



Upscaling Lowland Rice Production to Improve Food Security through Improved Solar Powered Irrigation Practices

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SPIS Configurations Report

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Acronyms and Abbreviations

AfDB	African Development Bank
AIICO	Agriculture Infrastructure Investment Company
AWD	Alternate Wetting and Drying
CAC	County Agriculture Coordinator
CAO	County Agriculture Officer
CARI	Competitive African Rice Initiative
CHAP	Community of Hope Agriculture Project
CTCN	Climate Technology Centre and Network
DAO	District Agriculture Officer
DOA	Department of Agriculture
EIA	Environmental Impact Assessment
EPA	The Environmental Protection Agency of Liberia
FAO	Food and Agriculture Organization of the United Nations
FED	Food and Enterprise Development Programme
FUN	Farmer Union Network
GAP	Good Agricultural Practices
GIS	Geographic Information System
LIGIS	Liberia Institute of Geo-Information Services
M&E	Monitoring and Evaluation
MoA	Ministry of Agriculture
NDE	National Designated Entity
NGO	Non-Governmental Organisation
PV	Photovoltaic
RAC	Region Agriculture Coordinator
SPIS	Solar Powered Irrigation Systems
SRI	System of Rice Intensification
SWG	Stakeholder Working Group
TA	Technical Assistance
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization (UNIDO)
USAID	United States Agency for International Development
WAAPP	West Africa Agricultural Productivity Program
WARDA	West Africa Rice Development Association
WUA	Water User Association

1. Executive Summary

1.1. Background

Agriculture is a major sector of Liberia employing more than 70% of the population. However, Liberia's agriculture system is predominantly rain-fed, with heavy dependence on consistent rainfall, and climate change is posing serious challenges to all sectors and is threatening the sustainability of agricultural production. This is happening prior to Liberia recovering from 14 years of civil conflict, global recession, Ebola, and now the COVID-19 pandemic.

In response, the adoption of Solar Powered Irrigation Systems (SPIS) and a System of Rice Intensification (SRI) is being investigated to increase rice yields whilst lowering water usage. Potential benefits of adopting this irrigation technology includes guaranteeing yields in an increasingly dry climate, where there is a lack of natural soil moisture, and reducing energy consumption as a climate change mitigation; whilst also reducing water consumption and avoiding the production of CO₂ and pollution from fossil fuel driven pumps.

1.2. Objectives and Scope of this Report

Against this background, the objective of the Technical Assistance (TA) is to introduce SPIS technology and SRI practices to increase rice production in one lowland county in Liberia (Selected as Bong County), with the intention of later upscaling at a national level. To achieve this, the TA is divided into six outcomes, as follows:

- Outcome 1: Analyse the current irrigation and rice cultivation practices in one county of Liberia
- Outcome 2: Design appropriate irrigation and solar water pumping technologies for SRI based farming in the selected county
- Outcome 3: Select an appropriate SPIS technology
- Outcome 4: Pilot a small-scale implementation of the solar pumping system in the selected county
- Outcome 5: Elaborate and disseminate training materials and workshops
- Outcome 6: Formulate an enabling environment roadmap and a M&E framework.

This report provides an update on work conducted to provide Outcome 2 and Outcome 3, covering six activities.

1.2.1. Outcome 2: Design appropriate irrigation and solar water pumping technologies for SRI based farming in the selected county

SPIS are relatively complex irrigation systems and require a detailed understanding of the water requirements and irrigation calendar for rice crop production (Demand Side), matched with the energy production and pumping requirements (Supply Side), which are also dependent on the choices of irrigation layout and application systems to suit the SRI method of production.

Data was obtained from the selected site(s) in Bong County for the calculation of crop water requirements and design of irrigation infrastructure, based on an assessment of the climate and water demands for rice production, accounting for SRI practices, as well as the soils and topography at the selected site, and the skills, knowledge and commitment of the farmers.

At the same time, data was obtained to adequately size the PhotoVoltaic (PV) energy and pump system to match the water demands and irrigation schedule with an efficient and effective array of solar panels, pump and control systems.

Various configurations of the SPIS were prepared to define appropriate options and technology choices most suited for SRI cultivation in the selected county in Liberia.

1.2.2. Outcome 3: Select appropriate SPIS technology

The various SPIS configuration options have been defined and elaborated in a series of Fact Sheets (See Appendices), presenting the key information and cost estimates that will enable stakeholders to understand and choose the most appropriate technologies for their different situations.

The range of configurations were presented to the Stakeholder Working Group (SWG) at a one-day workshop, at which the preferred option for the pilot SPIS scheme at Bong Mines was agreed.

Following the workshop, the selected technology was presented to a wider audience of stakeholders and farmers at a 3-hour stakeholders' workshop at Bong Mines, the selected site for the pilot scheme.

1.3. Water Demands Data

The report brings together information on the location, water resources, climate, soils and crop specific parameters for SRI based farming at the selected pilot scheme site in Bong County, for analysis to calculate the irrigation water demands for rice production and design of appropriate irrigation and solar pumping technologies. The selected site for the pilot scheme is located at Bong Mines, which experiences a tropical monsoon climate, with a rainy season between mid-April to the end of October and a dry season from November to April. The annual average rainfall is 2030 mm with a maximum of 384 mm occurring in September and minimum of 20 mm in January. Bong County is well endowed with water resources, but in the lowland areas, along valleys and floodplains, these water resources frequently recede during the dry season, with little available for irrigation. However, at Bong Mines there are scattered reservoirs and ponds across the area. The topography of Bong County is mostly undulating hill terrain, with the lowland flat valley floors, while the landscape at the pilot scheme site, has been significantly altered by mining operations and a large expanse of level lands created by the tailings dams, which have since been developed for agricultural production, with field drainage ditches. Figure 1-1 shows the pilot scheme area, water source and field layout.



Figure 1-1 - Selected Site - Bong Mines A

Variability in land levels within a field has an effect on rice crop management and crop yields and levees of sufficient height and soil density are required to maintain the water at the desired level in the fields and reduce seepage through to adjacent dry areas. The pilot scheme will make optimum use of the existing field layout and bunding, and the farming community will provide any additional labour to create new field structures.

In the lowland areas of the county, alluvial soils are present and are highly fertile, while at Bong Mines the soils are less fertile, with a shallow layer, rich in organic matter, overlying sandy soils resulting from the mine tailings operations; however, both are commonly utilized for rice production. Samples of both water and soils from the proposed pilot scheme site were taken for analysis and the results used in the analysis.

Rice cultivation in Liberia is presently restricted to the rainy season, except in a few small pockets, where water sources have been used for irrigation, and yields are approximately 1mt/ha, which is comparatively low. Longer crop growing periods require higher water demands, with the general rule that rice requires approximately 10mm of water per day, significantly more than other crops.

A summary of the data collected and required for the water demand analysis for the SPIS design is presented in Table 1-1. Unavailable data has been replaced with best assumptions and identified as areas for future research and development for the enabling environment roadmap.

Table 1-1 - Summary of Available/Required Data

Data Requirement	Current availability/Additional data required/Recommendations for the future
Location and altitude	<ul style="list-style-type: none"> • GPS location and satellite imagery provide extent of existing fields, latitude, longitude and approximate altitude • Distance (in km) of site from markets in county capital and Monrovia • Main access routes to site and their condition.
Climate	<ul style="list-style-type: none"> • Limited climate information (Liberia Meteorological Service, LMS) • Eight out eleven Automatic Weather Station (AWS) are operational, but none transmit data - No stations close to the proposed project site • Approximations used from FAO ClimWat and other public sources.
Water Resources	<ul style="list-style-type: none"> • Limited Hydrological Services (Liberian Hydrological Service, LHS) • Reliance on indigenous knowledge of which river(s)/stream(s) are perennial or non-perennial • Maximum and minimum flow levels in river(s)/stream(s) in the project area • Available quantity of surface water prior to onset of dry season • Establishment of hydrometric station on relevant river/stream • Extent of inundation during flooding • Groundwater data from existing boreholes/wells.
Soils	<ul style="list-style-type: none"> • Limited existing data on soils and geological maps of areas • Composite soil sample test results • Soils map of site.
Topography	<ul style="list-style-type: none"> • Limited detailed topographical maps of areas • Reliance on indigenous knowledge of water flows across fields • Topographical map of site to convenient scale for design of infrastructure.
Field preparation	<ul style="list-style-type: none"> • Previous land operations (Mining and agriculture), established field boundaries and basin borders. • Accurate land levelling requires deployment of laser-levelling equipment in the plots/basins.
Crop Data	<ul style="list-style-type: none"> • Limited data on practices, inputs, yields and incomes • Present cropping pattern within the project area.

1.4. Water Requirements (Demand Side) Analysis

The analysis follows the Food and Agriculture Organisation (FAO) guidelines and uses FAO CropWat software to develop the proposed irrigation demands and schedules. The Crop Water Requirement (CWR) is calculated as the quantity of water required by a crop to meet the demands of evapotranspiration (ET), dependent on the growth stage and climate, and the metabolic activities of the plants, plus any losses during the application of irrigation water, dependent on the method, and the quantity of water required for special operations, such as land preparation, transplanting, leaching etc. The Irrigation Requirement (IR) to be provided by the pumps is the balance remaining of the CWR after any Effective Rainfall (ER) and any contribution from the soil root zone have been

deducted. This water demand also allows for the conveyance and application efficiencies associated with losses in the supply and distribution systems and the application method; the irrigation efficiency ranges from 40-80% depending on the chosen technologies. Rice also requires water for land preparation (from 200 - 400 mm) and for nurseries (about 50 mm).

Considering the adequate rainfall during the wet season, rice is the recommended crop for the first season (April-August), with a second crop possible (September-January) utilising the residual moisture in the soil, together with supplemental irrigation, provided by the SPIS. A third crop (February-April) may also be grown, subject to the availability of water and depending on the market demand, and farmers' needs. Under the SRI practice of Alternate Wetting and Drying (AWD), the fields at the pilot scheme will be irrigated every 4-5 days to account for the high permeability of the sandy soils.

1.5. Pumping Requirements (Supply Side) Analysis

Based on the available data and assumptions, the water demands required for the proposed cropping pattern are summarised in the following table, which will be used to define the energy demand for solar irrigation, the PV capacity required, and the type of pumps, specifications and functionality.

Table 1-2 - Monthly Irrigation Requirements

Water requirements	Unit	Crop 1 (Rice)	Crop 2 (Rice)	Crop 3 (Vegetable*)
Jan	m ³ /ha/day		34.56	
Feb	m ³ /ha/day		21.60	
Mar	m ³ /ha/day			0
Apr	m ³ /ha/day			0
May	m ³ /ha/day			0
Jun	m ³ /ha/day	87.26		
Jul	m ³ /ha/day	0		
Aug	m ³ /ha/day	0.86		
Sep	m ³ /ha/day	0		
Oct	m ³ /ha/day	0	25.92	
Nov	m ³ /ha/day		71.71	
Dec	m ³ /ha/day		25.06	

1.6. SPIS Configurations Options

The SPIS comprises two main components of infrastructure; the Irrigation System and the Electrical System. The Irrigation System refers to the manner in which water is supplied and distributed to the fields (Conveyance) and how it is then applied to the crops (Application), while the Electrical System of PV panels, support structures, control electronics and pumps provides the energy to deliver the water.

The types of Irrigation System and the infrastructure requirements are described in the report, including the conveyance options of gravity-fed open channels or pressurised pipes, and a hybrid system is selected for the pilot scheme, involving pumping water through a relatively short supply pipeline, from where it is conveyed by gravity in an open channel to the fields. Various methods of irrigation application were considered, including surface/flood, overhead/sprinkler, drip and sub-surface irrigation, and the surface/flood method was selected by the SWG for the pilot scheme. It was recommended that the research potential of the pilot scheme could be maximised with part of the scheme under surface/flood irrigation and part under more efficient drip systems, but it was agreed this technology had limited success in the region.

Additional considerations for the irrigation system are described in the report, including night-time irrigation, fertigation, herbigation, automatic controls and elevated storage, but the SWG agreed that the pilot scheme should start with the simplest and most affordable system.

The Electrical System options, comprising the PV and pumping configurations, were considered, including Multi-Use Systems, Mini Grids and Hybrid Systems, but the simplest option of Direct Pumping was agreed to be the most appropriate. This system includes PV panels, a Maximum Power Point Tracking (MPPT) device and pump controller, providing power to a variable speed motor and pump, and a volume meter to record usage and potentially charge the farmer on a volume basis. It is the most widely used configuration and can achieve water to wire efficiencies of more than 50%.

