Opportunities and Limitations for Small Scale Irrigation Using Shallow Groundwater

Irrigable Land Potential (ILaP) Calculator Pilot Studies in Ethiopia

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List of Acronyms

Acronym	Term
A&E	Architecture and Engineering
AAU	Addis Ababa University
AMSL	Above Mean Sea Level
ATA	Agricultural Transformation Agency
BGS	Below Ground Surface
CSA	Central Statistical Agency [of Ethiopia]
DEM	Digital Elevation Models
EARO	Ethiopian Agricultural Research Organization
EC	Electrical Conductivity
ESRI	Environmental Systems Research Institute
ET	Evapotranspiration
FAO	[United Nations] Food and Agricultural Organization
GIS	Geographic Information System
GOE	Government of Ethiopia
GPS	Global Positioning System
HA	Hectares
ILaP	Irrigable Land Potential
IQC	Indefinite Quantities Contract
KM	Kilometer
LPD	Liters Per Day
LPP	Liters Per Person
LPS	Liters Per Second
M	Meters
MCM	Million Cubic Meters
NASA	National Aeronautics and Space Administration
NMA	National Meteorological Agency [of Ethiopia]
SAR	Sodium Adsorption Ratio
SRTM	Shuttle Radar Topographic Mission
TDS	Total Dissolved Solids
USAID	United States Agency for International Development
YR	Year

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1 INTRODUCTION

This project was undertaken for USAID under the Knowledge Management Task of the A&E Water IQC (Contract No. EDH-I-00-08-00025-00, DO 012) by the firms of MWH and UHL & Associates, Inc.

1.1 Project Objectives

The principal objectives of the project were to:

- Develop awareness of the opportunities and limitations for small-scale irrigation using shallow groundwater, and of the need for planning and management on a watershed basis so that the groundwater resource is developed sustainably.

- Introduce the principal output of this project: the ***Irrigable Land Potential (ILaP) Calculator***. The ILaP Calculator is a tool to assess available quantities of shallow groundwater for small-scale irrigation and develop realistic estimates of the potential land area within a watershed that can be sustainably irrigated.

- Apply the ILaP Calculator to two pilot study basins that are good candidates for expanding small-scale irrigation in the Highlands region of Ethiopia. These pilot study basins (watersheds) are: (1) the Gerbi Area, comprising the Sibilu River Basin, just north of Addis Ababa, and (2) the Tefki Area, a portion of the Awash Basin, west-southwest of Addis Ababa (**Appendix A, Figure 1**). Both basins have limited small-scale irrigation in place and most irrigation is for a few commercial enterprises for floriculture and vegetables.

The Gerbi and Tefki Area applications provide specific examples of the purposes and benefits of using the Calculator; provide an opportunity to guide the potential user through the Calculator Worksheets step-by-step; and provide a template with guidance and advice for users to rely on when addressing other basins. The Calculator is applicable to and can support and furnish a strong platform for the far-reaching small-scale irrigation planning and implementation programs that are underway for Ethiopia.

1.2 Context

Small-scale irrigation in Ethiopia is poised to increase markedly in the coming decades and much of the irrigation will come from groundwater. The Government of Ethiopia (GOE) plans to potentially move up to 6 million households into food security through a two-phase approach:

<u>Phase 1:</u> Irrigate 1.8 million hectares (ha) in the next few years, most through small-scale irrigation.

<u>Phase 2:</u> By 2020 sustainably move to medium-to-large scale irrigation, targeting 5 million hectares.

The GOE – Agricultural Transformation Agency (ATA) has identified as a primary constraint to this program, the evaluation of shallow groundwater availability and development feasibility of small-to-medium size watersheds countrywide.

The evaluation of shallow groundwater availability and development feasibility <u>before</u> development provides the opportunity to confine use to the renewable part of the resource, avoid over-exploitation, and preserve the resource for future generations. Acquiring this intelligence early in the planning stages facilitates investing in development only where it is feasible and has the potential to be most beneficial to the largest and most needy populations, while controlling non-desirable over-development by putting in place practical groundwater management and regulatory systems.

In many places, shallow groundwater availability is based on the limits of the watershed and thus watersheds are excellent basic units for evaluation. In this report, the terms watershed and basin are used interchangeably. Evaluating groundwater parameters on a watershed scale is relatively straightforward and can provide very clear insight as to how much groundwater can be developed sustainably while reserving a portion of groundwater recharge for important ecological water needs (e.g. stream dry weather flows (base flow), riverine vegetation, recession farming, wetlands, and certain agricultural crops).

The amount of shallow groundwater that is available is the key variable in assessing an array of important potential development parameters. The ILaP Calculator directly estimates or provides the basis to evaluate:

- The total hectares and percent of the available land that can be irrigated sustainably.
- The percent of the population that can benefit.
- The income value of the crops that can be grown.
- How much additional land can be irrigated if more efficient irrigation methods are implemented.
- The outlook for future populations.
- Sensitivity of the above to short-term and long-term drought conditions, and climate-change predictions.
- Potential for overexploitation of the groundwater resource.

1.3 Contributing Parties

The following parties have contributed in initiating, supporting and/or the implementation of this project:

- USAID Ethiopia: Abigail Jones and Dubale Admasu
- USAID Washington: Anthony Kolb
- MWH: John Velon and Eric Rawdon
- UHL & Associates: Vincent Uhl, Ashish Daw, and Jaclyn Baron
- Dr. Seifu Kebede and Addis Kailu from Addis Ababa University (AAU)

1.4 Report Sections

The remainder of this report is presented in four sections. **Section 2** gives an overview of the physical characteristics of the Gerbi and Tefki Areas, the two pilot study basins. **Section 3** describes the implementation process for the pilot studies including mapping products and the field reconnaissance consisting of a water-point inventory, field water-quality sampling, and short-term pumping tests. **Section 4** presents the Irrigable Land Potential Calculator starting with a discussion of its purpose and benefits. Step-by-step worksheets for the calculator algorithm are given using the example of the Gerbi Basin, and the worksheets are followed by the one-page ILaP Calculator forms produced for the Gerbi and Tefki Areas. The section ends with a discussion of the results for the two pilot basins with respect to irrigable land potential and its application to climate change variations. **Section 5** provides the project conclusions and recommendations for further effort to continue, build upon and broaden the application of the current work.

2 PILOT STUDY AREAS OVERVIEW

This section describes the physical setting of the two pilot study basins, the Gerbi Area and the Tefki Area.

2.1 Gerbi Area

The Gerbi Area (**Appendix A, Figure 3**) is 747 square kilometers (km^2) and located in a humid plateau north of Addis Ababa. The average annual precipitation is 1,300 millimeters per year (mm/year). National Highway 3 traverses the area and the largest towns are Sululta and Chancho.

The Sibilu River flows from south to north through the central part of the basin. About 10 smaller drainages in the basin are tributary to the Sibilu River. The Entoto mountain range forms the southern boundary of the basin with land elevations over 3,000 meters above mean sea level (m, amsl). The land elevation in the northern lowest part of the basin is on the order of 1,500 m, amsl near the confluence of the Sibilu River with the Muger River.

The basin topography is mountainous and rolling in the east - south/southeast with an extensive plateau area in the south and central areas. A slope analysis of the basin, which is discussed in Section 3.1, estimates the potentially irrigable land on the basis a 0 to 6% slope analysis at 30,600 ha or 41% of the total land in the basin.

The underlying bedrock is predominantly basalt (**Appendix A, Figure 2**). Shallow groundwater is accessible via hand-dug open wells in soil and the weathered bedrock developed in situ or transported and re-deposited in large plain areas. Two broad sub-zones have been recognized by their mode of groundwater occurrence, yield and recharge-discharge conditions, and aquifer composition:

- **Hills and Plateaus:** The hills are generally covered by drainable soils; in places competent bedrock is close to the surface with a thin weathered bedrock component. Shallow groundwater occurs in weathered bedrock. Because of the thin weathered bedrock profile, the storage of shallow groundwater is limited. The weathered bedrock is highly permeable leading to rapid drainage of recharge water to adjacent broad flood plains. The yields of shallow hand-dug wells in shallow basalt aquifers vary from 0.025 to 0.05 liters per second (LPS).

- **Broad Floodplains:** The seasonal flood plains are broad valleys where there is convergence of both surface water and groundwater. Groundwater occurs at the contact zone between the soils and underlying weathered basalt bedrock. The soil zone contains transported outwash sands and gravels, which enhance the permeability of the soil. The yields of shallow hand-dug wells in the shallow soil and weathered basalt vary from 0.01 and 0.50 LPS.

General morphological features of the Gerbi Area are depicted in Figure 1.

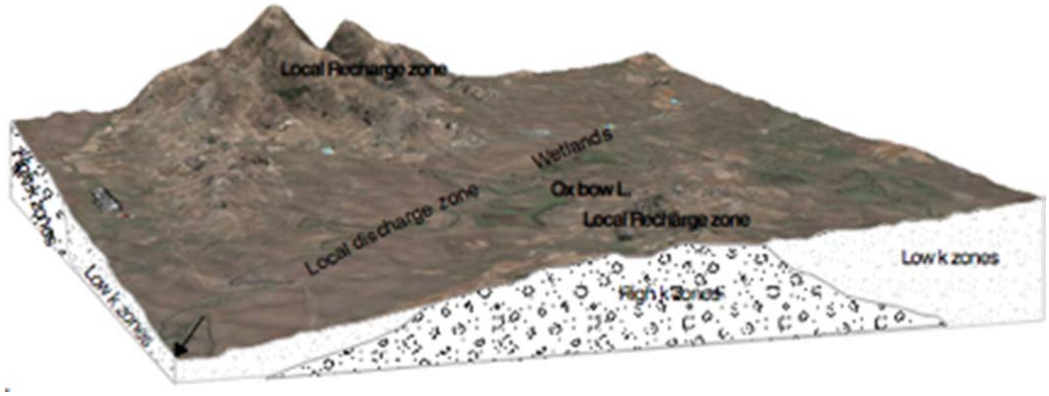


Figure 1: General Morphological Features of the Gerbi Area.

Minor depressions and associated morphologic features such as wetlands, ox bow lakes and minor groundwater zones with recharge zones and discharge in the depressions. Two aquifer zones can be recognized - the wetlands, oxbow lakes (ancient and modern) and river terraces, and the surrounding hills covered by variable thicknesses of in-situ developed soil/regolith. (Adapted from Figure 6.3, Groundwater in Ethiopia, 2013 by Dr. S. Kebede)

Agriculture is the mainstay of the economy in the basin and activities include hay production, livestock rearing, and crop production. Agro-industry is emerging and the main industries include dairy (dozens), poultry farms (dozens), horticulture (2), floriculture (1), tannery (1), water bottling (1) and micro- and small-scale enterprises (e.g. cement block production, wood and metal works). The basin is also becoming an important weekend resort for people coming from Addis Ababa.

Groundwater is used for drinking, livestock, commercial/industrial use, and limited irrigation in the basin. It is primarily accessed via hand-dug wells with depths ranging from a few meters to 15 meters and deeper. Many hand-dug wells are used for water supply (community, individual residences, small gardens, and livestock). Drilled wells (boreholes/tube wells) are principally used for town water supply, commercial/industrial uses, and commercial agriculture at two locations. Groundwater for irrigation use on a large scale is limited to four sites as summarized in **Table 1**.

Table 1: Major Groundwater Irrigation Uses in Gerbi Area

Site Name	Irrigated Area and Water Source	Description
Communal Spring	20 ha, spring	Vegetable production, individual land-holdings range from 0.03 ha to 0.25 ha; flood irrigation is applied (see Figure 3).
Vegetable Farm	8 ha, 2 deep wells	Vegetable production (mainly peas).
Floriculture Farm	4 ha, 1 deep well	Flowers for export; also provides water to adjacent horticulture farm with no fee.
Horticulture Farm	3 ha, connected to above floriculture farm well.	Vegetable production; former water source from two shallow hand-dug wells (3m diameter and 4m in depth); currently connected to the deep well in the adjacent floriculture farm (see above).

Figure 2: Hay Production in the Gerbi Area

Figure 3: Gerbi area – Communal Irrigation from Large Spring

2.2 Tefki Area

The Tefki Area (**Appendix A, Figure 4**) is located in a 2,000 km^2 plain in the Upper Awash River Basin (also called the Becho Plain) west-southwest of Addis Ababa. The average annual precipitation is about 1,000 mm/year. The Tefki Area is 666 km^2 and bounded by the Awash River to the south-southwest. National Highway 7 traverses the area and the largest towns include Tefki, Sebeta, and Dima.

The basin topography is characterized by extensive flat-lying areas with hilly and mountainous terrain in the north and a small hill in the southwest. Land areas with 0 to 6% slope that are potentially suitable for irrigation comprise about 48,600 ha or about 73% of the total land in this pilot area.

The underlying shallow bedrock is volcanic ash covered by black vertisol (clay-rich) soil (**Appendix A, Figure 2**). The volcanic ash aquifer unit is composed of inter-fingering/layered volcanic ash, alluvial sediments, soils and unconsolidated tuff. The thickness of the subsurface unit that can be hand-dug reaches more than 60m at places. Groundwater occurs in the volcanic ash units, which have high storage properties with porosities up to 70%, and flow to wells takes place along the contact of ash layers. Alluvial sediments also occur in this aquifer complex.

The yields of drilled and hand-dug wells range from less than 0.25 to greater than 1 LPS. The depth to groundwater ranges from 2m adjacent to streams up to 18m in the higher elevation areas surrounding the Becho Plain. This aquifer, particularly in the central part adjacent to the Awash River, is identified as the most promising zone for small-scale groundwater irrigation of areas from 0.25 to greater than 1 ha.

Agriculture is the mainstay of the economy in the area, and rain-fed and recession agriculture are the main practices. Rain-fed agriculture crops include teff and wheat. Vegetables and chickpeas are produced following the recession of the Awash River floods. Agro-industries are emerging and the main ones include horticulture and floriculture (5 or more). Small-to-medium size industries include textile manufacturing (3), water bottling (1), and micro/small-scale enterprises (e.g. cement block production, wood and metal works). Specific data as to hectares irrigated or water use by these industries is not currently available.

Shallow groundwater use for small-scale irrigation is at its incipient stage. **Table 2** provides summary details for two successful farmers that use shallow groundwater for irrigation.

Table 2: Examples of Small Farmer Groundwater Irrigation Use in Tefki Area

Site Name	Irrigated Area and Water Source	Description
Awash Belo Borehole	2 ha, manually drilled borehole, 35m deep, 4-inch casing, yield of 3 LPS	Vegetable production, produces 2 crops per year (see Figure 4).
Fikru large diameter hand-dug well	0.25 ha, 1.5m diameter well; water table at 6m, yield of 0.25 LPS	Vegetable production on 0.25 ha, other activities are diary and apiculture.

Figure 4: Tefki Area – Small Scale Irrigation in Awash Belo.

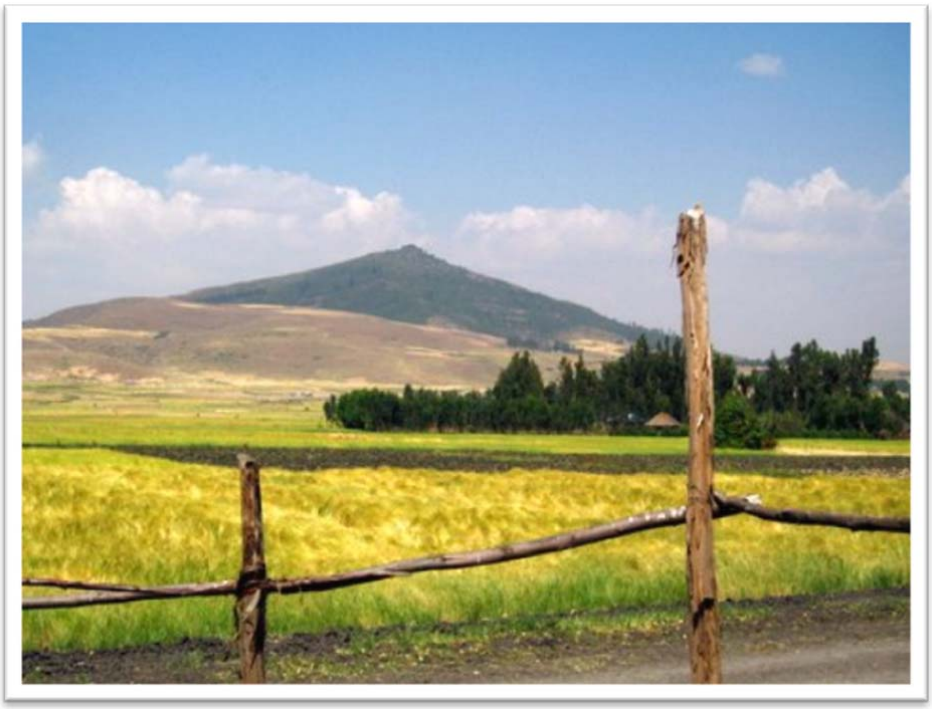


Figure 5: Tefki Area – View of Teff Fields and Forested Northern Part of Basin

Figure 6: Tefki Area – Treadle Pump Used for Water Supply.

