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156

Rapid Assessment of Water Availability and Appropriate Technologies for Small-scale Farming: Guidelines for Practitioners

Andrew Keller, Elizabeth Weight and Stuart Taylor

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Project

The AgWater Solutions Project was implemented in several countries in Africa and Asia between 2009 and 2012. The objective of the project was to identify investment options and opportunities in agricultural water management with the greatest potential to improve incomes and food security for poor farmers, and to develop tools and recommendations for stakeholders in the sector including policymakers, investors, nongovernmental organizations (NGOs) and smallholder farmers.

The leading implementing institutions were the International Water Management Institute (IWMI), the Food and Agriculture Organization of the United Nations (FAO), iDE, the International Food Policy Research Institute (IFPRI) and the Stockholm Environment Institute (SEI).

For more information on the project or for detailed reports, please visit the project website (http://awm-solutions.iwmi.org/home-page.aspx) or contact the AgWater Solutions Project Secretariat (AWMSolutions@cgiar.org).

Contents

Summary

Limited access to water is a key reason why millions of poor farmers struggle to grow enough food and marketable crops to improve their lives. It can be a challenging task for farmers and program managers (who implement programs to improve the lives of farmers) to determine the availability and accessibility, which in turn determines affordability, and the sustainability of water resources in locations where there is limited documented information on surface water and groundwater resources. Further, it is often challenging for program managers and farmers to determine the most appropriate water access and application technologies, given the particular biophysical and socioeconomic environment, and the available water resources.

While there is a need to improve smallholder farmers' access to and use of water resources in a sustainable manner, there is limited documented guidance on tested methods and tools to assess the availability, accessibility and sustainability of water resources, and to select appropriate water access and application technologies. This paper seeks to address this gap by providing guidance to managers who implement field projects that improve smallholders' access to water resources while also ensuring environmental sustainability of water extraction. The audience envisioned for these guidelines include public sector agencies (e.g., government extension departments and water resources management departments); civil society organizations (e.g., farmer-based organizations and NGOs); social enterprises catalyzing irrigated agricultural value chains; and donors investing in improving the lives of female and male farmers. It is envisioned that program managers will use these guidelines in combination with other methods and tools, e.g., agricultural value chain analyses, as one part of a broader approach to designing interventions that benefit smallholder farmers.

This paper is not a technical manual; rather, it is intended to provide guidance on the expertise, resources and information needed for managers to direct technical specialists. The guidelines describe a process which can be followed by managers to direct technical specialists to gather sufficient data and information rapidly, in order to understand the characteristics of broad-scale areas and progressively define specific locations with greater potential for individual smallholder farmers to access groundwater and surface water resources affordably and sustainably. The guidelines also present an approach to estimate the quantity of water resources available, and select individual[1] water-lifting and irrigation application technologies that are suited to available water resources. The assessment process described in this document is divided into two main stages:

1. Broad-scale assessment - the assessment team gathers and analyzes secondary data, and identifies areas with high potential for investment in agricultural water management (AWM) solutions.
2. Detailed field-level assessment - the assessment team collects and analyzes detailed data through fieldwork to identify appropriate AWM solutions in high-potential areas.

The assessment process moves from a broader scale to a detailed scale, progressively gathering sufficiently detailed information and data to make decisions and move on to the next phase. This process seeks to minimize the cost and time required to carry out a water resources assessment, by using practical, low-cost methods to gather sufficient information to progressively concentrate on areas of higher potential for smallholder farmers to access water affordably.

[1]The authors recognize the value of community-based access to and use of water resources, but have limited the scope of this paper to individual irrigation technologies because there is more information, methods and tools available in the public domain regarding the assessment and design of community-based and public irrigation schemes.

Additional, detailed data and information is then collected on the areas with higher potential to guide further decision making.

This paper is an initial effort to document an affordable approach to information gathering for decision making. Examples have been incorporated from the application of this approach in northern Ghana in 2010. This paper is not comprehensive, but the authors hope that it will serve as the basis for further refinement, testing and elaboration through repeated field applications.

INTRODUCTION

These guidelines were developed under the AgWater Solutions project, which was carried out between 2009 and 2012 in Burkina Faso, Ethiopia, Ghana, Tanzania, Zambia, and in two states in India: Madhya Pradesh and West Bengal. The project focused on resolving water issues faced by smallholder farmers. Water is often a key factor limiting smallholders' production, yields and crop diversification. As a result, many smallholder farmers only grow staple food crops during the rainy season and, thus, produce a limited variety and quantity of crops. Further, with limited access to water, farmers are vulnerable to increasingly variable rainfall patterns.

The AgWater Solutions project examined existing AWM methods and technologies together with factors that influence their adoption and scaling up. Analyses undertaken by the project demonstrated that scaling up certain household- or community-based AWM solutions could potentially increase agricultural productivity and net profits of millions of smallholder farmers. For example, the project analyses estimated that motorized pumps could potentially be scaled up to reach 185 million rural people in sub-Saharan Africa, and highlighted that improving access to water for rural farm households could support families to:

- grow irrigated, higher-value crops in the dry season, thereby increasing household incomes;
- expand the area cropped and increase the quantity of crops produced per unit of land;
- diversify cropping patterns, thereby reducing the risk of crop and market failures; and
- apply supplemental water during periods of limited rainfall to prevent crop failure.

In addition to identifying the huge potential to improve the lives of poor female and male smallholder farmers through improved access to and utilization of AWM solutions, the project also developed country-level analyses, maps, recommendations and investment profiles to guide investments in these solutions.

This paper complements other outputs from the AgWater Solutions project by offering a tested process to support decision makers who direct, design and/or implement projects that improve smallholders' access to water for crop production. The **users** of these guidelines may include public sector agencies (e.g., government extension departments and water resources management departments); civil society organizations (e.g., farmer-based organizations and NGOs); projects; social enterprises catalyzing irrigated agricultural value chains; and donors investing in improving the lives of female and male farmers.

The **goal** of this water resources assessment methodology is to assist these decision makers in determining the availability, accessibility, affordability and sustainability of water resources, and to select the most appropriate individual technologies for water access (e.g., treadle pump, rope and washer pump, engine pump, electric pump, solar thermal, photovoltaic, battery, rainwater harvesting, siphon) and application (e.g., surface, drip, sprinkle, in-situ) that are suitable for particular biophysical and socioeconomic environments, and the available water resources (e.g., groundwater, river or reservoir). The **guiding principles** underlying this methodology are to:

1. focus on benefiting poor female and male smallholder farmers;
2. maximize available water resources for livelihood benefits;
3. ensure environmentally-sustainable water extraction; and
4. focus on affordable access to water by highlighting areas where water resources can be

accessed and applied by individuals at a relatively low investment cost, based on the premise that affordability will enable a larger number of farmers to invest in water access. Farmers' costs are incorporated into the guidelines through an emphasis on the utilization of surface water and shallow groundwater, which are accessible to poor farmers at a lower cost than deeper groundwater (which requires more expensive drilling and higher pump operating costs). In addition, the recommendations for selecting suitable individual technologies for water abstraction and application emphasize lower-cost technologies.

This paper is not a technical manual, but is intended to provide overall guidance on the information, technical expertise and resources needed for managers to direct technical specialists in assessing and designing a program. As the focus of the guidelines is on the practical application of the knowledge generated, the methods described seek to balance constraints of time and cost with the need for sufficient information required for decision making. To accomplish this, the guidelines describe the following:

- A rapid, iterative process to understand the characteristics of broad-scale areas, and current water extraction and use in small-scale agriculture. Through this process, the team progressively defines locations with greater potential for individual smallholder farmers to access groundwater and surface water resources affordably.
- A method to estimate the quantity of water resources in areas defined as 'higher potential'.
- A method for selecting individual water-lifting and irrigation application technologies that are suited to the available water resources in the specific study areas.

The processes and methods described in this paper are dynamic and opportunistic, based on continual visual reconnaissance, and data and information gathered through many discussions. Local knowledge and engagement with farmers, value chain actors and others working with farmers (e.g., extension staff) are essential. Ideas, aspirations and feedback from female and male farmers are critical, as are inputs from national and local government officials, researchers, organizations working in the area, teachers and other individuals knowledgeable about agriculture, water resources, markets, and the social constructs that influence AWM investments and practices. Throughout the process, the field team jointly interprets information, ideas, feedback and data collected, and refines ideas on the opportunities to enhance farming practices.

The process described in this paper can be used in any context where limited documented information on surface water and groundwater resources creates challenges in determining the availability and accessibility, and hence the affordability of water resources.

The process described in this paper starts with a national-level reconnaissance and progressively focuses on smaller geographic areas with greater potential for smallholder farmers to access water affordably and sustainably. For example, in Ghana, the team started at the national level and then narrowed in and targeted sub-district areas where the potential was greater. Although the method described was initiated at the national level, this approach could be used at other levels and at various points in the decision-making process. For example, government extension agencies at sub-national level could use this process within their administrative domain in order to determine specific areas with higher potential for affordable and sustainable water access, and to select appropriate water access and application technologies.

It is envisioned that program managers will use these guidelines in combination with other methods and tools, e.g., agricultural value chain analyses, as one part of a broader approach to designing interventions that benefit smallholder farmers. For example, the assessment process described here can be used together with other project outputs, such as the multi-country and country-level biophysical suitability and livelihood-based suitability maps of selected AWM technologies (for more information, visit http://awm-solutions.iwmi.org). Further, these guidelines can be incorporated into agricultural value chain analyses to determine high-value market opportunities for smallholder farmers as well as irrigation requirements for those selected high-value crops (see, for example, Webber 2007).

In 2010, the AgWater Solutions project used the approach described in this paper to assess and identify areas in northern Ghana that had accessible water resources (shallow groundwater and surface water) with a high potential for utilization by smallholder farmers to improve their livelihoods. Examples from the assessment process undertaken in Ghana are provided in these guidelines. The assessment in Ghana and preparation of this paper were financially supported by the AgWater Solutions project; however, the knowledge summarized here draws on experience gained from conducting similar assessments in Ethiopia, Zambia, Nepal, Myanmar and India.

This paper is an initial effort to document an affordable approach to information gathering for decision making. It is not comprehensive, so the authors hope that it will serve as the basis for further refinement, testing and elaboration through repeated field applications.

OVERVIEW OF THE WATER RESOURCES ASSESSMENT PROCESS

The assessment broadly encompasses the following process:

Phase 1: Broad-scale assessment to identify high-potential areas for AWM investment. This phase involves three steps:

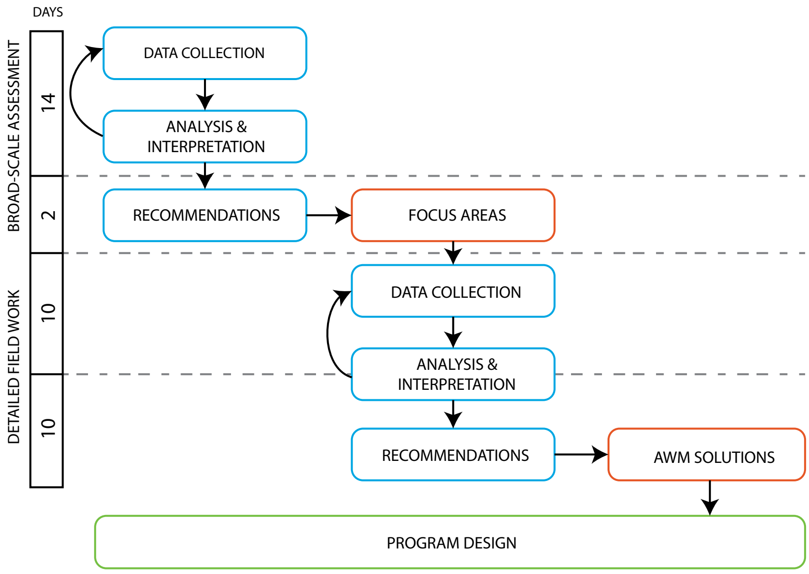
- Data collection through secondary data.
- Analysis and interpretation (ongoing).
- Making recommendations of high-potential areas.

Phase 2: Detailed field-level assessment to identify appropriate AWM solutions in high-potential areas. This phase involves three key steps:

- Data collection through fieldwork.
- Analysis and interpretation (ongoing).
- Develop recommendations for intervention design, including technologies best suited for use by smallholders in accordance with site-specific conditions.

This phased process seeks to minimize the cost and time required to carry out a water resources assessment, by using practical, low-cost methods to gather sufficient information to progressively concentrate on areas of higher potential for smallholder farmers to access water affordably. Additional, detailed data and information is then collected on the areas of higher potential to guide further decision making. The process moves from a broader scale to a detailed scale, progressively gathering sufficiently detailed information and data to make decisions and move on to the next phase. Thus, it eliminates the need for exhaustive data collection in geographical areas with minimal potential for affordable and/or sustainable access to water resources. Figure 1 illustrates the recommended phases for the assessment with an approximate time period and outputs for each phase. The following sections provide more details on each step in the process.

FIGURE 1. Diagram of the rapid water assessment process, showing approximate time period and outputs for each phase. It must be noted that the assessment process forms one input into program design, which draws on many other sources of information.



Phase 1: Broad-scale data collection and interpretation

Credit: Stuart Taylor.

PHASE 1: BROAD-SCALE ASSESSMENT TO IDENTIFY HIGH-POTENTIAL AREAS FOR AWM INVESTMENT

Phase 1 of the water resources assessment serves as an initial screening to select areas of higher potential for small-scale irrigated agricultural development. The aim of this first phase is to understand the broad-scale context (i.e., national scale) in order to identify and hone in on geographic areas where the following four key criteria coincide (as depicted in Figure 2):

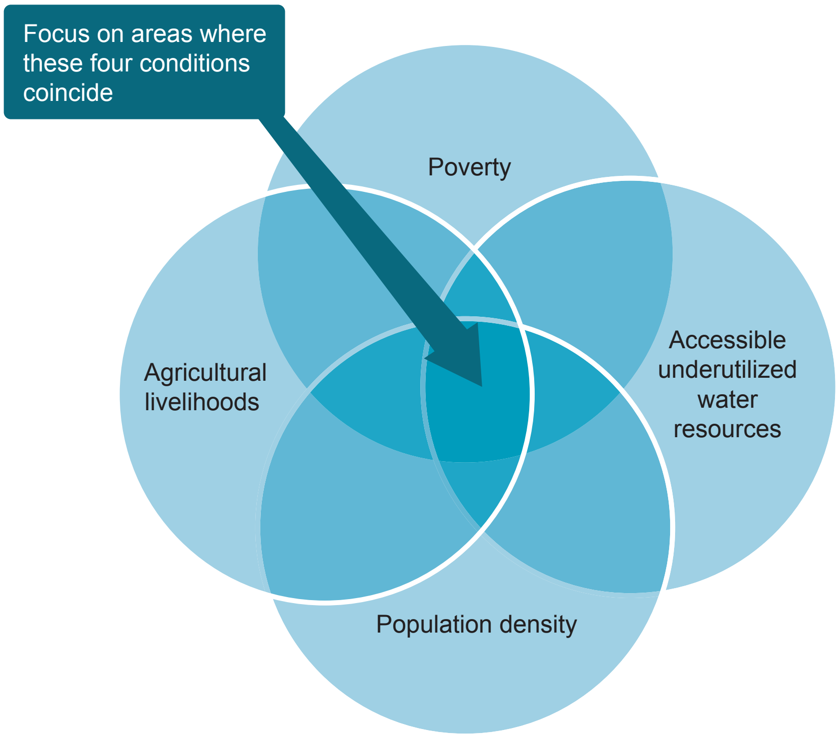
1. Physical availability and accessibility of underutilized surface water and/or shallow groundwater resources. Here, shallow groundwater is accessible from a maximum depth of 18 meters (m) from the land surface to the water table. If water is being manually pumped for irrigation purposes on larger than subsistence size plots, a 12-m depth is the practical limit for a hand or rope and washer pump.

2. Significant population density, which helps to ensure that an intervention benefits a large number of people, reduces costs, and may support self-replication and scaling through farmer-to-farmer sharing and through private sector replication. Successful, sustained interventions for smallholders generally require population densities of 100 or more persons per square kilometer.

3. High rates of poverty to help ensure that an intervention improves the lives of the poor. High rates of poverty are indicated by areas with infant mortality rates greater than 75 per 1,000 live births, and where 30% or more of the children aged between 0 and 5 are underweight.

4. Agriculture-based livelihood patterns, which ensure that an intervention would meet the needs and constraints of the population based on their occupation.

FIGURE 2. Areas where AWM interventions would be an ideal entry point.



Credit: Elizabeth Weight.