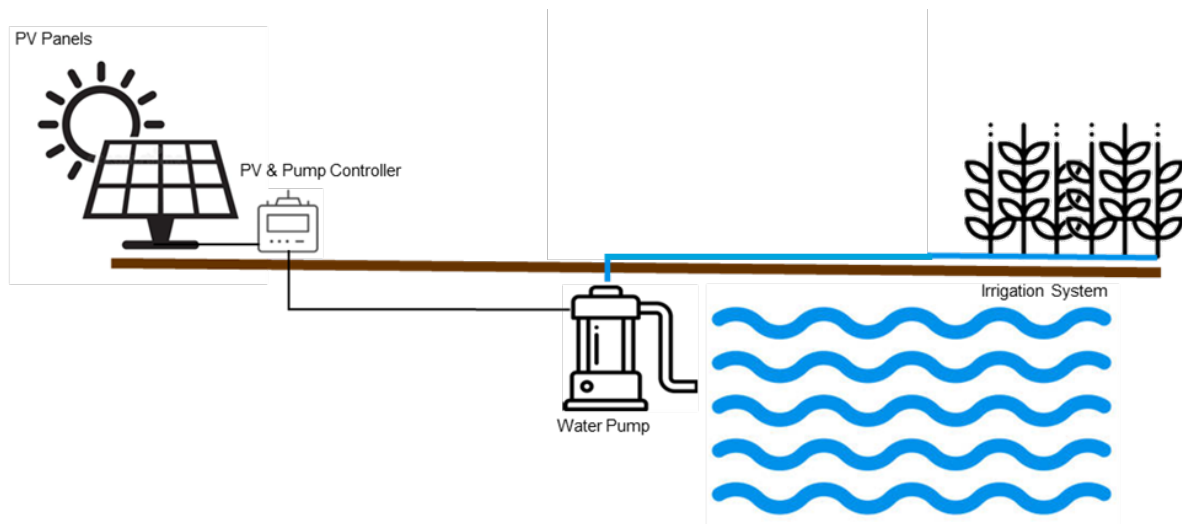


Figure 1-2 - Selected SPIS Configuration - Direct Pumping, No Storage, Surface Irrigation

The options for battery storage have also been reviewed, but since the SPIS would be primarily run during daylight hours, the value addition for inclusion of batteries was considered marginal. However, the option for future uses for other productive activities, such as rice milling, was considered appropriate and the electrical systems will be designed to provide this flexibility.

1.7. Financing and Payment Options for Nationwide Roll-out

A number of options for Ownership, Capital Financing and Payment have been described in the report, with a view to developing a roadmap for the nationwide roll-out of SPIS across the country. These will be further developed in later activities.

1.8. Options to Improve / Adapt to Gender and Youth Needs

At the sites visited to date and selected for the pilot scheme, women's and youth participation in the farmer-based organisations has been significant (over 50%), a figure which clearly indicates the vital roles of women and youth in smallholder farming. The participation of women and youth will continue to be documented throughout the project and their influence on the successful outcome of the pilot maximised.

1.9. Conclusions & Recommendations

1.9.1. Pilot Site Selection

Following the initial reconnaissance site visits further visits to a number of proposed sites in Bong County were undertaken and data was collected on the key characteristics of these sites in order to make an assessment of their suitability for the pilot scheme. Based on the predetermined selection criteria approved by the SWG, not all

the selection criteria could be achieved, but the site at Bong Mines A was identified as the best and proposed as the most suitable for the pilot scheme. This was agreed at the SWG workshop and the Team revisited the site to re-confirm the selection, analyse various cropping patterns and varieties, and meet with a large group of farmers and stakeholders to outline the proposals for the pilot scheme and initiate a process of engagement that will continue through to the end of the TA. Other discussions with FAO and BRAC International resulted in expressions of interest to support the pilot scheme at Bong Mines, with training and supply of good quality rice seed and other agro inputs.

1.9.2. Configuration Selection

The SPIS configuration options, including the key components of the Electrical, Irrigation and Agriculture Systems outlined in this report, were presented and discussed at a workshop with the SWG members. It was noted that, whilst the choice was dependent on multiple factors, including available water resources, soils, crop/variety and agricultural production processes, climate and other potential energy uses, the predominate factor was the farmers' level of skills and the available budget. Therefore the simplest and cost effective configuration was agreed to proceed to the next stage of implementation.

2. Introduction

2.1. Background

Liberia is a small West African state with borders in the north with the Republic of Guinea, in east with Ivory Coast, in the west, with Sierra Leone and in the south with the Atlantic Ocean. The total land area is estimated at 11,137,000 ha (Food and Agriculture Organization of the United Nations (FAO), 2002). In 2002, the total cultivated area (arable land and area under permanent crops) was estimated at 600,000 ha. The arable land (annual crops) estimated at 380,000 ha and the area under permanent crops accounted for 220,000 ha. The population estimated in 2008 by Liberia Institute of Geo-Information Services (LIGIS) was 3.5 million people, of which 52% lives in rural communities with the population density of 31 inhabitants per km².

Agriculture is a major sector of Liberia's economy, employing more than 70% of the population, with the majority of the rural population dependent on food crop production as their source of livelihood and income generation. However, agriculture in Liberia is predominantly rain-fed, with heavy dependence on consistent rainfall, and climate change is posing serious challenges to the sector, threatening the sustainability of agricultural production in the country. Recent data, obtained by the Environmental Protection Agency of Liberia (EPA), shows that warmer temperatures are affecting food crops production and impacting livestock as well¹. Farmers provide anecdotal evidence about the fluctuation in rainfall patterns, with observations showing that May and June are wetter than expected and implications for farm productivity. May and June are predominantly used by farmers for planting, especially those engaged in upland agriculture, and the excess rains during this time of the year can wash away plant seeds and sprouting plants, leading to low productivity (EPA, 2019). Similarly, as a result of prolonged dry seasons, there is a trend to change the farming calendar and move to lowland areas where there is longer access to water resources (The Environmental Protection Agency of Liberia (EPA), 2019).

These impacts are becoming apparent as Liberia is still recovering from 14 years of the civil conflict, which ruined some major agricultural infrastructure (e.g. farm electricity supplies), and coupled with the global recession, Ebola and COVID-19. Prior to the war, there were estimates about the irrigation potential in the country (FAO, 2004), but today there is little information about full or partially controlled irrigation (e.g. surface, sprinkler and localized irrigation) or the percentage of areas irrigated from groundwater or from surface water.

In response, the Government of Liberia is investigating the adoption of Solar Powered Irrigation Systems (SPIS) and Systems of Rice Intensification (SRI) in the country. These technologies aim to address the high cost of electricity and potential for pollution and CO₂ emissions from the alternative fossil fuel driven pumps, and to increase rice yields whilst lowering water usage by applying crop-targeted drip irrigation. SPIS should ensure sustainable use of the limited available surface and ground water resources, and minimise the impact of climate change on developing agriculture in Liberia.

Rice is Liberia's staple food, but over 80 percent of the country's rice needs are imported at a cost of about US\$ 80 million a year, and the population is growing, increasing this demand. Overall agricultural productivity, including rice, is low because of poor facilities; a lack of basic infrastructure, including agricultural machines, farming equipment and tools, farm-to-market roads and food storage capacity, as well as inadequate use of fertilizers and pesticides. However, results from projects and demonstrations indicate a large potential for improving local production (FAO 2021). FAO's Integrated Sustainable Rice System Development Project worked to enhance water availability combined with the application of Systems of Rice Intensification (SRI) best practices and provision of improved rice seeds, and enabled the beneficiary farmers to boost their yields, as well as to increase rice intensity from one to two crops per year.

¹ Historical climate change scenarios suggest increased average annual temperatures of 0.8°C throughout the country, and a 15.7% increase of hot nights which lead to a decline in mean annual rainfall.

This Technical Assistance project seeks to further this experience by supporting lowland rice production through SPIS irrigation technology, coupled with SRI.

2.1.1. Solar Powered Irrigation Systems (SPIS)

Irrigation is the most climate-sensitive use of water; the yields and profitability of irrigated land relative to dryland farming tend to increase as conditions become hotter and drier. The potential benefits of adopting SPIS technology in the agriculture sector include:

- Safeguarding yields of agricultural crops in an increasingly dry climate; as projected future dry conditions lead to depleted levels of natural moisture in the soil.
- Reducing water and energy consumption for irrigation needs, as an adaptation to climate change and as a driver towards more sustainable energy sources and reduced carbon footprint from fossil fuels.

2.1.2. Systems of Rice Intensification (SRI)

There are large variations in rice yields in Liberia, dependent on the interaction between genotype (choice of rice cultivar), environment (soils, water, etc.) and management, including both the biophysical side (e.g. nutrient management and irrigation) and the socio-economic and cultural side (e.g. land tenure, labour allocation, market and cultural value of different cultivars). Variety selection and nutrient management are important variables within the cultural management, but yield differences among rice farmers in the same locality and with the same varieties indicate the effects of different farmer management practices in their fields. Improving these management practices almost always leads to increased yields and this is the focus of Systems of Rice Intensification (SRI).

SRI is not a prescribed set of practices, but a context-specific basket of practices for intensification of rice farming, which entails both the agro-ecological and socio-economic context and their mutual interplay. The majority of Liberian farmers are smallholders and small farmers tend to prefer to minimise risks rather than maximise yield (Richards 1985), while local varieties and local resource-based methods are often better suited to risk situations (Rijal and Synnevag 2005); therefore it may be better to look at the practices in individual farmers' fields, allowing for the possibility that farmers adopt SRI-like practices (or a subset of them) in some fields, whereas they do not adopt (or discontinue earlier adoptions) in other fields². Such practices may then subsequently understand in the framework of larger-scale processes of agricultural intensification and the mechanisms shaping agricultural intensification.

In Liberia, the use of chemical fertilisers, improved seeds and other modern inputs by small farmers continues to be low. Most of the agricultural research organisations focus on variety development and cost effectiveness of external inputs. However, studies have shown that most of the benefits of such research findings go to rich farmers instead of poor farmers (Griffin 1976; Pearce 1980). Under such conditions, alternatives that rely on lower external inputs would be attractive to resource-poor farmers, especially if the lower inputs can still result in high yields.

SRI is a farm-based method developed in Madagascar for rice cultivation and is characterised by five major components:

- Transplanting of younger seedlings at the 3rd leaf stage (8-15 days), without transplanting shock (With the 4th leaf, rice plants starts tillering, so transplanting is better before tillering starts).
- Wider spacing (Generally 25 x 25 cm or 20 x 20 cm for short duration varieties)
- Alternate wetting and drying system of irrigation for soil aeration during the vegetative stage
- Better weed management, including early first weeding and a second weeding 15-20 days later

² Berkhout and Glover (2011) recommended investigation both of the reasons why different farmers or farmers belonging to different communities and regions are more or less likely to adopt particular SRI methods or why these farmers apply them on certain fields or in particular seasons. Noltze et al. (2012) conducted a study in Timor Leste on SRI adoption. They regarded SRI as a location-specific package of practices. A combination of both analytical approaches may be advantageous.

- Improved nutrient management, particularly the addition of organic matter (manure and/or compost).

a. Transplanting Younger Seedlings

There are several studies (Barison, 1997; Makarim et al., 2002; Menete et al., 2008; Pasuquin et al. 2008; Manjunatha et al. 2010) that reported positive effects of transplanting younger seedlings on rice yield. Menete et al. (2008) also reported different levels of effect of young seedlings on different varieties.

b. Spacing

Spacing is another important area of rice cultivation practice, with several studies (Laulanie, 1992) finding that 25x25 cm spacing is better for highland and 40x40cm for lower-altitude fields near the coast. Plant spacing wider than 25x25 cm was not found to be beneficial (Barison, 1997 and Rajaonarison 1999) and 40x40 cm resulted in much lower yields (5.10 t/ha), with the best yields of 7.53 t/ha at 25x15 cm (Latif et al, 2005; 2009). Similarly, Ceasay et al. (2006), Thakur et al. (2010), and Mishra and Alokhe (2010) found higher yields at 20x20 cm spacing³. However, Uprety (2011) suggests that the best spacing is dependent on variety and soil fertility, with long-duration and high-tillering varieties performing better in wider spacing (30x30cm) and fertile soils, but some modern short duration (low-tillering) varieties performing better with close spacing (20x20cm).

c. Alternate Wetting and Drying (AWD)

Water management is critical for rice production, which is a major user of fresh water; IRRI researchers carried out extensive research on rice cultivation systems that could save water with increasing water productivity (Belder et al., 2004; Belder et al., 2005; Bouman et al., 2006), through Alternate Wetting and Drying. Significant water savings have been reported with higher yields by these methods (Vijayakumar et al, 2006, Zhang et al, 2007, Zhao et al, 2009 and Thakur et al, 2011), although the water-saving and water productivity improvements may only be possible when combined with effective weed management (Krupnik et al. (2010).

d. Weed Management

Better weed management can increase rice yields (Anitha and Chellappan, 2011); particularly weeding by cono-weeder, which gives a higher yield than manual weeding. Efficient weed management further increases yields of rice grown under SRI, due to the wider spacing and AWD system of irrigation. Several studies reported weed management as a critical part of SRI method (Yadao and Zamora, 2007; Krupnik et al., 2010, Uprety, 2011), with the greatest benefit achieved by early first weeding after transplanting (Laulanie, 1993).

e. Nutrient Management

Besides seedling and transplanting related practices, improved nutrient management is another important aspect of rice cultivation that can enhance the improvements of the other SRI practices above⁴. Long-term, indiscriminate use of chemical fertilizers has negative effects on crop yield and overall soil fertility and location-specific nutrient management the use is recommended (IRRI, Doberman), with several studies reporting the benefits of organic manure on rice yields (Bhattacharya et al., 2003; 003; Sahrawat, 2004; He and Ma, 2005; Nayak et al., 2009; Tsujimoto et al., 2009).