3 PILOT BASINS STUDY PROCESS

This section describes the pilot basins study process as the basis to develop the ILaP calculator inputs and products described in Section 4 of this report. These included:

- The development of mapping products for the field program and irrigable land potential analysis.
- A field reconnaissance of the Gerbi and Tefki Areas conducted from November 2014 through January 2015, which involved:
    - An inventory of a subset of representative water points in each basin.
    - Field water-quality testing of delivered water from the water points with functional pumping systems.
    - Short-term pumping tests on selected hand-dug open wells.

3.1 Mapping Products

The mapping products developed for this study were derived from data that are publicly available to the user as outlined below. Two primary datasets were used – Digital Elevation Models (DEMs) and satellite imagery (Landsat 8 platform). DEMs were used for generating watershed basin boundaries (**Appendix A, Figure 1**), slope maps (**Appendix A, Figures 3 and 4**), and ground topographic contours (**Appendix A, Figures 5 and 6**). Satellite images were used for understanding the land use/land cover patterns (**Appendix A, Figures 8 and 9**). A precipitation map (**Appendix A, Figure 7**) was generated by interpolating data from nearby weather stations, with records available for the past two decades.

Watershed basin boundaries can be defined manually by analyzing published topographic maps. Where such data is not readily available, basin boundaries can be generated from DEMs. There are

a variety of sources for accessing and downloading DEMs; for the purpose of this study, DEMs generated from the February 2000 (United States National Aeronautics and Space Administration (NASA) Shuttle Radar Topographic Mission (SRTM) were used.

The DEMs for the Gerbi and Tefki Areas were processed utilizing Environmental Systems Research Institute (ESRI) geographic information system (GIS) software ArcGIS. Hydrology tools in ArcGIS were used to develop the watershed basin boundaries for the two areas (**Appendix A, Figures 3 and 4**). Initially, numerous smaller sub-watersheds were delineated in the two areas and the final basin boundaries were developed after combining a series of sub-watersheds based on topographic contours and stream patterns in each area. Finally, the total area of the basins were calculated and used as the input to the ILaP Calculator.

Slope maps (expressed as percent slope) were derived from the DEM data (**Appendix A, Figures 3 and 4**). As a rule of thumb, land areas with slopes from 0 to 6 percent are considered suitable for irrigation; slopes from 6 to 12 percent require advanced techniques for irrigation use (e.g., land contouring, terrace construction); and slopes greater than 12 percent are considered non-ideal for irrigation. The distribution of land area within the three slope categories for the Gerbi and Tefki Areas is summarized below.

Table 3: Land Area Distribution (as percentage of total area)

	0–6 % slope	6–12 % slope	>12 % slope
Gerbi Area	41 %	24 %	35 %
Tefki Area	73 %	12 %	15 %

Land use/land cover for the basins was evaluated from a December 1, 2013 Landsat 8 image. This image was optimal for this study because it had minimal cloud cover, coincided with post-rainy season harvesting activities, and was in the same timeframe as the field team survey from November 2014 to January 2015. The Landsat 8 image was minimally processed and four broad classifications were defined (**Appendix A, Figures 8 and 9**):

1. Dark brown: Managed forests.
2. Light blue: Towns/rural settlements and rivers/streams.
3. Green: Rain-fed and irrigated agriculture.
4. Light brown: Wetlands (and post-rainy season hay cultivation).

Two sets of base maps (DEM and satellite image bases) were generated. The watershed basin boundary and land use/land cover were verified (ground-truthed) during the field program, and the maps served as the bases for data collection during the water point survey.
Precipitation maps for the two basins were developed by interpolating data from nearby weather stations. The closest precipitation stations to the basins are shown in **Appendix A, Figures 3 and 4** and the distribution of precipitation within each basin is shown in **Appendix A, Figure 7**. An area-weighted value was determined and used as the input to the ILaP Calculator for each basin.

The water points surveyed in the Gerbi and Tefki Areas were entered into a GIS database and plotted as shown in **Appendix A, Figures 5 and 6**. The water points were classified based on type (hand-dug well, drilled well, or spring) and use (drinking/livestock, drinking/irrigation, irrigation, and commercial/industrial).

3.2 Field Reconnaissance of Pilot Basins

The field reconnaissance of the Gerbi and Tefki Areas included the following components:

- An inventory of a subset of representative water points in each basin.
- Field water-quality testing of delivered water from the water points with functional pumping systems.
- Short-term pumping tests on selected hand-dug open wells.

3.2.1 Water Point Inventory

A principal objective of the water-point inventory was to develop an overview of how groundwater is accessed and utilized in each pilot basin. Information recorded for the inventoried water points included:

- Type – hand-dug well, borehole/drilled well, spring; and age, if known.
- Global positioning system (GPS) coordinates and elevation.
- Construction details – depth, diameter, and yield, to the extent data were available.
- Measurement of the depth to water (static water level) and available information from water point owners regarding seasonal water-level fluctuations.
- Groundwater use(s) – drinking, commercial/industrial, livestock, irrigation.

A primary use of the collected information was to develop estimated annual groundwater use by category – for input to the ILaP Calculator.

Appendix A, Figures 5 and 6 show the locations of the inventoried water point and water-point uses in the Gerbi and Tefki Areas. The water points are subdivided with specific symbols for type: hand dug; drilled; spring, and different colors for use: drinking/livestock, drinking/irrigation, irrigation, and commercial/industrial.

***Gerbi Area Summary* (Appendix A, Figure 5):** In the Gerbi Area, 108 wells were inventoried. The hand-dug well depths ranged from a few meters (m) up to 18 m, below ground surface (bgs). Drilled wells or borehole depths ranged from 30 m to 300 m, bgs.

- **Static water levels** ranged from less than a meter below ground surface to as much as 9 m, bgs.

- **Well pumping systems** included hand pumps (48%); electrical or diesel motors (9%), and rope and buckets (43 %).

- **Use:** Of the water points inventoried, 86% were used for drinking water/livestock, 7% for livestock, 2% for irrigation, and 5% for industry. Many wells are multipurpose.

***Tefki Area Summary* (Appendix A, Figure 6):** In the Tefki Area, 79 wells were inventoried. The hand-dug well depths ranged from a few meters up to 24 m, bgs. Drilled well (borehole) depths ranged from 31 m to 100 m, bgs.

- **Static water levels** ranged from 3 m, bgs to as much as 15 m, bgs.

- **Well pumping systems** included hand pumps or in three cases, treadle pumps (57%); electrical or diesel motors (5%), and rope and buckets (38%).

- **Use:** Of the water points inventoried, 69% were utilized for drinking water/livestock, 15% for livestock, 15% for irrigation, and 1% for Industry. Many wells are multipurpose.

In both areas, the great majority of the inventoried water points consisted of shallow hand-dug wells that were dug into the weathered bedrock. The data from the short-term pumping tests (see section 3.2.3) showed that the existing network of these wells provide yields that are limiting, even for irrigating small plots of land (0.1 to 1 ha). Alternatives that might be viable include: (a) deepening existing wells into the consolidated bedrock; and (b) alternative construction to the traditional methods, e.g. digging larger diameter wells which could be further advanced below the weathered zone into consolidated bedrock.

3.2.2 Field Water-Quality Sampling

A key component in this field evaluation focused on irrigation feasibility was the field water-quality testing of accessible water points for Total Dissolved Solids (TDS); Electrical Conductivity (EC); and pH (a measure of acidity). TDS, EC, and pH were measured at operational water points during the field survey. TDS and EC concentrations indicate the level of mineralization of the groundwater and are the basis for the classification of groundwater as fresh, brackish or saline. Groundwater with high TDS concentrations [>2,000 milligrams per liter (mg/l)] indicates that a severe salinity hazard exists. Different crops exhibit different levels of salinity (TDS) tolerance.

In addition, the irrigation of crops with high TDS groundwater can result in salt build-up on the soil and ultimately the destruction of the soil for agricultural uses. While a pH reading outside of the normal range may not affect the crop, it is an indication that other hazards may exist and further water quality testing should be conducted. Water quality guidelines, adapted from "Water Quality for Agriculture, FAO Irrigation and Drainage Paper 29 Rev 1, 1994" are presented in **Table 4**:

Table 4: Water Quality for Agriculture [adapted from "Water Quality for Agriculture", FAO Irrigation and Drainage Paper 29 Rev 1, 1994]

Constituent	Degree of Restriction on Use		
	None	**Slight to Moderate**	**Severe**
TDS (mg/l)	< 450	450 – 2,000	> 2,000
EC (µmhos/cm)	< 700	700 – 30,000	> 30,000
Sodium Adsorption Ratio (SAR) – Surface Irrigation	< 3	3 – 9	> 9
SAR – Sprinkler Irrigation	< 3	> 3	
pH	Normal Range: 6.5-8.4		

The sodium adsorption ration (SAR), is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of dissolved solids in groundwater (Lenntech, 2015). Calculating the SAR requires knowing specific sodium, calcium, and magnesium concentrations in the irrigation water. This parameter requires laboratory testing of water samples.

A summary of the field water-quality results for hand-dug and drilled wells inventoried in the Gerbi and Tefki Areas is presented in **Table 5**:

Table 5: Summary of Water Quality in Gerbi and Tefki Areas

Basin	Constituent	Minimum	Maximum	Average
Gerbi Area	TDS (mg/l)	39	1086	221
	EC (µmhos/cm)	63	1598	333
	pH	6.4	8.6	7.4
Tefki Area	TDS (mg/l)	165	1400	496
	EC (µmhos/cm)	36	2730	733
	pH	6.0	8.3	7.2

The low levels of TDS for the majority of water points sampled in the Gerbi and Tefki Areas indicate no salinity hazard. Average TDS for the Gerbi and Tefki Area water points were 221 and 496 mg/l respectively. A few isolated water points were above the lower end values (450 mg/l TDS and 700 umhos/cm) for the slight to moderate restrictions on use outlined in the United Nations Food and Agricultural Organization (FAO) Table 4.

Finally, since industry will increase in both of these areas, future irrigation development initiatives should be undertaken in close coordination with the Ministry of Industry to prevent/avoid/minimize impacts on irrigated crops by potential industrial pollution. Future water quality testing may be required for additional parameters.

3.2.3 Short-Term Pumping Tests

Short-term pumping tests were conducted on a subset of the inventoried hand-dug open wells to develop an understanding of the yields. **Appendix B, Table 1** provides summary details for the 16 pumping tests conducted: 11 in the Gerbi Area and 5 in the Tefki Area.

The existing installed well pump (electric or diesel) or a portable pump was used for the testing. The well was pumped until the water level had declined 0.50 to 1 m below the measured static water level, and the rate of water-level recovery was measured for up to 120 minutes after the stop of pumping. The rate of recovery was converted to LPS.

Gerbi Area Tests: The rate of recovery or replenishment in the hand-dug open wells that were tested ranged from 0.010 to 0.42 LPS. Using 1 LPS/ha as a general irrigation crop water demand (as discussed in Section 4.2), a 0.010 LPS well yield would lend the ability to irrigate 0.010 ha or a 10 square meter (m^2) garden. The higher well yield of 0.42 LPS could irrigate almost 0.5 ha.

Tefki Area Tests: The rate of recovery or replenishment in the hand-dug open wells that were tested in the Tefki Area ranged from 0.017 to 0.184 LPS. The 0.017 LPS well has the ability to irrigate approximately 0.017 ha or a 17 m^2 garden. The higher yield of 0.184 LPS, could irrigate almost 0.2 ha.

These tests should be considered as giving only an approximation of the yield characteristics of the current hand-dug well systems, however the results point to the need for improved open-well infrastructure to achieve higher well yields for small-scale irrigation.

4 IRRIGABLE LAND POTENTIAL (ILAP) CALCULATOR

This report section walks the reader through the steps that are involved in developing and applying the ILaP Calculator to a watershed. Section 4.1 outlines the purposes and benefits of the Calculator; Section 4.2 takes the user step by step through the application of the ILaP Calculator for the Gerbi Area. It discusses the means for defining the set of input parameters and illustrates the Calculator's strengths in giving the user the ability to adjust inputs for the examination of and sensitivity to different climatic, population, crop, and irrigation type scenarios. Section 4.3 explains the easy-to-use one-page Calculator format and explanatory Pie Charts with the completed ILaP Calculators for the Gerbi and Tefki Areas. Section 4.4 provides a discussion of the results for both the Gerbi and Tefki Areas, and Section 4.5 outlines how the ILaP Calculator can be utilized to facilitate simulations of how climate change may affect the irrigable land potential based on groundwater availability.

4.1 Purpose and Benefits

The ILaP Calculator (Calculator) provides the user with a reasonable expectation of how much land may be sustainably irrigated using only the renewable part of the groundwater resource while protecting other uses and ecological needs in a watershed. It directly estimates or provides the basis to evaluate:

- The total hectares and percent of the available land that can be irrigated sustainably.
- The percent of the population that can benefit.
- The income value of the crops that can be grown.
- How much additional land can be irrigated if more efficient irrigation methods are implemented.
- The outlook for future populations.
- Sensitivity of the above to short-term and long-term drought conditions, and climate-change predictions.
- Potential for over-exploitation of the groundwater resource.

This information is directly useful for ascertaining which watersheds would pose the most valuable opportunities for implementation of small-scale farmer irrigation. It will also place reasonable constraints on planning and implementation programs.

The ILaP Calculator is a tool to guide the user in thinking through the concepts and dimensions that are important, and acquiring accurate and representative inputs. The Calculator inputs include those that are fixed (e.g., total watershed area) and those (most inputs) that can be variable (e.g., population, precipitation, irrigation water demand).

The Calculator inputs also include three factors for: (1) total groundwater recharge (as a percent of precipitation); (2) ecological recharge reserve (as a percent of total groundwater recharge); and (3) irrigation water demand (as a percent reduction of the water demand per hectare achieved with standard practices). These factors can be adjusted to lend a nuanced flexibility to the Calculator helpful to the planner in looking at development scenarios or the sensitivity of various input parameters.

The Calculator directs these inputs into a relatively straightforward calculation of how much land can be sustainably irrigated. This calculation can be very simply run multiple times to assess the watershed's response to the variable inputs and factors.

4.2 The ILaP Calculator Worksheets Step by Step (Gerbi Area)

This section walks the user step by step through the application of the ILaP Calculator for the Gerbi Area. It discusses the means for defining the set of input parameters and illustrates the Calculator's strengths in giving the user the ability to adjust inputs for the examination of and sensitivity to different climatic, population, crop, and irrigation type scenarios.

A Master List of the Calculator's input and output parameters are summarized in **Appendix B, Table 2**. The algorithm that makes up the Calculator is presented on Worksheets 1 through 5, presented at the end of Section 4.2. The input parameters and the equations for the output parameters are described both verbally and mathematically. The detailed calculations for the Gerbi Area, showing the unit conversions, are shown at the bottom of these Worksheets.

Calculator Worksheet 1

Preparing the Groundwater Recharge Estimate –

Estimating the total amount of annual groundwater recharge for a watershed is the critical first step for beginning an analysis of the irrigable land potential using groundwater. This parameter represents the part of the groundwater resource that is renewable, and is available for distribution between competing - drinking, livestock, commercial/industrial, agricultural, and ecological - uses.