When conducting this initial broad-scale screening, important factors that need to be considered include land and water rights and entitlements, which influence farmers' decision-making, investments and perceptions of risk. These factors frequently shape social and economic dynamics and patterns of poverty. For example, in India, farmers' right to access water has supported the emergence of markets for groundwater, which enables poor smallholder farmers to purchase water for irrigation. In some locations, however, where water is limited, wealthier farmers may be able to drill deeper wells, purchase more powerful pumps to extract water, and/or purchase or access land in order to access water resources.

This initial screening phase gathers information available at a broad-scale (i.e., national-level) relating to formal and informal rights and entitlements to access and use land and water resources. Given that the application of national laws and policies at local levels may be influenced by local traditions and cultures, later phases of the assessment process provide an opportunity for the project team to understand farmers' perceptions of their rights and entitlements. In this, it is important to hold discussions with female farmers in order to understand the gendered aspects of these rights and entitlements. This knowledge is useful to design a program that pragmatically addresses the constraints faced by both female and male farmers in accessing and using land and water resources for irrigated crop production.

Data Collection in Phase 1

Phase 1 uses desk research to collate previous studies, data and information related to the four key criteria: water resources, population, poverty and livelihoods.

Table 1 lists important data that need to be collected in relation to the four criteria. The table also provides typical sources of this information. In addition to the sources listed, it is useful to interview government officials, university staff and development organizations to gather information on areas where there are accessible and underutilized water resources, high population densities, high rates of poverty, and agriculture-based livelihood patterns.

As the objective of phase 1 is to narrow the geographic focus of the assessment to areas with the highest potential for AWM interventions in order to achieve the biggest potential impact, not all the information listed in Table 1 is required for phase 1. However, all data listed will eventually be required to complete the assessment. Since this is the primary data collection phase, it is usually expedient to obtain all information that will be used throughout the assessment as early as possible in the process. Furthermore, the collection of some data often leads to finding additional details and identifying information sources that could be helpful to the overall process.

TABLE 1. Collection of data and information, and sources for obtaining this information.

Data and information	Typical source of information
Water, climate, soils, crops	
• Surface water resources (perennial streams and lakes) • Groundwater resources (depth to water table, seasonal fluctuation in water table depth, saturated thickness or depth to barrier, aquifer material or characteristics, overburden conditions) • Floodplains, wetlands/dambos, etc. • Climate (monthly precipitation and frequency distribution, maximum and minimum temperatures, monthly evapotranspiration) • Data on soils (map and characteristics) • Crop data (types, varieties, growing seasons, water requirements, yields)** • Data on other agricultural input use	Much of this information can be gathered from government offices (e.g., departments of agriculture, natural resources, environment, land registration/land use, national agricultural research systems [NARS], Geodetic/Survey/Map Bureau, etc.); universities; international sources and organizations (e.g., FAO, CGIAR, geographic information system [GIS] data portals [ESRI, Center for International Earth Science Information Network (CIESIN), GRID, etc.]; topographic maps; Digital Elevation Model [DEM] for groundwater mapping [see Appendix 1]; water and sanitation program information; FAO ClimWat database and CropWat decision support tool; FAO second level soils map; etc.). See section*, Sources of Water Resource Data and Information,* for more details.
Population	
• Population density and distribution data	Census data from government sources at the scale of the smallest available administrative unit (e.g., village, ward, district, county, *kebele*, etc.). Need corresponding map of administrative units.
Poverty	
• Poverty data and distribution	Government sources, United Nations Development Programme (UNDP), Demographic and Health Surveys (DHS), poverty proxies from census data.

(Continued)

TABLE 1. Collection of data and information, and sources for obtaining this information. (Continued)

Data and information	Typical source of information
Livelihoods • Livelihood patterns • Agroecological zones • Patterns of land and water ownership; land tenure, land and water access and use rights and usage patterns, and whether/how these differ for women and men and different ethnic groups/castes • Tribal, private, public and protected land areas • Policies and laws related to and affecting smallholder agricultural production and marketing	This information can often be gathered from interviews held with government offices (e.g., Department of Agriculture, NARS, Census Bureau); universities and development practitioners based on their knowledge; local experts (e.g., extension agents, agricultural officers, etc.); international organizations (e.g., FAO, CGIAR, development banks, United Nations Environment Programme [UNEP], etc.); livelihood mapping by FAO; etc.

Credit: Andrew Keller.
Notes: ** Information is collected on both rainfed and irrigated crop production patterns. In areas with an existing culture of irrigation, support can be provided to improve existing irrigation practices (e.g., introducing pumps where farmers use labor-intensive bucket irrigation). In areas where a few farmers have added irrigated crops to their rainfed crop portfolio, there may be potential to scale up irrigated agricultural production because these areas have accessible water resources and farmers who do not irrigate may be aware of the advantages and disadvantages of irrigation. In areas where rainfed crop production is practiced, the introduction of irrigation can make a dramatic difference to the lives of farmers, but more time and support will be required to adjust to the culture of irrigated agricultural production.

Sources of Water Resource Data and Information

Government offices generally have some data and information on surface water and groundwater resources. However, it is often challenging to find reliable, systematized data and maps on surface water and groundwater resources, aquifers and geo-morphological data. In many cases, there is a lack of long-term, quality hydrological data, in particular, at smaller scales. For example, in Ghana, the Water Resources Commission had information and maps of wells and well yields in the country, but did not have complete maps and data on the depth of groundwater. For this reason, it is useful to create maps of available water-related data in order to assess water resources.

The essential information on surface water resources can be obtained by identifying the location of perennial streams and lakes. This information serves two purposes: 1) identifies surface water resources that can be directly tapped by smallholders for irrigation of crops in adjacent fields during the dry season. The dry season is usually the period when the value of irrigated crops is at its highest, and hence employment and market opportunities are often greater in the dry season. Also, the dry season is the period when non-perennial water sources are more likely to dry up and/or become unreliable; and 2) perennial surface water sources are generally coincidental with the water table and, thus, key to mapping the depth to groundwater. Topographic maps at scales of 1:50,000 or smaller are good information sources for the location of perennial surface water sources. Most of the map work in phase 1 will be at a broader ~1:250,000 scale. However, at such a scale, it is difficult to identify the start of perennial streams and extent of areas with a high water table. Thus, at least a scattering of 1:50,000 or smaller scale topographic maps is needed to locate the start of perennial streams and shallow water tables, in the absence of sufficient depth to the water table shown in data from other sources for mapping groundwater. Perennial streams are often denoted on topographic maps by continuous stream lines rather than the dot-dash pattern denoting intermittent streams. Another common mapping convention is to label perennial streams with their name all in capital letters.

The key groundwater resource information needed for assessment of smallholder AWM opportunities is the depth to the water table and the relative water yield. Here, low-yielding wells are those with sustained flow rates which are insufficient to irrigate a 0.1-hectare (ha) area during periods of peak demand (e.g., less than approximately 0.1 liters per second [lps]). High-yielding wells have at least ten times the sustainable flow (e.g., greater than 1.0 lps and sufficient to irrigate at least a 1.0-ha area). Other important parameters are: seasonal fluctuation in depth to the water table, saturated thickness or depth to barrier, aquifer material or characteristics, and overburden conditions. Seasonal fluctuation in depth to the water table provides an indication of the reliability and potential of shallow groundwater for irrigation of small plots. Saturated thickness or depth to barrier and aquifer material or characteristics (transmissivity, specific storage, particle size and grading, etc.) provide indications of well yield and drawdown. Information on the surface geology or nature of the overburden, e.g., soil type, presence of cobble or rock, and existence and thickness of hard layers (e.g., regolith), provides an indication of the potential for well drilling or digging.

These data are often unavailable, especially for shallow groundwater accessible to smallholders, or the data are limited to studies of inadequate geographic scope for a regional assessment. Information related to drinking water sources and programs (e.g., from water, sanitation and health programs, municipal and rural domestic water supply systems, etc.) can provide helpful clues, and some relevant groundwater information (e.g., overburden and aquifer characteristics) can be inferred from soils and surface geology maps. Municipal wells are generally much deeper than the shallow groundwater that smallholders can easily access. However, data on municipal wells provide useful groundwater information, e.g., overburden and aquifer characteristics, water level trends, etc. In Ethiopia, for example, much of the available groundwater information comes from data on municipal wells. Good estimates of the depth to shallow groundwater can be made by GIS analysis using a DEM, location of perennial water bodies, and climate data as described in Appendix 1. Mapping of the resulting depth to groundwater can then be used to narrow the geographic focus of the assessment to areas with potential and additional groundwater information collected during phase 2, field-level data collection.

Ideally, this information is mapped in a GIS to visualize and analyze the overlay of these features. Information sources include maps, reports and studies, and databases. Since the objective is to find geographic areas where the four criteria overlap, most of the data must exist in a map or in GIS form or be tabular with point location attributes so that they can be mapped within a GIS.

Throughout the process, the team must continually review the data collected to date, with a view to identifying high-potential areas for further study and focusing on the four key criteria. This review will also highlight data gaps.

Outputs of Phase 1

The key output of phase 1 is a written description of the selected areas to focus on in phase 2, together with an explanation of why the areas were selected for detailed field data collection.

Other suggested outputs include the following:

1. A national map highlighting areas to focus on in phase 2, together with data/information on the four criteria (poverty, population, water resources, and agriculture-based livelihoods) for each area.

2. A brief description of areas deemed promising but not selected for detailed data collection, together with reasons why these areas were not selected (to be kept as a record if needed at a later stage).

Box 1 provides an example of the application of phase 1 of the water resources assessment methodology in Ghana.

Box 1. Phase 1 data collection – an example from Ghana.

The AgWater Solutions project combined secondary data and information with participatory GIS mapping techniques in Ghana, Burkina Faso, Ethiopia, Tanzania, Zambia and two states in India (Madhya Pradesh and West Bengal). The project produced maps of suitability domains of specific AWM solutions, which were identified as having higher potential to improve the lives of smallholder farmers. In other countries where this initial mapping and analysis has not yet been performed, it is useful to create broad-scale maps overlaying data/information on the four key criteria, in order to highlight areas where these conditions are prevalent. The areas where the conditions co-exist will have the highest potential for application of productive water technologies to enhance small-scale crop production.

The water resources assessment team gathered data and information from a variety of sources in Ghana, including the Water Resources Commission (WRC), Ghana Irrigation Development Authority (GIDA), Ministry of Food and Agriculture (MoFA), University of Legon, and organizations working in agricultural development and water research (including the International Water Management Institute [IWMI] and AgWater Solutions project team members).

The team reviewed and discussed the information as it was gathered, continually refining an overall picture of the country in relation to poverty (Appendix 2, Figure A2.1, Figure A2.2), population density (Appendix 2, Figure A2.3), livelihoods (Appendix 2, Figure A2.4), and water resources. Regions and districts with relatively high population densities were identified as the following: Greater Accra, Central Region, Upper East Region, the city of Tamale in the Northern Region, and the city of Kumasi in the Ashanti region (Appendix 2, Figure A2.5).

Examining these areas, the team decided not to focus on the Central Region because poverty in the Upper East Region is much higher: approximately 89% of the population in the Upper East Region is poor and approximately 82% is extremely poor; in the Central Region, 48% of the population is poor and 32% is extremely poor (Canagarajah and Pörtner 2003).

The team also found that poverty rates were relatively low (38%) in the Volta Region. However, in discussions held with government officials and researchers, the assessment team learned that numerous farmers in the Keta District of the Volta Region use groundwater to irrigate high-value vegetable crops to sell in the Accra market. So, the team decided to include this district in the assessment process to learn more about irrigated agriculture in the area.

The team produced an initial map (Appendix 2, Figure A2.5) showing the three distinct geographic zones of the areas selected through the initial scoping exercise: the Upper East Region (including Tamale in the Northern Region), the Kumasi area of the Ashanti Region and the Keta area of the Volta Region.

(Continued)

Box 1. Phase 1 data collection – an example from Ghana. (Continued)

The team then gathered additional information on these regions related to water resources, soils and agriculture in order to select one area for the detailed field-level data collection (see Appendix 3 for examples from Ghana). The comparative information regarding the three areas is shown below:

1. The Upper East Region, situated in the Volta River Basin, is characterized by savannah/woodlands with annual rainfall of 1,000 mm, good soils and good access to water, but farmers lack productive water access and application technologies. As a result, farmers primarily grow low-value rainfed staple crops and are dependent on rainfall. The region is located in the Sudan Savannah agroecological belt, with semi-arid climatic conditions, a dry terrain and Savannah grassland, with a strongly tropical and seasonal climate (annual rainfall varies between 700-1,200 mm, with more than 60% of rainfall occurring between July and September). In the dry season, especially in February, potential evapotranspiration rates are very high (about 10 mm/day) due to high temperatures, low humidity and strong winds. For this reason, agricultural water requirements are high (over 8 mm/day) during the dry season.
2. The Kumasi area of the Ashanti Region is semi-equatorial forest zone with a high population density, sandy soils and easily accessible surface water and groundwater all year. Farmers in the area have easy access to large input and output markets in Kumasi, significant peri-urban farming and lower poverty rates than farmers in the Upper East Region of Ghana. Constraints to production in the Kumasi area include labor for irrigation, crop diseases, potential land tenure issues, seed shortages and high cost of inputs.
3. The Keta area in the Volta Region is low, flat plains/Volta Delta area of coastal grassland and mangrove swamps with sandy soils. This area has an excellent climate for vegetable production, very shallow water levels and easy access to markets in Accra. The area has an existing irrigated agricultural economy using a variety of water access and application technologies (e.g., closely-spaced wells used for bucket irrigation, electric pump and hose/impact sprinklers). As a result, farmers' production and returns are good, agricultural diversity is high and poverty rates are much lower than in the Upper East Region. Overdevelopment of the freshwater resource could result in saltwater intrusion into the irrigation water supply.

Comparing the above three locations, the team concluded that opportunities existed to improve small-scale agricultural production in all three areas. However, given the high poverty rates, as well as the presence of good soils and minimal utilization of the available water resources, the team determined that improving access to water resources in the Upper East Region (and, more broadly, northern Ghana) had greater potential to significantly benefit the relatively large population. This is depicted in Figure 3, which compares the three areas in Ghana in relation to their 'unrealized' potential to increase small-farm incomes.

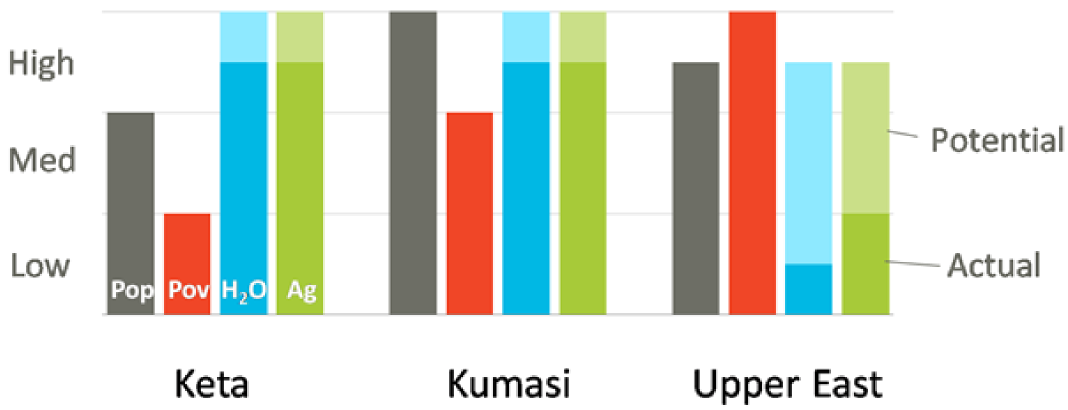
In much of northern Ghana, 30 to 40% of children (aged 0 to 5) are hungry. In portions of the Upper East Region, there are 10 to 25 underweight children (aged 0 to 5) per square kilometer and an infant mortality rate of 75 to 100 per 1,000 live births. The overall rural population density in the Upper East Region is 100 to 250 persons per square kilometer.

(Continued)

Box 1. Phase 1 data collection – an example from Ghana. (Continued)

The team then assembled a GIS database of northern Ghana and began mapping the stream network and depth to groundwater, and collecting more detailed information in preparation for phase 2, detailed field-level data collection in northern Ghana.

FIGURE 3. Rough comparison of three promising areas in Ghana using the four key criteria of population density, poverty, water resources and agricultural livelihoods (productivity and revenue). Note that, while there was high potential for water access and agricultural productivity/revenue in all three areas, the team concluded that the Upper East Region had the most *unrealized* potential, a function of its higher level of poverty and underutilized water resources.



Phase 2: Detailed field-level assessment.

Credit: Stuart Taylor.

