were simulated.

In BDZ, Dangila and Lemo, IDSS ex-ante simulations indicated that the proposed SSI interventions could be sustained by shallow groundwater recharge without affecting long-term groundwater storage or compromising the environmental health of the watersheds. In Adami Tulu, groundwater recharge rates might be inadequate to support extensive SSI; however, surface runoff rates were high, and runoff could be captured in ponds and used as a direct source of water for SSI or to recharge shallow groundwater. Moreover, higher recharge rates could occur in certain areas (such as along stream banks). Further research into areas with high recharge rates, as well as potential sites for water-harvesting structures (and their associated costs and benefits), was recommended.

Simulations also revealed very high soil erosion rates in BDZ, suggesting that neither the proposed SSI interventions nor the current cropping system 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 yields of both the irrigated dry-season crops and the rainy-season grains significantly. Farm-scale economic analyses indicated that, in BDZ, Dangila, Lemo and Adami, implementation of the proposed SSI interventions using gasoline motor or animal-powered pumps produced the highest net present value (NPV), net cash farm income (NCFI), and ending cash (EC) reserves of all the scenarios simulated. In all cases, forecasted sales of the irrigated dry-season crop contributed the bulk of profits 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 analyses. It is, therefore, proposed to expand 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.

Tanzania. ILSSI analyzed proposed SSI interventions in: Mkindo watershed, in the Mvomero district of the Morogoro region; Rudewa watershed, in the Kilosa district of the Morogoro region; and Babati

[31] Ex -ante analyses of small scale irrigation interventions - Robit
[32] Ex -ante analyses of small scale irrigation interventions - danglia dangeshta
[33] Ex -ante analyses of small scale irrigation interventions - adami tulu bochesa
[34] Ex -ante analyses of small scale irrigation interventions - Lemo upper gana

watershed, in the Babati district of the Manyara region. National and regional reports are available.[35] [36] [37] [38] At 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. Both current and alternative farming systems were simulated.

Ex-ante 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 environmental health of these watersheds. In Kilosa, however, simulated low water flows were reduced by the withdrawal of irrigation water, possibly affecting riparian ecosystems. Capture and use of runoff or groundwater for irrigation could mitigate these effects. Moreover, at all three of the target sites, irrigation of suitable fields far from rivers will require development of advanced surface water diversion and transfer technologies, capture of surface runoff, and/or wells. Further research into these options was recommended.

Simulations of stream flow, soil erosion, and crop yields at each of the sites showed that application of additional fertilizers would increase crop yields substantially and, at the Mvomero and Babati sites, would also decrease soil erosion. Implementation of multiple cropping systems also affected simulated crop yields and sediment losses, though results varied from site to site. The system of rice intensification (SRI) is an ongoing production system used by many farmers in the region. SRI rice production had greater crop water productivity than traditional, rain-fed rice, and the lengths of SRI drying and wetting periods affected yields.

Farm-scale economic analyses indicated that, in Mvomero, cultivation of SRI rice and multiple cropping of fertilized maize with irrigated vegetables (not fodder) produced the highest NPV, NCFI, and EC of all scenarios simulated. In Kilosa and Babati, cash income increased as irrigated area increased, and the most profitable scenario was the one that allocated the largest area of irrigable cropland to vegetables, fodder, and SRI rice.

Despite improvements in farm family economics at all three sites, some nutritional deficiencies persisted under the improved cropping systems—possibly because the ex-ante analyses only considered a few candidate crops. Expanding the types and areas of crops irrigated in the dry season could increase NCFI and family nutrition, but could lead to soil erosion or reductions in environmental benefits. Moreover, the lack of suitable cropland limits the expansion of SSI and cultivation of additional crops. Further investigation of additional crops and their environmental impacts was recommended.

Ghana. ILSSI analyzed proposed SSI interventions in: Bihinaayili watershed, located in the Savelugu-Nanton District in the Northern Region; Nimbasinia (or Dambiasinia/Dimbasinia) watershed, located in the Kassena Nankana District in the Upper East Region; and Zanlerigu watershed, located in the Nabdam District, also in the Upper East Region. National and regional reports are available.[39] [40] [41] [42] In each of the three target sites, ILSSI proposed implementing SSI (using irrigation water from either shallow

[35] Ex -ante analyses of small scale irrigation interventions - Tanzania
[36] Ex -ante analyses of small scale irrigation interventions - Mvomero
[37] Ex -ante analyses of small scale irrigation interventions - Kilosa
[38] Ex -ante analyses of small scale irrigation interventions - Babati
[39] Ex -ante analyses of small scale irrigation interventions - Ghana
[40] Ex -ante analyses of small scale irrigation interventions - Bihinaayili
[41] Ex -ante analyses of small scale irrigation interventions - Nimbasinia
[42] Ex -ante analyses of small scale irrigation interventions - Zanlerigu

groundwater or water-harvesting ponds, depending on the site) to maximize cultivation of high-value vegetable and fodder crops in the dry season. Current and alternative farming systems specific to each site were simulated. The simulations also compared the costs and benefits of three alternative water-lifting technologies, including pulley-and-bucket irrigation and diesel-pump irrigation (both rented and owned). IDSS simulations in Ghana also modeled solar-pump irrigation, although solar pumps were not tested in the field.

In Bihinaayili, water-harvesting ponds (or "dugouts," used to collect and store overflow from a nearby dam) served as the proposed source of irrigation water. IDSS ex-ante simulations indicated that there is ample water to support the proposed SSI interventions, but that the interventions would reduce average monthly stream flow and could have negative impacts on downstream systems. Moreover, the dugouts would be susceptible to siltation, and dredging sediment loads would be challenging. Further research into the exact upstream and downstream social and environmental costs and benefits, including sedimentation of dugouts, was recommended.

The proposed SSI interventions in the Nimbasinia and Zanlerigu watersheds relied on irrigation from shallow groundwater. At both sites, annual irrigation water requirements of selected dry-season crops exceeded average annual shallow groundwater recharge. Implementation of the proposed SSI interventions also caused modest reductions in monthly average, peak, and low stream flows at both sites. Irrigation from shallow groundwater could be combined with irrigation from other water sources, such as dugouts. Additionally, cultivation of water-efficient crops could minimize irrigation amounts and reductions in stream flows. Further research into dugout sites and scale, the costs and benefits of irrigating from dugouts, and alternative water-efficient crops, was recommended.

Simulations of crop yields showed that the application of additional fertilizers would increase crop yields substantially at each of the three sites. The implementation of multiple cropping of rainy-season grain crops with fodder significantly increased simulated grain yields without adversely affecting fodder yields; multiple cropping of rainy-season grain crops with tomato also increased simulated grain yields (although by lesser amounts), but significantly reduced tomato yields. In Bihinaayili, multiple cropping of soybean with dry-season crops did not significantly affect simulated yields of soybean or the dry-season crops. In Zanlerigu, high temperature stress was also a major factor limiting yields of certain crops. For example, the yield of rain-fed pepper planted in the cooler season was double that of irrigated, dry-season pepper. Planting temperature-sensitive crops (like pepper and oats) in the cooler season would therefore optimize yields.

Plot-scale simulations of flow and sediment indicated that the proposed SSI interventions in Nimbasinia and Zanlerigu would not significantly affect runoff and sediment yields. In Bihinaayili, however, multiple cropping of sorghum (at both current and improved fertilization rates) with fodder and pepper increased sediment yields.

Farm-scale economic analyses indicated that, in Bihinaayili, multiple cropping of dry-season crops with soybean would be far more profitable than multiple-cropping of dry-season crops with maize. Similarly, in Nimbasinia, the scenarios that implemented multiple cropping of the dry-season crops with sorghum (rather than maize) were preferable. Multiple-cropping with maize and millet was found to be equally profitable in the Zanlerigu community.

At all three sites, the scenarios that implemented multiple cropping of the preferred rainy-season crop(s) with diesel- and solar-pump-irrigated, dry-season crops produced by far the highest NPV, NCFI, and EC of the scenarios simulated. Additionally, considering the lower maintenance and environmental costs of solar pumps, simulations in Ethiopia and Tanzania suggested that investments in solar water-lifting technologies would pay dividends in the long run.

Despite substantial improvements in farm family economics resulting from the proposed SSI interventions, at all three sites levels of certain nutrients remained at merely adequate levels, and a nutritional deficiency in iron persisted under the improved cropping system in Bihinaayili. Research into alternative dry-season crops and their environmental impacts was recommended.

D. Integrated results and overarching conclusions

Ex-ante analyses of proposed interventions at the target sites indicated that, generally, there is sufficient groundwater or surface water to sustain the proposed SSI interventions; however, several environmental, production, and economic constraints on SSI and issues remain to be resolved in future modeling and field research. In Ethiopia, these included the need to identify:

- areas with higher groundwater recharge rates, as well as potential sites for small water-harvesting structures (and their associated costs and benefits), in Adami Tulu; and
- alternative cropping systems and other methods for reducing soil erosion rates in BDZ.

In Tanzania, issues raised in the IDSS ex-ante analysis included the need to identify:

- the potential for shallow-groundwater irrigation in areas too distant for use of surface water;
- appropriate fertilizer amounts for more intensive cropping systems involving production of irrigated vegetable, fodder, and grain crops in the dry season; and
- appropriate fertilizer rates and harvest practices for irrigated fodder production.

In Ghana, the IDSS ex-ante analysis indicated the need for further evaluation of:

- the exact upstream and downstream costs and benefits (both social and environmental) of decreases in average stream flows and peak flows, as well as increases in low flows;
- potential methods of addressing sedimentation of water-harvesting ponds where utilized;
- the potential scale and locations, as well as the costs and benefits, of water-harvesting ponds or structures to supplement shallow-groundwater irrigation in Nimbasinia and Zanlerigu; and
- specific water-efficient crops for cultivation.

The ex-ante analyses also recommended further evaluation and comparison of alternative crops and management practices, and associated impacts on soil erosion and environmental benefits. The high costs of labor and SSI technologies were also common impediments to adoption of SSI.

With collected field data, ILSSI has begun refining these results in ex-post analyses and assessing candidate constraints and their mitigation. Future integrated analyses will enable ILSSI to study and recommend optimal SSI solutions for agricultural production, environmental sustainability, and environmental outcomes.