In Ethiopia, groundwater recharge has been studied over many areas. **Appendix A, Figure 10** reproduces a published map showing a range of recharge rates in mm/yr for the Highland and Lowland areas (Chernet T. (1993) Hydrogeology of Ethiopia and Water Resources Development, Ethiopian Institute of Geological Surveys, Addis Ababa, as shown in Dr. Seifu Kebede (2013) Groundwater in Ethiopia, Fig. 7.1 Page 222). These recharge rates were derived from base-flow separation studies conducted in the early 1990s. This work was utilized in developing estimates of annual groundwater recharge for the Gerbi Area that are expressed in the Worksheet as a percentage of annual precipitation. Groundwater recharge is in the 150 to 250 mm/yr range; conservatively taking the lower end of the range (150 mm/yr), this translates to 12 percent of normal precipitation, which was used as the input to the Calculator.

It is recommended that the groundwater recharge be verified, if at all possible, by comparing the more regional recharge values as shown in **Appendix A, Figure 10** with base-flow analysis from local stream/river-flow gauging stations. For the Gerbi Area, the field team conducted a base-flow analysis for the Sibilu River Chancho Gauging Station (**Appendix A, Figure 7** and Resource 2). This analysis yielded an approximate value of 9.5 percent of normal precipitation, which lends confidence to the value above.

As a general comment, in carrying out the ILaP analysis for a specific basin or project area, groundwater recharge estimates should be developed and/or reviewed by an expert with specific knowledge of the locale or of similar settings, to confirm that the estimate makes practical sense and is scientifically valid.

Addressing Periods of Normal Precipitation and Drought –

To help build the foundation for assessing irrigation sustainability, the Calculator should be applied in parallel to two scenarios – one representing normal or average periods of precipitation and the second representing times of drought.

The annual normal groundwater recharge can be based on the average precipitation for the period of record. For the Gerbi Area, this was found to be 1,300 mm/yr, the annual average for the past 20 years of available data. In this case, because no official weather station is located within the basin, the normal annual rainfall amount was interpolated from the data collected at the stations shown on **Appendix A, Figure 7** (Resource 3).

The annual groundwater recharge in times of drought was taken as the single worst year of precipitation. For the Gerbi Area, the single worst year of 820 mm was measured in 1999 at the closest weather station (Derba Station). The user should also examine the whole of the annual precipitation records to get a sense of the frequency and duration of periods of drought.

Safeguarding Ecological Reserves –

Groundwater recharge serves to sustain the ecological components of a watershed, which may include stream flow and aquatic life, wetlands, habitats for endangered species, habitats for riverine (stream-flow recession) farming, and a variety of other situations. The percent of groundwater recharge that should be held in reserve to support the ecology or conversely to minimize ecological degradation will vary depending on the characteristics and land uses of the watershed. Knowledge of the nature of the watershed can and should be accumulated by contacting locals and local experts and getting out into the field for reconnaissance.

In the Gerbi Area, the field survey indicated that the watershed contains seasonal wetlands, which are wet in the rainy season during June through September. A hay crop is harvested when these lands dry up in November/December and many small-scale farmers depend on these seasonal wetlands for their livelihood. The Ecological Factor, or the percent of groundwater recharge held in reserve for ecological considerations, is set at a value of 40 percent. This factor can be adjusted to be more or less conservative, however the less conservative the value the higher the risk of degradation of the downstream ecology.

Available Groundwater Recharge –

The primary Calculator Worksheet 1 output is the amount of the annual groundwater recharge (renewable groundwater) that is available for use in the watershed. For the Gerbi Area, the calculated values are **70 Million Cubic Meters per Year (MCM/yr)** in a normal year and **44 MCM/yr** in a year of drought.

Calculator Worksheet 1 Resources:

1. Recharge Map of Ethiopia (in S. Kebede, Groundwater in Ethiopia, 2013).
2. Stream-flow Gauging Stations Data from Ministry of Water Irrigation and Energy, Hydrology Directorate
3. Precipitation Data from National Meteorological Agency of Ethiopia (NMA).

Calculator Worksheet 2

Developing Current Household, Commercial/Industrial, Livestock and Irrigation Groundwater Use Estimates –

The population of the watershed can be obtained from census data. For the Gerbi Area the current population is estimated at 150,000 persons (Resource 4).

The unit water use per person is usually available for a country/region as an accepted (default) value based on aggregated experience that is generally used for planning purposes. For this part of Ethiopia, the default value is 15 Liters per Person per Day (LPP/day) (Resource 5).

Commercial/industrial uses of water will usually be estimated based on the field reconnaissance or published data.

Livestock water demand can be based on recommended water intake guidance (average water consumption in liters per day (LPD)) for various domestic/farm animals and the number of animals in the basin. The recommended intakes and specific livestock populations of the Gerbi and Tefki Areas are shown in **Appendix B, Tables 3A and 3B** (compiled from Resource 6), and the total livestock water demand for the Gerbi Area is calculated at 2.3 MCM/yr.

For irrigation water demand, a broad-based (default) value is generally used in professional practice for planning purposes. Values of 0.8 LPS/hectare and 1 LPS/hectare are widely used, respectively, for humid and arid areas in Ethiopia (Resource 7). To add a layer of conservation to the calculation, the upper-end value of 1 LPS/hectare is used for the Gerbi Area. If specific crop water demands are known, this value can be further refined.

The number of hectares currently being irrigated in the Gerbi Area was estimated based on field reconnaissance. The irrigated area estimate will normally be dependent on compiling local knowledge and/or previous studies. For the Gerbi Area, the number of hectares under irrigation and the water demand are minimal at 40 hectares requiring 1.26 MCM/yr.

Total Current Groundwater Use –

The primary Calculator Worksheet 2 output is the total current amount of groundwater use in the watershed. For the Gerbi Area, the calculated value is 6 MCM/yr.

Calculator Worksheet 2 Resources:

4. Central Statistical Agency of Ethiopia (CSA).
5. National WASH Framework.
6. Ethiopian Agricultural Research Organization (EARO). Sileshi, Z. et. al.
7. Dr. S. Kebede.

Calculator Worksheet 3

Net Available Groundwater Recharge –

Calculator Worksheet 3 is a simple subtraction of the total current groundwater use (primary Calculator Worksheet 2 output) from the available groundwater recharge (primary Calculator Worksheet 1 output). This yields the remaining amount of renewable groundwater available for new irrigation use. For the Gerbi Area, the amount of groundwater available is calculated to be 64 MCM/yr in a time of normal precipitation and 38 MCM/yr in a time of drought.

Calculator Worksheet 4

Water Demand per Hectare per Growing Season –

The growing season in the Gerbi Area is entered as 120 days, which is a general estimate for a typical 4-month growing season for grains and vegetables. If other types of crops are expected, the growing season for these crops may be specified.

As described for the Calculator Worksheet 2, a broad-based (default) unit value of 1 LPS/hectare irrigation water demand is used for planning purposes. This value reflects typical current irrigation methods, i.e., flood and furrow irrigation. However, there are several means of increasing irrigation efficiency (using less water per hectare) by using modern innovative conveyance and/or application methods - for example, drip irrigation, which applies water right at the root zone, or plastic covering to decrease water loss via evapotranspiration for high-value vegetable crops.

Therefore, the Calculator includes a factor representing a potential future increase in irrigation efficiency. This factor is expressed as the percent reduction in water demand from the current value. For example, the factor is set at 0 percent reduction for the current value of 1 LPS/hectare. To simulate a scenario where a more sophisticated irrigation method would require only 0.90 LPS/hectare (adjusted water demand), a reduction factor of 10 percent would be inserted.

Using the 1 LPS/hectare irrigation water demand default value, the groundwater use per growing season estimate in the Gerbi Area is calculated to be 10,400 m^3/ha.

Irrigable Land Potential (ILaP) –

The primary Calculator Worksheet 4 output is the Irrigable Land Potential (ILaP) – the amount of land in the watershed that can be sustainably irrigated with the available annual groundwater recharge. For the Gerbi Area, the Irrigable Land Potential (ILaP) is calculated to be 6,114 hectares in normal years and 3,614 hectares in times of drought.

Calculator Worksheet 5

Available Land for Irrigation Based on Slope –

Land areas with slopes of 0 to 6 percent (i.e., relatively flat) are considered reasonably suitable for irrigation.

For the Gerbi Area, the slope analysis was completed using DEM data (Section 3.1 and Resource 8). Slope percentages were calculated in three categories: 0-6 percent, 6-12 percent and >12 percent. The calculated areas were then populated on a Landsat 8 image from December 1, 2013 (Resource 9) to verify if the calculated slope percentages and the corresponding areas correlated with interpreted land use. The analysis indicates that land with slope of 0-6 percent that is suitable for irrigation comprises 30,627 ha or 41 percent of the total watershed area.

Comparison of the Irrigable Land Potential (ILaP) (Based on Groundwater Availability) with Suitable Land for Irrigation (Based on Slope) –

The last column of the Calculator Worksheet 5 expresses the Irrigable Land Potential (ILaP) based on groundwater availability (primary Calculator Worksheet 4 output) as a percentage of the suitable land for irrigation based on slope. Lower percentage indicates a need for overall integrated watershed management, given the potential for over-development and over-exploiting the groundwater resource.

For the Gerbi Area, this percentage of the suitable land that can be sustainability irrigated in a year of normal precipitation is calculated as 6,114 ha over 30,627 ha, or **20 percent.** (The calculated percentage of land decreases to **12 percent** in a year of drought.). The remaining 24,513 ha or 80 percent of this land is susceptible to over-development.

Calculator Worksheet 5 Resources:

8. Digital Elevation Model data, February 2000 NASA Shuttle Radar Topographic Mission (SRTM) – Downloaded from Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov
9. Landsat December 1, 2013 Image – Downloaded from Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov

Calculator Worksheet 1

AVAILABLE ANNUAL GROUNDWATER RECHARGE IN GERBI BASIN

	[A]	*[B]*	*[C]*	*[D] = [A] x [B] x [C]*	*[E]*	*[F] = [D] x [E]*	*[G] = [D] - [F]*
	Total Watershed Area *km²*	*Precipitation* *mm/Yr*	*Recharge Factor as % of Precipitation*	*Total Groundwater Recharge* *MCM/Yr*	*Ecological Factor as % of Total Groundwater Recharge*	*Ecological Groundwater Recharge Reserve MCM/Yr*	*Available Groundwater Recharge MCM/Yr*
Average Precipitation	**747**	**1,300**	**12%**	**117**	**40%**	**47**	**70**
Drought	**(74,700 ha)**	**820**	**12%**	**74**	**40%**	**30**	**44**

Where:

Average Precipitation = Annual Mean over the 20-year period of record.

Drought Precipitation = Annual Minimum over the 20-year period of record.

Total Groundwater Recharge is assumed to be approximately 12 percent of Precipitation.

The Groundwater Recharge to be held in reserve for ecological needs is 40 percent of the Total Groundwater Recharge.

The Available Groundwater Recharge is therefore the remaining recharge amount after subtracting the Ecological Reserve.

Units:

km² - Square Kilometers

ha - Hectares

mm/Yr - Millimeters per Year

MCM/Yr - Million Cubic Meters per Year

1 MCM = 1,000,000 m

Calculations:

$$[\mathrm{D}] = \left[747\ \mathrm{km}^2 \times \frac{1,000,000\ \mathrm{m}^2}{\mathrm{km}^2}\right] \times \left[\frac{1,300\ \mathrm{mm}}{\mathrm{Yr}} \times \frac{\mathrm{m}}{1000\ \mathrm{mm}}\right] \times \frac{1\ \mathrm{MCM}}{1,000,000\ \mathrm{m}^3} \times 0.12 = 117\ \mathrm{MCM/Yr}$$

$$[\mathrm{F}] = [117\ \mathrm{MCM/Yr}] \times 0.40 = 47\ \mathrm{MCM/Yr}$$

$$[\mathrm{G}] = [117\ \mathrm{MCM/Yr}] - [47\ \mathrm{MCM/Yr}] = 70\ \mathrm{MCM/Yr}$$

Calculator Worksheet 2

CURRENT GROUNDWATER USE IN GERBI BASIN

[H]	*[I]*	*[J] = [H] x [I]*	*[K]*	*[L]*	*[M]*	*[N]*	*[O] = [M] x [N]*	*[P] = [J] + [K] +[L] + [O]*
Household Use			Livestock Use	Commercial/ Industrial Use (Estimate)	*Existing Irrigation Use*			*Total Current Groundwater Use*
Population	*Use per Person*	*Total Household Use*			*Number of Hectares*	*Water Demand per Hectare*	*Total Irrigation Demand*	
	LPP/day	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*ha*	LPS/ha	*MCM/Yr*	*MCM/Yr*
150,000	15	0.82	2.3	1.5	40	1	1.26	6

Where:
Population from census data.
Commercial/Industrial use is estimated
Irrigation use is estimated from field surveys.
Livestock data from Appendix B, Tables 3A & B

Units:
ha - Hectares
LPS/ha - Liters per Second per Hectare
LPP/day - Liters per Person per Day
MCM/Yr - Million Cubic Meters per Year

Calculations:

$$[\mathrm{J}] = [150{,}000\ \mathrm{persons}] \times \left[\frac{15\ \mathrm{L}}{\mathrm{day/person}} \times \frac{\mathrm{m}^3}{1000\ \mathrm{L}} \times \frac{365\ \mathrm{day}}{\mathrm{Yr}} \times \frac{1\ \mathrm{MCM}}{1{,}000{,}000\ \mathrm{m}^3}\right] = 0.82\ \mathrm{MCM/Yr}$$

$$[\mathrm{O}] = [40\ \mathrm{ha}] \times \left[\frac{1\ \mathrm{L}}{\mathrm{s/ha}} \times \frac{\mathrm{m}^3}{1000\ \mathrm{L}} \times \frac{60\ \mathrm{s}}{\mathrm{min}} \times \frac{60\ \mathrm{min}}{\mathrm{hr}} \times \frac{24\ \mathrm{hr}}{\mathrm{day}} \times \frac{365\ \mathrm{day}}{\mathrm{Yr}} \times \frac{1\ \mathrm{MCM}}{1{,}000{,}000\ \mathrm{m}^3}\right] = 1.26\ \mathrm{MCM/Yr}$$

$$[\mathrm{P}] = [0.82\ \mathrm{MCM/Yr}] + [2.3\ \mathrm{MCM/Yr}] + [1.5\ \mathrm{MCM/Yr}] + [1.26\ \mathrm{MCM/Yr}] = 6\ \mathrm{MCM/Yr}$$

Calculator Worksheet 3

NET AVAILABLE ANNUAL GROUNDWATER RECHARGE IN GERBI BASIN

	[G]	*[P]*	*[Q] = [G] - [P]*
	Available Groundwater Recharge ***MCM/Yr***	***Total Current Groundwater Use*** ***MCM/Yr***	***Net Available Groundwater Recharge*** ***MCM/Yr***
Average Precipitation	**70**	**6**	**64**
Drought	**44**	**6**	**38**

Units:

MCM/Yr - Million Cubic Meters per Year

Calculations:

$$[\mathbf{Q}] = [\mathbf{70\ MCM/Yr}] - [\mathbf{6\ MCM/Yr}] = \mathbf{64\ MCM/Yr}$$

Calculator Worksheet 4

IRRIGABLE LAND POTENTIAL (ILaP) BASED ON
NET AVAILABLE ANNUAL GROUNDWATER RECHARGE IN GERBI BASIN

	[Q]	*[R]*	*[N]*	*[S]*	*[T] = [N] - [S] x [N]*	*[U] = [R] x [T]*	*[V] = [Q]/[U] - [M]*
	Net Available Groundwater Recharge *MCM/Yr*	*Growing Season* *Days*	*Water Demand per Hectare* *LPS/ha*	*% Reduction in Water Demand*	*Adjusted Water Demand* *LPS/ha*	*Groundwater Use per Hectare Per Growing Season* *m^3/ha*	*Irrigable Land Potential (ILaP)* *ha*
Average Precipitation	**64**	**120**	**1**	**0%**	**1**	**10,400**	**6,114**
Drought	**38**	**120**	**1**	**0%**	**1**	**10,400**	**3,614**

Where:
The growing season is based on the type of crops.
% Reduction in water demand is achieved by more efficient irrigation methods.