PHASE 2: DETAILED FIELD-LEVEL ASSESSMENT TO IDENTIFY APPROPRIATE AWM SOLUTIONS IN HIGH-POTENTIAL AREAS

In the second phase of the water resources assessment, the team visits geographic areas identified in the first phase to achieve the following two key objectives:

1. **Verify the four key criteria** (surface water and/or groundwater resources, high population density, high rates of poverty and livelihoods based on agriculture) and collect fine-scale data and information, which are incorporated into the GIS to add detail and improve resolution.

   The team should visit potentially accessible water sources, which were identified during the first phase of the broad-scale assessment, to confirm that these are appropriate for use by smallholder farmers (e.g., areas of shallow groundwater availability, accessible surface water and/or dams). At this time, the team also seeks to understand farmers' perceptions of their formal and informal rights and entitlements to access and use land and water resources. This should include discussions with female farmers to understand their perceptions of the gender aspects of their rights and entitlements. Through these discussions, the team seeks to understand whether and how utilization by individuals or groups of farmers could potentially impact others.

2. **Collect additional data for program design**: For those areas where field-level visual reconnaissance confirms the presence of the four key criteria and confirms that groundwater and/or surface water resources are accessible for utilization by smallholder farmers, the team collects additional field-level data and information in order to design appropriate and effective AWM interventions. Appendix 4 provides an overview of the type of information to be collected, reasons for collecting the information and typical sources for collecting the information.

The section below provides recommendations to consider throughout the detailed field-level assessment.

Recommendation: Build on Local Knowledge

Given the general lack of high-resolution data for many parameters, local, site-specific knowledge is a vital source of information on water resources and livelihoods. During this phase of the assessment process, which is an informal, qualitative, rapid validation of the population, poverty and agricultural livelihood conditions, it is critically important to talk with female and male farmers to understand their perspectives, livelihoods, water use and challenges.

For example, if the assessment team sees a group of women walking with buckets of water, they would talk with the women to learn about their water source, number of households using the water source, how women and men use water, distances from their houses to the water source, number of months that water is available from that source, problems with water access, other sources of water, and rights and entitlements to access and use the water by women, men and different ethnic groups, etc. (see Box 2).

In addition, engaging local field technicians and/or farmers, who speak the local language and are familiar with the area, is essential to find and document water sources that would otherwise be missed by an outside assessment team. Field technicians and/or farmers can be engaged and trained in data collection during the rapid field assessment, and then continue to collect the data needed to confirm the rapid analysis and detail and enhance program design.

Recommendation: Emphasize Rapid Analysis and Adjustment

During the initial field study, it is important to analyze data as quickly as possible, so that the team can promptly make necessary adjustments to the assessment while in the field. Field data collected during the day should be analyzed and mapped during the evening, and discussed and interpreted by the team before proceeding into the field the next day.

For example, well drawdown data collected during the day should be processed in the evening to determine groundwater yield (see section, *Estimate Potential Yield of Well Water*). If this analysis determines that groundwater yield is too low to irrigate an area of sufficient size to be economically viable to the farmer then the team can opt to change the field trip itinerary to visit areas that may have greater potential for irrigated agricultural production (e.g., different soils and geology, shallower groundwater).

Recommendation: Use GIS Tools

The water resources assessment and selection of suitable AWM solutions for smallholder farmers is essentially a mapping exercise that is well suited to GIS analysis. The overall analytical process is to describe and map the dominant water resource typologies of the study area, and then assign suitable combinations of water-lifting (pumps) technologies with irrigation application methods as described in Appendix 5.

Box 2. Building on local knowledge – an example from Ghana.

Much of the information on local water resources is obtained from local informants, formally and casually. As an example of the latter, when the northern Ghana water resources team was traveling on a road about 7 km west of Tamale (towards the White Volta), they saw a group of women fetching water from a shallow dug well (Figure 4). The team stopped to talk to the women and also took well measurements, which showed that the water in the well was 1.0 m below the ground surface with an electrical conductivity of 65 μS/cm (very low salinity) and the depth of the well was 3.1 m.

The women said that the water level was high because of recent rainfall, which also explained the low salinity. The women estimated that the well would be dry in two months (by the end of January or early February) and they would have to get water from a reservoir which was "nearby" (about a kilometer away). The women said that there were other wells such as this one in the vicinity and many along the road, but they would all be "finished" (dry) in a couple of months. The wells had been dug down to the level of the hard laterite layer, because it was too hard to dig deeper and there was little water below the hard layer. The women were not aware of anybody irrigating from wells.

From this encounter, the team learned that there was very limited potential for shallow groundwater development in this area. The permeability of the soils was very low; there did not appear to be any significant water-bearing soil layers within 30 m or so of the ground surface; and the laterite layer was difficult to dig through. Furthermore, the water table appears to drop by about 1 m per month following cessation of the rainy season.

FIGURE 4. Women fetching water from a dug well near Tamale in northern Ghana.

Photo: Elizabeth Weight.

Data Collection in Phase 2

Estimate Groundwater Resources

Because of its generally ubiquitous distribution and relative accessibility, shallow groundwater is the most common and important source of water for smallholder farmers. However, groundwater is usually also the water resource with the least amount of available information. Consequently, at the reconnaissance level of the assessment, the team will need to use inference models and analyses to extrapolate and map groundwater characteristics and typologies. The key parameters for defining groundwater typologies are the depth to the groundwater table and the water yield potential of wells penetrating the water table. The following sections describe these techniques in more detail.

Map Groundwater Depth

The most essential analysis of the water resource assessment is mapping the depth of the groundwater (see Appendix 1 for details). Not only is this important for developing groundwater typologies, it also supports the understanding of surface water typologies. For example, a mapped groundwater table within half a meter of the land surface typically indicates flat, poorly-drained, seasonally-saturated areas, inland valleys and valley bottoms. By overlaying these high water table areas with soils maps in the GIS, the potential for AWM can be assessed. If the soils are indicative of chronically flooded conditions then irrigated agriculture will likely be limited to rice production. If soils are sandy, simple wells with suction-only treadle pumps might be well suited for dry-season irrigated agriculture. If the soils in areas with a high water table are heavy clays, wells are unlikely to be successful, but motorized pumps delivering water from the associated perennial river to the fertile bottomlands could be very successful.

Estimate Potential Yield of Well Water

Once the depth of groundwater is mapped, the potential water yields of wells must be estimated so that the appropriate pump and irrigation technologies for the resource can be identified. The water yield of a well is the flow rate that can be continuously pumped without drawing the water level in the well below the pump intake. For the assessment, relative water yield estimates are sufficient, e.g., low-yielding (less than ~0.1 lps), high-yielding (greater than ~1.0 lps) and medium-yielding (in between low and high). Well water yields can be roughly inferred using remote-sensing data (e.g., slopes and topographic analysis, surface geology, and soil maps and data), but unless data is available on actual wells in the immediate vicinity of the area of interest, remote methods will only produce rough approximations. To improve estimates of groundwater yield, the team should perform drawdown tests on a few wells in areas of interest during phase 2 of the fieldwork.

A well drawdown test consists of pumping a well at a measured flow rate and measuring the drop in the water surface elevation during the pumping. Once the water level stops dropping or all the water has been pumped out of the well, pumping is stopped and the rise in the water table is measured as the well recovers. By measuring the diameter of the well and the drop or rise in water surface elevation, the change in the amount of water stored in the well can be calculated. Dividing this change in storage by the time interval between measurements gives the rate of change in storage. Subtracting this rate of change in storage from the pump flow rate gives the rate of groundwater recharge. During recovery, the rate of change in storage equals the rate of groundwater recharge. From the rate of groundwater recharge and dimensions of the well, the daily water yield is determined. If the well has significant storage, as in the case of dug wells with diameters of 1 m or more, the pump rate can be much higher than the recharge rate provided that the well recovers between pumping intervals. When wells have limited storage, for example, small (e.g., 5 cm) diameter manually drilled wells, the pump flow rate is limited to the groundwater recharge rate. Drawdown tests vary in the length of time, but typically take less than half a day for the level of accuracy needed for a rapid assessment. Tests of dug wells with diameters of 1 to 1.5 m take approximately three hours to conduct, if using a low-flow pump (e.g., treadle pump at less than 1 lps) and it is a low-yielding well. If it is a high-yielding well, there will be no measurable drawdown with a 1-lps pump and it can quickly (after less than an hour of testing) be determined that well water yield is greater than or equal to the pump flow rate.

Calculate Water Requirements

Knowing crop irrigation water requirements is critical to conducting water balances, determining appropriate irrigation technologies, designing irrigation systems, and assessing the technical feasibility and economic suitability of irrigated agriculture to benefit smallholders. Crop irrigation water requirements are calculated as the difference between the consumptive water use (evapotranspiration) of crops and the effective precipitation. Generally, local climate data are used in mathematical functions to estimate the evapotranspiration from a well-water reference crop. Crop coefficients specific to the crop of interest, and adjusted for the appropriate planting, development and harvest dates, are then applied to relate the reference crop water use to the crop of interest (Allen et al. 1998 or similar studies). At the reconnaissance level of the assessment, peak daily water requirements and monthly estimates of evapotranspiration are generally sufficient. Analytical tools for calculating evapotranspiration and crop irrigation requirements are available (e.g., FAO's ClimWat database and CropWat decision support tool) as are global GIS datasets of gridded climate parameters and products (e.g., IWMI's World Water and Climate Atlas).

Analyze Water Balance

In areas where the assessment team confirms the presence of the four key criteria and unrealized potential for development of water resources and agricultural productivity, it is important to analyze the limitations of sustainable water extraction for irrigated agricultural production. A water balance approach estimates these limitations by integrating data related to precipitation, water storage, recharge rates, and interactions of shallow groundwater and surface water. This is critical to the resource protection aspect of the assessment, whether surface water or groundwater.

The water balance is an accounting framework that balances water inflows (e.g., precipitation) with outflows (e.g., evapotranspiration) over a period of time, usually a year. If outflows exceed inflows, the difference comes from storage (e.g., soil moisture and groundwater). Under natural conditions, outflows are equal to or less than inflows and the balance of inflows become runoff. Under conditions of irrigated agriculture, seasonal evapotranspiration by crops usually exceeds the effective precipitation, which results in a depletion of water from storage. An unsustainable situation exists if the depletion of water from storage continuously exceeds the annual recharge rate. Seasonal problems can also arise if the water withdrawal from storage results in a lowering of water levels beyond physical reach or causes conflicts among water users, depending on their location within a watershed.

The water balance requires the following data:

- Measurements from a sample of wells of surface to water depth, depth of well, diameter of the well and water-lifting capacity of the specific irrigation technology currently being utilized (e.g., number of liters in a bucket).
- Tests of water drawdown and recharge rates in selected wells.
- Water salinity measurements.
- Measurements of farmer's plot size.
- Time required by the farmer to water their plot of land.
- Global Positioning System (GPS) locations of wells, different types of irrigation technologies, rivers and other key parameters.
- Potential maximum density of shallow wells without interference.
- Understanding of local hydrological characteristics.

Develop Recommendations for Intervention Design

This section outlines a few key decision-making parameters to assist in using the data and information gathered from the field assessment to design programs that benefit poor female and male smallholder farmers.

Through the process of collecting information and data, the assessment team continually analyzes potential opportunities for smallholder farmers to improve agricultural production. Typically, the most transformative opportunities connect crop opportunities and water access opportunities:

1. Opportunities to leverage the specific advantages of small-scale agricultural crop production, e.g., by selecting crops that require a higher level of care and are, therefore, challenging to grow on a large-scale, such as irrigated vegetables.
2. Opportunities to improve smallholder farmers' access to and utilization of available water resources, particularly where the analysis has identified areas with significant unrealized potential.

For each opportunity identified, it is useful to develop scenarios to evaluate anticipated positive or negative impacts on income, water resources, gender and other social dynamics, market changes, etc., based on scaling up the intervention to the potential geographic extent identified in the GIS maps. Developing scenarios can help to ensure that the program design addresses and monitors potentially negative impacts.

Following the initial rapid assessment and scenario development described above, the assessment team should collect additional data within identified high potential areas to confirm the selection of these areas and provide the further details needed for scenario development and program design. For example, following the rapid assessment, water resources should be monitored at various times throughout the year to observe seasonal fluctuations (e.g., depth to water in wells) to confirm water resource availability for utilization by farmers. In addition, detailed data can be gathered on various parameters of interest (e.g., crops, livelihood patterns, pests and diseases, female and male divisions of labor, and cropping patterns) to support program design. Local field technicians and/or farmers who supported the initial field assessment can be trained to collect this additional data. For this, field technicians/farmers need to be trained in the use of, and provided with, GPS as a means of measuring depth to water in wells, and formal survey forms to ensure the organized collection of the necessary data.

Linking Technologies to Water Source Typologies

This step includes determination of the most appropriate water-lifting and application technologies for smallholder farmers given the site-specific conditions. It is important to take a 'systems approach' when dealing with small-plot irrigation rather than treating individual technologies as unrelated sub-systems. An irrigation system includes:

- a water source/supply;
- water lifting/pressurizing (pump);
- a way to get the water from the source to the plot (conveyance); and
- a means of applying water to the soil, where crop roots can extract it (irrigation application method).

This section ranks the suitability of various water-lifting technologies according to the typology of the water source and the irrigation application method. Table 2 describes nine water source typologies: four from groundwater, three from rivers and two from reservoirs. Appendix 5 provides further details on these typologies.

TABLE 2. Water source typologies for smallholder water access and irrigation suitability ranking.

Typology	Source	Description
1	Groundwater	Low-yielding[a], very shallow[c] well
2	Groundwater	High-yielding[b], very shallow[c] well
3	Groundwater	Low-yielding[a], 'deeper'[d] (beyond suction depth) well
4	Groundwater	High-yielding[b], 'deeper'[d] (beyond suction depth) well
5	River	Perennial rivers with defined river banks
6	River	Seasonal/ephemeral rivers
7	River	Flat, poorly-drained, seasonally-saturated areas/inland valleys/ valley bottoms
8	Reservoir	Reservoirs with functioning outlets
9	Reservoir	Reservoirs without functioning outlets

Credit: Andrew Keller.
Notes:[a] Low-yielding - less than ~0.1 lps sustainable flow during the dry season.
[b] High-yielding - greater than ~1.0 lps sustainable flow during the dry season.
[c] Very shallow - water level within suction lift limit (~8.0 m) at the end of the dry season.
[d] Beyond suction depth - water level beyond suction lift limit at the end of the dry season.

Table 3 provides suitability scores for various groups of pump types and irrigation application methods for the nine water source typologies listed in Table 2. Irrigation application methods included in Table 3 are conventional surface irrigation, piped furrow/piped basin irrigation, drip irrigation, sprinkler irrigation, hose and hand-carried buckets. Only irrigation application methods that are suitable for pairing with a particular pump type and under a particular water source typology are scored. The suitability scores range from '3' for high suitability to '1' for low suitability and ‘0’ for unsuitable or not applicable. For example, suction-only treadle pumps (SOTP) are highly suitable for conventional surface and piped furrow/basin irrigation under high-yielding, very shallow groundwater conditions. However, when a SOTP is used to pump water from a river, a long suction pipe is usually required to reach the water from the river up the riverbank, and to the high point in the field. Suction pipes are expensive (because each pipe has to be round and rigid enough not to collapse under suction, e.g., it cannot be cheap lay-flat tubing) and difficult to keep from leaking (small holes in the discharge pipe are not a problem, but a pinhole can make a suction line useless). Thus, SOTPs are given a suitability score of zero (unsuitable) for perennial and seasonal rivers. However, the floodplains of large perennial rivers (typology 7, seasonally-saturated areas) can be suitable for SOTPs. The suitability scoring is based on experience and best judgment, and is somewhat subjective. Thus, the scores in Table 3 should not be taken as being universally applicable. The most important aspect of Table 3 is not the scores listed, but the methodology used for determining suitable irrigation systems for smallholder farmers under various water supply situations.