E. Key constraints to and options for mitigating adoption of small-scale irrigation interventions

In June and July 2016, ILSSI hosted participatory meetings of national experts and stakeholders in Ethiopia, Tanzania, and Ghana, with the goal of developing a prioritized, country-specific short list of constraints on SSI for each of the three target countries. These workshops provided experts and stakeholders an opportunity to discuss the IDSS ex ante analyses and to provide input based on their knowledge and experience and their institutional interests and priorities.

Comprehensive reports on the stakeholder meetings, detailing workshop objectives, participants, proceedings, and conclusions, are available.[43] [44] [45] [46] Ultimately, the stakeholder workshops produced a consensus-based, consolidated list of prioritized constraints specific to each country (Table 6).

Table 6. Ranked priority constraints in Ethiopia, Ghana, and Tanzania

Rank	Ethiopia	Ghana	Tanzania
1	Access to markets	Access to markets	Capacity development and irrigation expertise
2	Water availability and access	Water lifting technology access	Finance modalities and access to electricity, solar and wind
3	Access to appropriate SSI technology and knowledge	Climate change	Policy constraints and market access
4	Market access: Affordable and relevant inputs	Water availability and access	Climate change: water, temperature variability
5	Risks and vulnerabilities	Land issues	Competing water uses (with other sectors)
	Institutional issues	Diseases and Pests	Soil management and fertility
7		High labor cost for women	Cultural and social practices of stereotyping crops e.g. fodder vs rice perception
8		Access to knowledge and information services (capacity development)	Fodder technology is targeted to specific systems, either intensive or extensive system
9		Inadequate access to inputs and labor	Low genetic potential for livestock
10			Source of energy

Prior to the workshops, ILSSI provided workshop participants with (1) summaries of the ex ante analyses of study sites in the relevant country (including the country-specific gaps and constraints on SSI identified by the IDSS team), and (2) an example analysis on the gaps and constraints analysis of SSI systems in the Robit watershed in Ethiopia,[47] so that workshop participants could clearly understand the calculus required in assessing and weighing constraints. Table 7 summarizes the constraints on SSI in the Robit watershed, and possible mitigating strategies, as detailed in the IDSS team's report:

[43] Consolidated stakeholder workshop report
[44] Stakeholder workshop report - Ethiopia
[45] Stakeholder workshop report - Tanzania
[46] Stakeholder workshop report - Ghana
[47] An example gaps and constraints analysis for small scale irrigation systems in the robit watershed

Table 7: Possible mitigating strategies for priority constraints on SSI interventions in Robit

Constraints	Possible Mitigating Strategies
Lack of adequate irrigation water at the field scale	Use water-harvesting structures to store locally-generated surface runoff
Adverse environmental effects at the watershed scale resulting from reductions in stream/peak flows	Combine shallow groundwater and harvested surface runoff
Low soil fertility, ineffective management practices	Apply fertilizers and irrigation at optimal rates
High soil erosion rates	Implement terracing; identify and implement alternative cropping systems to reduce erosion; use water harvesting structures to minimize runoff
High irrigation labor costs	Consider whether additional family labor is feasible and available; use less labor-intensive irrigation methods (e.g., mechanized water lifting and scheduling)
Lack of experience with operation and troubleshooting of water-lifting technologies	Provide proper training for new users
Policy limitations (e.g., high import taxes on solar)	Advocate changes in policies

The IDSS team has begun analyzing the prioritized list of constraints for Ethiopia, with the goal of producing context-specific proposals for mitigation of these constraints in year four. IDSS analyses of gaps, constraints and mitigations in Tanzania and Ghana will be initiated in year four.

F. Key opportunities for small-scale irrigation expansion: Insights from upscaling

ILSSI studies thus far focused primarily on targeted study sites in Ethiopia, Tanzania, and Ghana. Results of targeted studies at the watershed, sub-basin, and field scales are encouraging for the broader use of SSI in the project countries, indicating that in many areas there is ample irrigation water to support expanded SSI, as well as promising methods of implementing SSI and mitigating constraints on SSI. In the last quarters of year three, ILSSI began to examine opportunities for "upscaling" watershed-level results to other locations in the project countries, and the consequences for agricultural production, environmental sustainability, and socio-economic outcomes of expanding SSI to the regional or country level.

In Ethiopia, upscaling analysis is underway and is slated for completion in year four. A summary report on the methodology and progress of this analysis is available,[48] and a more detailed report is in draft.[49] Data collection is almost complete. The pre-suitability analysis has been completed, and preliminary results were presented at the 2016 International SWAT Conference in China as a poster.[50] Slope and rainfall deficit were found to be the most important factors in assessing suitability for irrigation, followed by population density and soil characteristics. The preliminary suitability map values range from 30% to 97%, where 30% indicates the least suitable land and 97% the most suitable land (fig. 6).

[48] Scale up of biophysical and environmental analysis of proposed small scale irrigation interventions a summary of aims, timelines, methodology and progress

[49] Upscaling analysis

[50] Assessing irrigation potential and land suitability in Ethiopia

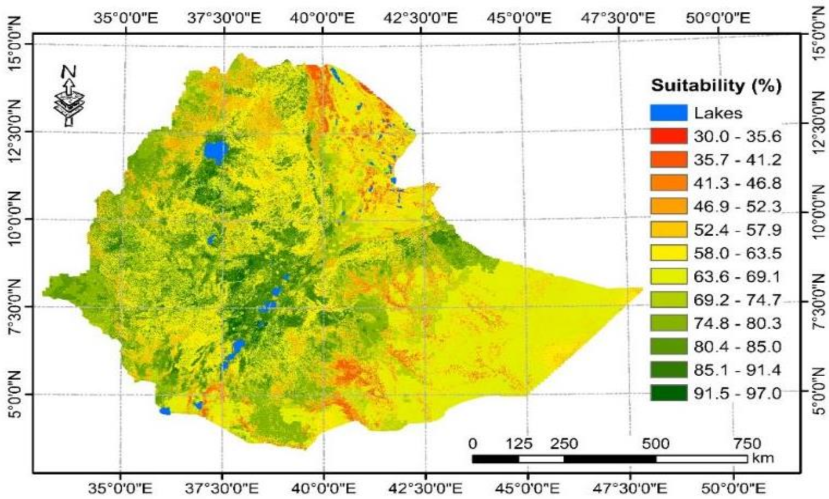

Figure 6. Preliminary suitable land for SSI

After excluding areas with constraints on SSI, such as water bodies and protected and urban areas, nearly 5.3% of the landmass, or approximately 60,025 km^2, was deemed suitable for SSI (i.e., having a suitability value of greater than 85%). The optimized irrigation suitability map shows the location and percentage of irrigable land in each of the major river basins (fig. 7). Abbay basin has the largest area of suitable land (21,186 km^2), while Rift Valley basin has the highest percentage (20%).

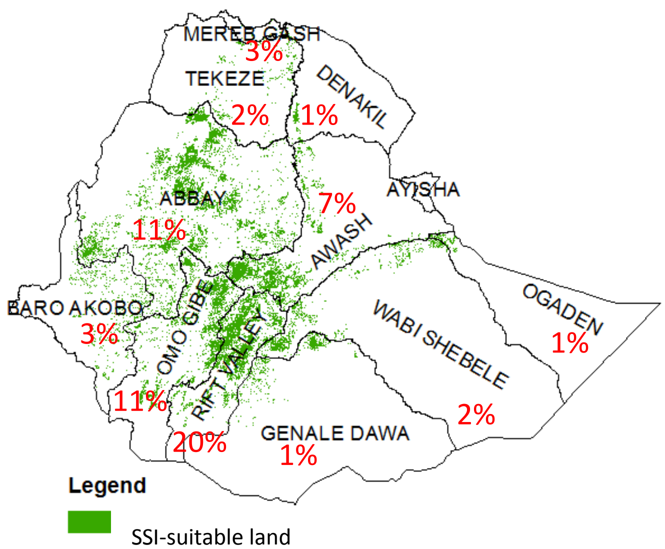

Figure 7. Suitable irrigable land map, after excluding constraints and applying suitability threshold

A paper summarizing the completed analysis will be presented at the upcoming AGU conference.[51] The team is also preparing a scientific journal article on groundwater irrigation potential in Ethiopia.

SWAT modeling is underway in Ethiopia, and spatially disaggregated estimates of water availability, irrigation water consumption, and irrigated crop yields are being provided to the ABM for the irrigation

51 Assessing potential land suitability for surface irrigation using groundwater in Ethiopia

expansion simulation. SWAT is simulating a variety of potential irrigated, dry-season crops, including tomato. Preliminary findings show that tomato yield can range from less than 1 ton/ha to 2.8 ton/ha, and that available water resources (including surface runoff and ground water) across agricultural fields can range from less than 100 mm to over 2000 mm.[52]

ILSSI is using the ABM to simulate and analyze a variety of candidate crops, including vegetables and pulse and root crops. Simulations will ultimately evaluate and compare the suitability and profitability of the candidate crops and investment requirements. Preliminary results indicate that SSI development potential in Ethiopia is about 800,000 ha, mainly in Oromia, Amhara, and SNNP (fig. 8(a)). Simulations show that SSI adoption is most likely to be successful in select areas such as the Central Rift Valley and areas near Lake Tana. The ILSSI team recommends that future endeavors promoting SSI adoption target these areas. ABM simulations also identified river basins that are prone to water scarcity (fig. 8(b)). In these regions, it is also recommended that appropriate institutional arrangements be made in conjunction with SSI investment (e.g., mitigating strategies discussed in Section III.C-E, including government-assisted installation of water-harvesting ponds/structures to store water for use in the dry season, as appropriate to the particular site), to reduce negative environmental and socioeconomic consequences of SSI development.