Units:
ha - Hectares
m^3 - Cubic Meters
m^3/day - Cubic Meters per Day
MCM/Yr - Million Cubic Meters per Year
LPS/ha - Liters per Second per Hectare

Calculations:

$$[\mathrm{U}] = [120\ \mathrm{days}] \times \left[\frac{1\ \mathrm{L}}{\mathrm{s}} \times \frac{1}{\mathrm{ha}} \times \frac{\mathrm{m}^3}{1000\ \mathrm{L}} \times \frac{60\ \mathrm{s}}{\mathrm{min}} \times \frac{60\ \mathrm{min}}{\mathrm{hr}} \times \frac{24\ \mathrm{hr}}{\mathrm{day}}\right] = 10,400\ \mathrm{m}^3/\mathrm{ha}$$

$$[\mathrm{V}] = \left[\frac{64\ \mathrm{MCM}}{(\mathrm{Yr})} \times \frac{1,000,000\ \mathrm{m}^3}{\mathrm{MCM}}\right] \Big/ \left[10,400 \frac{\mathrm{m}^3}{\mathrm{ha}}\right] - [40\ \mathrm{ha}] = 6,114\ \mathrm{ha}$$

The Irrigable Land Potential (ILaP) For the Gerbi Basin is the Net Available Annual Groundwater Recharge divided by the Groundwater Use per hectare for a 120 Day Growing Season.

Calculator Worksheet 5

IRRIGABLE LAND POTENTIAL (ILaP) BASED ON GROUNDWATER AVAILABILITY vs. SUITABLE LAND FOR IRRIGATION

	[V]	*[W]*	*[X] = [A] x [W] - [M]*	*[Y] = [V] / [X]*
	Irrigable Land Potential (ILaP) *ha*	*Percent of Total Watershed Area with Slopes Suitable for Irrigation*	*Suitable Land for Irrigation* *ha*	*Percent of Suitable Land that can be Irrigated*
Average Precipitation	**6,114**	**41%**	**30,627**	**20%**
Drought	**3,614**	**41%**	**30,627**	**12%**

Calculations:

$$[\mathbf{W}] = [\mathbf{74,700\ ha}] \times \mathbf{0.41} = \mathbf{30,627\ ha}$$

$$[\mathbf{X}] = [\mathbf{6,114}]/[\mathbf{30,627}] \times \mathbf{100} = \mathbf{21}\ \%$$

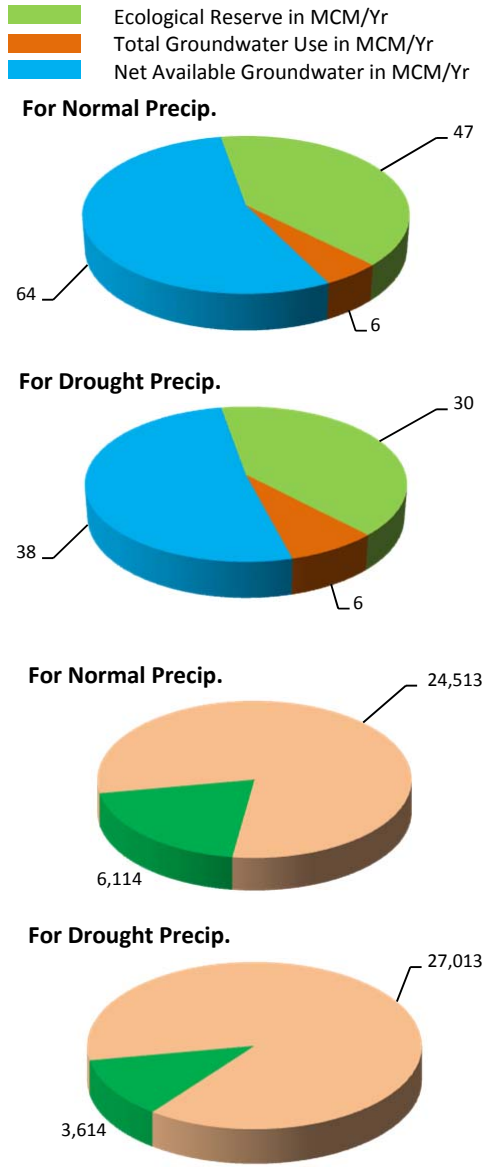
The Percent of Available Land that can be Irrigated is the Irrigable Land Potential (ILaP) based on groundwater availability divided by the Available Land for Irrigation based on suitable slope.

4.3 The ILaP Calculator for the Gerbi and Tefki Areas

The ILaP Calculator is comprised of an easy-to-use one-page format. The Input Boxes are coded in blue, where the Calculator input information is to be added. Calculated output information is shown either in Output Boxes or in graphical form (i.e., Pie Charts). The completed ILaP Calculators for the Gerbi and Tefki Areas are provided on the following pages.

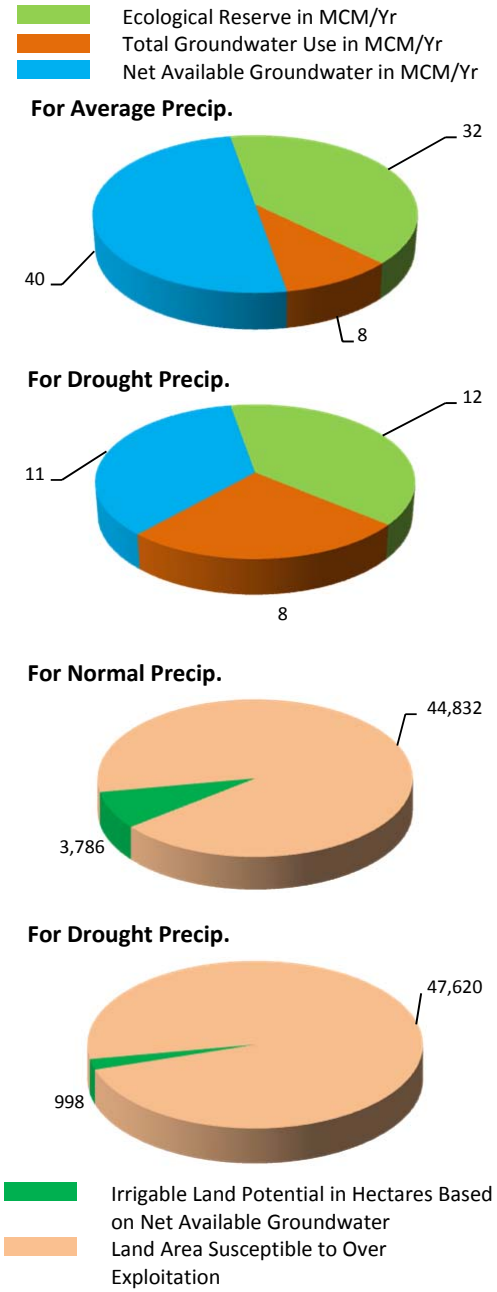
Watershed: **Gerbi Area**

						Normal	Drought	Units
Area						**747**	**747**	*km²*
Precipitation						**1,300**	**820**	*mm/Yr*
Total Groundwater Recharge						**117**	**74**	*MCM/Yr*
% of Precipitation	*12%*							
Ecological Reserve						**47**	**30**	*MCM/Yr*
% of Total Groundwater Recharge	*40%*							
Available Groundwater Recharge						**70**	**43**	*MCM/Yr*
Total Groundwater Use						**6**	**6**	*MCM/Yr*
Household	*Population*	*150,000*		*0.82*	*MCM/Yr*			
	Demand	*15*	*LPP/day*					
Livestock				*2.3*	*MCM/Yr*			
Commercial/Industrial				*1.5*	*MCM/Yr*			
Irrigation	*Area*	*40*	*Hectares*	*1.26*	*MCM/Yr*			
	Demand	*1*	*LPS/ha*					
Net Available Groundwater						**64**	**38**	*MCM/Yr*
Groundwater Demand per Hectare Per Growing Season						**10,400**	**10,400**	m³/ha
No of Days in Growing Season	*120*	*days*						
Future Reduction in Wateruse	*0%*							
Adjusted Future Water Demand	*1*	*LPS/ha*						
Irrigable Land Potential (ILaP)						**6,114**	**3,614**	*ha*
Percentage of Available Land That Can Be Irrigated						**20%**	**12%**	



Watershed: **Tefki Area**

						Normal	Drought	Units
Area						**666**	**666**	*km²*
Precipitation						**1,000**	**388**	*mm/Yr*
Total Groundwater Recharge						**80**	**31**	*MCM/Yr*
% of Precipitation	*12%*							
Ecological Reserve						**32**	**12**	*MCM/Yr*
% of Total Groundwater Recharge	*40%*							
Available Groundwater Recharge						**48**	**19**	*MCM/Yr*
Total Groundwater Use						**8**	**8**	*MCM/Yr*
Household	*Population*	*90,000*		*0.49*	*MCM/Yr*			
	Demand	*15*	*LPP/day*					
Livestock				*1.5*	*MCM/Yr*			
Commercial/Industrial				*4.0*	*MCM/Yr*			
Irrigation	*Area*	*60*	*Hectares*	*1.89*	*MCM/Yr*			
	Demand	*1*	*LPS/ha*					
Net Available Groundwater						**40**	**11**	*MCM/Yr*
Groundwater Demand per Hectare Per Growing Season						**10,400**	**10,400**	m³/ha
No of Days in Growing Season	*120*	*days*						
Future Reduction in Wateruse	*0%*							
Adjusted Future Water Demand	*1*	*LPS/ha*						
Irrigable Land Potential (ILaP)						**3,786**	**998**	***ha***
Percentage of Available Land That Can Be Irrigated						**8%**	**2%**	



4.4 Discussion of Results

4.4.1 Gerbi Area

The Gerbi Area is a densely populated watershed in the Highlands that receives a fairly high amount (1,300 mm/yr) of precipitation. It receives most of its rainfall during the rainy season from June through September. Small-scale farming during the rainy season is essential to the livelihoods of the population. Growing an irrigated second crop in the dry seasons would yield enormous benefit. Currently, it is estimated that 40 hectares, only a fraction of the total watershed area of 74,700 hectares, are under irrigation.

Current groundwater use in the Gerbi Area is low, estimated for all uses – drinking/ household, livestock, commercial/industrial and irrigation - at 6 MCM/yr. The total amount of normal groundwater recharge in the basin, which is considered to be the renewable part of the groundwater resource, is conservatively estimated at 12 percent of precipitation or 117 MCM/yr.

In this basin, small-scale farmers harvest hay from seasonal wetlands. Therefore, it is very important to conserve the nature of these wetlands and the ecological reserve of the total groundwater recharge is set as 40 percent, or 47 MCM/yr. Even taking this low-end total groundwater recharge estimate and ecological conservation factor, there is still a net of over half of the groundwater recharge, **64 MCM/yr**, available for new irrigation and other uses.

For this part of Ethiopia, an irrigation water demand value of 0.8 LPS/ha is generally used for planning purposes; a more conservative value of 1 LPS/ha is used herein. Based on the 64 MCM/yr of available groundwater and assuming a 120-day growing season for grains and/or vegetables, approximately 6,114 hectares in the basin could be irrigated for an additional growing season. This land area of 6,114 hectares represents 8.2 percent of the total land (74,700 hectares) in the Gerbi Area, and 20 percent of the land with a 0 to 6 percent slope (30,627 hectares), which is regarded as suitable for growing crops under irrigation.

These results indicate that initiatives to implement small-scale irrigation in the Gerbi Area are well worthwhile, because many hectares could be brought under irrigation. If small-scale farms of 0.25-hectares each are considered, a land area of 6,114 hectares would yield 24,456 individual family plots that could be irrigated. Given the estimated total population of 150,000 persons in the basin and assuming 5 persons per household, the benefits of irrigating these plots could reach a high percentage of the population.

These results also indicate that land is abundant compared to groundwater availability. Therefore, land management regarding the irrigated cropping is critical so as not to expand irrigated farming beyond the limits of the groundwater resource and stay within the bounds of sustainability.

The sensitivity and resiliency of the watershed to drought are also important factors to consider. In the worst-case year of drought, based on the 20-year historical period of record, precipitation is 63 percent of normal and the net groundwater availability for irrigation is on the order of 38 MCM/yr, as compared with 64 MCM/yr in a time of normal precipitation. If the ecological reserve were to be kept at 47 MCM/yr (instead of calculated as 40 percent of precipitation), then the net available groundwater in the time of drought would be reduced to 21 MCM/yr.

The groundwater storage (static reserve) in the watershed is estimated to be about 934 MCM (for 25 m of saturated thickness). If 6,114 hectares were to continue to be irrigated, even in times of no precipitation or groundwater recharge, the water in storage would last about 14 years. This is a reasonable buffer against a drought period.

4.4.2 Tefki Area

The Tefki Area is another densely populated watershed in the Highlands. At 66,600 ha, it is somewhat smaller than Gerbi, with about 60 percent of the population. In the Tefki Area as well, small-scale farming during the rainy season is essential to the livelihoods of the population and growing an irrigated second crop in the dry season would yield enormous benefit. Currently, it is estimated that 60 hectares, less than 1 percent of the total land area, are under irrigation.

Normal precipitation, 1,000 mm/yr, is lower than in Gerbi, by about 23 percent. The total groundwater recharge, the renewable part of the groundwater resource, here also conservatively estimated at 12 percent of precipitation, is calculated to be 80 MCM/yr.

In the Tefki Area, small-scale farmers harvest teff from seasonal wetlands. Therefore, similarly to the Gerbi Area, the ecological reserve of the total groundwater recharge is set at 40 percent, or 32 MCM/yr for the purpose of the calculations. The total current groundwater use is calculated as 8 MCM/yr. Therefore, a net of **40 MCM/yr** of groundwater recharge is available for new irrigation and other uses.

Based on 40 MCM/yr of available groundwater and assuming a general irrigation water use value of 1 LPS/ha and a 120-day growing season for grains and/or vegetables, approximately 3,786 hectares in the basin could be irrigated for an additional growing season. This area represents 5.7 percent of the total land (66,600 hectares) in the Tefki Area, and approximately 7.8 percent of the land with a 0 to 6 percent slope (48,600 hectares), which is regarded as suitable for growing crops under irrigation.

These results indicate that initiatives to implement small-scale irrigation in this watershed are well worthwhile, because many hectares could be brought under irrigation. If small-scale farms of 0.25-hectares each are considered, a land area of 3,786 hectares would yield 15,100 individual family plots that could be irrigated. Given the total population of 90,000 persons, and assuming 5 persons per household, the benefits of irrigating these plots could reach a high percentage of the population.

It may be noted from the above that there is significantly more land with a 0 to 6 percent slope than would be regarded as suitable for growing crops under irrigation in the Tefki Area compared to the Gerbi Area (48,600 compared to 30,600 hectares), yet less land that could be sustainably irrigated (3,786 compared to 6,114 hectares) based on lower precipitation and reduced groundwater availability. The hectares that could be sustainably irrigated represent less than 8 percent of this land in the Tefki Area as compared with 20 percent in the Gerbi Area. **Therefore, land management regarding the irrigated cropping is even more critical so as not to expand irrigated farming beyond the limits of the groundwater resource and stay within the bounds of sustainability.**

In the worst-case year of drought, based on the 20-year historical period of record at the Boneya weather station (**Appendix A, Figure 4**), precipitation is 39 percent of normal, and net groundwater availability for irrigation is on the order of 11 MCM/yr as compared with 40 MCM/yr in a time of normal precipitation. It may be noted that the total amount of groundwater recharge of 31 MCM/yr calculated in this year of drought is about the same magnitude as the ecological reserve of 32 MCM/yr set aside during a time of normal precipitation (using a factor of 40 percent of normal precipitation). The analysis illuminates an apparent significant sensitivity of the watershed to drought conditions.

4.5 Climate Change Variations

The ILaP Calculator can be utilized to facilitate simulations of how climate change may affect the irrigable land potential based on groundwater availability by changing one or all of three input parameters. These are:

1. Normal and drought precipitation values may be changed based on dryer/wetter predictions.
2. Total groundwater recharge as a percentage of precipitation may be adjusted to simulate higher/lower evapotranspiration (ET) due to higher/lower temperatures.
3. Crop unit water demand values may be adjusted to simulate higher/lower ET due to higher/lower temperatures.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results for both the Gerbi and Tefki Areas indicate conditions in which the opportunities for small-scale irrigation initiatives are substantial and can have large and lasting benefits for the populace. Several thousands of hectares may be irrigated which represent tens of thousands of small-scale farming plots. However, conditions are such that available land is more abundant than the groundwater resource. These two watersheds are both good examples of places where land management policy will be critical to achieving sustainable and lasting growth.