TABLE 3. Suitability of smallholder pump types according to water source typology and irrigation method.*

	Typology (see Table 2)	Application method	Manual pumping			Motorized pumping			Solar-powered pumping		Other
			Suction-only treadle pump	Pressure treadle pump	Rope and washer pump	Small engine pump (petrol or diesel)	Electric pump[a]	Shared borehole[b] with electric pump[a]	Solar thermal pump[c]	Photovoltaic and/or battery pump	Siphon
GROUNDWATER	1 Low-yielding, very shallow well	Surface	1								
		Bucket			1						
		Hose		2			1				
		Piped	2		1				1	1	
		Sprinkler		1			1				
		Drip		3	2		1		3	3	
	2 High-yielding, very shallow well	Surface	3			2	2	2			
		Bucket			1						
		Hose		3							
		Piped	3		1	2	2	2	2	2	
		Sprinkler		1		2	2	2			
		Drip		3	1	2	3	2	3	3	
	3 Low-yielding, deeper well	Surface									
		Bucket			2						
		Hose									
		Piped			1		1[d]			1	
		Sprinkler					1[d]				
		Drip			3		2[d]			3	
	4 High-yielding, deeper well	Surface					2[d]	2[d]			
		Bucket			2						
		Hose									
		Piped			2		2[d]	3[d]		2	
		Sprinkler					2[d]	3[d]			
		Drip			3		3[d]	3[d]		3	

(Continued)

TABLE 3. Suitability of smallholder pump types according to water source typology and irrigation method.* (Continued)

			Manual pumping			Motorized pumping			Solar-powered pumping		Other
	Typology (see Table 2)	Application method	Suction-only treadle pump	Pressure treadle pump	Rope and washer pump	Small engine pump (petrol or diesel)	Electric pump[a]	Shared borehole[b] with electric pump[a]	Solar thermal pump[c]	Photovoltaic and/or battery pump	Siphon
RIVER	5 Perennial river	Surface				3	[e]	[e]			
		Bucket									
		Hose		1							
		Piped				3					
		Sprinkler		1		3					
		Drip		1		2				1	
	6 Seasonal river	Surface				3	[e]	[e]			
		Bucket									
		Hose		1							
		Piped				3					
		Sprinkler		1		3					
		Drip		1		2				1	
	7 Seasonally-saturated area	Surface	2			2	[e]	[e]			
		Bucket									
		Hose		1							
		Piped	2			3					
		Sprinkler		1		2					
		Drip		1		1				1	

(Continued)

TABLE 3. Suitability of smallholder pump types according to water source typology and irrigation method.* (Continued)

	Typology (see Table 2)	Application method	Manual pumping			Motorized pumping			Solar-powered pumping		Other
			Suction-only treadle pump	Pressure treadle pump	Rope and washer pump	Small engine pump (petrol or diesel)	Electric pump[a]	Shared borehole[b] with electric pump[a]	Solar thermal pump[c]	Photovoltaic and/or battery pump	Siphon
RESERVOIR	8 Reservoir with outlet	Surface[f]	3			2	[e]	[e]			
		Bucket									
		Hose[f]		3							
		Piped	3			2			1	1	
		Sprinkler		1		2					
		Drip		3		1			2	2	
	9 Reservoir without outlet	Surface[g]	2			1	[e]	[e]			3
		Bucket									
		Hose[g]		3							
		Piped	2			1			1	1	2
		Sprinkler		1		1					
		Drip		3		1			2	2	

3	High suitability
2	Low suitability
1	Unsuitable or not applicable

Credits: Design: Stuart Taylor; *Content:* Elizabeth Weight and Andrew Keller.

Notes: [a] Electricity supplied from electric grid.
[b] Machine-drilled shared borehole.
[c] Pump with water storage 1 to 2 m above ground surface.
[d] Submersible electric pump.
[e] Electric pumps powered by the electric grid are generally unsuitable for low-cost surface water diversions, where seasonal flooding may affect pump location and electrical connections.
[f] Pumping from dugouts fed from reservoir outlet and shallow groundwater induced by reservoir.
[g] Pumping from shallow groundwater induced by reservoir.
*Application method: 'surface' - conventional surface irrigation; 'bucket' - bucket; 'hose' - hose; 'piped' - piped furrow/basin irrigation; 'sprinkler' - sprinkler; and 'drip' - drip irrigation.

Outputs of Phase 2

The key output of phase 2 is a set of recommended AWM solutions and related considerations for use in program design.

Other outputs of phase 2 include the following:

1. Verification of the four key criteria identified in phase 1.
2. A general characterization of smallholder agricultural patterns of the population, including the relative importance of farming in their livelihood strategies, and the roles of male and female farmers in agricultural production and marketing.
3. A characterization of rights and entitlements for women and men of different castes/ethnic groups to access and use land and water resources for agricultural production.
4. An understanding of challenges (e.g., pests and diseases, livestock encroachment, market issues) faced by female and male farmers at different times of the year.
5. Data collected to calculate a water resource balance, in order to analyze the limitations of sustainable water extraction for irrigated agricultural production.

Box 3 summarizes an example of phase 2 data collection, analysis and intervention design, focusing on the areas in northern Ghana selected through the phase 1 analysis. As described in Box 3, the assessment team focused on the selected area in Ghana to characterize smallholder agricultural patterns, understand water resource use, understand the challenges faced by smallholder farmers, assess the water resource balance and design an intervention.

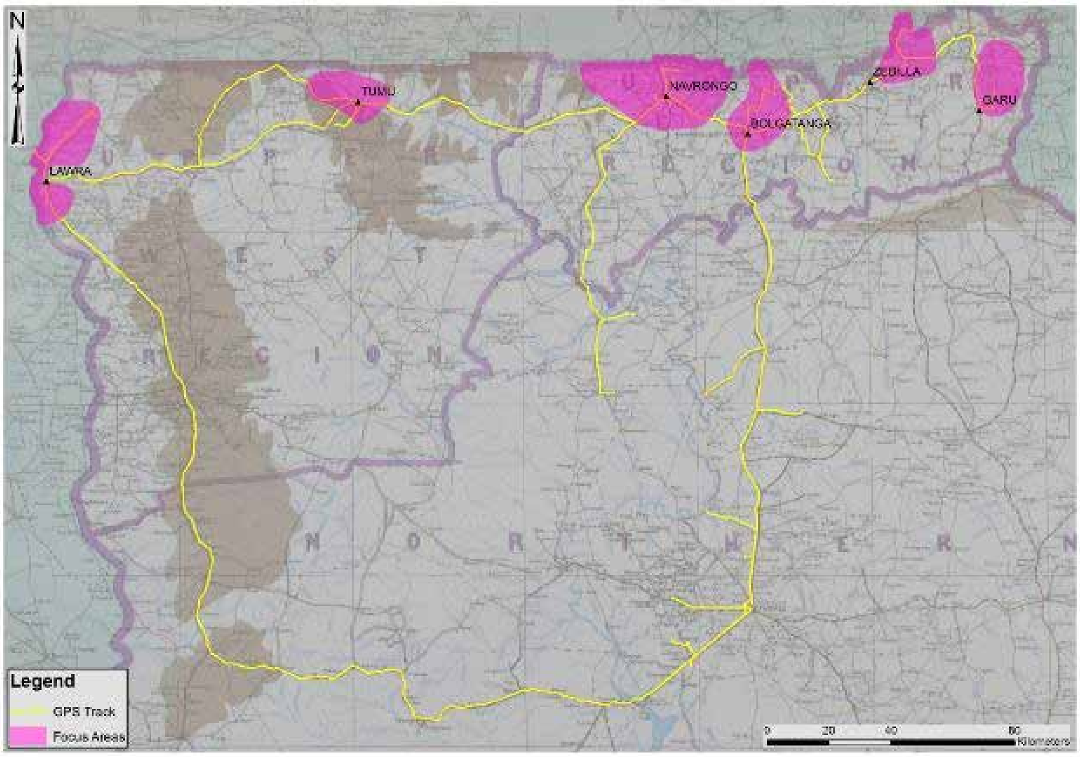
Box 3. Phase 2 data collection – an example from Ghana.

VERIFICATION OF THE FOUR KEY CRITERIA IN NORTHERN GHANA

Once northern Ghana was identified as having high unrealized potential for smallholder agricultural production, the assessment team visited the Northern Region, the Upper East Region and the Upper West Region in northern Ghana. Visual reconnaissance in the field confirmed the initial determination that northern Ghana exhibits accessible surface water and groundwater resources, relatively high rural population density, high rates of poverty and agriculture-based livelihoods.

Figure 5 shows the GPS track for phase 2 of the assessment. Because the broad-scale assessment under phase 1 pointed to the Upper East Region as the area with the highest population and poverty rates, this region was given the greatest focus during phase 2, as evident by the GPS track. Still, as seen in Figure 5, the field assessment was not able to cover the focus areas very intensively, due to the limited time available and inaccessibility by road. For much of the fieldwork, the team split into two groups to cover more areas, collect more detailed data on water resources and conduct more interviews.

FIGURE 5. GPS track of the field visit made by the AWM assessment team to northern Ghana in December 2010. Highlighting marks areas with high AWM potential. The highlighted area near Zebilla, on the border with Burkina Faso, is the Sapeliga area described in the sample notes from the fieldwork in Box 4.



Credit: Ian Wilson (Keller-Bliesner Engineering).

(Continued)

Box 3. Phase 2 data collection – an example from Ghana. (Continued)

Characterization of smallholder agricultural patterns in northern Ghana

The detailed fieldwork in northern Ghana revealed that smallholder agriculture is largely characterized by the production of rainfed staple crops (e.g., millet, sorghum) in poor soils, supplemented with the rearing of small ruminants, poultry and fishing. At a finer scale, the team determined that agricultural conditions, e.g., soil type, topography, geology, access to water, etc., are heterogeneous, which has resulted in a diversity of agricultural production activities as an adaptive response. In general, in areas with very limited water resources, farmers typically practice rainfed-only farming and/or limit the area of land cultivated under irrigation. Many farmers use local seed varieties, which results in poor crop productivity but enables farmers to reproduce seeds themselves for future crops. Migration to southern Ghana for work during the dry season is a common strategy to cope with the lack of agricultural opportunities. Land tenure and access are complex and variable. While most farmers reported that they do not own land, they raised no concerns regarding their entitlement to use the land and access water to irrigate their plots. In some areas, landowners cultivate the land only during the rainy season for staple crop production and rent the land (for a fee or for a portion of the crop) to other farmers during the dry season.

Understanding water resource use in northern Ghana

Where water is accessible at a reasonable cost in northern Ghana, a small percentage of farmers cultivate high-value crops, e.g., chili and tomatoes, in the dry season and earn significant extra income. The AgWater Solutions project estimated that approximately 500,000 farmers in Ghana cultivate irrigated crops primarily using buckets (70%) and motor pumps (30%) (Giordano et al. 2012). Both female and male farmers cultivate these dry-season irrigated crops, but women are primarily responsible for marketing the harvest. Both female and male farmers reported that they are able to sell their agricultural produce either at local markets or to traders who travel to the farm gate to purchase vegetables (often to be re-sold in urban centers in southern Ghana). While profitability of irrigated vegetable crops is high for smallholder farmers, the risks of growing these crops are also high due to pests, diseases, market risks, etc. These farmers reported receiving little training or other support from the government or other institutions; most reported learning about irrigation technologies, high-value crop production, agricultural management, etc., from neighbors and other family members.

Farmers accessing water in the dry season typically use three types of water resources: rivers, shallow aquifers or reservoirs. Each of these water resources is described below, together with a brief description of the types of water access technologies and farming practices that are common with each type of water resource.

Rivers. Where farmers have access to perennial rivers or riverbeds that retain water during the dry season, they pump water from the river/riverbed for irrigation using motorized pumps that have either been rented or provided by MoFA. Many farmers stated a preference for petrol rather than diesel pumps for use in riverbeds for two reasons. First, since farmers transport pumps to the riverbed, they preferred smaller and more portable petrol pumps rather than larger diesel pumps. Second, some farmers reported that larger diesel pumps can extract large quantities of water, so they felt that petrol pumps were better suited to riverbed conditions with limited water supplies. On the other hand, some farmers reported a preference for diesel pumps for extracting water from large rivers and reservoirs, because it

(Continued)

Box 3. Phase 2 data collection – an example from Ghana. (Continued)

was generally not necessary to move the pump from the river and water limitations did not determine pump choice. Diesel and petrol pumps seen in the field were exclusively owned and operated by men. In addition, farmers confirmed that farming in riverbeds required farmers to remain at the plot at all times to ensure that livestock did not encroach on the farm plot. Since riverbed plots were typically located a distance from the household and most women wanted to remain close to the household, male farmers primarily practiced riverbed farming.

Shallow aquifers. In instances where farmers in northern Ghana did not have access to a river, some of them dug one or more wells on their land by hand and used buckets to lift the water for irrigated vegetable production, especially in inland valley areas. In sandy and other loose soils, farmers reported that hand-dug wells often lasted only 1 year and then require re-excavation. Some farmers reported that they dug a well for dry-season farming, filled it at the end of the dry season, cultivated rainy season crops and then dug the well again in the following dry season. In general, labor exchange is used to dig wells, which has restricted the number of wells on plots of land cultivated by women.

While hand-dug wells may allow a large water storage capacity, it is often not possible to dig a well by hand deep enough to obtain a sufficient volume of water for irrigation throughout the dry season. As a result, many farmers reported that their wells dry out before the end of the dry season. For this reason, some farmers have multiple wells on a single plot of land; in addition to providing more water, multiple wells reduce the labor required to irrigate a plot of land.

Farmers reported a preference for smaller petrol pumps for use in hand-dug wells; however, motorized pumps were not seen in any hand-dug wells during the field assessment: farmers were exclusively watering their plots using buckets. Bucket irrigation is laborious and time consuming; some farmers reported that their children did not attend school during the dry season, so that they could assist with irrigation.

Reservoirs. Where farmers live in proximity to a reservoir, they often use motorized or diesel pumps to extract water. Reservoirs often have a water users' association (WUA), which manages the water resource (e.g., timing of the release of water from the dam). The WUA also collects fees for maintenance of the reservoir structure. Both women and men have access to land in proximity to the reservoir and to use water from the reservoir. Livestock encroachment was not reported as a problem in proximity to reservoirs, because the large number of people working near the reservoir control the entry of livestock.

Challenges faced by smallholder farmers in northern Ghana

Livestock encroachment on individual farm plots was reported to be a problem by many farmers. During the dry season, when high temperatures and high evapotranspiration rates result in a shortage of food for livestock, livestock are often allowed to roam freely to forage for food. Many farmers without resources for adequate fencing or with crops grown in riverbeds without fencing reported problems with livestock encroachment on their farms.

In some specific locations in northern Ghana, groundwater is saline and either unsuitable for farming or suitable only for specific crops; in these locations, farmers do not use the water for irrigation.

(Continued)

Box 3. Phase 2 data collection – an example from Ghana. (Continued)

Assessing the water resource balance in northern Ghana

Mapping groundwater depth

The results of the analysis and mapping of the depth to groundwater in northern Ghana using the 2k grid cell model (a model in which 2000 grid cells are required for a perennial stream best fits the hydrologic conditions and existing shallow well water level data for northern Ghana) are shown in Figures 6 and 7. The map of the depth to groundwater shown in Figure 6 also includes the location of reservoirs and serves as the basis for mapping the water source typologies described in Appendix 5. Details along with additional maps of the process for the close-up area are given in Appendix 1.

Estimating potential well-water yield

A drawdown and recovery test was conducted in the afternoon of December 7, 2010, on a dug well near Nyangua in the Upper East Region. The well had an average diameter of 0.7 m (water surface area of 0.4 m). Water was pumped from the well using a treadle pump. At the start of the testing, the water level in the well was 7.26 m below the ground surface. After pumping for 32 minutes (until 4:53 pm), the water level dropped 59 cm to 7.85 m below the ground surface. This was near the suction limit of the pump and it was performing poorly. The well was then allowed to recover and the depth to the water was measured periodically. Over the course of 42 minutes (until 5:35 pm), the water level rose 20 cm to 7.65 m below the ground surface. This recovery in 42 minutes represented a volume of 80 liters (1.9 liters per minute or 2.7 liters per day). This is a slow recharge rate, which is barely sufficient to irrigate a 300 square meter (m^2) vegetable plot when the crop irrigation requirement is over 8 mm per day. The storage offered by a dug well is what makes this slow recharge usable, since farmers can drawdown stored water in the well during the day and then leave the well to recharge overnight. A tube well without storage would be unsuccessful under these conditions.