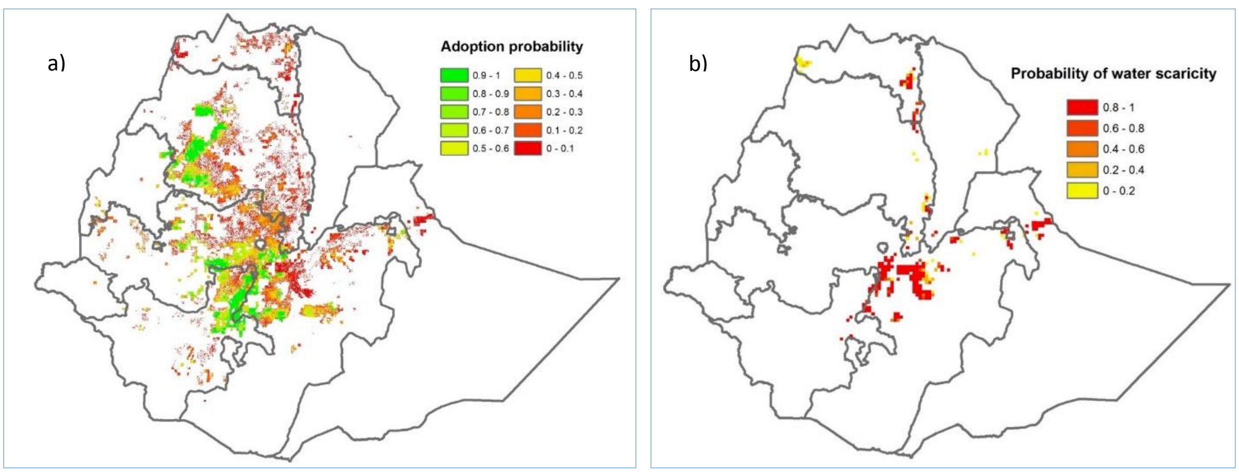

Figure 8. (a) Adoption probability of SSI in Ethiopia; and (b) risk of water scarcity associated with SSI expansion

The upscaling analysis in Ethiopia is slated for completion in year four. Data collection efforts are underway for upscaling analyses in Tanzania and Ghana, which will begin in year four.

IV. ENGAGEMENT AND CAPACITY BUILDING TO SUPPORT SMALL SCALE IRRIGATION

A. Engagement approaches and results

ILSSI considers continual engagement and national partnerships the foundation to ensuring relevant research and effective use of results. Engagement is a process that includes activities related to capacity

[52] Upscaling analysis

development at different levels, outreach to policy and decision-makers, co-researching with technical experts and planners, as well as general communications. As a starting point, ILSSI identified the most influential partners and stakeholders to target, the most appropriate stage in the research project cycle to engage the various targets, and the most suitable outputs for each target group for effective sharing of research methods and results. ILSSI also has an External Advisory Committee, which provides advice on research design, process and preliminary results, and acts as a link to key national stakeholders.

More specifically, ILSSI mapped partners and stakeholders for each project country, including research institutions, scientists, practitioners and technical experts, representatives from research, government, the private sector, USAID missions and other donor agencies, and sub-national cooperatives, extension offices and farmers' groups. Engagement activities with the various stakeholders have been documented across project years, which enable monitoring of progress on the impact pathway. Engagement activities began at project inception with national stakeholder consultation in each country, which identified key issues and opportunities in SSI and helped to identify the gaps in knowledge for increasing SSI in each country.[1] [2] [3] The consultation was followed by research partner workshops to refine scientific question and design. Selecting participant farmers also involved engagement with local authorities, community leaders, and men and women farmers. Subsequently, farmer and local stakeholder forums have been held each year to reflect on lessons and plan.[4] The engagement at farm, sub-national and national levels has been critical to understanding constraints and opportunities.

In addition, the project holds subject workshops in project countries. For example, in project year three, ILSSI held training workshops on gender and irrigation in each country. The workshop results were consolidated into a project note on the gender implications of irrigation that should be considered to ensure that both men and women have the opportunity to adopt irrigation technologies and benefit from these investments.[5] The workshops also led to further invitations for ILSSI to contribute to policy-level inputs on gender and irrigation. Another example from year three is sub-national training workshops on FEAST and established irrigated forages.

In addition to seeking local and national stakeholder input, ILSSI has also sought to engage investment and planning decision-makers in regional and global events. Such forums influence global thinking, practice and investments in agricultural water development. In 2016, ILSSI initiated various panels and sessions toward that end. For example, ILSSI presented at the University of Nebraska Water for Food meeting[6] [7] and organized a panel at Africa Water Week in Tanzania on approaches to gender inclusivity in irrigation investments. ILSSI and partners initiated a session at World Water Week on "Enabling investment in irrigation in sub-Saharan Africa", which presented the project to an audience of NGO representatives, researchers, donors, and government agencies and was featured in global media.[8] [9]

Beyond direct engagement, ILSSI also utilizes social media to share project activities and results; communications and outreach contributes to uptake through maintaining steady stakeholder interest

[1] Stakeholder consultation proceedings Ethiopia
[2] Stakeholder consultation proceedings Tanzania
[3] Stakeholder consultation proceedings Ghana
[4] Ghana Farmer Forum Report 2016
[5] Project Paper - Promoting gender equality and irrigation
[6] The Opportunities and Challenges of Expanding Smallholder Irrigation in sub-Saharan Africa Part 1
[7] The Opportunities and Challenges of Expanding Smallholder Irrigation in sub-Saharan Africa Part 2
[8] Stockholm World Water Week - Enabling investment in irrigation in sub-Saharan Africa
[9] Irrigation on rise in Africa as farmers face erratic weather

across the project cycle. ILSSI publishes stories online via a primary project website and linked web pages through CGIAR partner sites. [10] [11] [12] In addition, ILSSI uses social media and blogs to share stories and generate discussion around the research. [13] [14] [15] Where applicable, ILSSI has also reached out to news media.[16] Outreach through various media and high profile events are supported through communications products, such as project briefs, which are updated regularly.[17] [18] [19] [20] Communications materials follow branding guidelines outlined by the donor.[21]

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[10] Not so quiet on the wetting front - A new irrigation technology is helping Ethiopian farmers assess crop water requirements
[11] Smallholder irrigation taking root - USAID and Texas A&M team field visit to ILSSI sites in Ethiopia
[12] ILSSI Technical Workshops in Ethiopia, Tanzania and Ghana to address Gender issues in Small Scale Irrigation
[13] Irrigation on rise in Africa as farmers face erratic weather
[14] What should we be asking to understand gender dynamics in irrigation
[15] Water smart investment benefits ripple beyond food security
[16] Irrigation on rise in Africa as farmers face erratic weather
[17] Factsheet - Feed The Future Innovation Lab for Small Scale Irrigation
[18] ILSSI Factsheet - Tanzania
[19] ILSSI Factsheet - Ethiopia
[20] ILSSI Fact Sheet - Ghana
[21] ILSSI Branding Strategy
[22] Project Paper - Promoting gender equality and irrigation
[23] The Opportunities and Challenges of Expanding Smallholder Irrigation in sub-Saharan Africa Part 1
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[28] ILSSI Technical Workshops in Ethiopia, Tanzania and Ghana to address Gender issues in Small Scale Irrigation

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B. Capacity development

a. Short-term training

i. In-field

ILSSI's capacity development efforts respond to the needs identified by national stakeholders in consultation workshops. Along with partners, ILSSI considers capacity development as necessary for SSI technologies, tools and practices to be scaled. Capacity needs to be strengthened at regional and national level for planning, monitoring and regulating, and also at national and sub-national level for supporting field level implementation of SSI. As such, ILSSI targets capacity development interventions at multiple levels, including farmers (women, men, youth), local artisans, extension and subject matter specialists, as well as researchers, scientists, national planners, and decision-makers. ILSSI considers the private sector to be a special interest target group with its own knowledge needs. Capacity development is approached as an integrated activity within field-level interventions, research implementation, use of research and planning methods and tools (including but not limited to IDSS and participatory action research) and application of evidence generated by the project. In addition, ILSSI aims to produce capacity development materials that can continue to be used, and thereby contribute to impact after project closure.

Toward strengthening capacity in the first three years of the project, ILSSI has implemented multiple streams of short-term training, including:

- local level trainings for farmers, extension, financial cooperatives, technical specialists (irrigation and agricultural water management, agronomy, irrigated farming as a business, installing and repairing technologies, savings and loans, managing revolving loan funds, FEAST, fodder)
- national level trainings on gender and irrigation

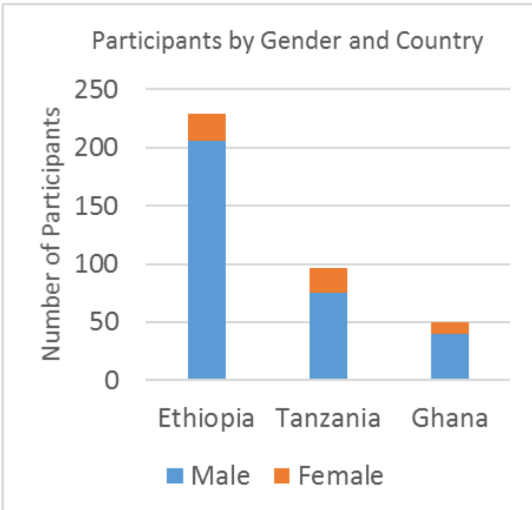
Since project inception, ILSSI has provided capacity development short short-term trainings to 2270 individuals from the private sector, civil society and the government. Disaggregation of trainees can be found below in Figures 9 and 10.

ii. IDSS/analysis training

During the first three years of the ILSSI project, the IDSS team provided short-term training on the IDSS and its component models to almost 400 participants (including 54 women) through a total of six

[29] Irrigation on rise in Africa as farmers face erratic weather
[30] What should we be asking to understand gender dynamics in irrigation
[31] Water smart investment benefits ripple beyond food security
[32] Irrigation on rise in Africa as farmers face erratic weather
[33] Factsheet - Feed The Future Innovation Lab for Small Scale Irrigation
[34] ILSSI Factsheet - Tanzania
[35] ILSSI Factsheet - Ethiopia
[36] ILSSI Fact Sheet - Ghana
[37] ILSSI Branding Strategy

workshops: three in Ethiopia, two in Tanzania, and one in Ghana. An integrated report on the structure, goals and impact of the IDSS short-term training is available.[38] Figure 9(a) indicates the number of individuals (by gender) that have participated in IDSS training workshops in each target country thus far. Figure 9(b) shows the number of total trainees (by gender) for each of the first three years of the ILSSI project.