The application of the Irrigable Land Potential (ILaP) Calculator for these two watersheds shows how the process of utilizing the Calculator effectively pulls together scientific analysis and local practices and knowledge to gain a qualitative and quantitative understanding of the opportunities and constraints for small-scale irrigation. The Calculator provides a concise summary of the critical properties of a watershed with respect to groundwater resource availability and the land that can potentially be irrigated. The Calculator also provides the basis for developing a good sense of the sensitivity and resiliency of a watershed under irrigation to drought conditions.

The Irrigated Land Potential (ILaP) Calculator is applicable to and can be used to support and furnish a strong platform for launching small-scale irrigation initiatives in Ethiopia.

5.2 Recommendations

Based on utilizing the new ILaP Calculator tool to assess the potential for small-scale irrigation in two pilot study basins (watersheds) in the Highlands of Ethiopia, the following recommendations are made:

1. **Expand to Other Basins in Ethiopia** - Apply the ILaP Calculator to additional similar-sized basins and possibly larger basins/project areas in Ethiopia where the significant expansion of small-scale irrigation is planned.

2. **Expand use to Other Countries** - Identify and apply the ILap Calculator in other countries in Sub Saharan Africa where Feed the Future and other USAID agricultural initiatives are in-place or planned.

3. **Incorporate ATA Soil/Crop Tool** - Integrate the ILaP calculator with the Ethiopian ATA and other models that analyze irrigation water demand based on soil types and cropping patterns in a basin.

4. **Additional Technical Support in Gerbi and Tefki** - Follow-up the ILaP analysis of the irrigable land potential of the Gerbi and Tefki Areas with a focused small-scale irrigation feasibility study, which would include:

    - Identifying optimal areas for hand-dug wells using field geologic surveys, remote sensing platforms, and limited geophysical surveys to map the shallow groundwater, top of consolidated bedrock; and thickness of shallow saturated zones.

    - Evaluating well technologies that are applicable to specific areas/watersheds including hand-dug wells; larger diameter hand-dug wells for enhanced storage; larger and deeper hand-dug wells that penetrate into consolidated bedrock using pneumatic methods and drilled boreholes.

    - Field-testing of innovative well technologies (5 to 10 per project area).

    - Evaluating pumping systems that are economical and practical for local farmers including hand pumps; treadle pumps; solar; wind; electric and diesel- driven pumping systems.

5. **Country-wide Groundwater Policy** - Investigate ways to incorporate the ILaP analysis into a groundwater abstraction regulatory system on a basin and regional basis.

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United States NASA Landsat 8 Image, December 1, 2013, downloaded from Land Processes Distributed Active Archive Center (LP DAAC), USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov

Appendix A

Additional Report Figures

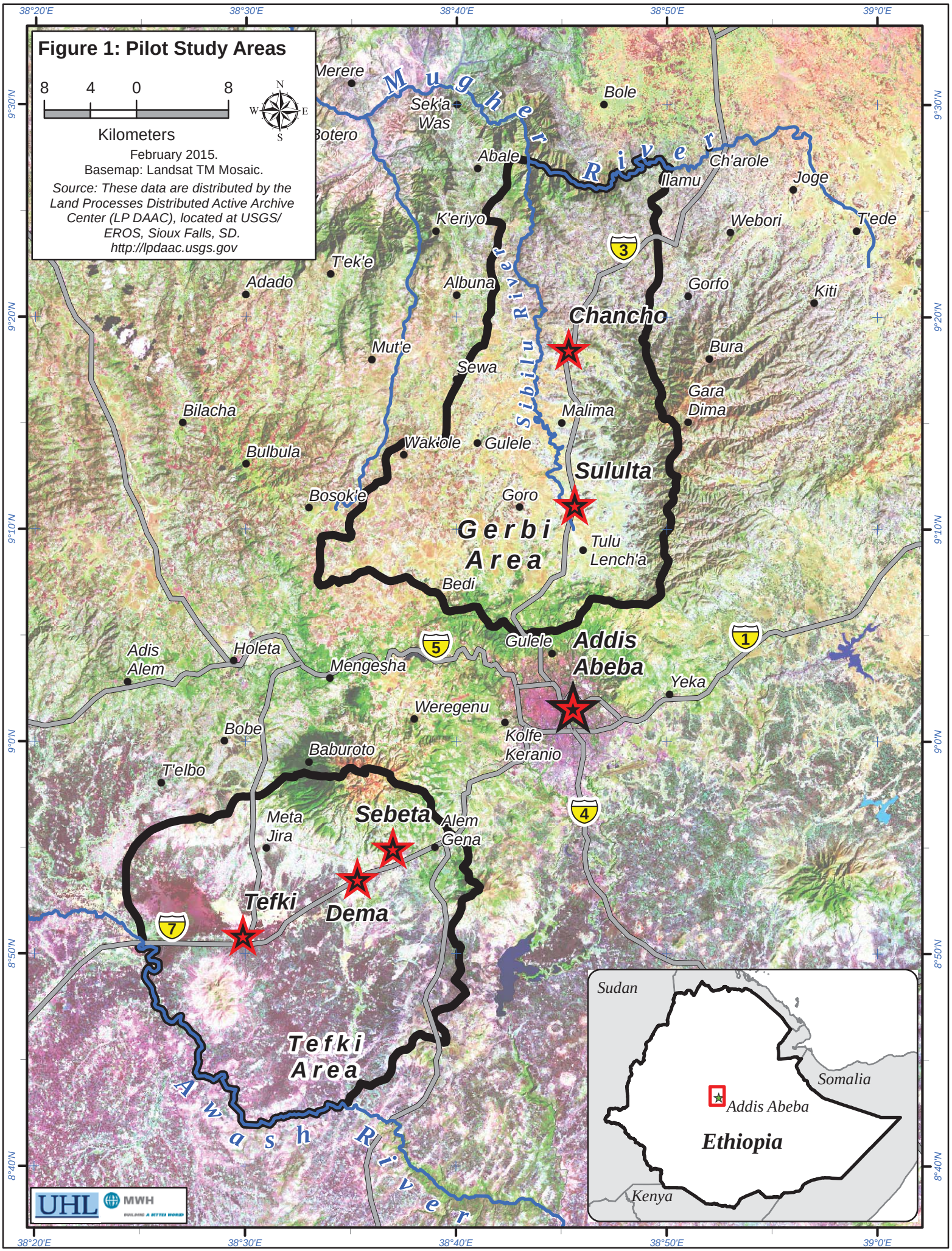
Figure 1: Pilot Study Areas
8 4 0 8
Kilometers
February 2015.
Basemap: Landsat TM Mosaic.
Source: These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/ EROS, Sioux Falls, SD.
http://lpdaac.usgs.gov
N
S
E
W
38°20'E
38°30'E
38°40'E
38°50'E
39°0'E
9°30'N
9°20'N
9°10'N
9°0'N
8°50'N
8°40'N
Merere
Sek'a Was
Botero
Bole
Mugher River
Abale
Ch'arole
Ilamu
Joge
Webori
T'ede
K'eriyo
T'ek'e
Adado
Albuna
Sibilu River
Gorfo
Kiti
Chancho
Mut'e
Sewa
Bura
Gara Dima
Bilacha
Malima
Wak'ole
Gulele
Bulbula
Sululta
Bosok'e
Goro
Gerbi Area
Tulu Lench'a
Bedi
Gulele
Addis Abeba
Adis Alem
Holeta
Mengesha
Yeka
Weregenu
Bobe
Kolfe Keranio
Baburoto
T'elbo
Meta Jira
Sebeta
Alem Gena
Tefki
Dema
Tefki Area
Awash River
Sudan
Somalia
Addis Abeba
Ethiopia
Kenya
UHL
MWH
BUILDING A BETTER WORLD

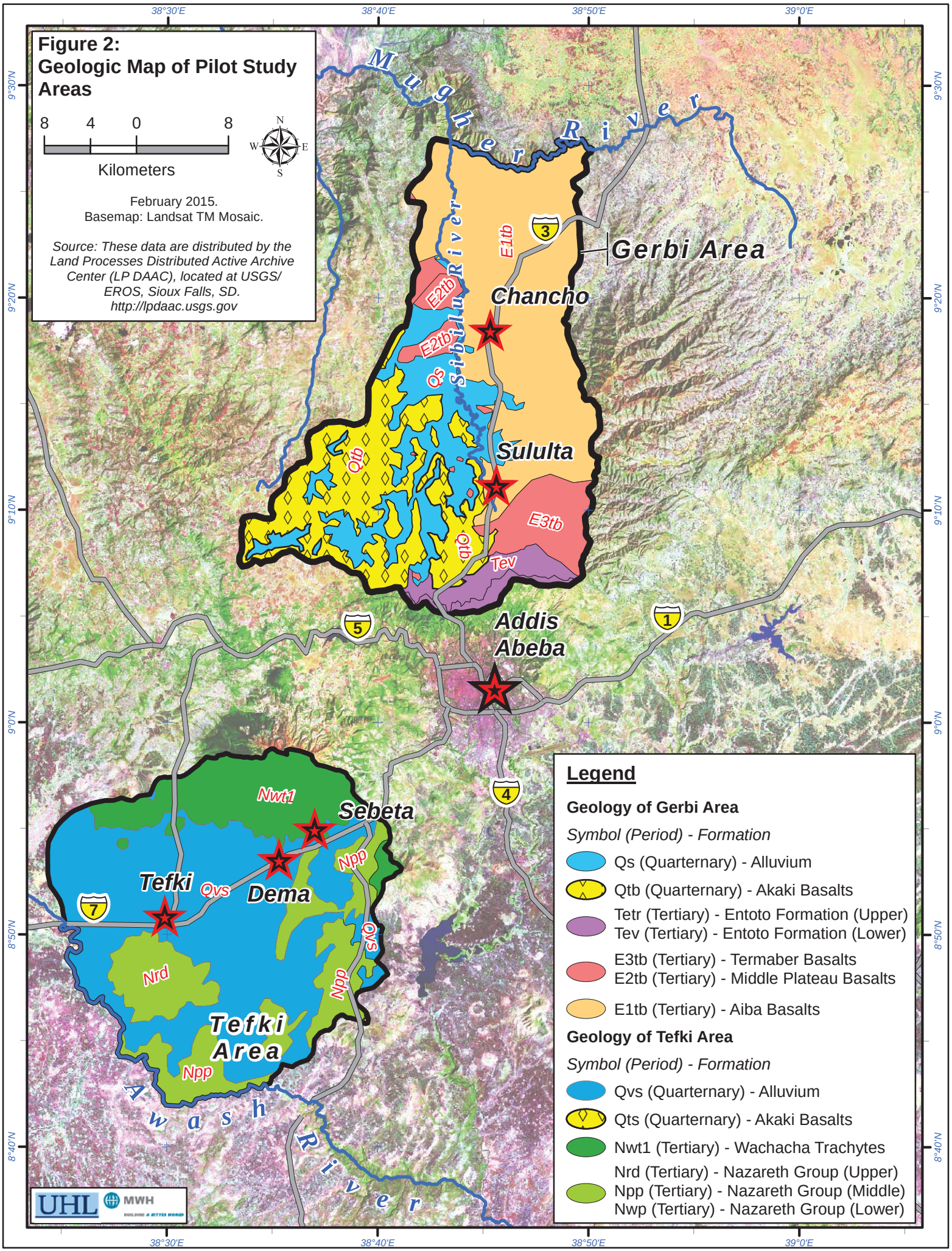
Figure 2:
Geologic Map of Pilot Study Areas
8 4 0 8
Kilometers
N
W
E
S
February 2015.
Basemap: Landsat TM Mosaic.
Source: These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/ EROS, Sioux Falls, SD.
http://lpdaac.usgs.gov
38°30'E
38°40'E
38°50'E
39°0'E
9°30'N
9°20'N
9°10'N
9°0'N
8°50'N
8°40'N
Mugher River
Sibilu River
Gerbi Area
Chancho
Sululta
Addis Abeba
Sebeta
Dema
Tefki
Tefki Area
Awash River
E1tb
E2tb
E3tb
Qs
Qtb
Tev
Nwt1
Npp
Qvs
Nrd
3
5
1
4
7
UHL
MWH
Legend
Geology of Gerbi Area
Symbol (Period) - Formation
Qs (Quarternary) - Alluvium
Qtb (Quarternary) - Akaki Basalts
Tetr (Tertiary) - Entoto Formation (Upper)
Tev (Tertiary) - Entoto Formation (Lower)
E3tb (Tertiary) - Termaber Basalts
E2tb (Tertiary) - Middle Plateau Basalts
E1tb (Tertiary) - Aiba Basalts
Geology of Tefki Area
Symbol (Period) - Formation
Qvs (Quarternary) - Alluvium
Qts (Quarternary) - Akaki Basalts
Nwt1 (Tertiary) - Wachacha Trachytes
Nrd (Tertiary) - Nazareth Group (Upper)
Npp (Tertiary) - Nazareth Group (Middle)
Nwp (Tertiary) - Nazareth Group (Lower)

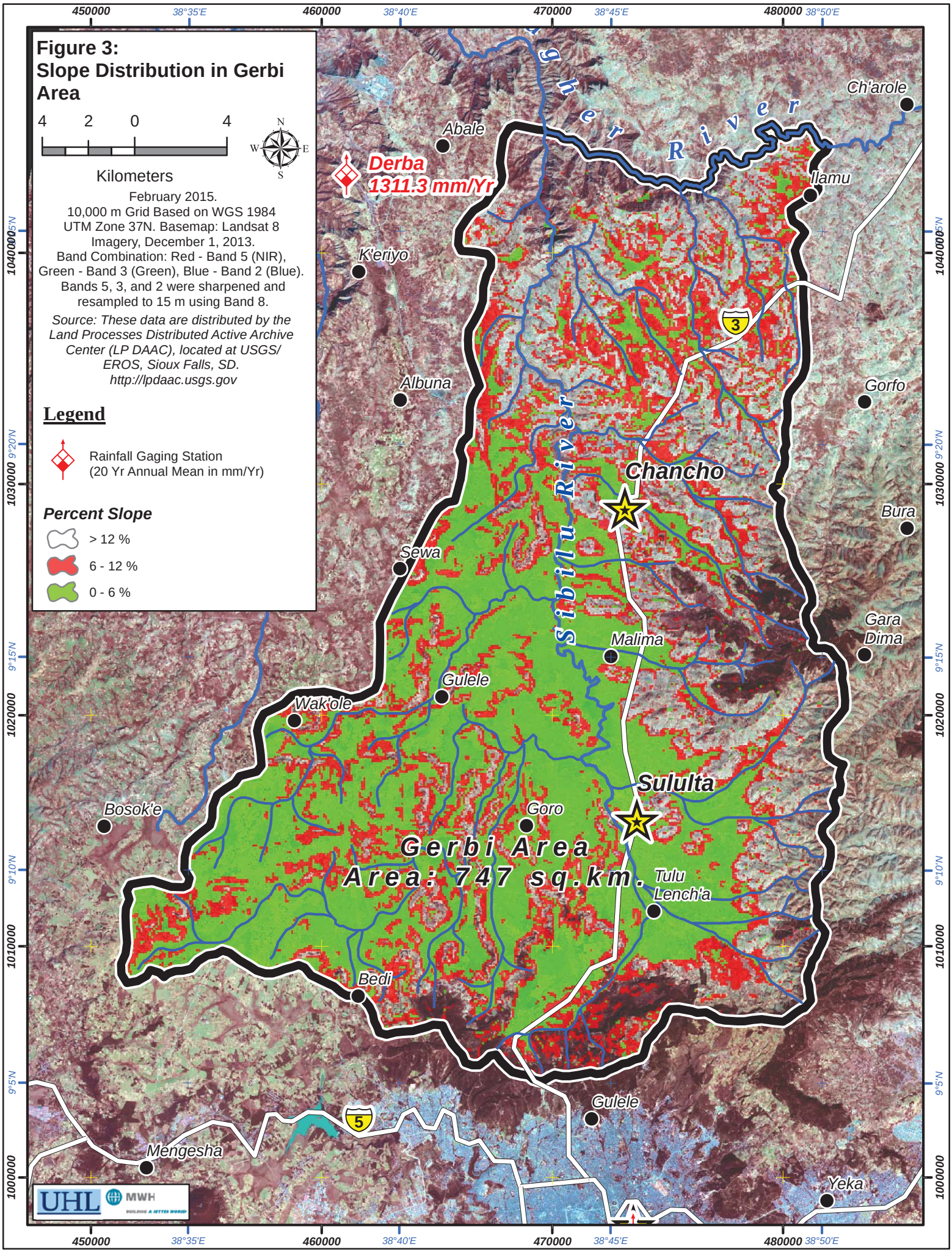
Figure 3:
Slope Distribution in Gerbi Area
4 2 0 4
Kilometers
February 2015.
10,000 m Grid Based on WGS 1984 UTM Zone 37N. Basemap: Landsat 8 Imagery, December 1, 2013.
Band Combination: Red - Band 5 (NIR), Green - Band 3 (Green), Blue - Band 2 (Blue).
Bands 5, 3, and 2 were sharpened and resampled to 15 m using Band 8.
Source: These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/ EROS, Sioux Falls, SD.
http://lpdaac.usgs.gov
Legend
Rainfall Gaging Station (20 Yr Annual Mean in mm/Yr)
Percent Slope
> 12 %
6 - 12 %
0 - 6 %
Derba
1311.3 mm/Yr
Abale
Ch'arole
Ilamu
K'eriyo
Albuna
Gorfo
Chancho
Bura
Sewa
Gara Dima
Malima
Gulele
Wak'ole
Sululta
Bosok'e
Goro
Gerbi Area
Area: 747 sq.km.
Tulu Lench'a
Bedi
Gulele
Mengesha
Yeka
Sibilu River
Gher River
UHL
MWH
450000
460000
470000
480000
38°35'E
38°40'E
38°45'E
38°50'E
1040000
1030000
1020000
1010000
1000000
9°20'N
9°15'N
9°10'N
9°5'N