2.2. CTCN Response

The Climate Technology Centre and Network (CTCN) is the operational arm of the United Nations Framework Convention on Climate Change (UNFCCC) Technology Mechanism and co-hosted by the United Nations Environment (UN Environment) in collaboration with the United Nations Industrial Development Organization (UNIDO) and supported by 11 partner institutions with expertise in climate technologies. The mission of the CTCN

³ A further study conducted in China found the medium-range planting density (90,000-120000 hills/ha) better than low (40,000 hills/ha) or high density (Wu et al., 2005; Bao et al., 2008).

⁴ During a study conducted in Nepal, Dhungana et al. (2004) found that less efficient farmers used more urea (nitrogenous fertilizer).

is to promote accelerated development and transfer of climate technologies at the request of developing countries for energy-efficient, low-carbon and climate-resilient development.

A request for Technical Assistance (TA) was submitted to the CTCN by the National Designated Entity (NDE) of Liberia, Mr. Christopher B. Kabah TNA National Coordinator Environmental Protection Agency (EPA) of Liberia.

2.2.1. Technical Assistance Basic Information

The Technical Assistance (TA) Basic Information is provided in Table 2-1 below.

Table 2-1 - Technical Assistance (TA) Basic Information

Basic Information	
Title of Response Plan	Upscaling Lowland Rice Production to improve food security through improved solar powered irrigation practices
Technical Assistance Reference Number	AFCIA 2021000017
Country / Countries	Liberia
NDE Focal Point and Organisation	Mr. Christopher B. Kabah TNA National Coordinator Environmental Protection Agency of Liberia kabahchristopher@gmail.com
Sector(s) Addressed	Renewable Energy
Technologies Supported	Solar Powered Irrigation Systems (SPIS) i.e., solar water pumps with crop-targeted drip irrigation system.
Implementation Period and Total Duration	22/11/2021 - 17/02/2023 (14 Months)
Total Budget for Implementation	USD 233,825
Designer of the Response Plan	CTCN
Implementer of Response Plan	CARES Limited and INTEGRATION environment & energy GmbH

2.2.2. Objectives

The objective of the TA is to introduce solar powered irrigation technology and practices to intensify rice cultivation and production in one lowland county in Liberia, to be selected between Lofa and Bong, with the intention of upscaling the technology as an adaptation measure to climate change at a national level. To achieve this objective, the TA has been divided into six main outcomes, as follows:

- Outcome 1: Analyse the current irrigation and rice cultivation practices in one county of Liberia
- Outcome 2: Design appropriate irrigation and solar water pumping technologies for SRI based farming in the selected county
- Outcome 3: Select an appropriate SPIS technology
- Outcome 4: Pilot a small-scale implementation of the solar pumping system in the selected county
- Outcome 5: Elaborate and disseminate training materials and workshops
- Outcome 6: Formulate an enabling environment roadmap and a M&E framework.

2.2.3. Scope of Work

The detailed scope of work is outlined in the following outcomes and activities:

Outcome 1: Analyse the Current Irrigation and Rice Cultivation Practices in Liberia

- Activity 1.1: Map relevant stakeholders and establish a stakeholder working group.
- Activity 1.2: Conduct a virtual inception meeting
- Activity 1.3: Diagnose current irrigation system in Bong and Lofa

- Activity 1.4: Select best pilot sites between Bong and Lofa
- Activity 1.5: Benchmark international best irrigation practices in SRI from countries with similar socio-economic, geographic and climatic conditions
- Activity 1.6: Identify challenges and requirements in the context of irrigation and rice cultivation practices, taking into account specific barriers for women and youth

Outcome 2: Design Appropriate Irrigation and Solar Water Pumping Technologies for SRI Based Farming in the Selected County

- Activity 2.1: Gather data to understand the demand side of the fit-for-purpose SPIS
- Activity 2.2: Collect data to define PV pump system and irrigation infrastructure (supply side)
- Activity 2.3: Define the configuration of the SPIS

Outcome 3: Select Appropriate SPIS Technology

- Activity 3.1: Elaborate fact sheets on appropriate technologies for the SPIS configuration defined
- Activity 3.2: Define cost estimation of the identified technologies under the configuration designed
- Activity 3.3: Organize a one-day workshop with the stakeholder working group
- Activity 3.4: Organize a 3-hours stakeholders' workshop to present the selected technology

Outcome 4: Pilot a Small-Scale Implementation of the Solar Pumping System in the Selected County of Liberia

- Activity 4.1: Choose a plot in the selected county for a small-scale pilot implementation of the selected SPIS
- Activity 4.2: Plan the implementation of the pilot project
- Activity 4.3: Organize an online meeting to discuss the logistics and implementation of the pilot
- Activity 4.4: Route the technology to the selected area
- Activity 4.5: Implement the small-scale project in the pilot area

Outcome 5: Elaborate and Disseminate Training's Materials and Workshops

- Activity 5.1: Redact a detailed manual on the use and maintenance of the technology
- Activity 5.2: Organize a learn by doing workshop
- Activity 5.3: Organize a stakeholder consultation workshop
- Activity 5.4: Organise a training to Municipal and National officers

Outcome 6: Formulate an Enabling Environment Roadmap and M&E Framework

- Activity 6.1: Design a M&E Framework
- Activity 6.2: Formulate an enabling environment roadmap to scale up the use of SPIS
- Activity 6.3: Organize a workshop with municipal and national officers to present the M&E and enabling environment roadmap
- Activity 6.4: Train rice farmers on the M&E framework

2.2.4. CARES/INTee Team

CARES are leading the TA assignment and their Team staff involved to date comprise the following members:

- Oliver Taylor (Team Leader / Water Resources Expert)
- Sanco Lysander (Gender Expert)
- Rajendra Uprety (Expert in Rice Production/SRI)
- Pandian Balamurugan (Rice Production Expert)
- George Oboli (Communication Expert)
- Matthew Baker (Environmental Specialist)
- Yaw Asare (Office Manager, Liberia).

Partnered with CARES, INTEGRATION Environment & Energy Team (INTee) provides expertise in technical assistance, focussing on the solar energy and pumping aspects, with the following team members involved to date:

- Yalun Jin (Energy Consultant)

- Muhammad Imran (Expert in Solar Irrigation Pumping System)
- Frankie Eckersley-Carr (Expert in GIS and Data Management)
- Dr Ulrich Frings (Expert in Solar Irrigation Pumping System).

2.3. Report Scope and Structure

The previous SRI Irrigation Report provided an update on work conducted up to Outcome 1, covering six activities. This report provides an update on work conducted to provide the second and third outcomes of the Technical Assistance, as follows:

Outcome 2: Design appropriate irrigation and solar water pumping technologies for SRI based farming in the selected county

Activities undertaken to provide this outcome and the relevant chapter in this report are provided in Table 2-2 below.

Table 2-2 - Activities for Outcome 2

Activity		Chapter(s)
2.1	Gather data to understand the Demand Side of the fit-for-purpose SPIS	3, 4
2.2	Collect data to define PV pump system and irrigation infrastructure (Supply Side)	5
2.3	Define the configuration of the SPIS	6

Outcome 3: Select appropriate SPIS technology

Activities undertaken to provide this outcome and the relevant chapter in this report are provided in Table 2-3 below.

Table 2-3 - Activities for Outcome 3

Activity		Chapter(s)
3.1	Elaborate fact sheets on appropriate technologies for the SPIS configuration defined	Appendix A
3.2	Define cost estimation of the identified technologies under the configuration designed	6
3.3	Organize a one-day workshop with the stakeholder working group	7
3.4	Organize a 3-hours stakeholders' workshop to present the selected technology	7

3. Water Demands Data Requirements

The design of appropriate irrigation and solar pumping technologies, requires data and analysis to calculate the irrigation water demands for rice production. This relates to the location, water resources, climate, soils and crop specific parameters for SRI based farming in Bong County. This Section provides a detailed description of the data required, that which was found to be available and collected, as well as identifying any gaps that will be addressed for the pilot scheme with estimates or where further research or data collection will be required for future SPIS development nationwide. A summary of outstanding data requirements is presented in Table 3-5.

3.1. Location and Altitude

The selected site for the pilot scheme is located at Bong Mines in Bong County, which is one of the third largest counties in Liberia; it is situated in north-central part of the country, with Gbarnga as the capital. It lies in the latitude of 7° 0' N, longitude of 9° 40' W, with a minimum altitude elevation of 186 m and maximum of 566 m.

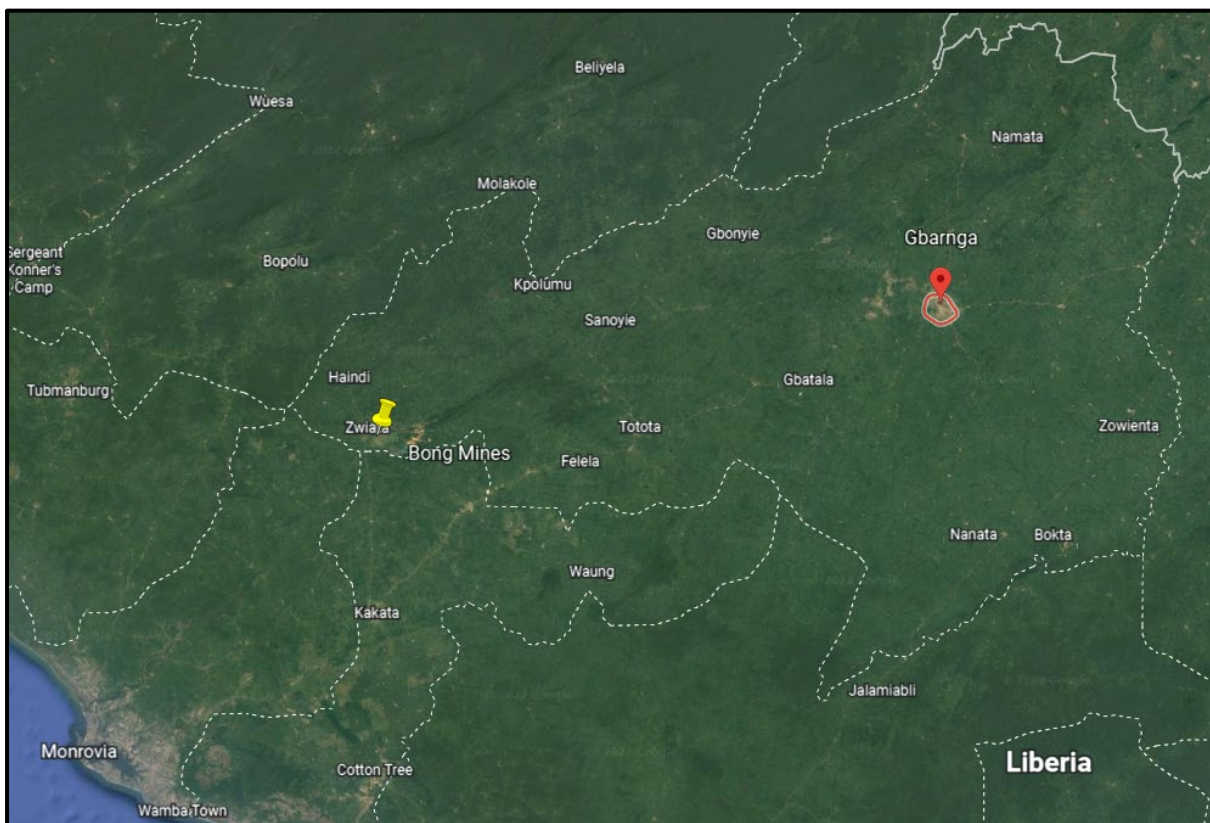


Figure 3-1 - Location Map for Pilot Scheme Site in Bong County

3.2. Climate

Bong county experiences tropical monsoon climate, with two main weather seasons; rainy and dry. The rainy season is uni-modal, with a single peak in rainfall between mid-April to the end of October. The dry season starts in November and ends in April. The average maximum temperature varies from 32.5°C in March to 28.1°C in August and the minimum temperature ranges between 20.3° in November and 17.4° in February. The annual average rainfall is 2030 mm with a maximum of 384 mm occurring in September and minimum of 20 mm in January. Relative humidity reaches 90-100% during rainy season and 60-90% during the dry season. The times for sunrise

and sunset don't differ much in the country because of the proximity to the equator, but the longest day is approximately 12 hrs 30 min, which happens during June.