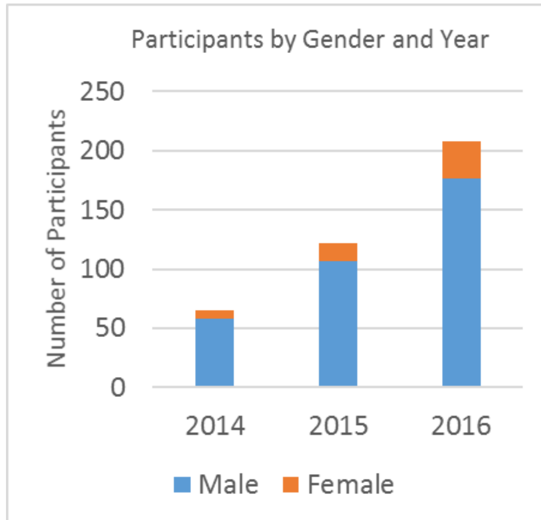


Figure 9. Total trainees (by gender) in: (a) each target country; and (b) each of the first three project years

Most workshop participants have been faculty, staff, and/or graduate students at universities in the target countries; a sizeable minority of workshop participants have represented international and local research institutes, government ministries, and extension agencies. Figure 10 indicates the professional affiliations (civil society, government, the private sector) of the workshop participants in each of the three target countries.

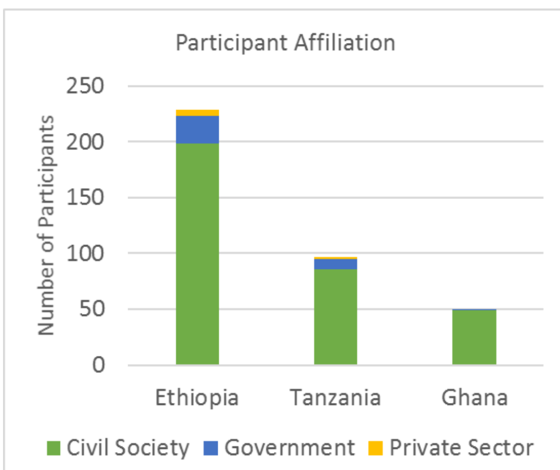


Figure 10. Affiliations of workshop participants in each of the three target countries

[38] Results and Impacts of IDSS workshops in Tanzania, Ghana and Ethiopia: Country-specific reports on training sessions conducted in Ethiopia, Tanzania, and Ghana (including their participants and effectiveness) are discussed and referenced in subsequent sections of this report.

The five-day basic IDSS workshop generally begins with a half-day overview into the IDSS and its component models. Participants then break into three groups for hands-on, in-depth training in one of the three models. On the fifth and final day, participants come back together for a case study of the integrated capabilities of the IDSS and small-group integration exercises. The IDSS team has also provided interested participants with additional courses in Advanced SWAT, as well as SWAT and FARMSIM clinics designed to provide one-on-one support to those already using FARMSIM and SWAT in project analysis.

Following completion of each of the short-term training sessions, the IDSS team has also continued to provide ongoing support and assistance to numerous workshop participants, such as those described in Section IV.B.c ("Measures of impact").

b. Long-term training

ILSSI is currently supporting three postdoctoral fellows and one M.S. student at Texas A&M Agrilife Research laboratories, all of whom are male and are African nationals. See Appendix 1 for additional details regarding those students currently enrolled in a degree program funded in full or part by USAID.

ILSSI is also supporting a number of students at project partner institutions and cooperating national institutions in Ethiopia, Tanzania, and Ghana in the use and application of the IDSS and its component models (SWAT, APEX, and FARMSIM). The students receiving IDSS model training can be broken down as follows:

Ethiopia: ILSSI is supporting two male students at Bahir Dar University (BDU) in use of APEX. ILSSI is also supervising two Ph.D. students at Addis Ababa University (AAU). Gebrekidan Worku Tefera, a Ph.D. student from AAU's College of Development Studies, is preparing a Ph.D. thesis on "Watershed Management Scenarios under Changing Climate in Jemma Sub Basin, Blue Nile Basin" using the SWAT model. Temesgen Gashaw, a Ph.D. at AAU's Center for Environmental Science, is preparing a thesis on "Valuation of land use/land cover change effects on stream flow patterns in the Upper Blue Nile Basin, Northwestern Ethiopia." Additionally, ILSSI has discussed the use and integration of FARMSIM in thesis research with three male students from Ethiopia. One is currently pursuing his PhD in Germany (Getachew Legese Feye), while the two others are Have been admitted into PhD programs in this fall (Berihun Tefera and Kaleb Shiferaw). Discussions will continue with these students in the coming year after they finalize their research proposals.

Moreover, through the ILSSI project, Tewodros Assefa is a Ph.D. candidate studying APEX modeling at NCA&T. Tewodros visited the Texas A&M modeling team in October 2015 for training and support in this modeling effort. As a result the modeling focus has shifted from SWAT to APEX modeling after consultation with the modeling team at large. In addition NCA&T has also trained a female Vietnamese Ph.D. student in EPIC.

Tanzania: ILSSI is supporting: three male students in the use of APEX, two of whom are faculty at Sokoine Agricultural University (SUA); one faculty member and one Ph.D. student (both male) at the University of Dar es Salaam (UDES) in the use of SWAT; and two male Ph.D. students at SUA in the use of SWAT.

Ghana: ILSSI is supporting one female Ph.D. student, Fati Aziz, in the use of SWAT in her Ph.D. thesis. Ms. Aziz was a guest scientist at College Station from June-November, 2015. ILSSI is also supporting

Dinko Hanaan Dinko, who is pursuing a M.Phil. in the Department of Geography and Resource Development Department at the University of Ghana. Mr. Dinko's thesis is on "Climate change/variability and water security in the Sudan Savannah zone of Ghana."

Additionally, from June 1 – September 30, 2016, Texas A&M AgriLife Research hosted three male students from BDU and two male students from SUA to provide in-depth training on the use of various IDSS model components in research activities

c. Measures of impact

The IDSS team measures the effectiveness of its training by conducting online surveys of participants both before and after its workshops. These surveys, discussed in greater detail in country-specific summaries of the IDSS training workshops,[39] [40] [41] have enabled the team to assess the evaluate improvements in respondents':

- level of knowledge and experience with relevant software, tools, and databases,
- depth of understanding of the general subject matter (e.g., for a participant in the SWAT workshop, his or her understanding of fundamental hydrology, the water cycle, vegetation growth, etc.), and
- relevant skill levels (e.g., for a participant in the SWAT course, his or her ability to prepare spatial and temporal data and soil and land use tables, to set up watershed delineation models, etc.).

In addition, the comments section of the post-workshop surveys enables respondents to evaluate training content, presentations and materials, as well as to share recommendations for future courses.

The surveys indicate that the workshops have produced substantial improvements in respondents' understanding of relevant software, tools, and databases, and in their understanding of the models and ability to perform relevant modeling tasks. Improvements in average competency and skills, as measured by the surveys (and described in greater detail in the referenced reports), ranged from almost 30% to almost 115%.

Participants have generally been extremely favorable in their evaluations of the IDSS workshops, and the workshops' content, materials, and instructors. In the comments section of the post-workshop surveys, many respondents recommended increasing the length and frequency of the IDSS workshops, and many indicated an eagerness to apply the models in their current and future research. In fact, the IDSS team has provided post-workshop support to scientists already employing IDSS models, including:

- a scientist at the Water and Land Resource Center and Wollo University modeling land degradation and siltation reduction in the Abbay Basin;
- a GIS analyst at the International Center for Tropical Agriculture modelling watersheds with limited data;
- a hydro-geologist at the Ethiopian Water Works Design and Construction Enterprise estimating groundwater recharge for multiple projects
- six Ethiopian Ph.D. or M.Sc. students using IDSS models in their research;

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[39] Report on IDSS Workshop Ethiopia
[40] Report on IDSS Workshop - Tanzania
[41] Report on IDSS Workshop - Ghana

- four former students from Sokoine University of Agriculture in Tanzania using the FARMSIM model in their research; and
- an employee of ILRI-LIVES project who is pursuing admission into a PhD program and researching the production efficiency of dairy farmers.

The post-workshop interactions of the IDSS team with participants, like the survey responses noted above, indicate that many of the workshop participants will use or have already begun using knowledge gained in the IDSS workshops in future and current research activities. Some of the participants are already engaged in ILSSI activities, and are now ready to apply what they have learned in the project.

V. IMPACT OF ILSSI PROJECT

In the previous sections of this report, a brief overview, detailed description of the ILSSI methods and results, and overview of ILSSI stakeholder engagement and capacity building are covered. In this section of the report, the products and interventions described in the previous sections are summarized and placed in perspective to demonstrate precisely how ILSSI is addressing its goals stated in the theory of change and the pathway to outcomes. Examples of emerging products and key overall messages about the ILSSI product are also provided in this section of the report.

The ILSSI results framework is shown in Figure 11. It demonstrates how ILSSI is progressing from indicators to activities and outputs and how the detailed experiments are contributing to USAID goals at varying levels of scale up to the overall FtF goal.