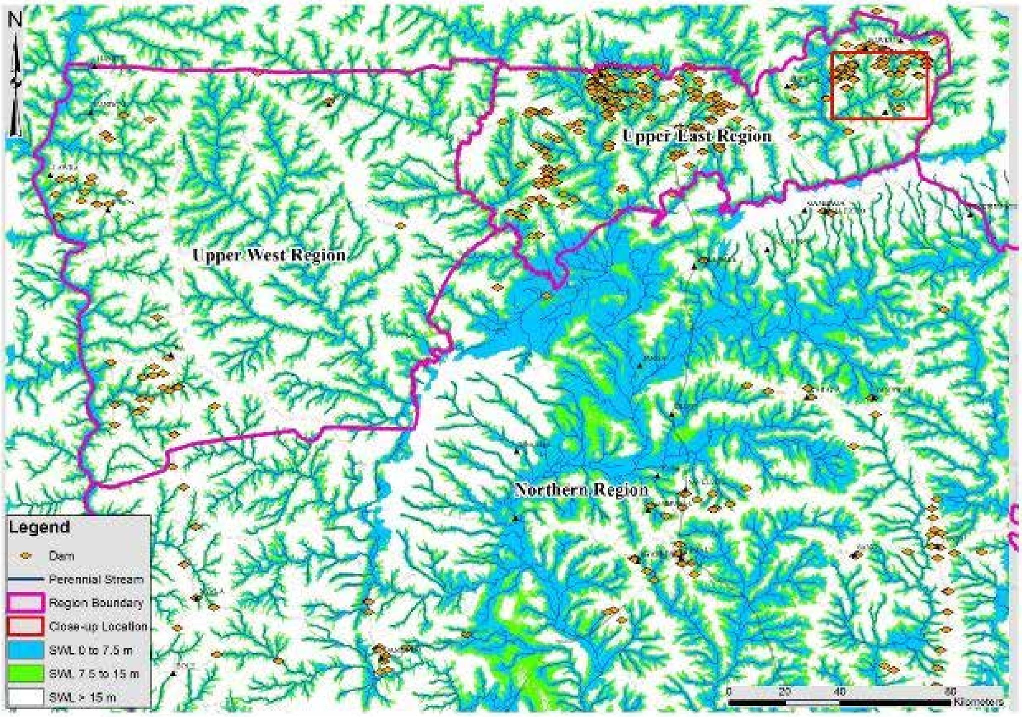
General water balance

The average estimate of groundwater recharge in northern Ghana is 7.5% of annual precipitation (average from five studies in the north of Ghana summarized by Anayah and Kaluarachchi 2009). Average annual precipitation for Navrongo is 996 mm (from FAO's ClimWat 2.0 database for Navrongo). Thus, groundwater recharge is approximately 75 mm/year. The crop consumptive irrigation requirement (crop evapotranspiration minus effective precipitation) for tomatoes cultivated in November 1 and harvested by March 25 (145 day growing season) is 624 mm (computed using FAO's CropWat version 8.0 with data from ClimWat 2.0 database for Navrongo). Dividing the consumptive irrigation requirement by the groundwater recharge provides an estimate of the ratio of the area irrigated with groundwater to the area required for recharge, i.e., 624/75 gives 8.3; in other words, for every 1,000 m^2 irrigated, 8,300 m^2 of recharge area (this includes the irrigated area) is required for sustainable groundwater abstraction. Stated differently, for every square kilometer (100 ha) of total land area in northern Ghana (using Navrongo as a proxy), approximately 12 ha can be sustainably irrigated. As most groundwater abstraction is from wells located in valley bottoms where the depth to groundwater is shallow (blue and green areas in Figures 6 and 7), the recharge area (e.g., the entire area) will generally be sufficient for sustainable shallow groundwater development.

(Continued)

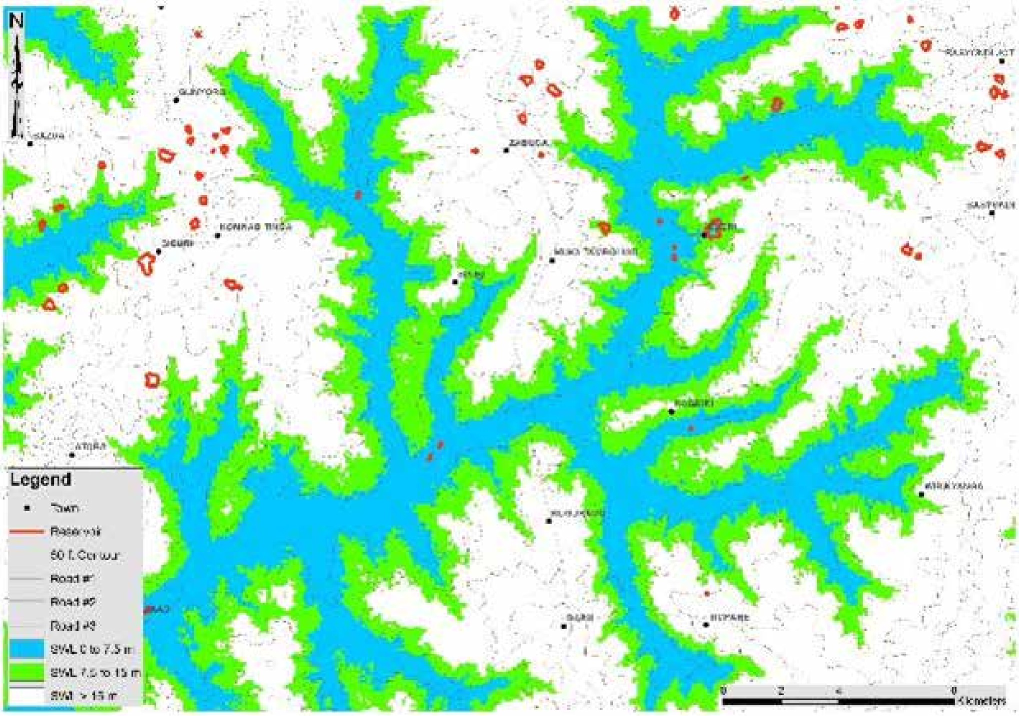
Box 3. Phase 2 data collection – an example from Ghana. (Continued)

FIGURE 6. Modeled depth to groundwater for northern Ghana (the locations of the reservoirs are also shown).



Credit: Ian Wilson (Keller-Bliesner Engineering).
Note: SWL – Static water level.

FIGURE 7. Close-up of modeled depth to groundwater in northeastern Ghana.



Credit: Ian Wilson (Keller-Bliesner Engineering).
Notes: SWL - Static water level; ft – feet (1 foot = 0.3048 meters).

(Continued)

Box 3. Phase 2 data collection – an example from Ghana. (Continued)

Designing an effective irrigation intervention in northern Ghana

As noted earlier, the agricultural conditions (e.g., topography, geology and soils) are heterogeneous in northern Ghana. As a result, there are locations with high potential for groundwater development in close proximity to areas where water is not easily accessible due to hard rock. This heterogeneity creates challenges for implementing a cost-effective irrigation-oriented intervention, because no single technology solution will be applicable in all locations. While introducing a range of technologies and delivery mechanisms for AWM solutions is appropriate for the heterogeneity of conditions in northern Ghana, it is more costly and requires a range of expertise to design and implement suitable interventions.

Examples of the measures developed by the assessment team in Ghana to address the priority constraints faced by smallholder farmers are given below:

1. Agricultural management

   Training in crop diversification to reduce risks (e.g., environmental, disease, price and market risks).

   Training in best soil management practices to improve the quality of soil, which reduces water consumption, improves soil nutrients and soil structures, and increases water productivity.

   Training in crop selection based on the soil and water parameters in the specific locality. For example, some areas visited had high salinity. So, crops that can grow under conditions of high salinity need to be selected.

   Where farmers do not currently produce high-value crops, these crops can be promoted by establishing demonstration plots to show water and crop production practices and benefits.

2. Water

   Regular monitoring of groundwater use helps to safeguard against groundwater overdraft and to understand various impacts of water development.

   Training in water scheduling and application to decrease water consumption.

3. Other

   Livestock fencing to reduce field losses due to livestock encroachment.

   Establish effective private sector repair services and supply chains for replacement parts.

Box 4 presents sample notes from the phase 2 field assessment conducted in Ghana. These notes provide an example of one segment of the detailed field-level data collection process and findings that emerged during the process.

Box 4. Sample notes from fieldwork, phase 2.

Based on the phase 1 country-level scoping work, one of the regions highlighted as having greater potential for irrigated agriculture was the Upper East Region in northern Ghana. The team traveled to Bolgatanga, the capital of the Upper East Region, and initiated discussions with government officials and other experts, including a local schoolteacher, to develop an overview of farming practices and water resources in the region. Local experts consistently identified a few areas with higher AWM potential, including Bawku West District.

The team traveled to Zebilla, the capital of Bawku West District, and met with Charles Akwotiga, a district officer of the Ministry of Food and Agriculture (MoFA), who provided an overview of farming practices in the district. A summary of notes from this meeting are given below.

- Livelihoods. Farming is the primary occupation of many people in the district. Many smallholder farmers generate income through dry-season vegetable production using buckets to extract shallow groundwater. The second most important livelihood activity is livestock rearing, primarily sheep, goats and cattle. The third most important livelihood activity is fishing.
- Crops. Farmers grow pepe, okra, leafy vegetables, onion and watermelon during the dry season. Market buyers travel to dams or farmers sell crops in the market in Zebilla.
- Water access.

  Groundwater. From Garu-Tempane to Gambaga, farmers use groundwater extensively. Farmers dig a well in the dry season to access groundwater, fill the well at the end of the dry season and then cultivate maize. In the following dry season, farmers dig the well again in the same location. There are areas in Bawku West District where shallow groundwater is prevalent but farmers cannot easily access the water due to the existence of hard rock.

  Rivers. Many farmers use river water for irrigation, including digging a well in the riverbeds, where water is often available throughout the dry season. Landowners often use land near rivers for rainfed farming; in the dry season, landowners often loan the land to other farmers.

  Dams. There are no large reservoirs in the district, only small-scale dams which belong to the community. Around most dams, women and men have equitable access to land. After construction, dams are maintained and the water is managed by communities through water users' associations. Community members help to control livestock from damaging crops. In years with poor rainfall, some dams do not have sufficient water for farmers to use throughout the dry season.
- Challenges: Water is critical for dry-season crop production, but many farmers cannot access water; where water is available, many farmers cannot afford a pump. Livestock encroachment on farm plots is a challenge. Farmers stay on the plot to protect crops; as a result, female farmers generally do not crop in or near rivers because these plots are not located near their homestead.

(Continued)

Box 4. Sample notes from fieldwork, phase 2. (Continued)

- Recommended areas to visit: Garu-Tempane area: river water utilization; Gambaga valley bottom: groundwater; Sapeliga: shallow wells, poor soils; and east from Garu-Tempane (by road, south from Tili towards Binaba): some groundwater usage.

Field discussions in the Sapeliga area

Based on the above overview, the team traveled to areas highlighted as having shallow groundwater and/or accessible river water. Discussions with approximately 12 female and male farmers working next to the White Volta River highlighted the following: approximately 110 farmers, 67 of whom were women, farm approximately a 1/8-acre (1 acre = 0.404686 hectares) (500 m^2) plot of land using hand-dug wells. Maximum water depth in the wells was reported as 4 m; farmers state that they reach rock when digging wells, which limits the quantity of water that can be extracted and the plot size. So, farmers do not expand their plots and only grow onions due to the small plot size. Starting in May, farmers grow rice. Farmers use sprinkler cans, buckets and palm oil containers to withdraw water.

Sample data collected during field discussions is summarized in Table 4.

TABLE 4. Summarized samples of field data collected in the Upper East Region, Ghana.

Location	Observation
GPS #1 N11.08504 W0.37197	Very shallow groundwater in a hand-dug well. Surface to water depth: 0.8 m. Salinity: 266 µS.
GPS #3 N11.08747 W0.37249	Female farmer's plot cultivated with onion. Hand-dug well that she dug herself with help from other women. By February/March, the water will be at the bottom of the well, where rock is too hard to dig. The farmer reported slow infiltration rate. Surface to water depth: 1.17 m. Diameter of well: 1.5 m.
GPS #4 N11.08695 W0.37273	Hand-dug well. Depth to bottom: 1.8 m; water at 1 m.
GPS #7 N10.98379 W0.39076	Farmers using a large motorized pump to extract water from the river reported that, as part of an African Development Bank project, male farmers formed a group and MoFA gave them a pump and free land. They grow onions and will repay the cost (GHS 1,700) of the pump over 3 years.
GPS #19 N10.85575 W0.15720	Dry stream. Indicates water table lower than streambed.
GPS #20 N10.85457 W0.15708	Female farmer pays someone to dig a well 'up to her height' in the riverbed each dry season, and she extracts water throughout the dry season using a calabash. She sells onions and alefu in the Garu-Tempane market. She uses fertilizer and farmyard manure.
GPS #21 N10.89079 W0.13768	Farmers extract water from the riverbed using buckets and palm oil containers, not pumps.

Credits: Elizabeth Weight and Andrew Keller.

RECOMMENDED EXPERTISE WITHIN THE WATER RESOURCES ASSESSMENT TEAM

Recommended expertise within the water resources assessment team includes the following:

- Irrigation engineer with expertise in AWM solutions for smallholder farmers.
- Hydrologist/hydrogeologist with expertise in local conditions.
- GIS specialist.
- Soil expert and/or agronomist/horticulturist.
- Sociologist and/or gender specialist.
- Additional expertise that relate to the long-term goals. For example, a market expert should be included in the assessment team, if the objective of the program is to improve farmers' access to markets for irrigated high-value crops.

It is extremely important that team members understand the needs and limitations of smallholder farmers, and recommend and design suitable interventions accordingly. For example, an irrigation engineer with experience only in large, formal canal systems may not be well suited for designing appropriate AWM solutions to benefit individual smallholder farmers. This smallholder perspective is on affordable (low capital cost), labor-saving, locally available and maintainable, individualized solutions. Occasionally, these conditions can be met by large systems shared by multiple farmers, but designing appropriate solutions still requires taking into account the smallholder perspective. This is very different from the perspective of the designers of large irrigation schemes, which require life-cycle economic analysis and are often capital intensive.

Because the assessment depends heavily on GIS analysis, it is helpful for the team to include a designated GIS specialist. The GIS specialist should also have other expertise required by the team, e.g., irrigation engineering, hydrology, geology or soils.

Box 5 provides an example of the expertise deployed in the water resources assessment team in Ghana.

Local field technicians, who speak local languages and dialects and are familiar with local agriculture and hydrographic features, should be engaged in the focus area of the assessment. These field technicians can continue with specific data collection after the departure of the full team. For example, local field technicians could monitor groundwater levels and map features of the areas that the full team is unable to visit. Qualified field technicians should have an associate's degree or equivalent in agriculture, rural development or hydrology.

To cover as much ground as possible, and for expedience, the assessment team should split up into groups each field day and re-assemble during the evenings to discuss findings. The team may also find it advantageous to change the composition of the groups from time to time, so that the different experts get the experience and perspectives of the various disciplines held by others on the full team.

A typical assessment will require a team of five or six experts for at least three weeks. The three-week minimum assumes that the focus area of the study has already been narrowed down to a few options, broad-scale data collection is already well underway and essential meetings with government officials, NARS, university sources, implementing NGOs and other organizations have been pre-scheduled to fit in with the agenda of the assessment team. The four-week time period for the full team is a more realistic estimate of the minimum level of effort required. The first week will be for phase 1 of the assessment. Broad-scale data collection may be carried out by a few members of the team for a couple of weeks and then completed by the full team over a couple of days, culminating with the interpretation of the broad-scale data and selection of the study area. Typically, the phase 2 field trip will take 7 to 10 days depending on the size of the focus area, its remoteness and accessibility. Data analyses and interpretation are conducted throughout all phases of the assessment as data are collected. Final data analysis and development of recommendations take place in the final 10 days. If local field technicians are hired to collect additional data which are key to the development of the recommendations made by the assessment then the time to obtain and analyze the additional data must be factored in to the assessment.

If the assessment team is entrusted with intervention design beyond making recommendations, then an additional week of time will likely be necessary in order to work with the implementing organization/s on design details. This, however, would not necessarily require the full assessment team, but it is recommended that the full team participate in outlining the recommendations made by the assessment and general aspects of the intervention design.

Budgets will vary considerably depending on transportation costs and distances in every country, and will also depend largely on the expertise available. Table 5 provides a sample budget for a water resources assessment, which was derived from the assessment conducted in Ghana in 2010. This budget assumes that three national and three international experts require a four-week level of effort. The total cost, including international travel, per diems, field vehicles and equipment (GPS, water level, water quality, etc.), is approximately USD 129,000. The bulk of the cost is the labor charges for international experts. If costs are an issue, replacing international experts with national experts reduces the cost to USD 70,350.

Box 5. Expertise of the water resources assessment team – an example from Ghana.