Table 3-1 - Average monthly weather data for Gbarnga (Bong County)

Month	Min temp (Night °C)	Max temp (Day °C)	Humidity (%)	Wind (km/day)	Ave Daily Sun hours	Radiation (MJ/m ² /day)	ETo (mm/day)	Rainfall (mm)
January	18.7	31.5	69	78	5.3	15.9	3.50	19
February	17.7	32.6	64	78	5.5	17.1	3.86	59
March	18.1	32.5	66	78	5.4	17.7	3.98	152
April	19	32.3	68	78	5.2	17.4	3.93	175
May	19.7	31.5	74	95	4.6	16.1	3.69	199
June	19.3	30.2	72	164	3.6	14.2	3.69	197
July	19.5	28.7	78	199	2.6	12.9	3.32	204
August	18.1	27.5	76	199	2.2	12.6	3.25	159
September	19.6	29.5	68	164	2.7	13.5	3.64	361
October	20.5	30.5	80	112	4.3	15.5	3.42	220
November	21.2	30.5	82	112	5.1	15.7	3.41	98
December	19.7	31.1	78	78	4.2	14.1	3.08	36
Ave/Total	19.3	30.7	72.9	119.6	4.2	15.2	3.56	1879

Source: [FAO ClimWat for Station: SUAKOKO, Altitude: 150 m. Latitude: 7.00 °N Longitude: 9.58 °W](#)

Evaporation is commonly measured by a U.S Class A pan-evaporimeter and depends on climatic conditions, such as temperature, humidity, wind and sunlight hours, while the evapotranspiration of a crop also depends on the soil characteristics and water content, rooting depth and growth stage of the plant. The total evapotranspiration for a rice crop during its entire growing period is between 800 and 1200mm of water, dependent on the variety and length of the growing period.

3.3. Water Resources

Generally, Bong County is well endowed with water resources, with a number of principal rivers and small streams, including the St. John, Mano and Naye rivers, and the Zoi and Yja Creeks. In some lowland areas, spillways have been constructed and these are being used to feed irrigation channels for irrigating crops, especially rice, during the early part of the wet season, when water remains available. However, when these water resources recede, there is little remaining for irrigation during the remainder of the dry season.

Ground water levels in the county are generally shallow, ranging from between 5 - 40 m, but yields are limited for irrigation purposes.

The water resources at Bong Mines are scattered reservoirs and ponds distributed across the area. These were predominantly created during the mining operations as tailings dams and they fill naturally during the rainy season from water run-off arising in their associates catchment areas.

A water sample from the selected pilot scheme site at Bong Mines was analysed at the Water Research Institute, Environmental Chemistry Division in Accra, Ghana, with the results shown in the following table.

Table 3-2 - Water Sample Analysis from Bong Mines (Bong County)

Parameter	Method No.	Unit	Value	GS 175-1	WHO Guideline
pH	4	pH Units	6.74	6.5-8.5	6.5-8.5
Conductivity	1	µSiem	3.84	-	-
Calcium	23	mg/l	0.160	200	200
Magnesium	26	mg/l	0.389	150	150
Total Iron	31	mg/l	<0.010	0.3	0.3
Chloride	24	mg/l	<1.00	250	250
Bicarbonate (as Ca(HCO ₃) ₂)	22	mg/l	1.22	-	-
Carbonate	22	mg/l	0.00	-	-
Aluminium	-	mg/l	<0.001	0.20	0.20

These results indicate that the pH and EC are in suitable range for irrigation, whilst other elements, particularly Iron and other cations and anions value are almost negligible.

3.4. Soils

The soils across Liberia are diversified, with Latosols occurring in areas of rolling countryside, covering about 75% of the total land area, which have low to medium fertility; Lithosols found in hilly and rugged terrain, covering approximately 12.5% of land area, but generally shallow and coarse; and Regosols or sandy soils found along the coastal plains, which are mostly infertile due to their lack of organic content and free draining texture.

In the lowland areas in Bong County, along valleys and floodplains, alluvial soils are present and are highly fertile and therefore commonly utilized for agriculture. Generally, these soils have low to medium levels of Nitrogen, medium levels of Phosphorus and high levels of potassium, and the water holding capacity is high because of an impervious layer formed by the clay portion of the soil. However, these areas represent only a small percentage of the total land area and most of the lowland areas visited by the Team had severely limited water resources during the dry season (Ref. SRI Irrigation Report, April 2022).

The sites identified for the pilot scheme at Bong Mines were preferred because of the readily available water supplies; however the soils are less fertile, with a shallow layer, rich in organic matter, overlying sandy soils resulting from the tailings operations, which will likely be subject to high water losses through infiltration and deep percolation.

The amount of water that is lost through deep percolation below the root zone of the crop is dependent on:

- Soil type - Soils that have a high clay content to a depth will have much lower permeability than sandy soils.
- Presence of a restrictive layer or hard pan in the soil profile - Puddling will help to form a hard pan or restrictive layer in most soil types, which will reduce deep percolation.
- Depth of water in the field - Increasing the depth of water in the field increases the hydraulic pressure, which forces more water into the soil profile.
- Depth of the water table.

As in lowland areas, there is frequently a shortage of available Nitrogen during the initial stage of crop growth due to improper land preparation, leading to Nitrogen shortage. There is also a concern with iron toxicity generated from the iron ore workings.

All top soils can be subject to severe erosion due to the intensity of rainfall in the rainy season and where there is steep and undulating terrain. Generally, rice is grown in flat, lowland areas and rarely in upland locations, since the yield potential of upland varieties is relatively low, due to the soils and limited water.

Soil samples were taken from the selected sites at Bong Mines and a composite sent for analysis at the University of Ghana, Department of Soil Science, with the results shown in the following table.

Table 3-3 - Soil Sample Analysis from Bong Mines (Bong County)

Physical Properties - Textural analysis			
Sand %	Silt %	Clay %	Textural Class
81.0	6.5	12.5	Sandy Loam
Chemical Properties			
pH (1:1)	5.23	EC (dS/m)	0.29
C (g/kg)	6.10	N (g/kg)	1.05
NH₄-N (g/kg)	0.062	NO₃-N (g/kg)	0.084
Avail-P	6.46	Avail-K (cmol/kg)	0.20
CEC (cmol/kg)	8.79	Fe	ND*
Al	ND	Zn	ND

*ND = Not Detected

These test results are much as expected, based on visual assessment at the site. The pH and EC of the soil are within normal ranges and the major nutrients are in the medium to high level, however the clay fraction is at the lower end of the range for rice cultivation and it can be expected that this will increase the water usage and reduce the yield (A minimum clay fraction of 20% would be required for optimal yields). The soils are better suited to vegetable production.

All top soils can be subject to severe erosion due to the intensity of rainfall in the rainy season and where there is steep and undulating terrain. Generally, rice is grown in flat, lowland areas and rarely in upland locations, since the yield potential of upland varieties is relatively low, due to the soils and limited water.

3.5. Topography

The topography of Bong County is mostly undulating hill terrain, with the lowland cultivated areas constrained to the flat valley floors. At the pilot scheme site at Bong Mines, the landscape has been significantly altered by mining operations, with a number of tailings dams formed below the open cast mine workings, which flooded after operations halted in 1990. The large expanse of flat lands created by the tailings dams have since been developed for agricultural production, with an historical project to create an irrigation scheme layout partially completed before the civil war drew it to a close. The satellite image in the following figure shows how the entire area has now been laid out with farm plots and drainage channels; the two potential sites for the pilot scheme are also shown.



Figure 3-2 - Bong Mines Tailings Dams showing the Field Layout and two Pilot Scheme Sites

3.6. Field Preparation

Variability in land levels within a field has an effect on rice crop management and crop yields. Uneven fields require more water to wet the soil for land preparation and plant establishment; uneven water coverage often results in uneven crop stands, weed problems, uneven ripening and uneven yields within each field; typically, each 10mm of variation in the field level reduces grain yield by approximately 280kg/hectare. The average unevenness (i.e., the difference in height between the highest and lowest portions of the field) in typical Asian rice fields averages 160mm, with the range from 70 - 330mm. Whilst the work done to level and develop an irrigation layout at the Bong Mines site had progressed significantly, it is still expected that the unevenness will be wider in the pilot scheme rice fields. This means that an extra 80 - 100mm of water, or up to 10% of the total water requirement to grow the crop, may be needed in the field to attain complete water coverage.

Land preparation systems require water on the soil surface before tillage can commence, as in puddling, and typically use up to 20% of the total water requirement to grow the rice crop. When preparing the land wet, the field should initially be worked dry and water added just before the puddling operation. Between 100 - 300mm of water

is required to saturate and weaken the soil so that machines are able to plough it. Dry land preparation for rice production uses less water than wet land preparation and dry working helps reduce clod sizes, fills the soil cracks and reduces deep percolation of the water.

In addition, levees of sufficient height and soil density will be required to maintain the water at the desired level in the field and reduce seepage through to adjacent fields, which is generally more of a problem in dry season crops. These levees will require regular maintenance to stop water loss through the wall caused by pests and soil cracking in the dry season, while in dry periods water may need to be re-circulated from one field to another to help save the crop.

Finally, the field layout at Bong Mines already includes field drainage ditches. Drainage of water from the field can be very important during crop establishment and high rainfall events. In direct seeding situations, which include nurseries, fields often need to be drained during the establishment stage to improve both the rate and number of plants established. While a growing rice crop can withstand total inundation for short periods, major yield losses will occur if lodged crops are flooded during the grain ripening stage and water cannot be removed because of poor drainage. In most level fields, drains around the periphery of the field will be sufficient to drain off excess water in a timely manner. In large fields and some nurseries, small internal drains running from the centre of the field to the extremities of the field may also be needed.

3.7. Crop Data

The present area of rice cultivation in Liberia is close to 250,000ha and the total production is around 270,000mt; therefore, the productivity is approximately 1mt/ha, which is comparatively low. Most of this production is from upland, with only small areas of lowland rice cultivation scattered in very few counties, and restricted to the rainy season only. Double cropping of rice (i.e. two rice crops per year) is possible in a few small pockets, where water sources are available for supplemental irrigation.

The longer the crop growth period, the higher the water requirement. A general rule is that a rice crop will need approximately 10mm of water per day. Therefore, a crop that matures in 100 days will require approximately 1000mm of water, while a crop that matures in 150 days will require 50% more. In areas that are affected by deep water or surface flooding, later maturing crops may be necessary so that the crop is sufficiently developed and tall enough to withstand the higher levels of water.

The following table compares the typical growing period, rooting depth and water requirement for Rice against other commonly grown crops.

Table 3-4 - Typical Crop Duration, Rooting Depth and Water Requirements

Crop	Growing season (days)	Root Depth (cm)	Water Requirement (mm)	Crop coefficient (kc)	Critical periods of irrigation
Rice	100-130	40-60	900-1500	0.5-1.3	Crop elongation period Jointing period Flowering stage Dough stage
Maize	90-120	180-250	500-800	0.3-1.2	Crop elongation period Jointing period Flowering stage Dough stage
Tomato	60-90	50-60	400-800	0.6-1.25	Crop- elongation Flowering-stage
Cauliflower	55-120	60-100	350-500	0.7-1.05	Frequent irrigation from planting to harvest
Cabbage	60-100	60-100	350-500	0.7-1.05	During head formation and enlargement
Egg plant	100-150	50-60	450-800	0.58-1.05	Booting Flowering Dough stage
Green gram	60-90	20-30	300-400	0.35-1.2	Flower initiation Pod filling
Soya bean	60-120	150-200	450-700	0.4-1.15	Growing stage Pod formation stage
Pea	60-100	60-70	350-500	0.5-1.14	Growing stage Flowering stage
Cowpea	100-120	100-150	400-700	0.5-1.4	Vegetative Flowering Pod filling
Groundnut	100-130	35-40	550-600	0.4-1.15	Growing stage Jointing period Flowering stage Nut-formation stage
Potato	100 - 150	40-50	500 - 700	0.5-1.15	Growing stage Tuber shoot formation Tuberization stage
Sunflower	90 - 120	45-55	900 - 1300	0.35-1.32	Growing stage Before-flowering stage

3.8. Summary of Required Data

A summary of additional data required to complete the water demand analysis for the SPIS design is presented in Table 3-5.

Table 3-5 - Summary of Required Data

Data Requirement	Current availability/Additional data required/Recommendations for the future
Location and altitude	<ul style="list-style-type: none"> • GPS location and satellite imagery provide extent of existing fields, latitude, longitude and approximate altitude • Distance (in km) of site from markets in county capital and Monrovia • Main access routes to site and their condition.
Climate	<ul style="list-style-type: none"> • Limited climate information (Liberia Meteorological Service, LMS) • Eight out eleven Automatic Weather Station (AWS) are operational but none transmit data - No stations close to the proposed project site • Approximations used from FAO ClimWat and other public sources.
Water Resources	<ul style="list-style-type: none"> • Limited Hydrological Services (Liberian Hydrological Service, LHS) • Reliance on indigenous knowledge of which river(s)/stream(s) are perennial or non-perennial • Maximum and minimum flow levels in river(s)/stream(s) in the project area • Available quantity of surface water prior to onset of dry season • Establishment of hydrometric station on relevant river/stream • Extent of inundation during flooding • Groundwater data from existing boreholes/wells.
Soils	<ul style="list-style-type: none"> • Limited existing data on soils and geological maps of areas • Composite soil sample test results • Soils map of site.
Topography	<ul style="list-style-type: none"> • Limited detailed topographical maps of areas • Reliance on indigenous knowledge of water flows across fields • Topographical map of site to convenient scale for design of infrastructure.
Field preparation	<ul style="list-style-type: none"> • Previous land operations (Mining and agriculture), established field boundaries and basin borders. • Accurate land levelling requires deployment of laser-levelling equipment in the plots/basins.
Crop Data	<ul style="list-style-type: none"> • Limited data on practices, inputs, yields and incomes • Present cropping pattern within the project area.