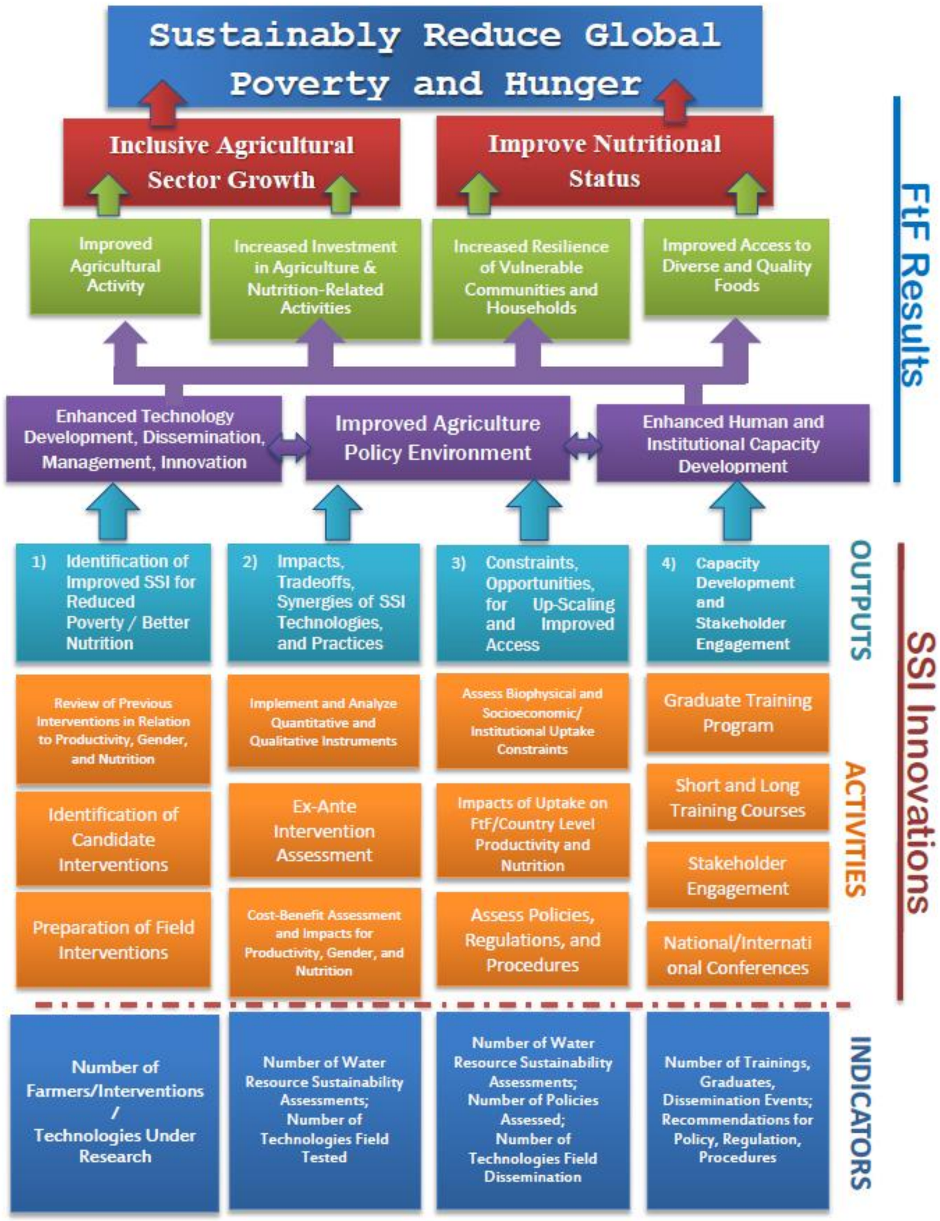

Figure 11: ILSSI and the Feed the Future Strategy Results Framework

Progress of ILSSI activities has been steady in the first three years of the project, as indicated by the detailed description of ILSSI activities and results in earlier sections of this report.

A. Impact to date

The ILSSI Results Framework (Table 8) outlines how the project utilized a research for development approach to progress from assessment and research of SSI technologies to the adoption of SSI technologies/interventions.

Table 8: ILSSI Project Detailed Results Framework

<table>
<tr><td colspan="4">Feed the Future Focus Areas
Climate Smart Development, Gender Integration, Improved Nutrition. Inclusive Agriculture Sector Growth, Research and Capacity Building</td></tr>
<tr><td colspan="4">Innovation Laboratory for Small Scale Irrigation
Increase food production, improve nutrition, protect the environment and accelerate economic development through improved access to small-scale irrigation technologies</td></tr>
<tr><td>Impacts</td><td colspan="3">Impact probably not measured during the LOP
▪ Farms adopting small scale irrigation systems
▪ Land area using small scale irrigation systems increased
▪ Improved economic impact of improved small scale irrigation systems at multiple levels of scale
▪ Improved farm family nutrition and economic well being
Environmental consequences of adopting small scale irrigation systems</td></tr>
<tr><td>Outcomes</td><td colspan="3">IDSS Model Outputs => Quantitative estimates of outcomes at field, regional, and national levels – integrated estimates of production, environmental, economic consequences of adoption
▪ Improved s production systems using SSI proposed
▪ Impacts, tradeoffs, synergies for alternative systems components
▪ Constraints identified and mitigations recommended
▪ Capacity development and stakeholder engagement
▪ Household nutrition of participating households improved
▪ Stakeholders at multiple levels informed for adoption decisions</td></tr>
<tr><td>Outputs</td><td>Results of field studies aggregated and reported

Training of farmers and local extension workers in SIPS</td><td>Household members trained on importance of nutrition

Pre and post field study assessment of nutrition and economic status</td><td>Ex ante and ex post assessment of consequences ILSSI intervention on production, environmental, economic, and nutrition
Constraints analyses

Scaling from field to national levels</td></tr>
<tr><td>Indicators</td><td>▪ 50 farmers participating in field studies
▪ 3 modified field study instrument developed for future use
▪ 2 field demonstrations sites
▪ 50 farmer kitchen gardens established
▪ 25 fodder-livestock farmer sites established</td><td>▪ 50 household surveys collected
▪ 2 surveys per year for two years
▪ Semiannual reports on progress with surveys and analysis
▪ Survey inputs to IDSS for integrated analysis

Mid-term and final reports on survey results and interpretation</td><td>▪ Semi –annual and annual reports on ex ante analysis of ILSSI scenarios – production, environment, and economic
▪ Updated IDSS models with enriched nutrition data for inputs for regional and larger scale
▪ Watershed application of ILSSI interventions for initial scaling
▪ Risk assessment report for overarching ILSSI scenario</td></tr>
<tr><td>Major Objectives</td><td>Field Studies</td><td>Surveys</td><td>Integrated Data Analysis</td></tr>
</table>

B. Summary of Impact Pathway and Theory of Change

The research for development paradigm used by ILSSI involves early and ongoing involvement with decision makers at multiple levels of scale. Figure 12 shows the integral interaction with stakeholders from inception to final product and how this engagement is central to the successful impact of the interventions studied. This iterative approach ensures that stakeholder's needs are continually considered and that their perspective and experience continue to guide the ongoing research and its interpretation. This assures relevance and creates ownership of the end products.

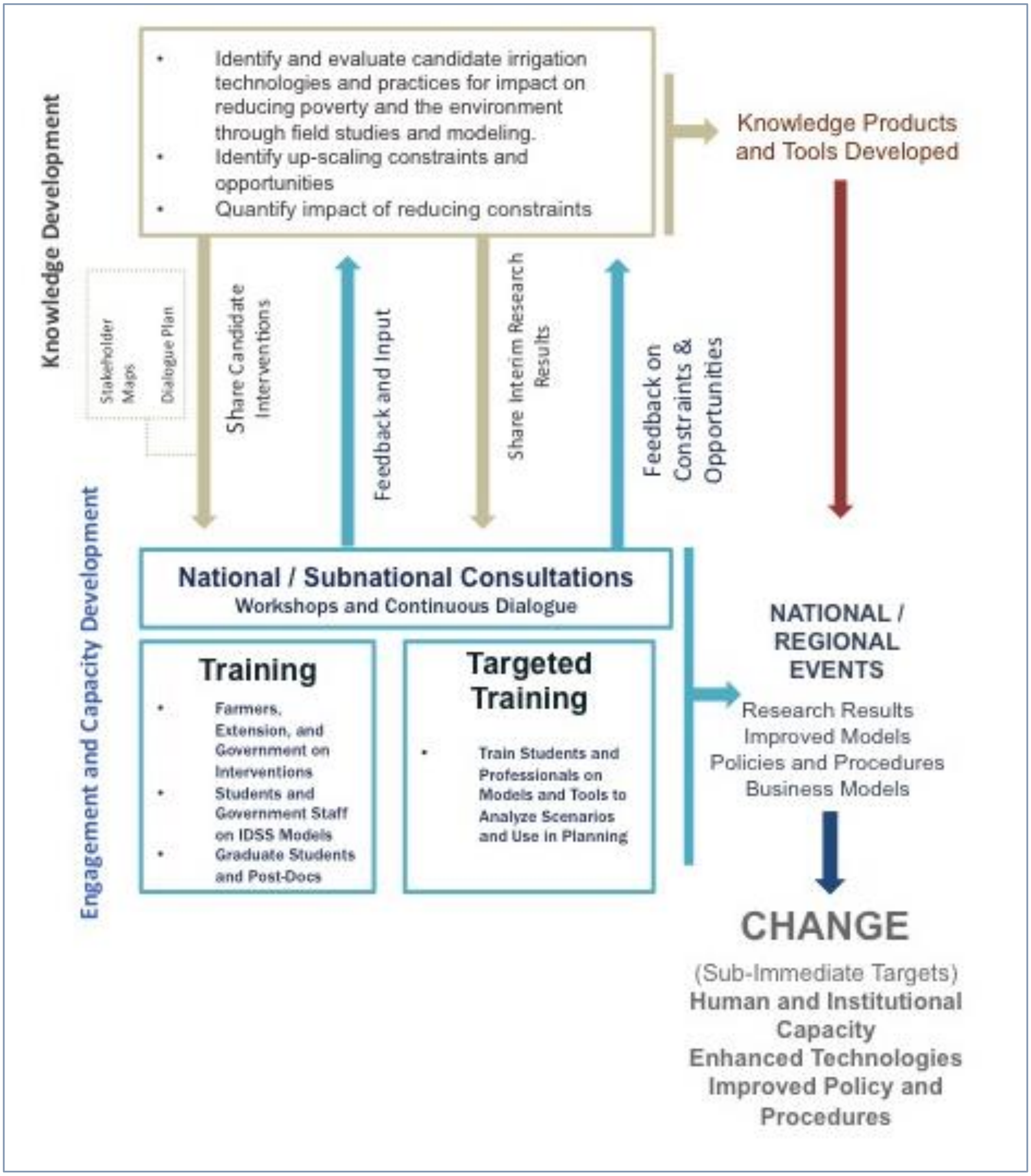

Figure 12: Impact of Interventions Leading to Change

C. Evolution of Impact Assessment/Pathway

The ILSSI project has followed the traditional impact pathway to ensure success during the life of the project and is focusing beyond on the traditional pathway (specifically on long-term outcomes and impacts by utilizing IDSS) to ensure a long-term and sustainable impact of program activities. Figure 13 depicts the traditional pathway to impact for new technology development. Inputs are purchased or natural resources are applied as constituents of the farming system under study. Outputs are the immediate product such as yield. The application of the IDSS provides an early estimate of the outcomes and impacts of the intervention, which is one of the key variables for success of ILSSI approach