The water resources assessment team in northern Ghana consisted of two international irrigation engineers, one of whom was the team leader and the other was an expert in smallholder markets and value chains; an international GIS specialist and hydrologist; an international social scientist with some gender expertise; an international soils scientist with hydrology expertise; and a national hydrogeologist. The field trip to northern Ghana took place during the period December 5-15, 2010. The collection of data began remotely via email in November 2010. The selection of the detailed study area, i.e., northern Ghana with emphasis on the Upper East Region, was made by the team on December 3, 2010, and logistical preparations for the field trip begun. Final data analysis and development of recommendations began immediately after the field trip while the full team was in the country. Writing assignments were completed and the team was dispersed by December 20, 2010. The recommendations from the assessment were immediately incorporated into implementation plans for northern Ghana by the iDE country program. However, formal reporting from the assessment languished. A key lesson learned is that reporting needs to be completed soon, e.g., within approximately two months following the field trip and should be part of the contractual agreement with the assessment team. Furthermore, as much of the reporting as possible should be made while the full team is still in the country. At a minimum, an annotated outline should be prepared with assignments for completion of each section, and the full team should agree on the conclusions and recommendations of the assessment prior to dispersing.

TABLE 5. Sample budget for an assessment team consisting of six experts for a four-week level of effort.

Item	Number	Unit	Unit rate (USD)	Extended cost (USD)
International experts	84	Person days	1,000	84,000
National experts	84	Person days	300	25,200
Field technicians and guides	20	Person days	50	1,000
Field vehicles	20	Vehicle days	150	3,000
International airfare	3	Round trip	2,000	6,000
Per diem in capital	33	Days	150	4,950
Per diem in field	60	Days	50	3,000
Equipment	2	Set	1,000	2,000
Total				129,150

Credit: Andrew Keller.

ISSUES AND CHALLENGES WITH THIS METHODOLOGY

The major challenge with the assessment methodology is quick access to water resources and population data at adequate spatial resolution and in readily mappable format. Water is the resource being assessed, but often, particularly in countries where the assessment is most needed, quantitative information with spatial attributes and data showing annual and intra-annual variability are simply unavailable, and models using remote data must be deployed to make initial estimates prior to proceeding with detailed fieldwork. The methodology also depends on rural population density and poverty data to select the detailed focus area. These data are often unavailable in a fast GIS input form with spatial resolutions below the secondary national (regional) level. Furthermore, information regarding the location of the population does not necessarily connect them to land that they farm or have rights to farm. For this reason, patterns often have to be interpreted using remote and lower resolution data.

The depth to groundwater modeling using DEM (presented in Appendix 1) produces results that are well suited to estimating where the potential is for accessing water, but gaining knowledge of other key parameters (e.g., saturated thickness, yield and characteristics of the overburden) about the groundwater usually requires going to the field. This takes time to collect and may be impractical to obtain prior to selection of the detailed field study area. Thus, promising areas with groundwater potential may be overlooked by the assessment simply because rapidly accessible key data were not available.

Another significant challenge of the assessment process is producing results that meet the needs of female and male farmers as well as the requirements of donors and implementers of AWM solutions. Unless the assessment is commissioned by the ultimate donor or implementer, financial support for the intervention that results from the assessment may be limited. Ideally, a rapid assessment of water availability is only one of several inputs informing a more extensive program design process requiring additional fieldwork to gather sufficient information on other key program parameters.

As already noted, this is a rapid assessment approach, which is oriented to providing program designers and managers with quick, 'good enough' information to assist in the development of a program strategy and design. Many of the aspects of this approach do not meet the gold standard for a more extensive and intensive study of the agroecology and hydrogeology of a given region. However, we have developed these guidelines specifically for those without the luxury of time or resources to conduct more elaborate studies, in order to maximize the quantity and quality of information available to assist with good program design.

Other limitations of the assessment methodology include its relatively high cost (while considerably cheaper than a full-blown research study, an estimated cost in excess of USD 100,000 may limit applicability in some cases), the potential difficulty of coordinating the availability of experts with the best field season and incorporation of data that may need to be collected over a period of time.

CONCLUSION

This paper describes a relatively low-cost approach for managers in the public sector, civil society and private sector to guide technical specialists to examine and select areas with high potential for female and male smallholder farmers to access, apply and use water in an affordable manner to improve their livelihoods. These guidelines are intended to be used in locations where there is limited documentation and information on surface water and groundwater resources. The authors hope that these guidelines improve practitioners' ability to conduct useful water resource assessments that consequently improve the quality and appropriateness of AWM interventions. It is also hoped that others will refine and improve this paper through further application in other contexts and conditions.

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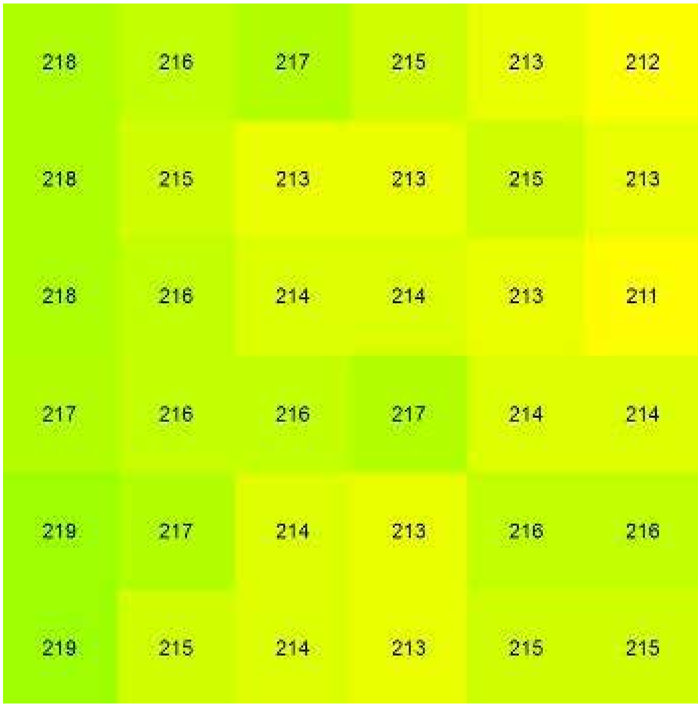
APPENDIX 1. STATIC WATER LEVEL MAPPING FROM DEM AND PERENNIAL STREAMS.

The procedure for creating a computer-generated, three-dimensional model of Static Water Level (SWL) surface utilizing tools and commands available in the GIS software, ArcView, is as follows:

1) Starting with a DEM, which is a grid of land surface elevation data, the Flow Direction tool is used to create a Flow Direction grid. The Sink tool is then used with the Flow Direction grid to create a Sink grid. The Sink grid indicates whether there are sinks (depressions) in the DEM. If there are sinks in the DEM, real or otherwise, they must be removed in order for this procedure to work. Real sinks, such as terminal lakes, can be removed by clipping holes in the DEM around the perimeter of the lake(s). Other sinks can be removed using the Fill tool once any real sinks have been clipped out of the DEM. This produces a DEM with no location for water to pool. Figure A1.1 shows a sample DEM and the numbers represent the average elevation in each grid square.

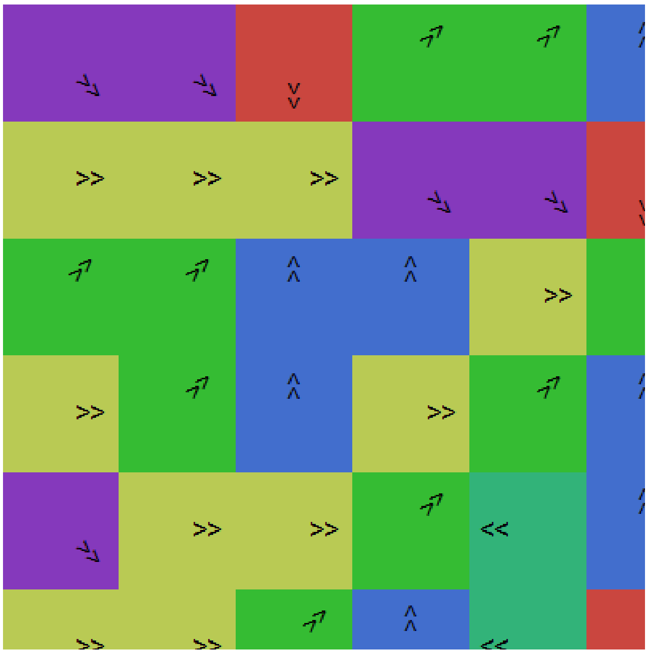
FIGURE A1.1. Example of the DEM grid.



Credit: Ian Wilson (Keller-Bliesner Engineering).

2) The Flow Direction tool is used on the sink-free DEM to produce a Flow Direction grid. The sample grid shown in Figure A1.2 indicates the direction of surface flow in each cell of the DEM.

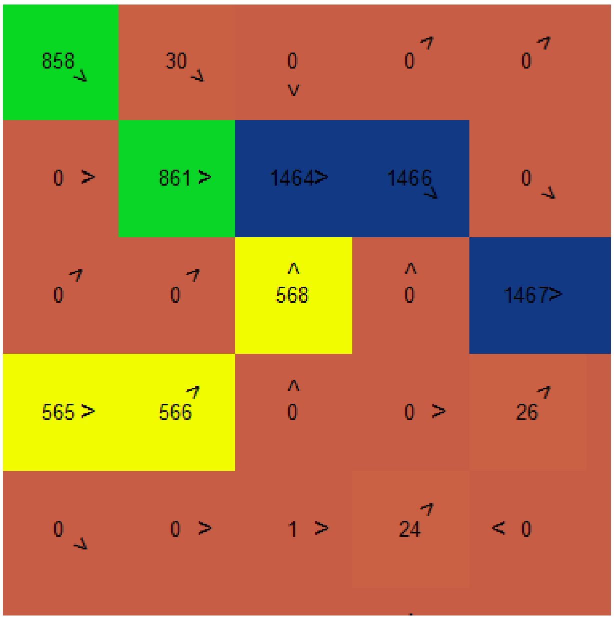
FIGURE A1.2. Direction of surface flow in each cell of the sample DEM.



Credit: Ian Wilson (Keller-Bliesner Engineering).

3) The Flow Accumulation tool is used with the Flow Direction grid to produce a Flow Accumulation grid. Each cell of the grid shown in Figure A1.3 contains the number of cells in the DEM that flow into it.

FIGURE A1.3. Example of the number of cells in the DEM that flow into it.



Credit: Ian Wilson (Keller-Bliesner Engineering).

4) The Conditional tool is used with the Flow Accumulation grid to select all the streamline cells in the Flow Accumulation grid that have values higher than some threshold value. This threshold value is meant to represent the minimum number of grid cells in the DEM required to create a watershed large enough to produce a perennial stream. The cell values in the grids, which get created by the Conditional tool using the inputs below, will be the elevations from the DEM along the streamlines with flow accumulation values higher than the threshold. The inputs for the Conditional tool are:

    a. The Input Conditional Raster = the Flow Accumulation grid
    b. The Expression = Value > X, where X = the threshold value
    c. Input True Raster = sink-free DEM
    d. Input False Raster = leave blank
    e. Output Raster = the name of the raster being created

Figure A1.4 shows (this is the close-up area shown in Figures 6 and 7 of northern Ghana) five overlapping grids, displayed one on top of another, created by the Conditional tool. The first grid was created using a threshold value of 40,000 DEM cells to create a perennial stream. This grid is the top grid in Figure A1.4 and is shown as blue streams.

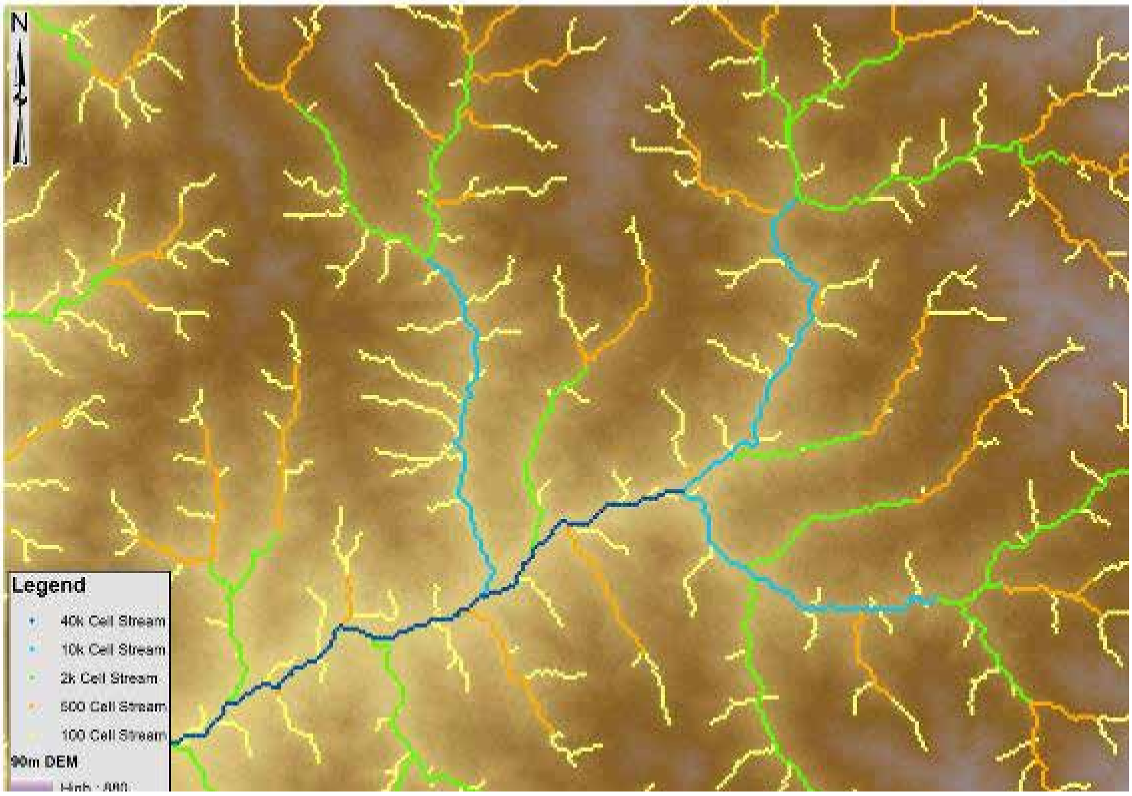
The second grid was created using a threshold value of 10,000 DEM cells. This grid is shown by the turquoise streams which also run under the blue streams. So, it is all the turquoise and blue streams.

The third grid was created using a threshold value of 2,000 DEM cells. This grid is the green streams which run under the turquoise and blue streams. So, it is all the green, turquoise and blue streams.

The fourth grid was created using a threshold value of 500 DEM cells. This grid is the orange streams which run under the green, turquoise and blue streams. So, it is all the orange, green, turquoise and blue streams.

The fifth grid was created using a threshold value of 100 DEM cells. This grid is the yellow streams which run under all the streams in the other colors. So, it is all the streams.

FIGURE A1.4. Example from the close-up area in northeastern Ghana of perennial streams per 40,000, 10,000, 2,000, 500 and 100 DEM cells.



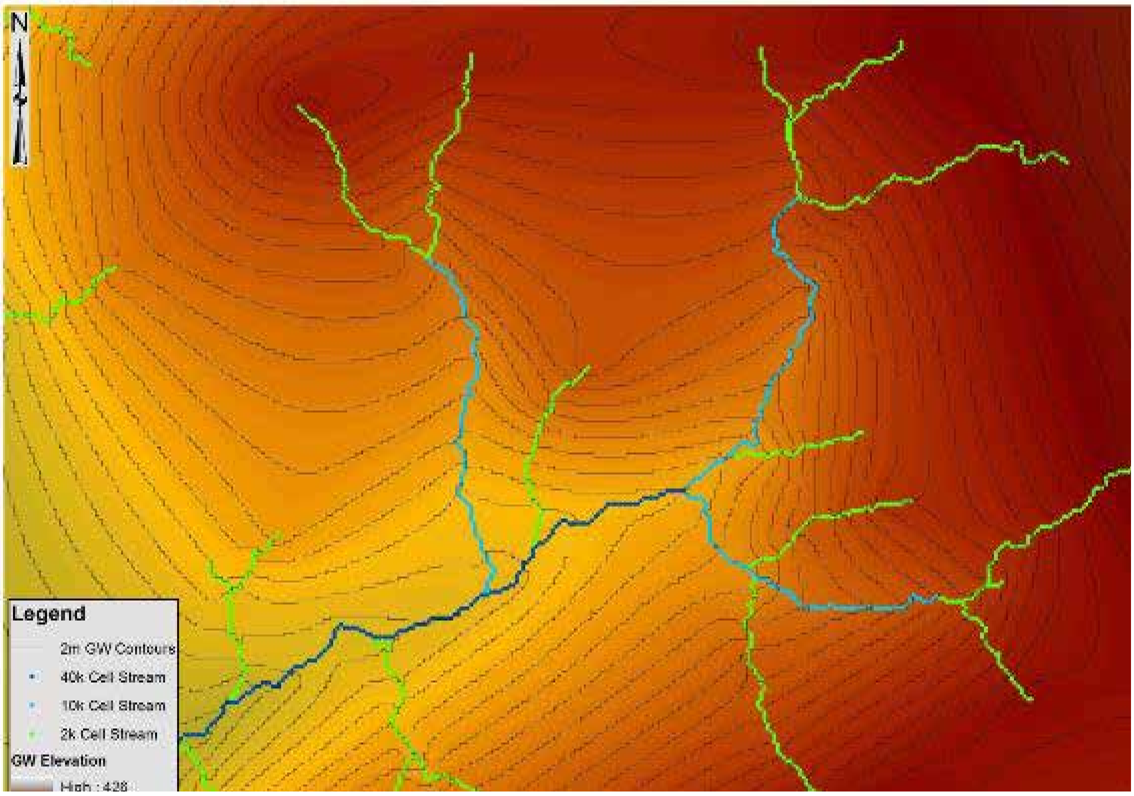
Credit: Ian Wilson (Keller-Bliesner Engineering).