4. Water Requirements (Demand Side)

This chapter presents an analysis to calculate Crop Water Requirements for rice production in Liberia and specifically at the pilot scheme site at Bong Mines. The methodology follows the Food and Agriculture Organisation (FAO) guidelines and uses FAO CropWat software to develop the proposed cropping patterns and irrigation schedules.

Crops need water for transpiration and evaporation processes; the plant roots take water from the soil, releasing most to the atmosphere as vapours through the plant leaves and stem, while retaining some in the plant cells. Transpiration governs the rate of a plant's growth and mainly happens during the daytime, while evaporation occurs as water escapes as vapours directly from the soil surface around a plant, from the plant leaves and the stem. Crop water requirement is the combination of transpiration and evaporation, called evapotranspiration, and irrigation aims to match the amount of water needed by a particular crop to optimise its growth. It depends on climate of the area, the type of crop and the growth stage of the crop.

4.1. Water Requirement of Crops

Crop Water Requirement (CWR) is defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops, in a given period of time of its normal growth, under field conditions at a given place. Water is required to meet the demands of evapotranspiration (ET), which is dependent on the growth stage and climate, and the metabolic activities of the plants. These two demands are together known as consumptive use (Cu). The water required for plant metabolism is generally negligible and hence the water requirement is usually assumed equal to evapotranspiration.

In addition to ET demands, the water requirement also includes losses during the application of irrigation water and the quantity of water required for special operations, such as land preparation, transplanting, leaching etc.

CWR = ET (or Cu) + application losses + special needs

A crop's water requirement can be supplied through precipitation (rainfall or snowfall), through irrigation or a combination of both. During dry periods, it becomes essential to supplement the precipitation with irrigation. Crop Water Requirement can also be described as follows:

CWR = IR + ER + S

Where **IR** = Irrigation Requirement of water at the field, exclusive of effective rainfall and soil profile contribution

ER = Effective Rainfall, which infiltrates the soil and is not lost to evaporation or runoff

S = Soil profile contribution, from the available moisture contained within the root zone

The field Irrigation Requirement can therefore be summarised as follows:.

IR = CWR - (ER+S) = ET + Application losses + Special needs - (ER+S)

4.2. Special Water Needs for Rice

Rice is a semi-aquatic plant and requires large quantities of water for its cultivation. The typical water requirement of rice cultivated under lowland conditions is 1110-1250 mm during the crop growth period, but water is also required for land preparation (varies from 200 - 400 mm depending upon the soil type) and nurseries require about 50 mm.

There are four critical stages in rice plant growth at which water supply is very important; seedling, tillering, flowering and milk dough grain stage. Water supply during the seedling stage helps to keep the soil moist and provides early rooting, while at tillering promotes more tiller production. Watering during panicle initiation and flowering facilitates development of fertile grains and at the final milk-dough stage for filling of grains. The most sensitive stage to

moisture stress is flowering, when a shortage of water may result in sterile spikelets, reducing yields or in the worst case a failed crop.

It is important to maintain optimum depth of water in the field; as the depth of water increases, the plant height increases, resulting in decreased culm strength and the crop tends to lodge. Tiller production is also greatly affected by prolonged stagnation of water.

Under SRI, the rice crop is irrigated by Alternate Wetting and Drying (AWD), whereby the field should be irrigated to a depth of 5 cm, then allowed to dry, and re-irrigated when the ponded water disappears. By adopting this method, there is water saving to the tune of 30-50% compared to continuous submergence wherein water always stagnated in the field.

When continuous submergence is followed, it is also important to drain the field once or twice during the growing period, particularly in poorly drained clay soils. Drainage at maximum tillering stage stimulates vigorous growth of roots and checks the development of ineffective tillers. The drainage period should last for 4-8 days depending upon the soil type.

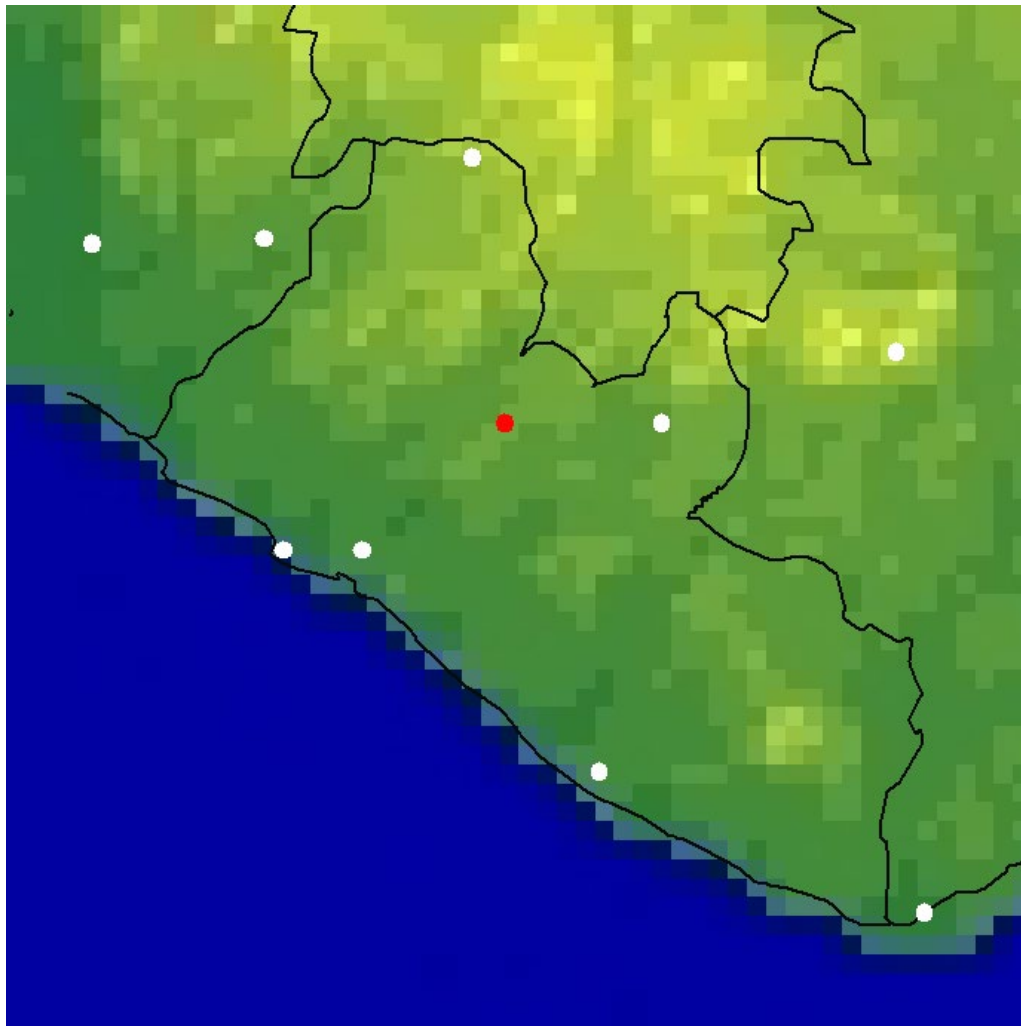
Water must also be withheld two weeks before harvest of crop to hasten ripening of grains and to promote favourable condition for harvesting.

4.3. Computation of Crop Water Requirement

A variety of formulae exist for the calculation of Crop Water Requirement (CWR), among which the Penman Monteith method, as detailed in the FAO Irrigation and Drainage Paper 56, is the most precise. It considers the relevant climatic factors, crop growth coefficients, effective rainfall, etc. CWR is first calculated for a reference crop and then converted to actual crop water needs by using crop coefficients for a certain crop and its different growth stages.

These calculations are encompassed in FAO software CropWat, which has been used to calculate the Crop Water Requirements in Liberia and for the specific pilot scheme site at Bong Mines. Where data is insufficient or unavailable, suitable assumptions and estimates have been used in the calculations, including the acquisition of climate data using FAO CLIMWAT 2.0.

The following figures and tables illustrate the steps followed in the computation process.



Nr.	Lon [°]	Lat [°]	Alt [m]	Name	Country
1	-7.36	4.41	21	TABOU	COTE D'IVOIRE
2	-7.51	7.38	340	MAN	COTE D'IVOIRE
3	-9.08	5.16	5	GREENVILLE	LIBERIA
4	-10.33	6.33	150	HARBEL	LIBERIA
5	-10.75	6.33	12	SPRIGGS-PAYNE-AIR-PORT	LIBERIA
6	-8.75	7	300	SAKLEIPIE	LIBERIA
7	-9.58	7	150	SUAKOKO	LIBERIA
8	-9.75	8.41	300	VOINJAMA	LIBERIA
9	-10.85	7.98	186	DARU	SIERRA LEONE
10	-11.76	7.95	93	BO	SIERRA LEONE

Country Station

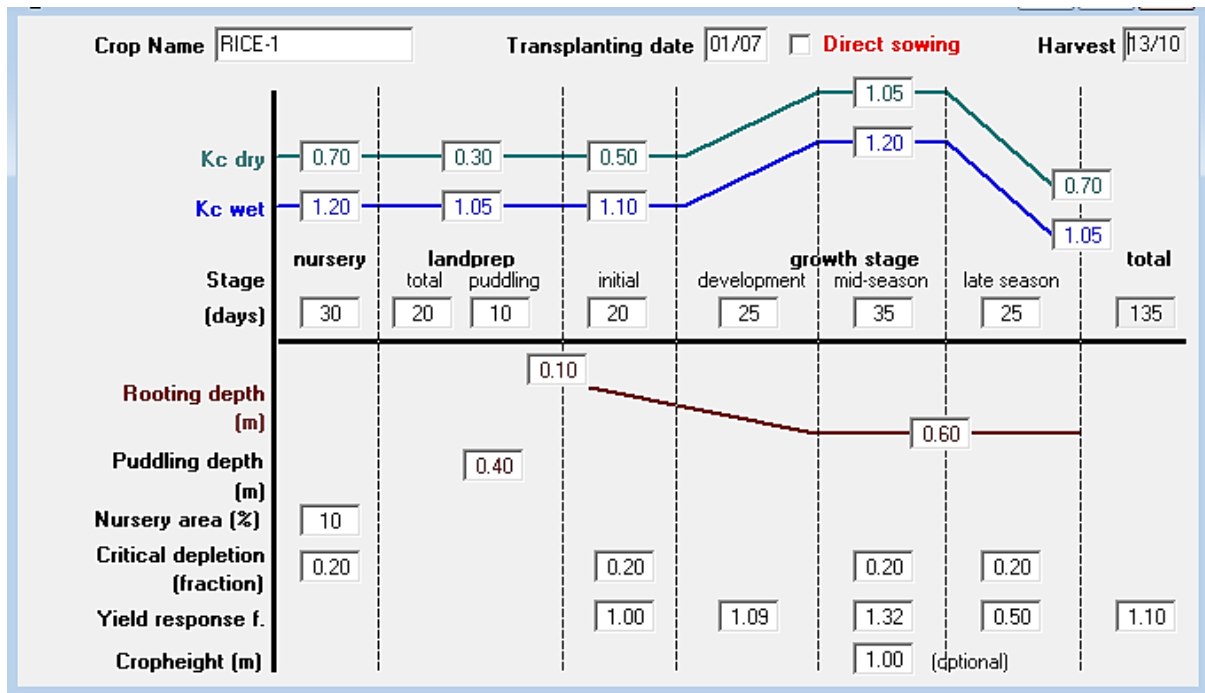
Altitude m. Latitude °N Longitude °W

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m ² /day	mm/day
January	18.7	31.5	69	78	5.3	15.9	3.50
February	17.7	32.6	64	78	5.5	17.1	3.86
March	18.1	32.5	66	78	5.4	17.7	3.98
April	19.0	32.3	68	78	5.2	17.5	3.93
May	19.7	31.5	74	95	4.6	16.1	3.69
June	19.3	30.2	72	164	3.6	14.2	3.69
July	19.5	28.7	78	199	2.6	12.9	3.32
August	18.1	27.5	76	199	2.2	12.6	3.25
September	19.6	29.5	68	164	2.7	13.5	3.64
October	20.5	30.5	80	112	4.3	15.4	3.42
November	21.2	30.5	82	112	5.1	15.8	3.41
December	19.7	31.1	78	78	4.2	14.0	3.08
Average	19.3	30.7	73	120	4.2	15.2	3.56

Station Eff. rain method

	Rain	Eff rain
	mm	mm
January	19.0	18.4
February	59.0	53.4
March	152.0	115.0
April	175.0	126.0
May	199.0	135.6
June	197.0	134.9
July	204.0	137.4
August	159.0	118.6
September	361.0	161.1
October	220.0	142.6
November	98.0	82.6
December	36.0	33.9
Total	1879.0	1259.6

Table 4-1 - FAO CropWat Results



Soil name

General soil data

Total available soil moisture (FC - WP)	<input type="text" value="140.0"/>	mm/meter
Maximum rain infiltration rate	<input type="text" value="30"/>	mm/day
Maximum rooting depth	<input type="text" value="900"/>	centimeters
Initial soil moisture depletion (as % TAM)	<input type="text" value="0"/>	%
Initial available soil moisture	<input type="text" value="140.0"/>	mm/meter