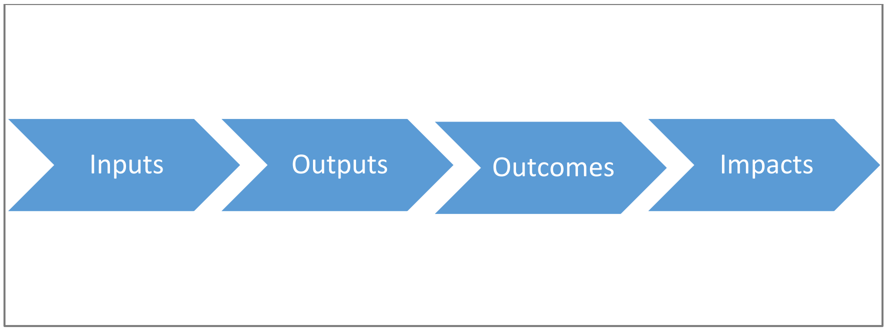

Figure 13: Evolution of Impact

Inputs and outputs are modeled as variables in a comprehensive integrated system to produce quantitative estimates of the production, environmental and economic consequences of the interventions in the context of the farming system of which it is a component part. The remaining components of the farming system can also be modeled to seek optimum solutions. Outcomes provide decision makers in the private sector and government (local and national levels) with a basis for making more informed decisions on the appropriateness and utility of the SSI intervention.

The application of the new technology or process often occurs after the completion of the research phase of the research and development chain. However, the IDSS provides a means of evaluating impact by modeling results at the end of the project in real-time based on a range of projected adoption rates, which enables the ILSSI team to forecast the impact of the project at the time it is completed. Because the IDSS is scalable, outcomes and impacts can be estimated at multiple levels from national to farm, thus resulting in long-term impacts on multiple levels.

The IDSS is part of a more comprehensive research approach wherein field studies provide more quantitative information on the performance of interventions under varying conditions. Household surveys provide input to the IDSS on the result of the intervention on household impact and nutrition.

The IDSS, applied under multiple conditions across the three ILSSI countries, is itself an outcome of the project. Through training and partnering with stakeholders at multiple levels of scale, the IDSS methodology is being put into action and national operators are receiving the experience that will allow its continued use well beyond the life of the ILSSI project.

D. Examples of Products of ILSSI Research

Recognizing that this report only covers three of the five-year project, the following list provides a substantial number of tangible public products that are emerging with varying levels of maturity. These products demonstrate the success of ILSSI's comprehensive research for development approach and how the ILSSI project is having and will continue to have an impact beyond the scope of the project.

- Assessment of water availability for SSI and demonstration of methods for planning siting of small-scale irrigation schemes.
- Demonstration of the performance of multiple small-scale irrigation systems in three countries with examples of related infrastructure development such as microfinance and availability of purchased equipment and its maintenance.
- Production, environmental, economic, and nutritional consequences of interventions evaluated to date.
- Ex ante and ex post analyses of SSI outcomes for three countries.
- Constraints and gap analyses with evaluation of alternative mitigation strategies.
- IDSS-IFPRI modeling suite with related national training and application.
- Networks of scientists and practitioners in the three countries that communicate and collaborate on the use of quantitative modeling.
- Establishment of an explicit IDSS team at Bahir Dar University to teach and use the system in a national setting.
- Specific applications that have emerged at multiple locations
    - Workbooks and manuals on use of SSI and IDSS analytic tools
    - Databases that enable future analytic efforts
    - Value chain analytic capacity with application for fodder
    - Wetting front detector application
    - Solar powered pump application

Products for long-term use by stakeholders

1. The IDSS-IFPRI modeling will be a major product from the projec that technical staff in government agencies and researchers at national universities can use and apply in the future. Many staff have been trained on components of the modeling suite.
2. Other capacity building and training activities will support future analysis of irrigation intervention scaling out across various types of stakeholders in the three countries. The project has established a network of scientists and practitioners in the three countries that communicate and collaborate on the use of the model suites. Specifically, the project has established an explicit IDSS team at Bahir Dar University to apply the IDSS models and to teach their application to BDU students.
3. Household survey data can be used by students and researchers for many other analyses after the data have been uploaded to dataverse. The protocols are already available on dataverse.
4. Other products that will be available for future use include the important stakeholder reports on constraints and opportunities for small-scale irrigation; all published journal articles; workbooks and manuals on use of SSI and IDSS analytic tools; databases that enable future analytic efforts; and focus group discussion protocols.
5. Results from new applications that can be replicated elsewhere, such as value chains for irrigated fodder; wetting front detector applications, and solar power application (together with Africa RISING).

E. Key Messages from ILSSI Research, Analysis and Capacity Building

ILSSI has and continues to show, through both modelled and empirical work, that smallholder irrigation has the potential to transform rural livelihoods. ILSSI informs on the entry points to sustainable, gender-sensitive uptake of small-scale irrigation in Ethiopia, Ghana and Tanzania with impacts beyond. ILSSI and SSI interventions contribute to global development goals in the following ways:

1. The sustainable small-scale irrigation potential is large, estimated approximately 6 million ha or nearly 5.3% of the landmass in Ethiopia based on ILSSI modeling[61]
2. Small-scale irrigation of crops increases yields, on average, by 35.5 percent and income 1.8 times compared to rainfed farmers in Ethiopia; similarly moving from buckets to pumps increases 2.4 times net revenues (for example vegetables in Ethiopia);
3. Irrigated fodder is viable in Ethiopia and likely for Tanzania;
4. Smallholders with limited animal resources may find sale of fodder as a cash crop more attractive than feeding it to owned livestock; [2]
5. Gender can act both as a constraint or a potential to women's empowerment in small-scale irrigation; [3]
6. Small-scale irrigation increases dietary diversity through increased incomes;
7. Small-scale irrigators spend less time on collecting water for domestic uses (statistically significant Ethiopia).

F. Exit Strategy

In this section, the projected achievements of the project at the end of its five-year term are summarized from the more detailed descriptions in the previous sections – and expressed in terms of deliverables. This section also identifies opportunities and approaches to build on and extend the work in ILSSI Phase 1, should a second phase of the project be considered.

1. Achievements

- An integrated team of U.S. universities, international centers, and national institutions in three countries with established procedures of interactive engagement to address the complex issues and opportunities to make small scale irrigation technologies available and useable for smallholders
- An integrated decision support system with capability to assess the production, environmental and economic consequences of the introduction of new small scale irrigation technology with the ability to scale up or out the results of field studies and household surveys at levels of scale from farm to country. A new methodology developed and demonstrated to quantitatively estimate outcomes and impact of research inputs and outputs for SSI and other related farming systems enterprises.
- Identification and verification via stakeholder engagement of the constraints to adoption of new small-scale irrigation innovations and analysis to show the pathways to mitigation of these constraints.
- Established and ongoing engagement with stakeholders at multiple levels in three countries – including investors in future technology development, decision makers in government, private

[1] http://ilssi.tamu.edu/media/1307/assessing-irrigiation-potential-and-land-suitability-in-ethiopia.pdf
[2] Cross regional comparison of FEAST results in Ethiopia, Tanzania and Ghana
[3] Small Scale Irrigation Technologies and Agricultural Water Management Practices: Analyzing nutrition, health and gender outcomes

sector entities providing supporting infrastructure for farming systems using small scale irrigation, local practitioners of SSI such as farmers and extension workers.

- The products of initial research for development with smallholder farmers to evaluate equipment and practices for small-scale irrigation and engagement with local and regional entities to facilitate infrastructure development and to advance the adoption of new technology.
- The results of household surveys conducted before and after the introduction of small scale irrigation to smallholder communities which estimate the impact of irrigation, especially in the dry season, on economic and nutritional status of the household and define the gender related issues, opportunities and constraints the adoption of small scale irrigation systems.
- The application of the IDSS to identify natural resources at the local to national levels appropriate to the sustainable smallholder farming systems using irrigation, to estimate the consequences of alternative interventions for SSI at scale from farm to country, to identify constraints and propose mitigation strategies at multiple levels of scale and to provide ex post analysis of results as decision tools for a variety of stakeholders and users.
- Education and training in the use and limitations of the SSI systems developed in Phase I of ILSSI for farmers, those providing related infrastructure to support SSI operations, faculty and students in national universities, and government and private sector investors.

2. Opportunities to complete, build on and extend SSI development in Phase II.

- Identify and address gaps in knowledge resulting from ILSSI Phase I – including the completion of any unachieved objectives deemed critical to future progress in the use of SSI.
- Continue and extend farm level research in broader areas of the three ILSSI countries to more comprehensively provide biophysical understanding of SSI covering the geographic diversity of the countries.
- Engage in expanded stakeholder collaboration to put in place and demonstrate the utility of SSI interventions at farm and regional levels of scale – moving the main emphasis from research to demonstration along value chains in Phase II.
- Extend regional and national household and other surveys in the three countries and perhaps new countries to evaluate the impact of SSI as it is put in place and practiced – with continuing focus on economic, nutritional results and identification and mitigation of gender related limitations to adoption of SSI.
- Develop joint efforts with private sector developers of small scale irrigation technology to develop and implement business plans for the infrastructure to develop alternative water lifting and delivery systems for irrigation.
- Assess cross-country common factors involved in SSI and develop transnational databases and analyses to provide further knowledge on the use of SSI across Sub-Saharan Africa and to develop inputs to the global decision making process.
- Extend the IDSS to provide the capacity to do value chain analyses on relevant commodities using small-scale irrigation as part of the farming system.
- Develop derivative management tools from the IDSS for farmers and planners at local levels that can be used for planning and evaluation at the enterprise level in developing countries.
- Continue and expand capacity building with practitioners, investors, decision makers and university faculty and students across multiple countries.
- Establish a web-based capacity for users of the IDSS in developing countries to streamline training and use of the system with mentoring from the IDSS group at Texas A&M.