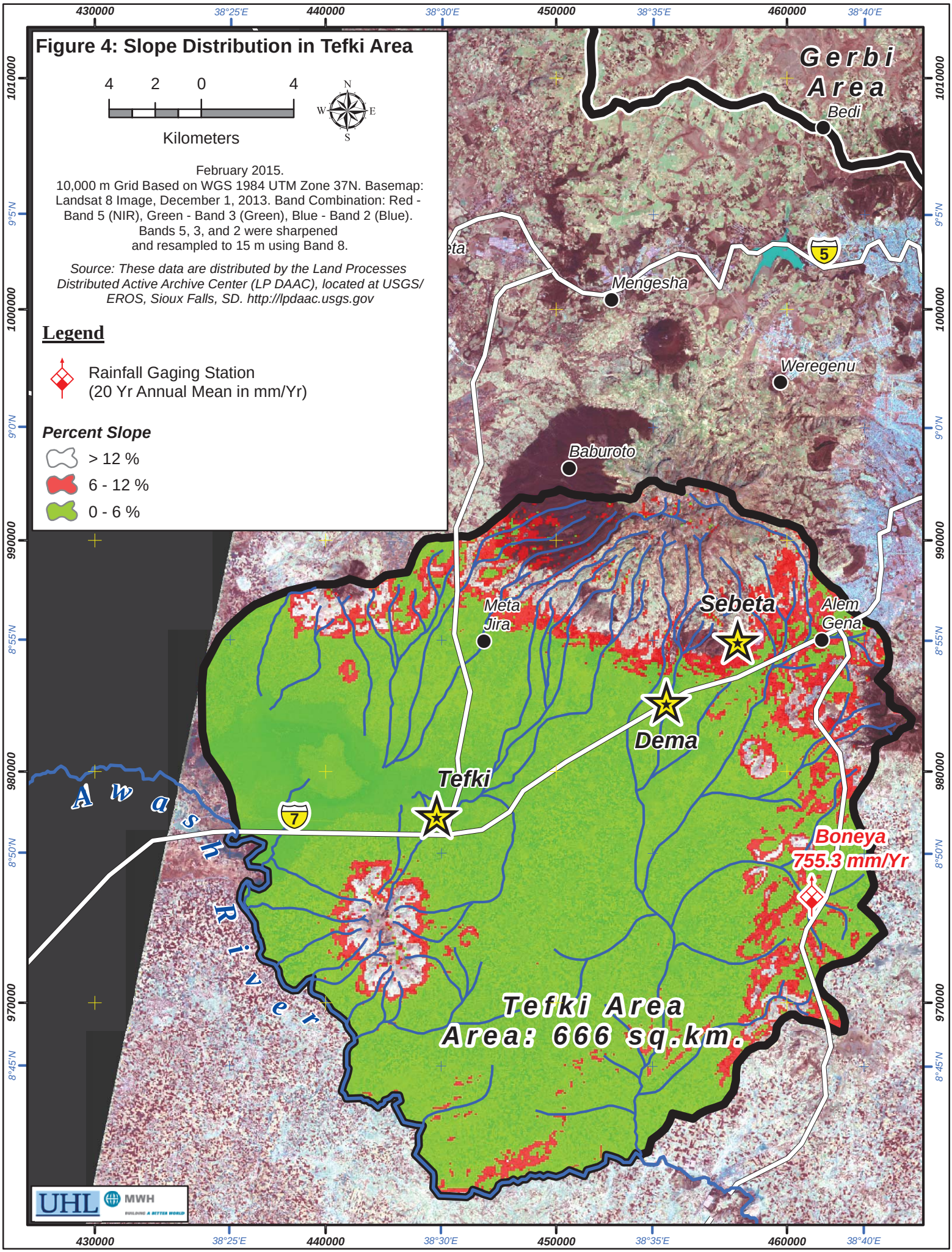
Figure 4: Slope Distribution in Tefki Area
4 2 0 4
Kilometers
N
W
E
S
February 2015.
10,000 m Grid Based on WGS 1984 UTM Zone 37N. Basemap: Landsat 8 Image, December 1, 2013. Band Combination: Red - Band 5 (NIR), Green - Band 3 (Green), Blue - Band 2 (Blue). Bands 5, 3, and 2 were sharpened and resampled to 15 m using Band 8.
Source: These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/ EROS, Sioux Falls, SD. http://lpdaac.usgs.gov
Legend
Rainfall Gaging Station (20 Yr Annual Mean in mm/Yr)
Percent Slope
> 12 %
6 - 12 %
0 - 6 %
Gerbi Area
Bedi
Mengesha
Weregenu
Baburoto
Meta Jira
Sebeta
Alem Gena
Dema
Tefki
Boneya
755.3 mm/Yr
Awash River
Tefki Area
Area: 666 sq.km.
5
7
430000
440000
450000
460000
38°25'E
38°30'E
38°35'E
38°40'E
1010000
1000000
990000
980000
970000
9°5'N
9°0'N
8°55'N
8°50'N
8°45'N
UHL
MWH

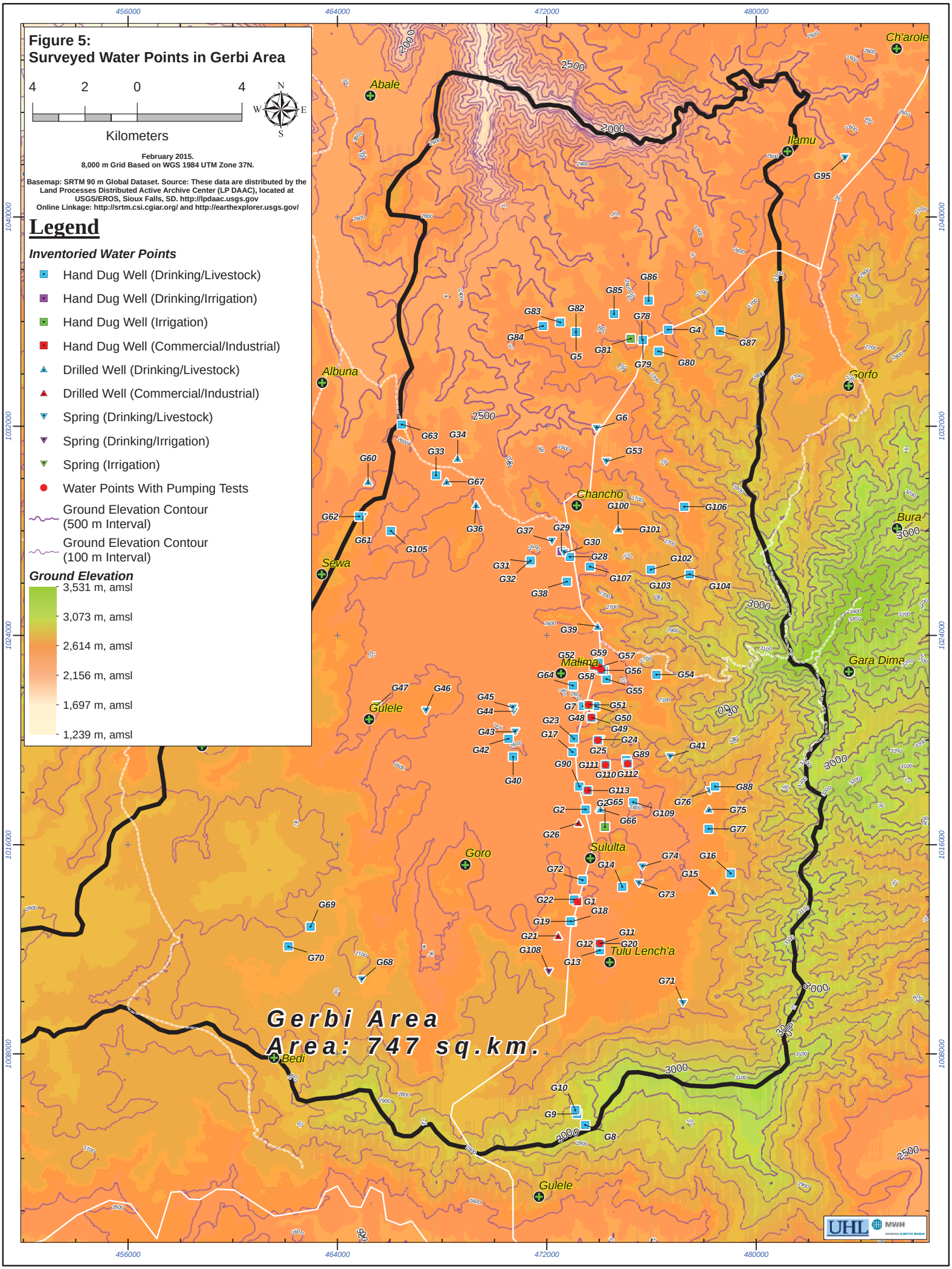
Figure 5:
Surveyed Water Points in Gerbi Area
4 2 0 4
Kilometers
N
W
E
S
February 2015.
8,000 m Grid Based on WGS 1984 UTM Zone 37N.
Basemap: SRTM 90 m Global Dataset. Source: These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov
Online Linkage: http://srtm.csi.cgiar.org/ and http://earthexplorer.usgs.gov/
Legend
Inventoried Water Points
Hand Dug Well (Drinking/Livestock)
Hand Dug Well (Drinking/Irrigation)
Hand Dug Well (Irrigation)
Hand Dug Well (Commercial/Industrial)
Drilled Well (Drinking/Livestock)
Drilled Well (Commercial/Industrial)
Spring (Drinking/Livestock)
Spring (Drinking/Irrigation)
Spring (Irrigation)
Water Points With Pumping Tests
Ground Elevation Contour (500 m Interval)
Ground Elevation Contour (100 m Interval)
Ground Elevation
3,531 m, amsl
3,073 m, amsl
2,614 m, amsl
2,156 m, amsl
1,697 m, amsl
1,239 m, amsl
Gerbi Area
Area: 747 sq.km.
Abale
Ch'arole
Ilamu
Albuna
Gorfo
Chancho
Bura
Sewa
Malima
Gara Dima
Gulele
Goro
Sululta
Tulu Lench'a
Bedi
456000
464000
472000
480000
1040000
1032000
1024000
1016000
1008000
UHL
MWH

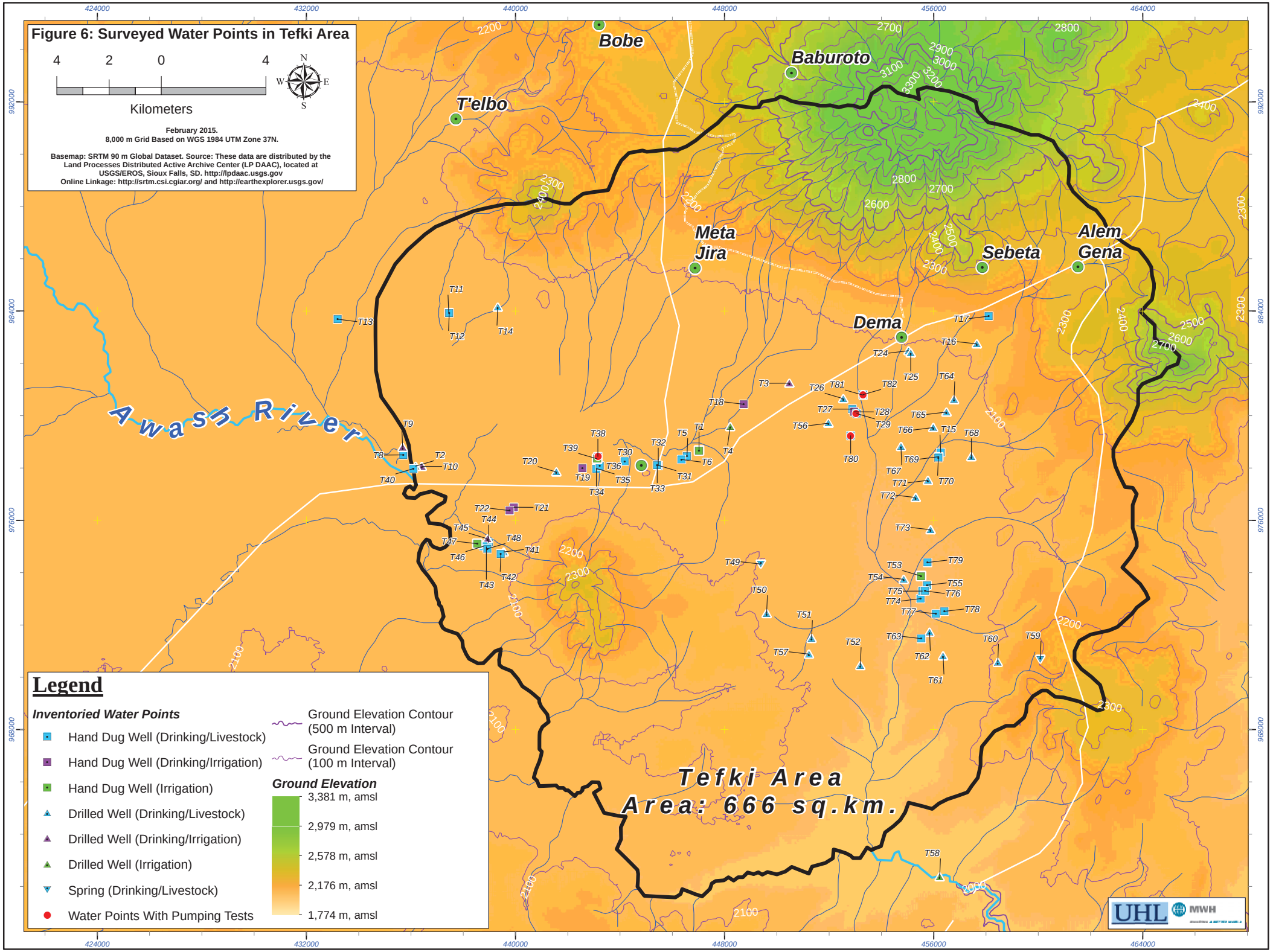
Figure 6: Surveyed Water Points in Tefki Area
4 2 0 4
Kilometers
N
W
E
S
February 2015.
8,000 m Grid Based on WGS 1984 UTM Zone 37N.
Basemap: SRTM 90 m Global Dataset. Source: These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov
Online Linkage: http://srtm.csi.cgiar.org/ and http://earthexplorer.usgs.gov/
Bobe
Baburoto
T'elbo
Meta Jira
Sebeta
Alem Gena
Dema
Awash River
Tefki Area
Area: 666 sq.km.
Legend
Inventoried Water Points
Hand Dug Well (Drinking/Livestock)
Hand Dug Well (Drinking/Irrigation)
Hand Dug Well (Irrigation)
Drilled Well (Drinking/Livestock)
Drilled Well (Drinking/Irrigation)
Drilled Well (Irrigation)
Spring (Drinking/Livestock)
Water Points With Pumping Tests
Ground Elevation Contour (500 m Interval)
Ground Elevation Contour (100 m Interval)
Ground Elevation
3,381 m, amsl
2,979 m, amsl
2,578 m, amsl
2,176 m, amsl
1,774 m, amsl
UHL
MWH