Additional soil data for rice calculations

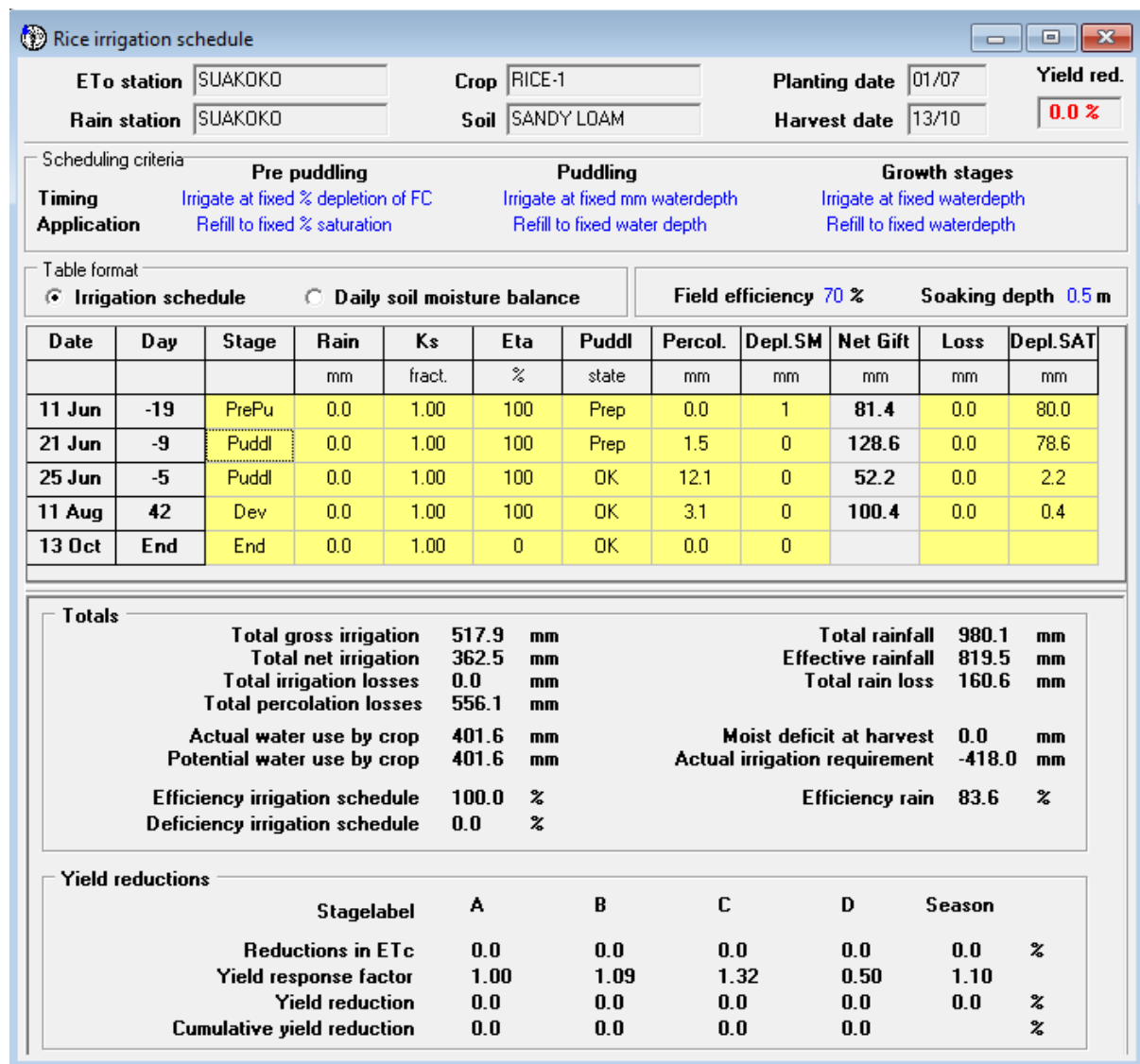
Drainable porosity (SAT - FC)	<input type="text" value="20"/>	%
Critical depletion for puddle cracking	<input type="text" value="0.50"/>	fraction
Maximum Percolation rate after puddling	<input type="text" value="3.1"/>	mm/day
Water availability at planting	<input type="text" value="100"/>	<input type="text" value="mm WD"/>
Maximum waterdepth	<input type="text" value="100"/>	mm

Crop Water Requirements _ □ ×

ETo station: Crop:

Rain station: Planting date:

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Nurs	1.20	0.44	4.4	45.0	0.0
Jun	2	Nurs/LPr	1.06	3.93	39.3	44.9	81.6
Jun	3	Nurs/LPr	1.06	3.79	37.9	45.2	181.4
Jul	1	Init	1.10	3.78	37.8	46.2	0.0
Jul	2	Init	1.10	3.65	36.5	46.8	0.0
Jul	3	Deve	1.12	3.68	40.5	44.4	0.0
Aug	1	Deve	1.15	3.75	37.5	39.7	0.0
Aug	2	Mid	1.17	3.80	38.0	36.6	1.4
Aug	3	Mid	1.17	3.96	43.6	42.3	1.3
Sep	1	Mid	1.17	4.11	41.1	50.9	0.0
Sep	2	Late	1.17	4.26	42.6	56.5	0.0
Sep	3	Late	1.12	4.00	40.0	53.5	0.0
Oct	1	Late	1.06	3.69	36.9	50.9	0.0
Oct	2	Late	1.02	3.47	10.4	14.8	0.0
					486.7	617.7	265.6



4.4. Irrigation Water Requirements

A critical factor in the derivation of net irrigation requirements is the overall water use efficiency. This factor is often largely over-estimated at the planning stage and therefore the importance of monitoring operation activities to assess the actual value of conveyance, distribution and on-farm efficiency should be emphasized for future design and operation.

The net irrigation demand is the crop water requirements, as calculated above, expressed as depth of water per day, but this excludes any losses in the conveyance and application. To convert the depth of water per day into a supply flow rate per unit area or gross irrigation demand, multiply the net irrigation demand by the total area under irrigation and divide by the irrigation efficiency. Overall irrigation system or scheme efficiency (η) is that part of the water supply that is effectively used by the plant, expressed as a percentage of the total supply, and is the product of both conveyance and application losses in an irrigation system. Conveyance efficiency represents efficiency of water transport in canals or pipelines, while application efficiency is the efficiency of water application in the field. The table below provides the recommended values of overall irrigation efficiency for traditional gravity and surface irrigation systems, compared with pressurised, overhead and low-head, drip irrigation techniques.

Table 4-2 - Typical Conveyance, Application and Overall Irrigation Efficiency for Different Technologies

Technology	Conveyance (%)	Application (%)	Overall (%)
Gravity:			
Unlined canal, surface/flood irrigation	55 - 70	Basin: 60 - 90 Border: 60 - 90 Furrow: 50 - 90	40
Lined canal, furrow irrigation	95	Furrow: 50 - 90	60
Pressurised:			
Piped supply, overhead sprinkler irrigation	60 - 80	Handmove: 65 - 80 Travelling Gun: 60 - 70 Center Pivot & Linear: 70 - 95 Solid Set: 70 - 85	75
Piped supply, surface/flood irrigation	60 - 80	Basin: 60 - 90 Border: 60 - 90 Furrow: 50 - 90	70
Piped supply, drip irrigation	60 - 80	75 - 95	80

Source: Internet

The option of piped supply, combined with surface/flood irrigation is the preferred method for the pilot scheme at Bong Mines.

4.5. Cropping Patterns

Farming in Liberia is predominantly traditional, with only limited commercial farms concentrating on cultivation of plantation crops, like rubber. Crop cultivation in the lowland and swampy areas tends to be more subsistence farming, with crops including rice, maize, cassava, vegetable and greens. The general cropping pattern in Liberia's lowland areas and at Bong Mines is for rice as the rainy season crop, followed by maize or vegetables as a second crop, as the soil moisture is depleted during the dry season; although rice can be the dry season crop, wherever irrigation facilities are available. In upland areas, upland rice and maize are generally the rainy season crop, but without sufficient water there is no second crop.

Considering the adequate rainfall and clayey soils in the lowland / swampy areas in Liberia, rice is the recommended crop for the first season (June-October⁵), and this would be the same for the pilot scheme at Bong Mines. To target Liberia's objective of double cropping rice in the country, the second crop (October-February) should also be rice, to utilise the residual moisture in the lowlands, together with supplemental irrigation, as will be provided by the SPIS. A third crop (March-May) can also be grown, subject to the availability of water and depending on the market demand, and farmers' needs. The recommended cropping patterns are as follows:

Rice – Rice

Rice – Maize

Rice – Vegetables

Rice – Rice – Vegetables

⁵ The start of the season will vary based on the particular location and the onset and cessation of rainfall in a particular year.

4.6. Irrigation Schedules

Absorption of water from the soil, its translocation through the plants and loss as water vapour through evapotranspiration is a continuous process, influenced by the atmospheric demand, plant characteristics and soil factors. These parameters must be considered for scheduling irrigation pumping and application to the fields, including: (i) soil moisture status, (ii) the phenological stage of crop (crop type and growth stage), (iii) meteorology/climate (temperature, wind, humidity and rainfall).

For the cultivation of rice, water is typically applied to the fields continuously, to maintain the depth of water, but under the SRI practice of Alternate Wetting and Drying (AWD), the fields will be irrigated every 7-10 days, to enhance the root system and development of healthy shoots, it also makes rice more tolerant for stress during later stages. For the pilot scheme at Bong Mines, to account for the high permeability of the sandy soils, it is envisaged that irrigation may be needed more frequently in 4-5 days intervals. In particular, during the vegetative stage (first 40-60 days), rice plants need moist soil (no stagnation) for best root and shoot development. Irrigation may also be needed more frequently during the flowering and milking stage, to maximise yields.

5. Pumping System (Supply Side)

This chapter presents the pumping data required to define the energy demand for solar irrigation, which will be used to calculate the PV capacity required, as well as the type of pumps, their specifications and functionality. Based on the water requirements and irrigation schedules proposed for rice production, as defined in the earlier chapter, the sizing of the key components of the SPIS pilot scheme at Bong Mines can be undertaken.

5.1. Data Requirements

The following parameters or inputs are required:

- **Area to be irrigated:** Define the area that will require water pumping.
- **Type of irrigation:** Define if the water will be transported to the land to irrigate with open channels or with pipes. Generally, open channels can be less efficient than pipes but are less capital intensive, so location specific analysis is required to decide what is more convenient.
- **Lowest groundwater level:** Defines how deep the water reservoir will be in case it is underwater. It is the most important value and should be verified by measuring comparable wells in the area.
- **Groundwater Level Seasonal Variation:** Important to understand if seasonally varying rainfall affects the underground water levels. If significant seasonal variations are identified, important to note the water level in the month when it is lowest, and to note in which month this happens.
- **Static water levels and Drawdown:** Measurements of available water resources in a pond, river or borehole, measured before and after pumping. It can only be defined if irrigation equipment is already existing, or by consulting with local farmers that practice irrigation.
- **Base of water tank above ground level:** Relevant if storage tank is to be installed on a raised location.
- **Type of soil:** Sandy, Loamy, Clay, etc
- **Drinkable Groundwater:** Yes/No
- **Contaminated Groundwater:** Yes/No
- **Irrigation Area Location:** GPS coordinates
- **PV System Location:** GPS coordinates
- **Proposed Storage Tank Location:** GPS coordinates and elevation.

5.2. Available Data and Assumptions

The following table serves as a template to collect this data before moving forward with the system design and summarises the data and assumptions made for the pilot scheme at Bong Mines.

Table 5-1 - Data Requirements for PV and Pump Design

Parameter	Unit	Value/Comment for Bong Mines
Area to Irrigate	m ²	400 x 200 m (8.0 ha) available
Type of Irrigation		Piped supply, surface/flood irrigation
Lowest Groundwater Level/ Depth of Ponds or Rivers	m	~2-3m
Seasonal Variations in Water Level	m	~1m
Month with lowest water level		Unknown, assumed to be 1-2 months after end of dry season
Drawdown during pumping	m	Unknown (No history of pumping undertaken)
Base of Water Tank above ground level (if applicable)	m	NA, no storage tanks proposed
Type of Soil (Texture)	% Fraction	Sandy Loam with low water holding capacity
Groundwater Contaminated?	Yes/No	NA
Groundwater Drinkable?	Yes/No	NA
Irrigation Location	GPS Coordinates	Latitude 6.8018823, Longitude -10.3411331
Altitude	m	169.42
PV System Location	GPS Coordinates	Latitude 6.8037948, Longitude -10.3427338
Storage Tank Location (if applicable)	GPS Coordinates	NA, no storage tanks proposed

5.3. Component Sizing/Specification

Based on the water requirements and irrigation schedules proposed for rice production in the previous chapter, the monthly water requirements for the three crop seasons is summarised in the following table and the key components of the pump and PV capacity have been sized and specified accordingly, including type and control functions required for obtaining quotations from suppliers.