5) The Raster to Point command creates a point shapefile from the grid output by the Conditional tool. The shapefile will have a point at the location of each cell in the grid output by the Conditional tool, and the value of each point will be the same as the grid cell it comes from. The inputs for the Raster to Point command are:
   a. Input Raster = grid output by the Conditional tool
   b. Field = VALUE
   c. Output Point Features = the name of the shapefile being created
6) The Natural Neighbor tool creates a grid of the water surface that goes through the perennial streamline points in the shapefile created in (5) above. Figure A1.5 shows the contoured groundwater surface resulting from the 2k perennial stream model for the close-up area in northeastern Ghana.

The inputs for the Natural Neighbor tool are:

   a. Input Points = the name of the shapefile created above
   b. Z Value Field = GRID_CODE
   c. Cell Size = cell size of DEM
   d. Output Raster = name of grid being created

FIGURE A1.5. The contoured groundwater surface resulting from the 2k perennial stream model for the close-up area in northeastern Ghana.



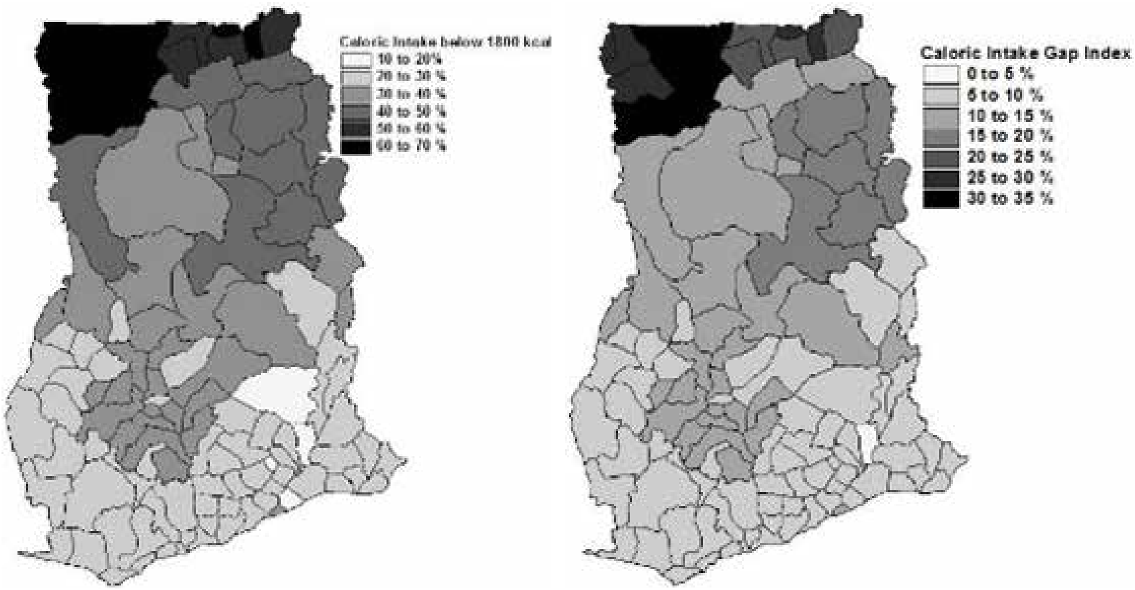
Credit: Ian Wilson (Keller-Bliesner Engineering).
Note: GW – groundwater.

7) Finally, the Raster Calculator command is used to subtract the grid of the water surface produced in (6) above from the sink-free DEM. This produces the SWL grid which gives the vertical distance from the ground level down to the water table.

APPENDIX 2. CASE STUDY ILLUSTRATIONS.

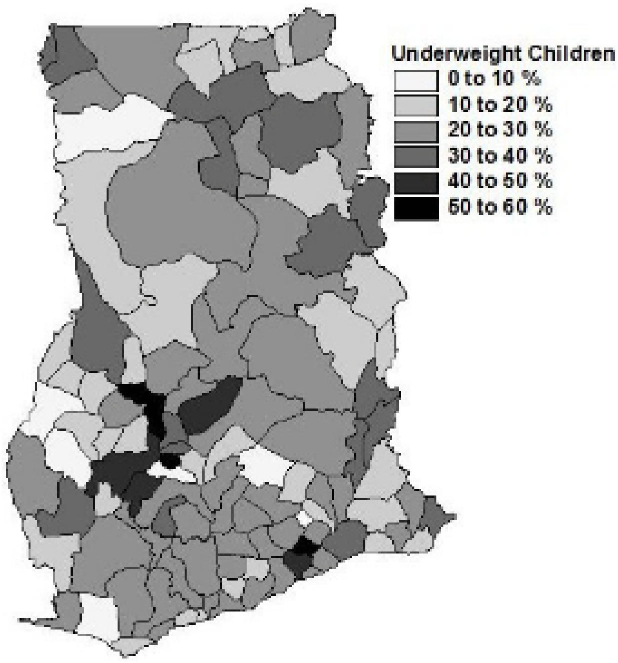
FIGURE A2.1. (a) Food insecurity head count, and (b) food insecurity gap.

(a) (b)



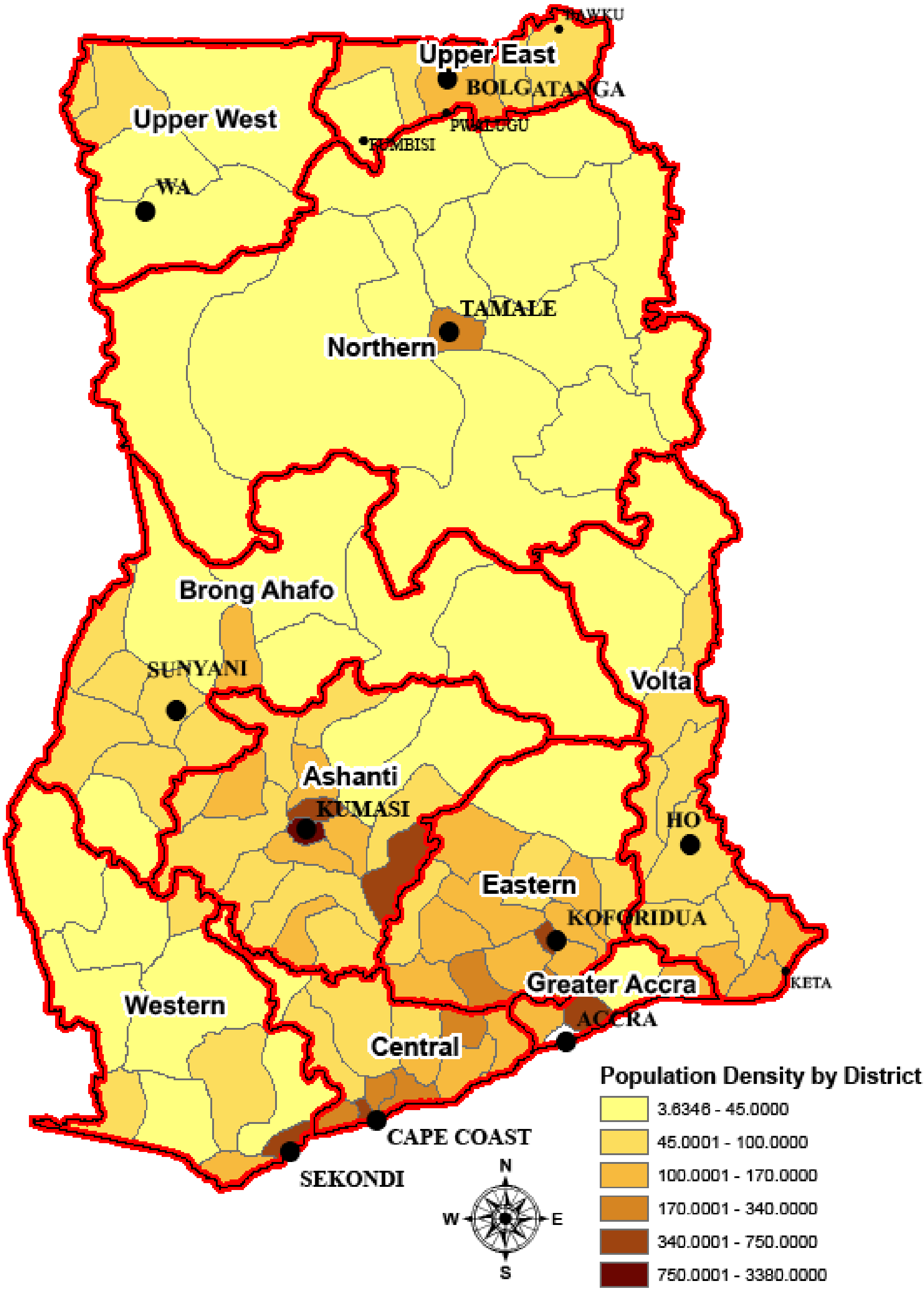
Source: World Bank 2011.
Note: kcal – kilocalorie.

FIGURE A2.2. Underweight children.



Source: World Bank 2011.

FIGURE A2.3. Population density by district.



Credit: Ian Wilson (Keller-Bliesner Engineering).

FIGURE A2.4. Livelihood zones of Ghana.

1: Cereals (sorghum/millet), legumes, yam, livestock (cattle)
2: Cereals (sorghum/millet), legumes, livestock (small ruminants and guinea fowl)
3: Maize, rice, tree crops (mango), livestock
4: Eastern corridor and Upper Volta: yam, cassava, livestock
5: Volta lake: fishing, maize, yam
6: Tubers (yam/cassava), maize, cashew, livestock
7: Middle Volta area: tree crops (cocoa/coffee), cassava, small ruminants
8: Maize (commercial), cassava and small ruminants; bimodal rainfall
9: Tree crops (cocoa/oil palm/citrus), poultry (commercial)
10: Rice (commercial) and livestock
11: Timber, tree crops (cocoa, oil palm, rubber), mining
12: Coastal zone: fishing, salt, vegetables

Source: FAO 2012.

FIGURE A2.5. Three focus areas.

Upper East Region

- White Volta at Pwalugu
- Sisili River Area
- Kulda River near Bolgatanga

Ashanti Region

- Kumasi - Urban
- Kumasi - Peri-urban

Volta Region

- Keta Strip
- North of Keta Lagoon

Credit: Ian Wilson (Keller-Bliesner Engineering).

APPENDIX 3. IDENTIFIED SOIL TYPES IN NORTHERN GHANA, SPECIFIC LOCATION AND SUITABILITY FOR MANUAL WELL DRILLING.

This appendix is an example of phase 1 of the AWM assessment, broad-scale data collection and interpretation. The dominant soils suitable for manual well drilling in northern Ghana are described in Table A3.1. Figure A3.1 provides a soil map of Ghana as an example of the data to be collected in the assessment process.

TABLE A3.1. Dominant soils suitable for manual well drilling in northern Ghana.

(ACf) Ferric Acrisols: Acrisols are acidic soils that are typically found in tropical, humid climates. These soils are susceptible to drought stress, crusting, compaction and erosion. Acrisols are typically used to grow yam, cocoyam, banana and lime. A ferric acrisol is iron-rich. They are typically oxisols that have undergone extreme weathering. These are sometimes referred to as Savannah Ochrosols. These ochrosols are developed in both forest and savanna environments under rainfall between 900 and 1,650 mm. **Specific location in northern Ghana:** Predominant around the Tamale Region. **Suitability for drilling:** Suitable for manual well drilling. A slowly permeable layer of clay or impermeable rock may exist at a depth of about 24 inches.
(ARb) Cambic Arenosols: The cambic is a subsurface horizon showing evidence of alteration relative to the underlying horizons. Arenosols are sandy soils featuring very weak or no soil development/differentiation on deep aeolian alluvial sands. **Specific location in northern Ghana:** To be determined. **Suitability for drilling:** Suitable for manual well drilling, with barely any presence of restricting layers.
(FLd) Dystric Fluvisols: New alluvial soils, sometimes saline, lying along coastal areas. Fluvisols are highly variable soils with organic matter varying between 0-30%. Most of the soils are acidic with a pH value of less than 5.5 (dystric fluvisols). Eutric fluvisols have a higher pH value and are from calcareous and basic igneous rocks or young marine deposits. **Specific location in northern Ghana:** Mainly interspersed along riparian and tributary areas of the Black Volta. **Suitability for drilling:** Suitable for manual well drilling, with barely any presence of restricting layers. High potential for shallow groundwater.
(FLe) Eutric Gleysols: Gleysols are soils with temporary or permanent wetness near the surface. Eutric soils have a very high base saturation. **Specific location in northern Ghana:** To be determined. **Suitability for drilling:** Suitable, but may turn unsuitable if an area has alternating wetting and drying cycles that can eventually create hardpans as a restricting layer.
(LPd) Leptosols: These are fairly shallow soils over very hard rock or gravely material (typically 15 cm or less). Dystric leptosols may commonly occur in areas with higher rainfall and are potentially subject to leaching, resulting in soils that are acidic with a pH value of less than 5. **(LPe) Eutric Leptosols** have a higher pH value and occur in areas of lower rainfall regimes. **(LPq) Lithic Leptosols** have a B Horizon that directly overlies hard rock, often occurring in mountainous forested landscapes.

(Continued)

TABLE A3.1. Dominant soils suitable for manual well drilling in northern Ghana. (Continued)

Specific location in northern Ghana: To be determined.
Suitability for drilling: Unsuitable for manual well drilling.

(LVh) Haplic Luvisol: Haplic is a term which indicates that the major part of the upper 0.5 m of the soil profile is whole-colored. Luvisols are soils with subsurface accumulation of high activity clays and medium to high base saturation.
Specific location in northern Ghana: To be determined.
Suitability for drilling: Suitable for manual well drilling.

(LX) Lixisols: These are strongly weathered soils in which clay was washed out of the eluvial horizon down to the argic (at least 8% clay with a sandy loam texture) subsurface horizon, which has low activity clays and a moderate to high base saturation level.
(LXf) Ferric Lixisol: Lixisol having within 100 cm of the soil surface with a ferric horizon (distinct mottles of iron that have undergone oxidation).
(LXg) Gleyic Lixisol: Lixisol with gleyic properties within the top 100 cm. Gleyic properties signify a soil that is temporarily or permanently covered by groundwater such that reducing conditions occur and hence gleyic color patterns emerge.
(LXh) Haplic Lixisol: Lixisols which show no further meaningful differentiation or characterization.
(LXp) Plinthic Lixisol: Lixisol with an iron-rich, humus poor mixture of kaolinitic clay with quartz and other constituents which changes irreversibly to a hardpan on exposure to repeated wetting and drying cycles with free access of oxygen (forming an ironstone hardpan).
Specific location in northern Ghana: To be determined.
Suitability for drilling: Usually has gravely constituents and may hinder manual well drilling. There could be a potential for manual well drilling in Ferric and Haplic lixisols. Unsuitable for manual well drilling in plinthic lixisols.

(PLd) Dystric Planosols: Planosol is a soil with a light-colored, coarse-textured, surface horizon that shows signs of periodic water stagnation and abruptly overlies a dense, slowly permeable subsoil with significantly more clay than the surface horizon. Dystic Planosols have a base saturation of less than 50%.
Specific location in northern Ghana: To be determined.
Suitability for drilling: Suitable for manual well drilling. Periodic water stagnation could induce gleying, and alternate wetness and drying cycles which in turn result in hard pans. For such cases, it would be unsuitable for manual well drilling.