- Extend the SSI thrust to address related critical questions related to climate change and climate smart agriculture – addressing how to best use water and other limited natural resources for production of food and fiber most efficiently in the future and which SSI technologies are best equipped to deal with varying climatic changes in the three countries.
- Expand ILSSI to two additional USAID FtF countries where SSI can make a dramatic difference to people's lives.
- Continue to seek partnerships with other FtF Innovation Laboratories and other research and development efforts to better leverage and extend ILSSI resources.

VI. LESSONS LEARNED AND OPPORTUNITIES FOR UPSCALING

A. Methodology and Experimental Design

The research for development paradigm used in field studies has a positive track record as used by the international centers to facilitate adoption by the stakeholder community. There remain, however, some limitations to this method regarding sample size and consistency of data over time. The overall experimental design linking field and survey studies with integrated modeling has been demonstrated to be successful in the first three years of the ILSSI project. Successful adoption and use of the ILSSI product is supported by a multifaceted approach to capacity building. The distribution of overall funding among the ILSSI components was designed to approach the optimum mix of resulting product and knowledge. The resulting experimental design reflects approach and resulting product. The following sections present the overall assessment of the experimental design – reflecting the positive aspects and identifying limitations and constraints to be considered in possible future studies.

<u>Field Research</u>: The strength of research for development in farmers' fields is the greater acceptance of results by other farmers and those who see the interventions working in the real world. The ILSSI team learned a tremendous amount from farmers who bring their site-specific expertise to bear on the field studies using interventions selected by stakeholder advice. The ongoing engagement with stakeholders provides better ownership of the product and its acceptance/use. The flip side of conducting research in farmers' fields is the limitation on control of the experimental design as farmers must adapt to their perceptions of changing scenarios in which they operate. The ILSSI team has been able to overcome some of these limitations by the active involvement of students who engage farm families directly to encourage rigor in the implementation and who are motivated to ensure good data as many are using these data as inputs to thesis projects. Farmers using new interventions or irrigating for the first time have had growing pains in their early years, which has limited the quality and quantity of data in some cases. Farmers have asked to modify their protocols to reflect their early experiences. In answering the question about low sampling rate, the ILSSI team has to ensure for each site it is recognized that there are multiple participating households. Ultimately the number of households studied is driven by the available funds. It is a judgment call to apportion the available funds across the multiple components of ILSSI. The ILSSI team does not expect to increase the number of households studied in ILSSI but will have marginal increases in northern Ethiopia as a result of the collaboration with SIPSIN. The CGIAR partners are very experienced in conducting research for development and have the skills to know how to report the results in either quantitative or qualitative terms while maintaining scientific integrity.

<u>Household Surveys</u>: IFPRI, the primary partner in these studies, has a wealth of worldwide experience in designing, conducting, and evaluating survey data. IWMI and ILRI are conducting smaller survey studies

and have similar experience. The sample size for IFPRI studies is much larger than the number of households involved in field studies. While households involved in field studies are included and sampled, the total population of the surveys is much larger. Because of the need to include a common population in the evaluation of biophysical studies in the field and social science studies in the surveys, compromises to meet both needs were necessary and carefully planned. In some cases this limits the statistical power of the social sciences study results. In all cases, our partners have the experience to frame out what can be said about the results.

Modeling Analysis: The application of the IDSS as a major component of ILSSI is not constrained by sample size. Other mathematical issues related to scaling to national levels and the integration of multiple kinds of data of varying quality and precision pose a different set of issues, which are addressed in the design and interpretation of these experiments. The IDSS team, in partnership with our international partners, especially IFPRI, is aware and experienced in interpretation of these results. Calibration of model component outputs is done to assure the models are performing in the real world – and modeling results are extrapolated from these calibrations to produce results that extend past explicit experience. While it is often not feasible to state precisely the estimate of error in the integrated model outputs, it is important to note that high levels of precision are not required to provide very useful information that takes the decision maker well past the uncertainties of expert opinion.

B. Constraints and Gaps

As shown in earlier chapters of this report, the product of early research and ex ante analyses identified constraints and gaps, which were discussed with national stakeholders for the three ILSSI countries. Stakeholders provided their feedback and a prioritized list of constraints that formed the framework for the subsequent constraints and mitigation analyses that are now underway. The following is a summary of these constraints.

The stakeholder workshops in Ethiopia, Ghana and Tanzania succeeded in bringing key national stakeholders together to share research and experiences on small-scale irrigation and irrigated fodder interventions, foster dialogue, networking and enhanced partnerships, and collaboratively prioritize the key constraints to successful and productive small-scale irrigation and irrigated fodder interventions in each country. The workshop outputs will be used for the next phase of analysis through the IIDSS. The results of the modelling in combination with the other research results will contribute to national dialogues towards out-scaling and up-scaling small-scale irrigation, including irrigated fodder, for improving livelihoods in each project country.

Each workshop produced a consolidated, ranked list of the priority constraints, outlined below in order ranked by the workshop participants.

Table 9: Cross country comparison of ranked priority constraints

Rank	Ethiopia	Ghana	Tanzania
1	Access to markets	Access to markets	Capacity development and irrigation expertise
2	Water availability and access	Water lifting technology access	Finance modalities and access to electricity, solar and wind
3	Access to appropriate SSI technology and knowledge	Climate change	Policy constraints and market access
4	Market access: Affordable and relevant inputs	Water availability and access	Climate change: water, temperature variability
5	Risks and vulnerabilities	Land issues	Competing water uses (with other sectors)
6	Institutional issues	Diseases and Pests	Soil management and fertility
7		High labor cost for women	Cultural and social practices of stereotyping crops e.g. fodder vs rice perception
8		Access to knowledge and information services (capacity development)	Fodder technology is targeted to specific systems, either intensive or extensive system
9		Inadequate access to inputs and labor	Low genetic potential for livestock
10			Source of energy

C. Factors to be considered in further studies

An overview of the experience and accomplishments of ILSSI at the three year mark suggests a number of observations, opportunities and issues that will be addressed in a Phase II of the project. The most important of these are summarized here.

1. Modeling at multiple scales shows significant differences in potential for adoption of small-scale irrigation as well as differences among suitable crops and technologies. SSI requires technologies in tune with landscape context, as this context defines soil quality, GW depth and other key parameters shaping profitability of irrigation.
2. Enabling access to microfinance remains a major challenge in all three countries for scaling: The three ILSSI countries rely on different finance options for different technologies, capacity of various types of MFIs generally limited, including limited literacy and numeracy in rural areas, also gendered differences in assets and access.
3. Capacity for irrigation in the dry season needs strengthening – this includes improved varieties and emerging crops (such as irrigated fodder), pests and disease control and marketing, which vary significantly from the dry to the rainy season.
4. Upscaling of irrigated fodder needs to recognize and strengthen the role of a fodder market

5. To realize the income opportunity in SSI Intensification requires balanced application of other inputs to the farming system, such as pest control and fertilizer and land resources.
6. Women have broader and different needs for productive water uses from men. To ensure that SSI achieves its potential it is important that their needs are taken into consideration during the design and implementation of any SSI project. Examples - Some gendered differences in technology (preliminary, Ethiopia): women prefer rope and washer and men pulley, particularly at larger depth; women experience more labor constraints.
7. Most companies and government agencies in the three countries still focus on rolling out technologies for increasing irrigated area. There is thus an under-appreciation of the need to also roll out technologies and develop capacity on irrigation scheduling and water conservation to ensure that water use closely follows crop water demands to avoid long-term adverse sustainability impacts, such as pollution and depletion.
8. Among irrigation technologies, solar is the most preferred *a priori;* solar pumps are also used for the home and side business to charge mobile phones.
9. Yields increases of 60 to more than100% can be achieved if irrigation advice is provided (soil moisture assessment or wetting front detectors). Farmers tend to under-irrigate with manual lifting devices and to over-irrigate with motorized pumps.

D. Experimental Design Considerations in Phase II

- Emulating the approach used by SIIL, ILSSI will adopt a “mother-baby” approach where experiments are conducted at a central location, using a more controlled approach, and then linked to less structured research in individual farmers’ fields where more variability is expected.
- It is difficult to attribute results in farming systems research to a single variable; the IDSS will be more actively used to model the results of one variable, holding others constant and using the system to seek optimum combinations of variables to achieve the most desirable impact.
- Linking nutritional consequences to farming systems production will be given more emphasis; methods to assess nutritional consequences of enhanced production of food using small scale irrigation at larger levels of scale will be undertaken.
- Continuing/ increased collaboration with other Innovation Labs will be stressed.
- Environmental monitoring and mitigation will be a more integral part of the experimental design in phase II.

VII. NEXT STEPS

- ILSSI will continue with the five-year plan of work with agreed objectives.
- ILSSI is entering its fourth of the five-year cooperative agreement. The field studies and most of the surveys will be completed in year four. These studies will be completed in year five with the development of analyses of results using the IDSS in an iterative engagement with other partners.
- A comparative analysis of the elements of the approved cooperative agreement and the projected achievements of ILSSI at the end of year five will be provided to the sponsor.
- Increased emphasis will be placed on stakeholder engagement in the remaining two years with the objective of moving as far as possible towards adoption and use of the SSI products. Engagement at multiple levels of scale with application of the methods to relevant stakeholder objectives will

be undertaken. Increased emphasis on stakeholder engagement with use of the IDSS will be stressed.