Table 5-2 - Monthly Irrigation Requirements

Water requirements	Unit	Crop 1 (Rice)	Crop 2 (Rice)	Crop 3 (Vegetable*)
Jan	m ³ /ha/day		34.56	
Feb	m ³ /ha/day		21.60	
Mar	m ³ /ha/day			0
Apr	m ³ /ha/day			0
May	m ³ /ha/day			0
Jun	m ³ /ha/day	87.26		
Jul	m ³ /ha/day	0		
Aug	m ³ /ha/day	0.86		
Sep	m ³ /ha/day	0		
Oct	m ³ /ha/day	0	25.92	
Nov	m ³ /ha/day		71.71	
Dec	m ³ /ha/day		25.06	

* Vegetables includes Onion, Garden Egg, Tomato, Pepper and Okro (Small vegetables FAO)

System sizing

Considering the above presented assumptions on water requirement and other site characteristics, the SPIS was designed using industry standard tools for sizing of such solar pumps (e.g., the product sizing tool provided by leading industry pump supplier Grundfos: <https://product-selection.grundfos.com/>). Several iterations of the sizing process were carried out considering the minimum water requirements for the main crop (rice) and the cost limitations.

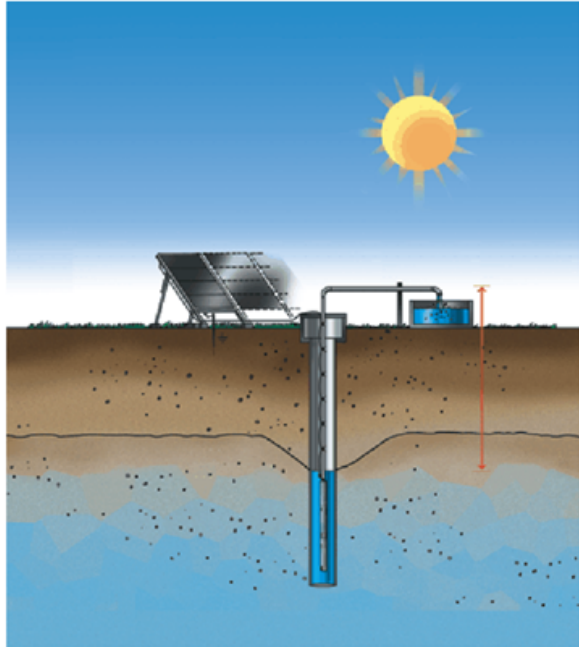
An example sizing result is presented below. It must be noted however, that details of individual solutions might differ slightly in capacities.



Company name:
Created by:
Phone:

Date: 18/08/2022

Installation and Input



Sizing Results

Water production, Peak flow and Price
Total water production per year: 207000 m³
Avg. water production per day: 567.6 m³/day
Average water production per watt per day: 67.6 l/Wp/day

Solar module configuration:
Number of solar modules in series: 8, in parallel: 3
Solar array rated power: 8.4 kW
Solar array rated volts: 314 V
Sun tracking: No (fixed)
Tilt angle: 7 deg.

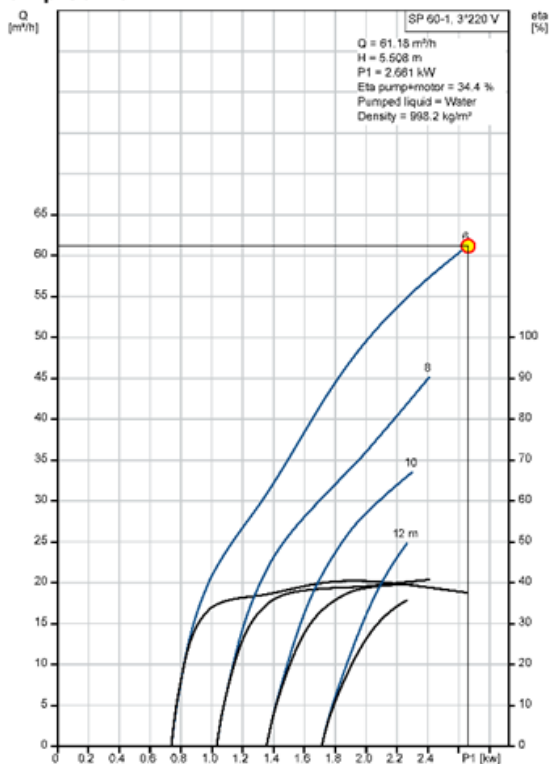
Typical performance at solar radiation 800 W/m²
Flow: 61.2 m³/h
Total head: 5.5 m

Cables and pipes:
Pump cable length: 13 m
Pump cable size: 0.75 mm²
Total cable loss: 4.7 %

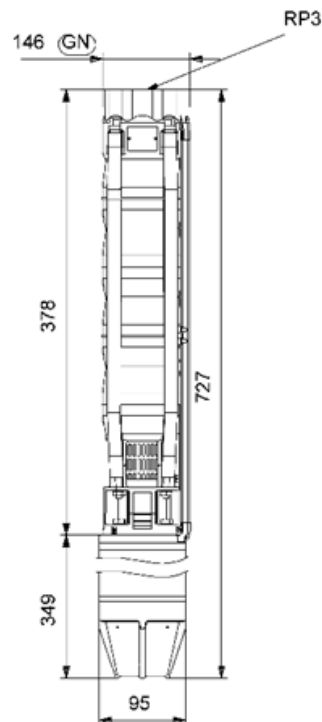
Friction losses: 0.508 m

Location: Margibi, Liberia
Latitude: 6.8018823 DD, Longitude: -10.341133 DD

Pump Curve



Dimensional Drawing



The resulting system parameters are listed in the table below, along with explanatory comments where relevant:

Parameter	Sizing	Comments
Designed water supply	560 m ³ /day	Considering the daily max 70 m ³ /ha/day water requirement over an area of approx. 8 ha
Pump type	3-4 kW	Surface mounted or submersible
Pump mounting	-	It is suggested to secure the pump at a reasonable location on the pond and protect it from damage (sediments, etc.) and theft.
PV size	6-8 kW	Exact size can vary depending on the rating of individual modules (e.g., 450 W x 12 = 5.4 kW). It is recommended to use module sizes of 350 W or above for achieving higher efficiency levels.
PV mounting	Yes	The substructure made of aluminium or hot dip galvanized steel is recommended to support the modules and withstand the local weather conditions. It must be sufficiently protected against corrosion for 20 years. Special anti-theft bolts and nuts to match the modules. Provision for earthing.
Controller	Yes	Depends on the pump model to be supplied.
Piping type	~700m	150-200mm diameter HDPE/uPVC pipe, fittings and valves
Fencing	-	It is highly recommended to build a secure fencing for the areas covering the pump and the PV panels, however this is not possible within the limited budget available.

CAPEX estimation

Component	Quantity	Unit cost	Expected cost (\$)	%
Equipment Costs				
Solar panels (Total Power)	8 kW	650 \$/kW	5,200	14%
Mounting + cabling + accessories	1	Lump sum	5,000	13%
Solar pump + controller	4 kW	1,000 \$/kW	4,000	11%
Irrigation Infrastructure				
200mm dia. Supply Pipeline (From Pump to Irrigation Distribution) PE PN6	92 m	20 \$/m	1,840	5%
150mm dia. Irrigation Pipelines (Distributing to Earth Canals) PE PN6	622 m	13 \$/m	8,086	22%
Elbows, Tees, End caps, Valves, etc	1	Lump Sum	1,874	5%
Irrigation canal excavation	400	Community contribution	0	0%
Drainage excavation	912		0	0%
Other costs				
Transport and logistics	1	Lump sum	1,500	4%
Civil works + earthing	1	Lump sum	2,000	5%
Installation	1	Lump sum	5,000	13%
Contingencies	1	Lump sum	3,000	8%
Total Project Cost			37,500	100%

The above costs are based on prices from local markets and suppliers in Liberia and quotations from international equipment manufacturers, such as Grundfos and Shakti pumps, including allowances and contingencies for soft starting, to compensate for the high starting current of the pump, and either a pump stand or shallow well, to protect the submersible pump from the abrasive effects of sediments and other solid particles on the pump impeller.

The Government of Liberia has suspended import tariffs on off-grid solar equipment and only the Custom User Fees (CUF) and the ECOWAS Trade Levy (ETL) are currently payable. However, for imported equipment these costs would increase to cover these customs and port handling fees, presumptive tax (4%) and service charges for clearing.

OPEX

With respect to operational costs, SPIS provides a major advantage in terms of costs and environmental impacts. Once the system is set up and functioning, it requires minimal O&M (dusting and cleaning of panels, clearing of PV foundations from vegetation, check of cables and wiring for breaks etc.) and can help to save on the expensive fuel consumption required with diesel operated pumps. Approximate savings on fuel and CO₂ emissions are briefly presently below:

Estimation of fuel savings:

- Considering a simple example of a 6 HP (4.5 kW) diesel pump which can pump approx. 50 m³/hour, 12 hours of equivalent diesel pump operation would be needed to provide the needed peak 560 m³/day water requirement at Bong Mines.
- Considering the seasonal variation, 8 hours of diesel pump operation can be considered as equivalent in this case. With an average fuel consumption of 1.25 litre/hour, the fuel consumption would be approximately 10 litres/day.
- This would translate to approximately 15 \$ of fuel per day or 3,000\$ of fuel on annual basis (assuming approx. 200 irrigation days in a year)

Estimation of CO₂ savings:

- Assuming a CO₂ emission factor of 2.5 kg/litre of diesel (Source: Carbon Trust Conversion Factors: <https://www.carbontrust.com/es/node/1008>), the project can provide CO₂ savings of up to 5,000 kg/year.

6. SPIS Configuration Options

The SPIS comprises two main components of infrastructure; the Irrigation System and the Electrical System. Different irrigation systems are more suitable to some situations than others and the choice will have an impact upon the overall irrigation efficiency. Irrigation infrastructure refers to the manner in which water is supplied and distributed to the fields (Conveyance) and how it is then applied to the crops (Application), each with particular infrastructure requirements. The choice of conveyance and application method depends on many factors, including the soil type, climate, crop and its physiological nature, the source and head of available water resources, land terrain, etc. The objective of selecting a particular irrigation system is to minimise water use and maximise yield. Similarly the Electrical System of PV panels, support structures, control electronics and pumps have a number of options that fit the particular situation and budget.

This Chapter considers which of these choices are most suitable for rice production in Liberia, Bong County and specifically for the pilot scheme at Bong Mines, and explores the options for solar energy generation, pumping and control that will interact with these systems to provide the farmers with a sustainable and effective scheme.

6.1. Irrigation Systems

6.1.1. Conveyance Infrastructure

There are two main forms of supply and distribution infrastructure used in irrigation; Gravity-fed open channels or Pressurised pipes (closed conduits).

Gravity-fed open channels (canals) can either be lined or unlined, depending on soil conditions and the need to minimise seepage losses, or to improve the hydraulic characteristics of the cross-section and profile to carry the required flow, or to a lesser extent to minimise maintenance operations⁶. They are generally used wherever the water source is higher than the point of delivery, so the water flows naturally under gravity. In some situations, gravity channels may be covered or run in closed culverts or pipelines to minimise evaporation losses or to negotiate difficult features in the terrain. Open channels can convey large volumes of water over significant distances for minimal capital and almost zero running costs, and are most usually combined with surface/flood methods of irrigation.

Pressurised pipes are used when the water source is lower than the point of delivery and pumps are required to raise it to the level of the field and/or provide a residual pressure at the field to be applied via overhead methods more suited for smaller volumes. Pressurised pipes are more expensive both in terms of capital and recurrent operating costs, they are suited to smaller volumes of water and should be sized to optimise the capital cost of the pipe material, which rises with increasing diameters, and the pump size and recurrent energy costs, which falls with increasing diameters.

Hybrid systems combine the benefits of open channels with pipelines in different ways, either raising water through a short supply pipeline, from where it is conveyed by gravity in an open channel to the fields, or supplying water via canal to the fields, but at level below ground, such that it has to be pumped to the fields.

6.1.2. Application Methods

The various methods of irrigation can be categorised as surface/flood, overhead/sprinkler, drip and sub-surface irrigation.

⁶ Cost is a major factor in deciding whether to line open channels.

a. Surface/Flood irrigation

In the surface/flood method of irrigation, water flows by gravity either through furrows, basins or borders that are integral to the layout of the fields and the type of crop. This method is the simplest system that has been used for many years by farmers, but also water losses in conveyance and deep percolation are usually high, with the efficiency of irrigation only 40-50% at field level. It is usually employed where water is in abundance and inexpensive, and where the fields are well levelled. There are limited controls over the rate of flow or distribution in the field and the wastage of water can be high; such uncontrolled or wild flooding is frequently the method used in lowland river valleys for rice crop. Efficiency can be improved by lining the field canals and by improved levelling of the field, and by the following adaptations:

Check basin method – in this method, the field is divided into number of plots and levelled. It is also known as bed method. This method is most suitable for levelled fields with low permeability and where water is not a constraint. In this method, water doesn't stand at a uniform depth over the entire check resulting in uneven distribution of water within the plot. Normally, the field channels and bunds occupy about 30% of the area.

Basin method – it is a modified check method adopted particularly in orchards. Basin is formed for each plant or for a number of plants and connected by ditches. Basins allow more water to be impounded as the root zone of orchard crops is very deep. The size of the basin is adjusted to soil permeability and size of streams. Each basin is flooded in turn and water is allowed to soak in to the soil. Basin method has the advantage that unskilled labour can be used as there is no danger of erosion. However, it has the disadvantage of high labour requirement and restriction in the use of modern machinery in the field.