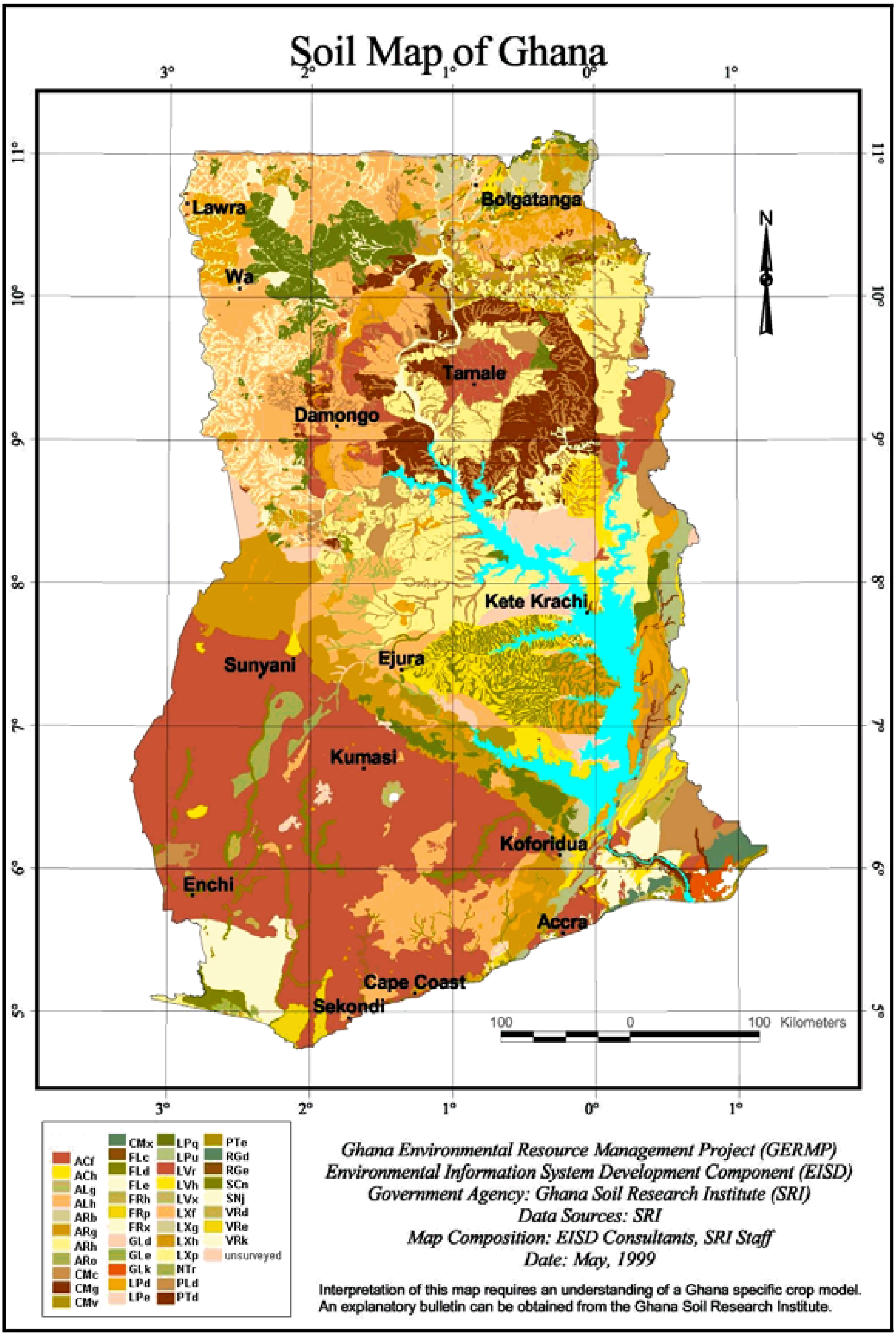
(PTd) Dystric Plinthosols: Plinthosols have clay minerals (chiefly kaolinite) and silica that hardens on exposure into ironstone concretions known as plinthite. The impenetrability of the hardened plinthite layer, as well as the fluctuating water table that produces it, restricts the use of these soils for grazing or forestry. Dystric plinthosols have a low base saturation typically less than 50%.
(PTe) Eutric Plinthosols: Plinthosols have a high base saturation and may be common in areas with lower rainfall regimes. These soils will also have a higher pH value.
Specific location in northern Ghana: To be determined.
Suitability for drilling: Not suitable for manual well drilling. Plinthite rock can sometimes be present at a depth of less than 50 cm.

(Continued)

TABLE A3.1. Dominant soils suitable for manual well drilling in northern Ghana. (Continued)

(VRk) Calcic Vertisols: Vertisols are dark clay soils which show swelling and cracking with changing moisture conditions. Calcic vertisols are vertisols with a subsurface layer containing 2-20% soft carbonate and 0-20% hard calcareous fragments and/or carbonate nodules. **Specific location in northern Ghana:** To be determined. **Suitability for drilling:** Suitable for manual well drilling. In some cases, the hard calcareous fragments may pose an impediment to manual well drilling. Depending on how dense the occurrence is, manual well drilling has a good potential for success if the fragments are very sparsely interspersed.

FIGURE A3.1. Soil map of Ghana.



APPENDIX 4. FIELD-LEVEL DATA AND INFORMATION COLLECTION.

Field-level data and information collected during phase 2 of the water resources assessment were used to provide more detailed data and information on areas with high potential for irrigated high-value agricultural production. Table A4.1 lists the type of information to be collected in phase 2, a brief explanation of the reasons for gathering the information and indicative sources of the information. Since the focus of this paper is on assessing water resources for small-scale agricultural production, the emphasis in Table A4.1 is on water resources data and information. While it is critical to gather other types of information on cropping patterns, soil conditions, livelihood patterns, and poverty patterns and trends, the type of data and sources of information are not described in detail because the focus of this paper is on water resources assessment. Further, numerous other resources provide information, methods and tools for data collection in relation to these other important aspects of field assessment and data collection.

The field-level data and information described below are gathered primarily through interviews held with female and male smallholder farmers, local organizations (e.g., agricultural cooperatives, and local and international NGOs operating in the area), researchers conducting research in the local area, agriculture university staff, local teachers, local chiefs, local government (e.g., irrigation and agriculture department staff and agricultural extension agents), and the private sector (e.g., private sector well drillers, market traders and agricultural input dealers).

TABLE A4.1. Field-level data and information collected during phase 2 of the water resources assessment.

Type of information	Reason for collecting information	Sources of data
	Water	
1. Availability and accessibility of surface water and groundwater resources throughout the year. 2. Precipitation. 3. Salinity*. 4. Smallholder access to water throughout the year for different purposes (domestic use, irrigation, etc.), differentiated by male and female usage (and other distinguishing differences, such as income or caste differences). 5. Where and how smallholder farmers obtain water (e.g., pumping from lakes, household wells, community wells, dams), differentiated by male and female usage (and other distinguishing differences, such as income or caste differences). 6. Understand how smallholder farmers currently utilize water resources (e.g., domestic use, irrigation), differentiated by	1. The location (distance from homes and farms with a small plot of land), accessibility (depth and level of difficulty to access water based on rock/soil profile), and availability of water resources during different times of the year affect farmers' costs and labor to access water. Therefore, gathering information on these parameters enables the team to develop approximate calculations of the costs that have to be incurred by farmers to access water resources. In addition, gathering this type of information enables the team to discuss different scenarios of water resources development with male and female farmers from different ethnic groups/castes, in order to assess whether they would, for example, invest in accessing water at specific locations at a specific cost. 2. Most vegetable and high-value crops require irrigation water	1. If available, well drilling logs can provide valuable information regarding characteristics of the soil, water depth, water yields, etc. 2. Database of boreholes, traditional wells and characteristics of water holes. Types of water holes in an area, average depth and static water level, wells, well drilling and water quality. 3. Discussions with farmers, local government entities and local support organizations provide qualitative verbal information on the use of water management technologies. Visual reconnaissance of farmers' use of technologies confirms verbal communication. Additional discussions with male and female farmers is useful to assess their interest and willingness to invest in water management technologies.

(Continued)

TABLE A4.1. Field-level data and information collected during phase 2 of the water resources assessment. (Continued)

Type of information	Reason for collecting information	Sources of data
male and female usage (and other distinguishing differences, such as income or caste differences). 7. Availability, and prevalence of use, of water management technologies, including types of water-lifting technologies (e.g., bucket, rope and washer pumps, treadle pumps, motorized pumps), differentiated by male and female usage (and other distinguishing differences, such as income or caste differences).	with EC < 750 µS/cm (TDS <525 mg/l). 3. Understanding the availability and use of water access technologies (bucket, rope and washer, motorized pumps) by men and women provides information on water accessibility and current farming practices as well as an insight into potential areas for improvement.	
	Livelihoods	
1. The relative importance of agricultural and non-agricultural activities in the livelihood and income-earning strategies of low-income families. 2. Ethnic, caste, religious and gender differences in livelihood strategies. 3. Prevalence and distribution of poverty.	1. As in phase 1, it is important to ensure that the proposed intervention fits in with current livelihood patterns in the communities. If, for example, the population is engaged in lucrative mining activities, there may be little interest in farming. 2. Understanding ethnic, caste, religious and gender differences in livelihood patterns provides opportunities to engage and benefit both men and women of different religions and ethnicities. 3. Field reconnaissance confirms national-level poverty information collected in phase 1.	1, 2, 3 Discussions with farmers, local government officials, local organizations operating in the area, local businesses, etc., and visual reconnaissance in the field, provide significant information regarding these variables.
	Land and agricultural management	
1. Crops cultivated in the area and crop diversification, including differences in crops grown by women and men[**] 2. Division of labor in AWM practices for those crops cultivated, e.g., weeding, water application. 3. Average farmer plot size for different crops. 4. Patterns of male and female landownership, formal and	1. Understanding how access to water could enhance current crop production and/or enable integration of higher-value irrigated crops into current production. 2. Understanding how an intervention might benefit men and women differently, and select measures that benefit women, e.g., by focusing on water management practices of crops that women are	

(Continued)

TABLE A4.1. Field-level data and information collected during phase 2 of the water resources assessment. (Continued)

Type of information	Reason for collecting information	Sources of data
informal land rights, and land use for agricultural activities. 5. *Soil.* Soil types, quality, fertility and current management practices. 6. *Inputs.* Inputs used by male and female farmers in crop production, quality of inputs. 7. *Pests/diseases.* Pest and disease issues, and effectiveness of current pest management practices. 8. Sources of information, training, agricultural support and advice.	responsible for. Understanding specific constraints for women/ ethnic groups that must be addressed, e.g., travel constraints and market access. 3. Determine potential crops and extent of cropping under irrigation. 4. Understanding how land tenure issues might affect investment in irrigation and irrigated agriculture.	
	Other	
1. Existing services and support mechanisms; male and female usage of those services (e.g., agricultural training services, financial products and services).	1. Understanding what services currently exist and evaluating whether those services address the needs of both male and female farmers enables program design to build on existing support services or identify gaps that need to be addressed. For example, agriculture extension services often do not provide advice regarding dry-season horticultural crops and do not engage women in training programs, so the program design could seek to build the skills of agricultural extension services while also addressing the skill gap of female farmers.	

Notes: EC - Electrical conductivity; TDS - Total dissolved solids.

[*] Salinity is measured using a portable electrical conductivity meter. The higher the EC, the more dissolved solids (measured in parts per million equivalent to milligrams per liter [mg/l]) in the water and the harder it is for plants to extract the water from the soil. General values are: Excellent: EC < 250 µS/cm, TDS < 175 mg/l; Good: EC 250-750 µS/cm, TDS 175-525 mg/l; Permissible: EC 750-2,000 µS/cm, TDS 525-1,400 mg/l.

[**] To learn more about the role played by both men and women in farming systems, the AgWater Solutions project developed a gender mapper for sub-Saharan Africa (available at http://gender.mappr.info/explore.php).

APPENDIX 5. TYPES OF WATER SOURCES AND IRRIGATION TECHNOLOGIES.

Groundwater

Shallow groundwater is the most common source of water for smallholder farmers, because of its generally ubiquitous distribution and relative accessibility. Important considerations for groundwater are the characteristics of the earth material that overlies the water table, depth to the water table and the rate at which water will recharge different sized wells (yield).

For the purpose of this study, shallow groundwater is water that can be accessed from water tables less than 18 m (a lift of 18.0 m is the practical and economical pumping limit for small plots, with the exception of those served by grid-supplied submersible electric pumps that can economically pump from greater depths. The greater the depth of groundwater, the more work [energy] is required to lift the water to the surface, resulting in practical limits for manual pumps and economical limits for motorized pumps due to the energy costs) below the ground surface at the end of the dry season, irrigation period (end of February in the case of northern Ghana). The groundwater typologies listed in Table 2 include 'very shallow', which is having water depths less than the suction lift limit (we recommend that the general default value for the highest practical suction lift for cool water should be 8 m [26 feet] when the smallholder's plot is at an elevation 500 m above sea level [masl] or less. The maximum lift should be reduced by 1 m for each additional 1,000 masl), and 'deeper', which is having water depths greater than the suction lift limit.

Low-yielding wells discussed here are those with sustained flow rates insufficient to irrigate 0.1 ha during the peak demand period (e.g., less than approximately 0.1 lps). Low-yielding aquifers require careful consideration of sustainability issues, including density of use, to ensure that the water level remains within pumping depths of the technology and the yield is sufficient to meet peak daily water requirements for the area being irrigated. The groundwater yield may decrease during the period of high demand (due to a reduction in saturated thickness). Daily effective yield can be increased using dug wells, which provide storage for water seeping into the well overnight. High-yielding wells are considered here to have at least ten times the flow of low-yielding wells (e.g., a sustained flow greater than 1.0 lps), which is generally sufficient to irrigate ten times the area (e.g., 1.0 ha) during times of high demand over a 24-hour period.

Most wells used by smallholders for irrigation are either hand-dug wells or manually drilled wells. Dug wells have the advantage of being a universally understood technology and, due to their large diameter, provide storage, which is particularly important in low-yielding groundwater conditions. Dug wells have the key disadvantage of not penetrating much below the water table. Dug wells are also often unsafe. The principle advantages of manually drilled wells are that they are low-cost under the right drilling conditions and there is the potential to drill wells below the water table, thereby increasing the well yield (well depth in the saturated zone below the water table is much more influential on well yield than well diameter) and reducing the risk of going dry during the dry season.

The most common manual well drilling techniques are simple sludge and rota sludge. Simple sludge manual well drilling is only applicable in high-yielding, shallow groundwater conditions with minimal rock or hardpan. Where simple sludge manual well drilling conditions exist, it is a highly suitable technique for developing access to irrigation water for smallholders. Rota sludge is required where there is rock or hardpan in the substrate and where well diameters greater than 6 cm are required (e.g., for installation of a rope and washer or other submersible pump). If the rock or hardpan is considerable, rota-sludge manually drilled wells will most likely be too costly for smallholder farmers. However, for deep, high-yielding aquifers without rock or hardpan in the substrate, rota-sludge wells may be economically viable for smallholder farmers.

Although machine-drilled tube wells with motorized submersible pumps shared by several smallholder farmers are technically feasible solutions for accessing groundwater, they often suffer from typical shared facility problems associated with operation and maintenance. Machine-drilled wells are not limited by rocks or hardpans and are capable of much greater aquifer penetration and, consequently, higher yields than manually drilled wells. However, because of the high cost of the drilling equipment and mobilization of the drill rig to the site, machine-drilled wells have to be shared by several smallholders and must be of adequate capacity to irrigate a sufficient area to make them economically viable. The northern Ghana field team did observe one machine-drilled tube well system with a submersible electric pump in northeastern Ghana, but the system was never completed and the electric power grid never reached the well.

Rivers and Reservoirs

Surface water supplies may be large, but individual smallholder farmers are usually confined to working along the banks of streams and rivers, or adjacent ponds, lakes and reservoirs. This is because they cannot afford to transfer water very far or up long steep slopes. Important characteristics of natural surface water supplies are their dependability as well as their proximity and elevation relative to the plots to be irrigated.

Small reservoirs, typical of northern Ghana, are community-scale rainwater harvesting systems. These may or may not have functioning outlets. Even without functioning outlets, small reservoirs provide access to water for irrigation by pumping directly from the reservoir, siphoning water over the dam and pumping from the groundwater recharged by the reservoir. Reservoirs are multiple-use water systems. Thus, when planning to access water for irrigation from a reservoir, it is important to calculate the land area that can be irrigated from the water in the reservoir without adversely affecting other existing uses and effectively manage water use from the reservoir.

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156 *Rapid Assessment of Water Availability and Appropriate Technologies for Small-scale Farming: Guidelines for Practitioners*. Andrew Keller, Elizabeth Weight and Stuart Taylor. 2013. (Also available in French)

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152 *Investing in Agricultural Water Management to Benefit Smallholder Farmers in Ethiopia. AgWater Solutions Project Country Synthesis Report.* Alexandra E. V. Evans, Meredith Giordano and Terry Clayton (Editors). 2012.

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