- Integration of the results of the ILSSI components into an integrated interpretation will be a key component of the remaining effort. Multiple publications and reports will be completed.
- Specific interpretive analyses will be focused on the needs of policy and decision makers at the national and regional levels, as well as on engagement with the USAID Missions in the three ILSSI countries and on private sector investors in small-scale irrigation infrastructure.
- Constraints, gaps, and related mitigation studies will be completed in year 4 and further incorporated into major findings in year five.
- The collaboration between ILSSI and the SIIL and the Nutrition Innovation Lab under SIPSIN will be continued; other pending FtF IL collaborations will be brought on stream as possible.
- The final report will be prepared for the agreement in year five.
- ILSSI will report the results of its final report in a special session of a recognized international water meeting in Sub-Saharan Africa.
- Support of the USAID External Review will be provided as requested.
- If the second phase of ILSSI is initiated by USAID, the appropriate proposal and budget will be developed in year five to provide continuity of ILSSI in the next phase. Some of the options for phase II activities are provided in the preceding section of this report.

VIII. APPENDIXES

Appendix I. – Long Term Training

Feed the Future Innovation Lab on Small Scale Irrigation in Ethiopia, Tanzania and Ghana

Name of Student	Gender	University of Study	Degree[7]	Major	Graduation Date	Home Country	Home Institution[8]
Tewodros Assefa	M	NCA&T State University	Ph.D.	Energy and Environmental Systems	December 31, 2017	Ethiopia	Bahir Dar University
Tsehay Azeref Wondmeneh	M	Bahir Dar University	M.S.	Agronomy	June 2017	Ethiopia	Bahir Dar University
Hailie Alebachew	F	Bahir Dar University	M.S.	Horticulture	June 2017	Ethiopia	Bahir Dar University
Mariana McKim	F	NCA&T State University	M.S.	Agricultural Education	August 2016	USA	N.C. A&T
Sintayehu Alemayehu Teshome	M	Texas A&M College of Agriculture and Life Sciences	M.S.	Ecosystem Science and Management (Range Mgmt)	June 2017	Ethiopia	TAMAR
Belainew Belete	M	Bahir Dar University	M.S.	Economics	October 2016	Ethiopia	Bahir Dar University
Talakie Asnake	F	Bahir Dar University	M.S.	Water resources Engineering	June 2016	Ethiopia	Bahir Dar University
Muluye Gedife	M	Bahir Dar University	M.S.	Water resources Engineering	December 2016	Ethiopia	Bahir Dar University
Adisu Wondimu	M	Bahir Dar University	M.S.	Chemical Engineering	June 2017	Ethiopia	Bahir Dar University
Debebe Lijalem	M	Bahir Dar University	Ph.D.	Water resources Engineering	June 2018	Ethiopia	Bahir Dar University
Misba Abdela	M	Bahir Dar University	M.S.	Water resources Engineering	June 2016	Ethiopia	Bahir Dar University
Abdu Yimer	M	Bahir Dar University	M.S.	Water resources Engineering	June 2016	Ethiopia	Bahir Dar University
Kassaw Beshaw	M	Arba Minch University	Ph.D.	Water resources Engineering	June 2019	Ethiopia	Arba Minch University
Demelash Wendemench	M	Arba Minch University	Ph.D.	Water resources Engineering	June 2019	Ethiopia	Arba Minch University
Tariku Yadeta Fufa	M	Arba Minch University	M.S.	Economics	December 2016	Ethiopia	Arba Minch University
Raymond Tetteh	M	UDS	M.S.				

[7] B.S., M.S., Ph.D., other (specify)
[8] Fill out for foreign students only. Specify if the student is from a NARS, an educational institution, the private sector, etc.

Appendix 2. Field-level monitoring

Summary of field level data collection - Biophysical

Measurement	Method	Temporal resolution	Ethiopia	Ghana	Tanzania
GPS of well, house hold surveys and field	GPS	At the beginning of each season	X	X	x
Hard pan resistance	Penetrometer	Before each cropping season	x (only hard pan)	N.A.	N.A.
Bulk density	Soil core	Before each cropping season	x		
Moisture content at top soil	TDR	Weekly interval, before and after irrigation	x	-	x
Moisture content throughout soil profile	Soil moisture profiler (1 m)	Before and after irrigation + weekly	x	-	-
Infiltration rate	Infiltrometer/double ring	Before and after the season	x (only hard pan)	N.A.	N.A.
Sediment concentration/yield and quality (N,P and K)	Laboratory – filtration	Event based	x (only hard pan)	N.A.	N.A.
Surface runoff	Manual	Event based	x (only hard pan)	N.A.	N.A.
Crop development stages	Manual observation	At crop development stages	x	x	x
Crop height	Meter	At crop development stages	x	x	x
Plant density	Measurement grid	At planting stage	x	x	x
Fertilizer Type and quantity	scale and laboratory (for organic fertilizer only if applicable)	At each application	x	x	x
Crop yield + biomass	Scale (quantification) + economic evaluation	At harvest	x	x	x
Soil physiochemical properties	Standard laboratory methods	Before/after each cropping season	x	x	x
Irrigation quantity applied	Field book on duration * discharge calibrated per technology	Each irrigation event	x	x	x
Nursery data	Field book	During Nursery	x	x	x

Summary of field level data collection – Additional socio-economic data

Measurement	Method	Frequency	Ethiopia	Ghana	Tanzania
For the intervention households: farm characteristics, farm family characteristics	Baseline survey	At project inception	x	x	x
Intervention installed	Baseline survey	At project inception	x	x	x
Livestock data (types, numbers, management, etc.) for the household	Baseline	At project inception	x	x	x
Descriptions of "typical" household gardens	Baseline	At project inception	x	x	x
Crop management data (dates/amounts of tillage, planting, harvesting, fertilizer, irrigation, etc.)	Field books & survey	Throughout the cropping season	x	x	x
Labor involved in irrigation and other agronomic activities during the irrigation season (gender disaggregated labor and cost)	Field books & survey	Throughout the cropping season	x	x	x
Daily wage rate during the same time (local currency)	Field books & survey	Throughout the cropping season	x	x	x
Cost of fertilizer, pesticide (if used), seed (local currency)	Field books & survey	Throughout the cropping season	x	x	x
Amount of seed in quantity	Field books & survey	Throughout the cropping season	x	x	x
Amount of seed in value (local currency)	Field books & survey	Throughout the cropping season	x	x	x
Total production/ crop yield in quantity and separation in quantity sold, consumed and donated	Field books & survey	Throughout the cropping season	x	x	x
Market price of vegetable (local currency)	Field books & survey	Throughout the cropping season	x	x	x
Repair and maintenance cost (local currency)	Field books & survey	Throughout the cropping season	x	x	x

Site interventions: Technology (number of farmers), water source, credit arrangement, crop (as at October 2016)

	Ethiopia sites				Ghana sites			Tanzania sites		
	Robit	Dangishita	Bochesa	Upper gana	Zanlerigu	Dimbisinia	Bihinaa yili	Mkindo	Rudewa	Babati
Rope & Washer	0	22	1	11						
Pulley	24	11	0	0						
Drip	0	0	0	3	2	8				
UDS drip					2	8				
Solar pump	0	0	0	3						
Diesel/petrol pump	0	0	12		8		8	14-16[9]	21-25	
Tank and hose					8		8			
Control group (watering can)					9	8	8			
WFD					8	8	8			
Pocket garden								10	10	
Water source					SGW; Rain harvesting	SGW	Surface	Surface	Surface	
Credit system	Local MFI loan	Local MFI loan	Local MFI loan	Local MFI loan	Project credit: pumps, tanks	Project credit: pumps, drip	Project credit: pumps	Project credit: pumps on fee per use	Project credit: pumps on fee per use	n/a
Crops (chosen by farmers)	Tomato; green pepper	Onion; green pepper	Cabbage, tomato, onion, green bean, maize	Avocado, fodder, carrot, cabbage	Local leafy vegetable; cow pea, black-eyed pea	Tomato	Corchorus; Onion	African eggplant, maize and tomato	African eggplant, maize and tomato	African eggplant, maize and tomato

[9] Number is a range in Tanzania sites because the field interventions are set up with groups, with each group being 7 to 8 people.

Appendix 3. Watershed Monitoring

Measurement	Method	Temporal resolution	Ethiopia	Ghana	Tanzania
Climatic data	Weather station	Continuously (10 min) for project weather stations and daily for secondary data	x	x	x
Potential evapotranspiration and actual crop evapotranspiration	Calculated according to Penman Monteith and FAO drainage paper 56	Continuously (Daily)	x	x	x
Characterization of main irrigated and rainfed crops + crop calendar	Manual observation & GIS	Once, start of the project	x		
DEM, Soil and land use map	Sampling & governmental agencies/university data, GIS, Standard laboratory analysis	At project inception	x	x	x
Stream water levels at outlets	Manually	Daily	x	x	x
Stream water levels at outlets	Pressure transducers	10 or 15 min (depending on watershed and lag time)	x	x	x
Sediment concentration/yield	Manual sampling (time based)	Continuously and event based & base flow in dry season	x		
Sediment quality at selected watershed locations	standard laboratory analysis	Event based & base flow in dry season	x	x	x
Groundwater table	Manual/Floating method or gauged	Twice daily in the rainy season and once a week in the dry season	x		
Infiltration rate (land use specific)	Infiltrometer/double ring	beginning and end of the rainy season	x		

IX. REFERENCES

A list of references as found cited in the body of the Mid Term Report has been included below. These references are separated by chapter and align with number assigned to them in the footnote. Please note that some references may be repeated across chapters.

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2. Stakeholder consultation proceedings Tanzania
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38. scale up of biophysical and environmental analysis of proposed ssi interventions summary of-aims timelines methodology and progress
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40. Assessing potential land suitability for surface irrigation using groundwater in Ethiopia

Chapter III – Summary of Results

1. Presentation on field level pilot interventions in small - scale irrigation and agricultural water management
2. Rainfall Run Off Process in the Upper Blue Nile Basin: The Case of the Dangishta Watershed
3. Insights and Opportunities from New Field Studies with small scale irrigation in Tanzania, Ghana and Ethiopia
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2. Stakeholder consultation proceedings Tanzania
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2. Cross regional comparison of FEAST results in Ethiopia, Tanzania and Ghana
3. Small Scale Irrigation Technologies and Agricultural Water Management Practices: Analyzing nutrition, health and gender outcomes