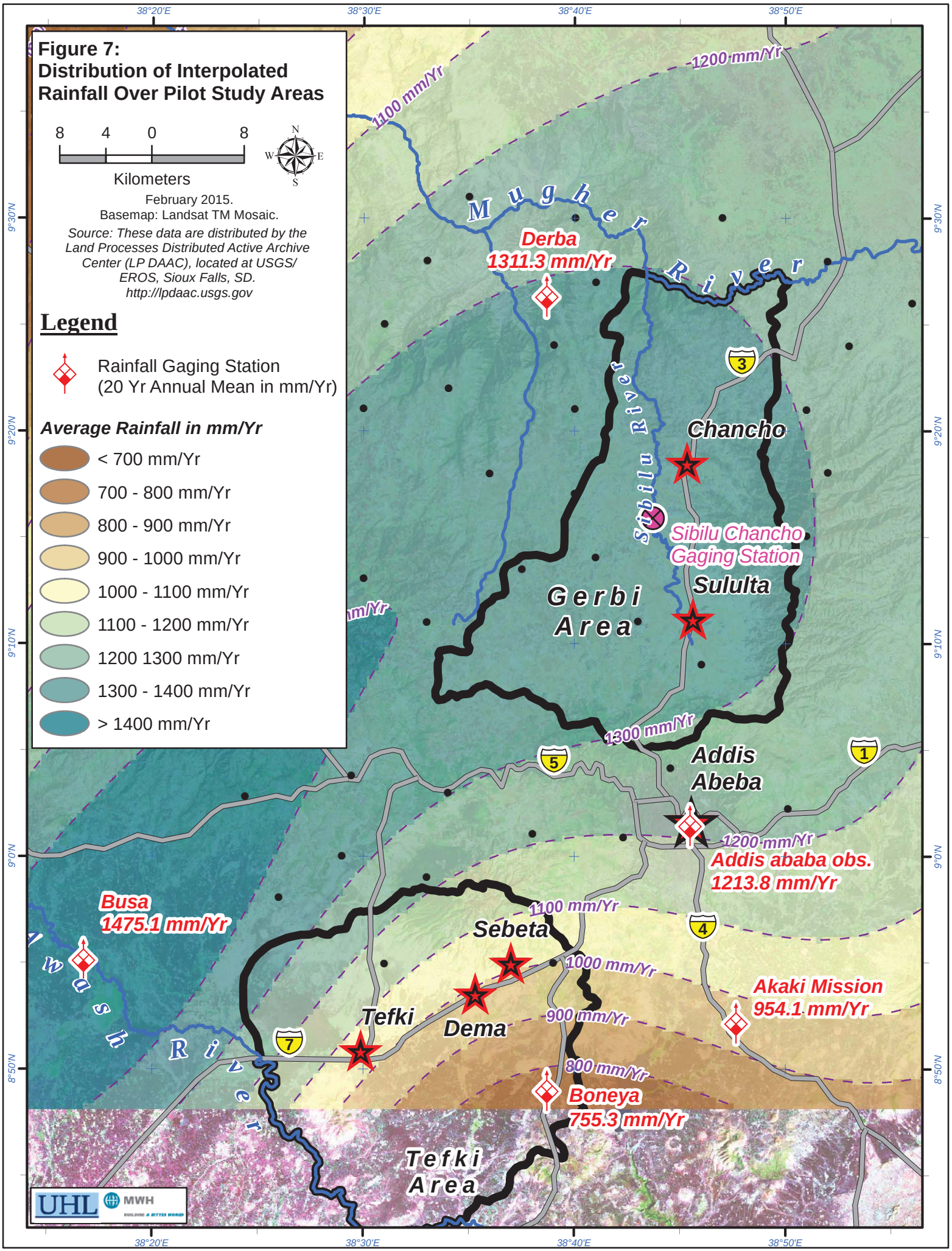
Figure 7:
Distribution of Interpolated Rainfall Over Pilot Study Areas
8 4 0 8
Kilometers
February 2015.
Basemap: Landsat TM Mosaic.
Source: These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/ EROS, Sioux Falls, SD.
http://lpdaac.usgs.gov
Legend
Rainfall Gaging Station (20 Yr Annual Mean in mm/Yr)
Average Rainfall in mm/Yr
< 700 mm/Yr
700 - 800 mm/Yr
800 - 900 mm/Yr
900 - 1000 mm/Yr
1000 - 1100 mm/Yr
1100 - 1200 mm/Yr
1200 1300 mm/Yr
1300 - 1400 mm/Yr
> 1400 mm/Yr
38°20'E
38°30'E
38°40'E
38°50'E
9°30'N
9°20'N
9°10'N
9°0'N
8°50'N
1100 mm/Yr
1200 mm/Yr
Mugher River
Derba
1311.3 mm/Yr
Sibilu River
Chancho
Sibilu Chancho Gaging Station
Sululta
Gerbi Area
1300 mm/Yr
Addis Abeba
Addis ababa obs.
1213.8 mm/Yr
Busa
1475.1 mm/Yr
Sebeta
1000 mm/Yr
Akaki Mission
954.1 mm/Yr
Tefki
Dema
900 mm/Yr
800 mm/Yr
Boneya
755.3 mm/Yr
Awash River
Tefki Area
UHL
MWH

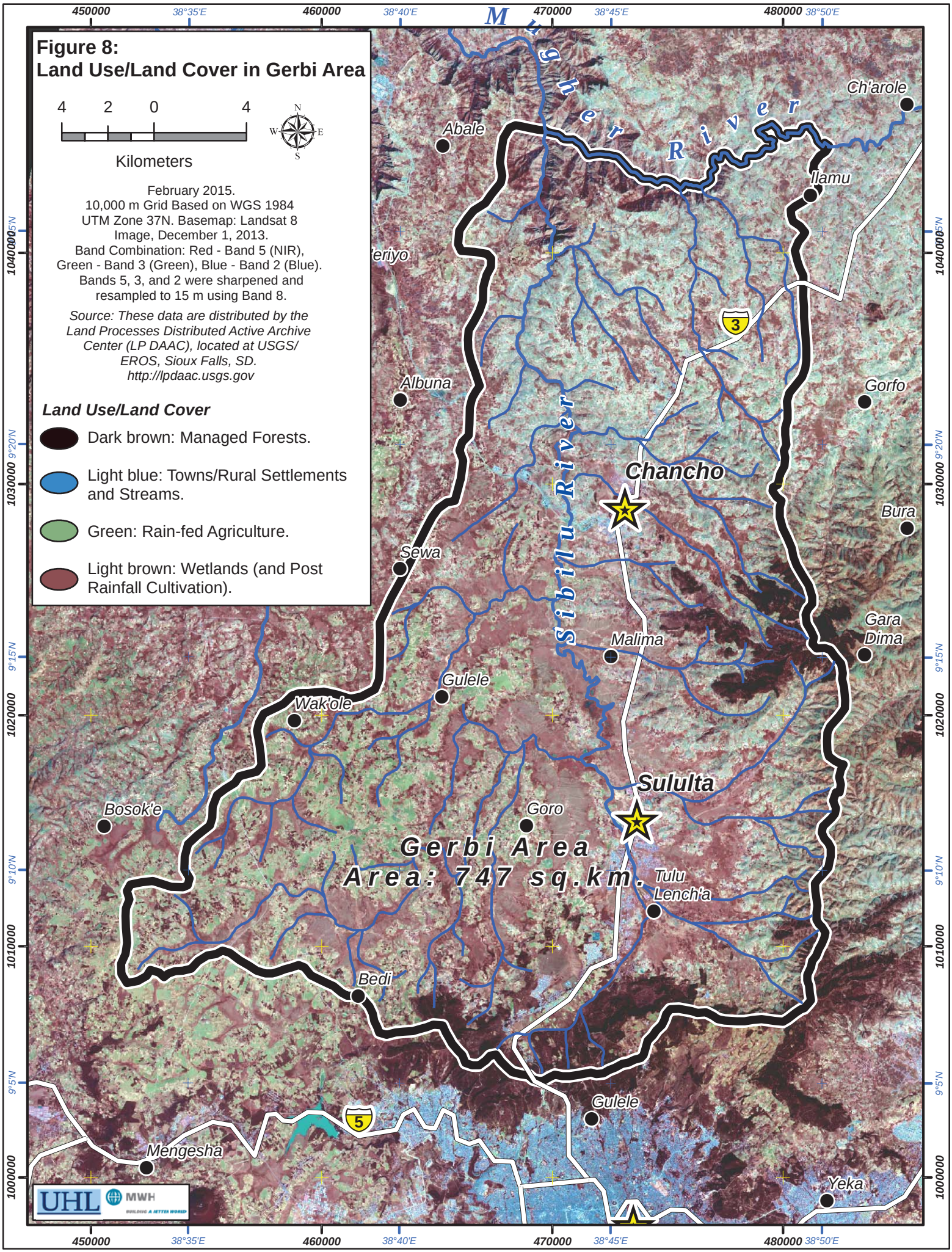
Figure 8:
Land Use/Land Cover in Gerbi Area
4 2 0 4
Kilometers
February 2015.
10,000 m Grid Based on WGS 1984
UTM Zone 37N. Basemap: Landsat 8
Image, December 1, 2013.
Band Combination: Red - Band 5 (NIR),
Green - Band 3 (Green), Blue - Band 2 (Blue).
Bands 5, 3, and 2 were sharpened and
resampled to 15 m using Band 8.
Source: These data are distributed by the
Land Processes Distributed Active Archive
Center (LP DAAC), located at USGS/
EROS, Sioux Falls, SD.
http://lpdaac.usgs.gov
Land Use/Land Cover
Dark brown: Managed Forests.
Light blue: Towns/Rural Settlements and Streams.
Green: Rain-fed Agriculture.
Light brown: Wetlands (and Post Rainfall Cultivation).
Mugher River
Sibilu River
Ch'arole
Abale
Ilamu
Albuna
Gorfo
Chancho
Bura
Sewa
Gara Dima
Malima
Gulele
Wak'ole
Sululta
Bosok'e
Goro
Gerbi Area
Area: 747 sq.km.
Tulu Lench'a
Bedi
Gulele
Mengesha
Yeka
450000
460000
470000
480000
38°35'E
38°40'E
38°45'E
38°50'E
1040000
1030000
1020000
1010000
1000000
9°20'N
9°15'N
9°10'N
9°5'N
UHL
MWH

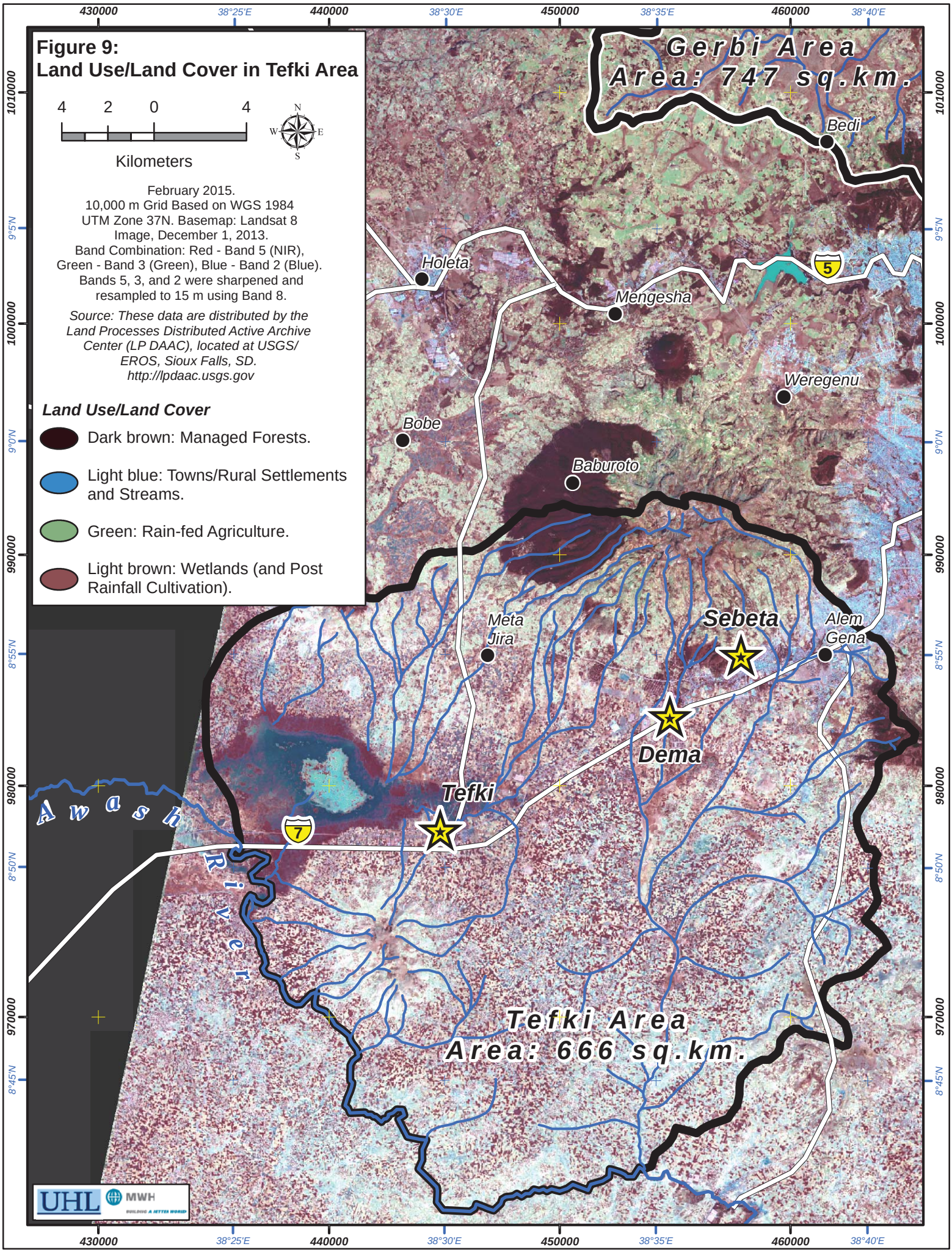
Figure 9:
Land Use/Land Cover in Tefki Area
4 2 0 4
Kilometers
N
W
E
S
February 2015.
10,000 m Grid Based on WGS 1984
UTM Zone 37N. Basemap: Landsat 8
Image, December 1, 2013.
Band Combination: Red - Band 5 (NIR),
Green - Band 3 (Green), Blue - Band 2 (Blue).
Bands 5, 3, and 2 were sharpened and
resampled to 15 m using Band 8.
Source: These data are distributed by the
Land Processes Distributed Active Archive
Center (LP DAAC), located at USGS/
EROS, Sioux Falls, SD.
http://lpdaac.usgs.gov
Land Use/Land Cover
Dark brown: Managed Forests.
Light blue: Towns/Rural Settlements and Streams.
Green: Rain-fed Agriculture.
Light brown: Wetlands (and Post Rainfall Cultivation).
Gerbi Area
Area: 747 sq.km.
Bedi
Holeta
Mengesha
Weregenu
Bobe
Baburoto
Meta Jira
Sebeta
Alem Gena
Dema
Tefki
Awash River
Tefki Area
Area: 666 sq.km.
5
7
430000
440000
450000
460000
38°25'E
38°30'E
38°35'E
38°40'E
1010000
1000000
990000
980000
970000
9°5'N
9°0'N
8°55'N
8°50'N
8°45'N
UHL
MWH

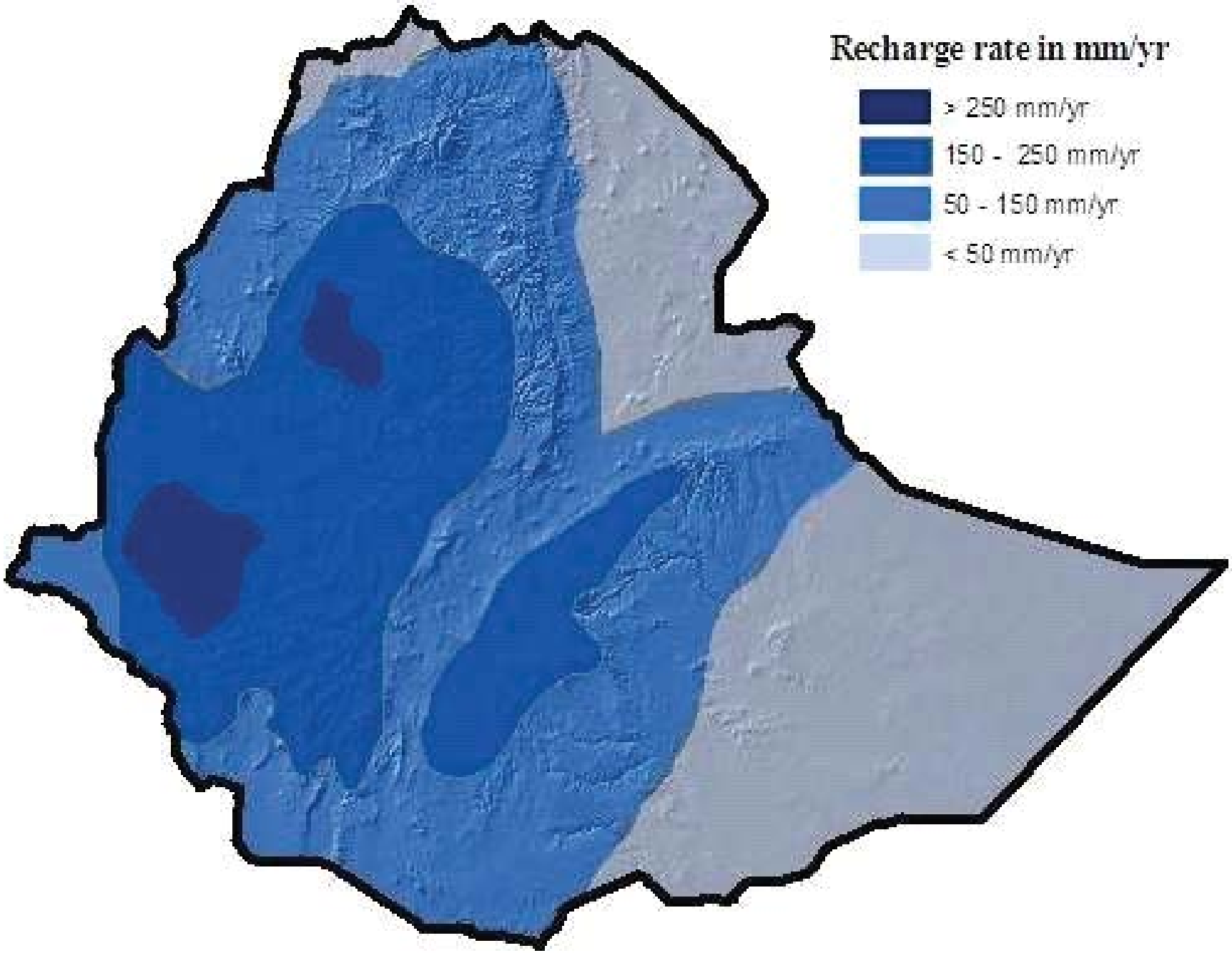

Figure 10: Groundwater Recharge Map for Ethiopia (Chernet, 1993)

Appendix B

Additional Report Tables

Table 1. Irrigable Land Potential (ILaP) Calculator - Inputs and Outputs Master List

	Parameter	Units	Units Abbrev.	Type
Worksheet 1 - Available Annual Groundwater Recharge				
[A]	Watershed Area	square kilometers	km^2	Input, Constant
[B]	Precipitation	millimeters per year	mm/yr	Input, Climate Change Variable
[C]	Recharge Factor, as percent of precipitation	percent	%	Input, Range, Climate Change Variable
[D]	Total Groundwater Recharge	million cubic meters per year	MCM/yr	Output
[E]	Ecological Factor, as percent of total groundwater recharge	percent	%	Input, Range
[F]	Ecological Groundwater Recharge Reserve	million cubic meters per year	MCM/yr	Output
[G]	Available Groundwater Recharge	million cubic meters per year	MCM/yr	Principal Output
Worksheet 2 - Current Groundwater Use				
[H]	Population	persons	P	Input, Future Planning Variable
[I]	Use Per Person	liters per person per day	LPP/day	Input, Future Planning Variable
[J]	Total Household Use	million cubic meters per year	MCM/yr	Output
[K]	Livestock Use	million cubic meters per year	MCM/yr	Input, Future Planning Variable
[L]	Commercial/Industrial Use Estimate	million cubic meters per year	MCM/yr	Input, Future Planning Variable
[M]	Amount of Land Currently Irrigated	hectares	ha	Input
[N]	Land Unit Irrigation Water Demand	liters per second per hectare	LPS/ha	Input, Climate Change Variable
[O]	Total Currrent Irrigation Demand	million cubic meters per year	MCM/yr	Output
[P]	Total Current Groundwater Use	million cubic meters per year	MCM/yr	Principal Output
Worksheet 3 - Net Available Annual Groundwater Recharge				
(Q]	Net Available Groundwater Recharge	million cubic meters per year	MCM/yr	Principal Output
Worksheet 4 - Irrigable Land Potential (ILaP) Based on Net Available Annual Groudwater Recharge				
[R]	Growing Season	Days	days	Input, Range
[S]	Irrigation Water Demand Reduction Factor	percent	%	Input, Future Planning Variable
[T]	Adjusted Unit Water Demand	liters per second per hectare	LPS/ha	Output
[U]	Land Unit Groundwater Use Per Growing Season	cubic meters per hectare	m^3/ha	Output
[V]	Irrigable Land Potential (ILaP) Based on Groundwater Availability	hectares	ha	Principal Output
Worksheet 5 - Irrigable Land Potential (ILaP) Based on Groundwater Availablity vs. Suitable Land for Irrigation				
[W]	Potential Irrigable Land, Based on Slope Analysis	percent	%	Input, Constant
[X]	Available Land for Irrigation, Based on Slope	hectares	ha	Output
[Y]	Percent of Irrigable Land Potential (ILaP), based on Groundwater Availability to Available Land for Irrigation, Based on Slope	percent	%	Principal Output

Table 2: Summary of Pumping Tests in Gerbi and Tefki Areas

Map ID	Date Tested	Town	Easting (m)	Northing (m)	Ground Elevation (m, amsl)	Depth (m, bgs)	Diameter (m)	Static Water Level (m, bmp)	Pumping Test Water Level (m, bmp)	Water Level at End of 120 Minutes (m, bmp)	Replenish-ment Rate (LPS)
Gerbi Area											
G1	11/17/2014	Sululta - Cement Block	473159	1013829	2609	7.0	1.0	2.33	2.81	2.55 (60 min)	0.056
G11	11/17/2014	Sululta - Flower Farm	474025	1012221	2884	4.5	3.1	1.02	2.02	1.62	0.420
G52	12/1/2014	Illamu Roba	473800	1022831	2570	7.0	0.8	3.30	4.40	3.87	0.037
G51	12/1/2014	Gerarso Malima	473601	1021348	2580	14.0	0.8	0.30	1.46	0.96	0.035
G48	12/1/2014	Wererso Malima	473708	1020860	2593	5.0	1.0	2.30	2.80	2.5	0.033
G25	12/1/2014	Wererso Keta	473957	1019990	2582	2.0	1.5	0.70	1.70	1.3	0.098
G58	12/2/2014	Illamu Roba	474087	1022690	2577	4.0	3.0	1.55	2.55	2.22	0.324
G57	12/2/2014	Illamu Roba	473990	1022795	2571	6.5	0.8	2.22	3.42	3.18	0.017
G112	1/1/2015	Wererso Galeyea	475092	1019098	2587	3.0	2.5	0.66	1.60	1.45	0.102
G111	1/1/2015	Wererso Keta	474247	1019049	2570	4.0	1.0	0.60	1.60	1.51	0.010
G113	1/1/2015	Wererso Keta	473559	1018071	2562	4.0	2.9	0.80	1.20	1.1	0.092
Tefki Area											
T-38	12/2/2014	Tefki	443157	978437	2063	7.0	1.0	5.4	6.48	6.30	0.019
T-80	12/4/2014	Dima Magno	452819	979237		6.0	0.8	2.7	2.95	2.70	0.017
T-29	12/4/2014	Dima Magno	453026	980084	2062	5.0	1.3	1.6	2.60	1.60	0.184
T-81	12/4/2014	Dima Magno	453301	980786	2070	4.0	0.8	3.3	3.70	3.24	0.037
T-82	12/4/2014	Dima Magno	453297	980808	2065	5.0	0.8	3.8	4.84	4.45	0.027

Units:
m - Meters
m, amsl - Meters Above Mean Sea Level
m, bgs - Meters Below Ground Surface
m, bmp - Meters Below Measuring Point
LPS - Liters per Second

Table 3A: Recommended Water Intake Guide for Various Domestic/Farm Animals

Livestock	Water Consumption (LPD)	Average Water Consumption (LPD)
Cattle	26 to 45	36
Goat/Sheep	5 to 15	10
Horses	30 to 45	38
Mules	10 to 16	14
Donkeys	12 to 16	14
Poultry	180 to 240 liters per 1000 birds	210 (per 1,000 birds)

Table 3B: Livestock Water Requirements in the Gerbi and Tefki Area

	Gerbi Area		Tefki Area	
Livestock	No. of Livestock	Average Water Consumption (LPD)	No. of Livestock	Average Water Consumption (LPD)
Cattle	125,612	4,522,047	87,639	3,155,003
Sheep	93,836	938,358	36,565	365,653
Goat	19,554	195,543	17,064	170,641
Horses	7,921	300,995	5,717	217,240
Mules	327	4,572	358	5,019
Donkeys	20,402	285,627	9,248	129,477
Poultry	71,264	14,965	63,055	13,242
Total Consumption (LPD)		***6,262,107***		***4,056,275***
Total Consumption (MCM/Yr)		***2.3***		***1.5***

Appendix C

Addis Ababa Workshop Description and List of Attendees

APPENDIX C
Addis Ababa Workshop Description and List of Attendees

Managing Shallow Groundwater Sustainably for Small Farm Irrigation Workshop & Field Trip

Dates: February 24 & 25, 2015

USAID, MWH, Uhl & Associates, and Addis Ababa University (AAU) put on a two-day workshop and study tour for the Government of Ethiopia, Donors, Policy Makers, NGOs and program implementers involved in small-scale irrigation. The goal was to introduce the Irrigated Land Potential (ILaP) Calculator tool and demonstrate the need for proper planning and management of shallow groundwater resources.

Day 1 – Workshop

The workshop was held at AAU's Arat Kilo Campus and approximately 40 people attended. Presentations were given by Gary Robbins (USAID), Vince Uhl (Uhl & Associates), Dr. Seifu Kebede (AAU), Eric Rawdon (MWH), Seyoum Getachew (ATA), and Alemseged Tamiru Haile (IWMI). The morning session provided an overview of the current state of knowledge of utilizing shallow groundwater for small farm irrigation in Ethiopia. ATA provided a summary of their current and future goals, and explained that one of their major constraints has been identifying and quantifying the availability of shallow groundwater in watersheds countrywide. Dr. Seifu and Vince Uhl provided an overview of the need for proper management of groundwater, and used India as an example of rapid growth and overexploitation of groundwater resources.

The afternoon session was devoted to working through the ILaP Calculator tool in detail using the Gerbi Basin as an example.

Day 2 – Field Trip

Dr. Seifu led approximately 20 attendees on a field trip to the Tefki Basin to show examples of successful small-scale irrigation initiatives as well as well siting and performance failures. The field trip also demonstrated well-point inventory procedures that included obtaining GPS coordinates, field water-quality testing (pH, TDS, EC, and temperature) and static water-level, well depth, and well diameter measurements. The sites visited included:

- Site 1: Several hand-dug drinking water wells in too close proximity. This highlighted the need for a better understanding of the best means of accessing groundwater, as closely spaced wells can interfere with each other and one or a few properly constructed wells would better serve the nearby village(s) drinking water needs.

- Site 2: An example of a failed community irrigation scheme, which highlighted the need to include operation and maintenance costs in the planning of the project.

- Site 3: An example of well sites that had to be abandoned due to improper drilling techniques, which highlighted the need for better well siting and drilling practices.

- Site 4: A well located at a dairy farm was shown as an example of reinforcing the well with metal rings.

- Site 5: An example of a successful small-scale irrigation farmer, who uses a treadle pump for drinking water and for the irrigation of mangos, banana, and avocado.

- Site 6: Another example of a successful small-scale irrigation farmer, who uses a tube well and a diesel pump to irrigate 0.5 hectares of maize. The farmer has been very successful and has been instrumental in encouraging other farmers in the area to irrigate.

The following are photographs from the field trip:

Figure 1 - Site 1: Dr. Seifu explaining the need for better understanding of groundwater resources. Please note that each red arrow represents an existing or abandoned shallow hand dug well.

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Figure 2 - Site 3: Dr. Seifu explaining why the construction of this well failed.

Figure 3 - Site 4: Shallow hand dug well constructed with metal rings.

Figure 4 - Site 6: A successful small scale irrigation farmer explaining how his irrigation system works. He also expressed that the yield of his well has dropped dramatically over the last two years. This is due to the build up of fine-grained sediments on the well screen.

APPENDIX C
Addis Ababa Workshop Description and List of Attendees

USAID | ETHIOPIA
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Workshop - Sign In Sheet

February 24th

No	Name	Position	Institution	Email contact address
1	Dr. Seifu Kebede *	Sr. Hydrogeologist	Addis Ababa University	seifukebede@yahoo.com
2	Vince Uhl *	Sr. Hydrogeologist	Uhl & Associates	vuhl@vuawater.com
3	Eric Rawdon *	Civil Engineer	MWH Global	Eric.E.Rawdon@mwhglobal.com
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5	Rutta Firdissa	Market Linkage Advisor, Horticulture Value Chain	SNV, Netherland Development Organization	rfirdissa@snvworld.org
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7	Alemseged Tamiru Haile *	Researcher – Hydrological modeling	IWMI	A.T.Haile@cgiar.org
8	Abigail Jones	Climate and Water Advisor	USAID/Ethiopia	abjones@usaid.gov
9	Gary Robbins *	Office Chief, Economic Growth and Transformation	USAID/Ethiopia	grobbins@usaid.gov
10	Mr. Seyoum Getachew *	Director	Agriculture Transformation Agency	Seyoum.Getachew@ata.gov.et
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18	Gezahegn Tadesse	Advisor	Embassy of Finland	gezahegn.tadesse@formin.fi
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20	Mr. Fumiaki Saso	PFA	JICA- Ethiopia	Saso.Fumiaki@jica.go.jp
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24	Dawit Tefera	General Manager	Tecmod Water Constr.	daslwit@yahoo.com
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38	Moghes Mekonen	Country Manager	MWH Global	Moghes.A.Mekonen@mwhglobal.com
39	Merry Tekle	Adminstrative	MWH Global	Merry.Tekle@mwhglobal.com

* Indicates that the individual was a presenter during the Workshop

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Addis Ababa Workshop Description and List of Attendees

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Field Trip - Sign In Sheet

February 25th

No.	Name	Position	Institution	Email contact address
1	Dr. Seifu Kebede	Sr. Hydrogeologist	Addis Ababa University	seifukebede@yahoo.com
2	Vince Uhl	Sr. Hydrogeologist	Uhl & Associates	vuhl@vuawater.com
3	Eric Rawdon	Civil Engineer	MWH Global	Eric.E.Rawdon@mwhglobal.com
4	Addis Hailu	Field Engineer - Hydrogeologist	Addis Ababa University	tayadu@gmail.com
5	Alemayehu Worku	WASH Advisor	Welt Hunger Hilfe	Alemayehu.Worku@welthungerhilfe.de
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7	Dr. Alemseged Tamiru Haile	Researcher – Hydrological modeling	IWMI	A.T.Haile@cgiar.org
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