Border strip method - in this method, the field is divided into narrow strips by small parallel ridges on the sides. The border strip is formed by levelling and grading the land between the ridges. Each border is irrigated by allowing the water to flow from the upper end of the border in a thin sheet. Water moves towards the lower end at non-erosive velocities covering the entire width of the border. This method can be used on all types of soil but it is best suited to soils having moderately low to moderately high infiltration rates. However, it is not suited to coarse sandy soils to clay type of soils.

Furrow methods - in furrow irrigation, water is applied in small streams between the rows of the crops, grown on ridges or furrow sides. The size and shape of the furrows depends upon the soil, crop spacing and the equipment used for the furrow forming. Water is applied into a small furrow and infiltrates into the soil and spreads laterally to wet the area between the furrows. This method of irrigation is generally used to irrigate row crops and vegetables. Furrow method is not recommended for very light soils with high infiltration capacity as water is wasted at the upper end of the furrow due to deep percolation.

b. Overhead/Sprinkler Irrigation

In this system, water is applied to simulate natural rainfall, with water conveyed through pipes and sprayed through sprinkler, usually rotating to cover a circular area. Water is applied to the crop above the ground surface in the form of spray developed by orifices or nozzles. Overhead/Sprinkler irrigation generally requires a pump to develop the desired operating pressure in the main supply lines, laterals and risers, to convey water to the sprinkler head or nozzle, where it discharges in spray form. The selection of the sprinkler head and spacing of sprinklers is the key to the efficient operation and even distribution of water and depends on the topography, head and climate conditions, such as temperature and wind, which can adversely effect the spray pattern and increase losses to evaporation. The rate of water application through the sprinkler should be less than the infiltration rate of the soil to prevent run off wastage. The advantage of this method is uniform and efficient distribution of water, particularly in uneven or sloping topography, and sandy soils.

Centre pivot, moving lateral or rain gun systems are derivations of overhead/sprinkler irrigation where the sprinklers are mounted on a movable structure that rotates around a central pivot point or moves in a straight motion, electrically or hydraulically powered, while remaining connected to the water supply by a flexible couple or pipe. These systems are popular because of their high efficiency, uniformity and ability to be automated by remote control. Centre pivot equipment is costly, but this is more than balanced by the significant savings in reduced land

levelling and less labour than many other irrigation methods. The system can also reduce the need for soil tillage, helps to reduce runoff and soil erosion, and reduces soil compaction.

c. Drip Irrigation

Drip irrigation is often termed as micro-irrigation as the approach involves controlled supply of water in small amounts, discharged at the root zone of a plant. It is frequently adopted in water scarce areas to conserve limited water resources. The water supply is measured by flow meter before it runs through distribution pipes to lateral drip lines, where the equally spaced drippers/emitters deliver the water to the plants.

Typical drip irrigation systems consist of a pumping unit to create a pressure, a filter unit to remove suspended impurities in the water, which might clog the drippers, and sometimes a system to dose dissolved fertilisers and herbicides. There is little water loss due to evaporation, therefore it is frequently used in arid and semi-arid regions, where the limited availability of water and high evaporative demands are the constraint to other cheaper methods. The method is best suited for wide spaced crops and is also very effective where only saline water is available for irrigation because the precise control of water enables the salinity to be controlled.

The disadvantages of the method are the capital and recurrent costs, which can be considerable, and the delicate nature of the drip lines and emitters, which can be easily damaged and blocked. It is also unsuitable to provide flooded conditions or large quantities of water to crops with high demands, such as rice and sugarcane.

d. Sub-surface Irrigation

In this method, the moisture in the root zone is controlled by maintaining an artificial water table at a shallow depth (0.3 - 1.0 m) depending upon the soil texture and rooting depth of crops. As such it is highly dependent on crop and location, and is not widely implemented except in areas of reclaimed land (i.e. Dutch polders or English fens).

6.1.3. Additional Irrigation Options

Additional considerations for the irrigation system include the following options:

a. Night-Time Irrigation

Farmers prefer to irrigate during the day, when they can easily monitor the progress and conditions in the field. However, irrigating at night has the advantage of reduced losses, due to evaporation and wind, which tends to be lower at night, and is applicable when water is limited and particularly for automated systems that the farmer can monitor and control remotely.

b. Fertigation

Fertigation combines the application of water (irrigation) and fertilisers by dissolving the fertilisers in the applied water. It is most commonly used with drip irrigation, where quantities of fertiliser application can be carefully controlled. The process minimises wastage of fertilisers and improves absorption level of crops, and reduces labour cost and time; yields are enhanced because fertiliser and water are supplied uniformly to the crops.

c. Herbigation

The application of herbicides in solution with the irrigation water is referred to as herbigation and is implemented in a similar way to fertigation. Maximum weed control is obtained when the correct amount of herbicide is applied based on soil type and herbicide properties. It is an effective method to control weeds amongst the crop, but depends on good management and uniform water application, usually associated with drip irrigation.

d. Automatic Controls

An automated irrigation system refers to the ability to operate the system with little or no manual intervention and is usually implemented with the help of timers, sensors, motor starters and mechanical actuators on valves and hydraulic gates, all controlled by computer. Automation can manage irrigation applications and fertigation and other processes, making a more efficient system and enabling labour to undertake other important farming tasks. It eliminates the manual operation of opening and closing valves, optimises the frequency of irrigation and fertigation applications, to increase water and fertiliser use efficiency, and can be operated remotely at night when water loss from evaporation is minimised; it can also optimise energy usage by integrating pump starts and stops when solar

energy is at its peak. However, automation systems are very expensive and complex, which generally makes them unsuitable for smallholder farmers.

e. Storage Tank

A storage tank allows farmers to irrigate at different times, such as at night or when there is no sunshine, but increases the capital cost. Irrigation directly from an elevated water tank only provides low pressure supply and is not suitable for overhead irrigation.

6.2. Electrical Systems (PV and Pumping Configurations)

6.2.1. Direct Pumping

In direct pumping, the system includes the PV panels, a pump controller that can have DC or AC motor, potentially a water storage elevated tank and the irrigation system (flood, sprinkler, micro-irrigation). Usually a maximum power point tracking (MPPT) device is used to improve the efficiency of the system. This system leads to variable motor speed and pump volume during the hours of sunlight, especially during cloud interfaces. The solar irrigation controller uses volume meter, instead of timer. The advantages of this configuration are that it is relatively simple and that it is adaptable to all sizes and irrigation methods. Additionally, fertigation can also be easily integrated, as well as other water treatments or chemical cleanings. It is the most widely used configuration, and water to wire efficiencies of more than 50% can be achieved with efficient systems. Usage can easily be monitored and charged to the farmer on a volume basis.

The schematic below is a simplified diagram of how this configuration could look like.

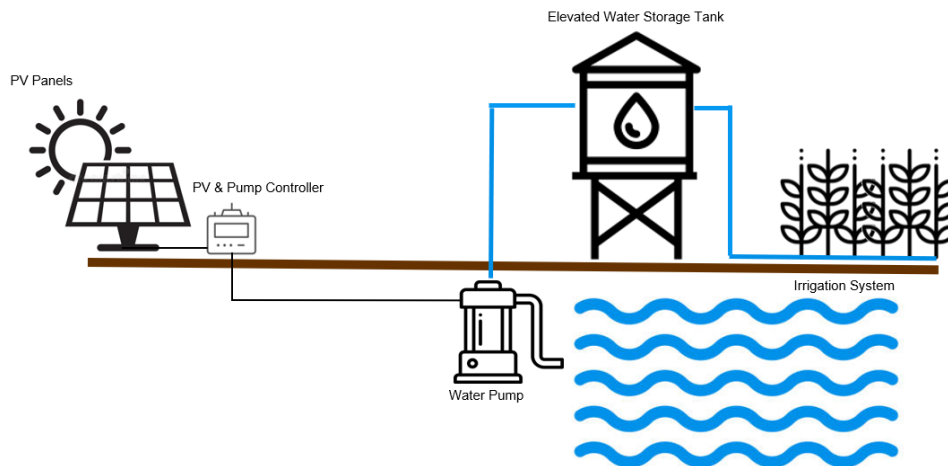


Figure 6-1 - Schematic of Direct Pumping Configuration

6.2.2. Multi-Use System

The Multi-Use System is essentially a Direct Pumping configuration, with the difference that when no pumping is required, excess energy can be used for other productive uses such as grinding, sawing, food processing, cooling, etc. It entails a higher level of complexity than simple direct pumping, and the controller is usually optimized for the pumping system. The energy needs of any other use must follow the pump, so the motors should have the same voltage as the pump motor and the same AC/DC configuration. For this system, use of batteries is only recommended with separate systems.

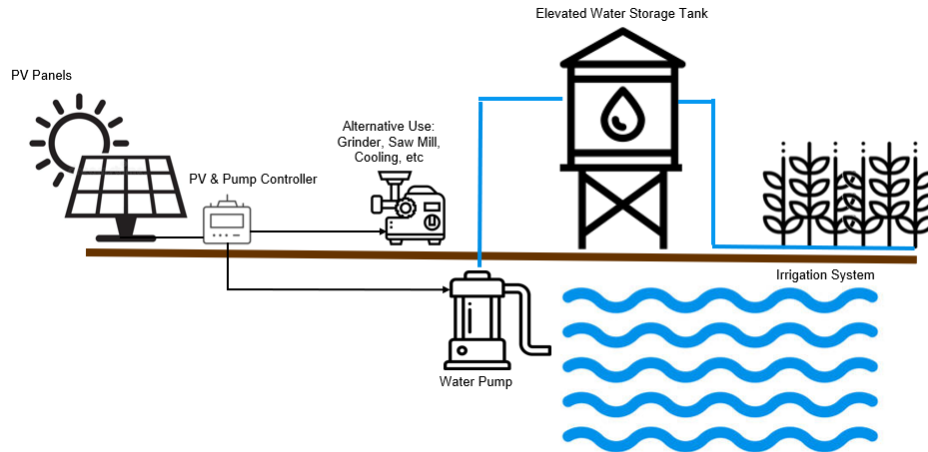


Figure 6-2 - Schematic of Multi-Use Configuration

6.2.3. Mini Grid

In this configuration, PV panels supply the power to various different uses, such as pumping, but also solar home systems, etc. It is a more complex solution, but technological solutions are being developed. Different uses can be accounted for, but important compromises on efficiency are necessary. A key consideration in Mini-Grid based pumping systems is the distance of the pump from the powerhouse. Within a low voltage (LV) network, it is recommended that the electrical load (pump in this case) is located no more than 1-1.5 km away from the powerhouse otherwise the voltage and power losses in the network are too high. In case the pump is located much further away, an alternative could be to supply power via a medium voltage (MV) network but this would come at higher distribution network costs and needs to be compared for financial viability of the entire system.

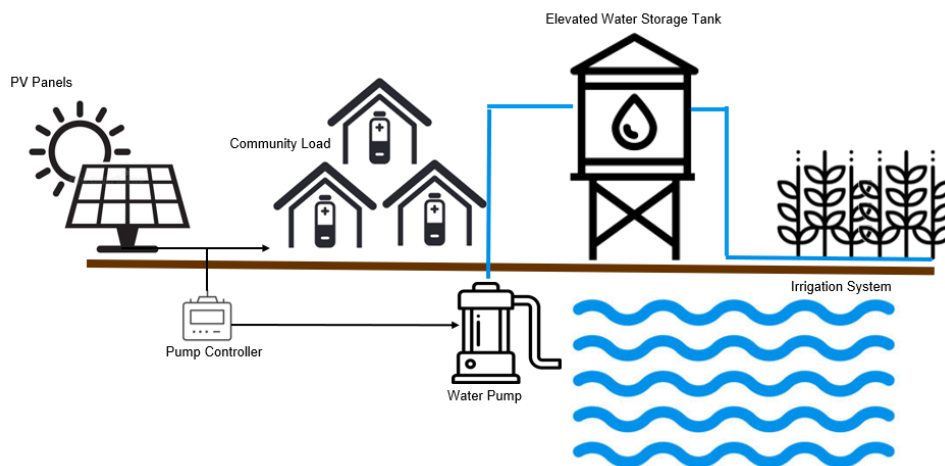


Figure 6-3 - Schematic of Mini Grid Configuration

6.2.4. Hybrid System

Another possible configuration are hybrid systems where the pump can be supplied electricity from the PV panels or from the grid directly. This would require use of special purpose hybrid inverters that allow switching of source power supply either based on time of the day or other pre-determined switching criteria (e.g., PV first, voltage stability, etc.). The switching can also be controlled manually in simpler systems but this would require an operator to physically approach the inverter and activate the switch. Hybrid systems are mostly suitable in cases where the pump is located close to the electrical grid and a fairly stable grid supply can be expected. If the grid supply is very poor (either in terms of hours of availability or power quality), the system would anyway need to run primarily on

the PV panel's power generation. However, if grid supply is reliable, then significant benefits can be derived as a much smaller PV system can be used, battery requirements can be minimized and the pump can run even beyond sun-shine hours. Increasing the flexibility for the farmers and improving crop yields.

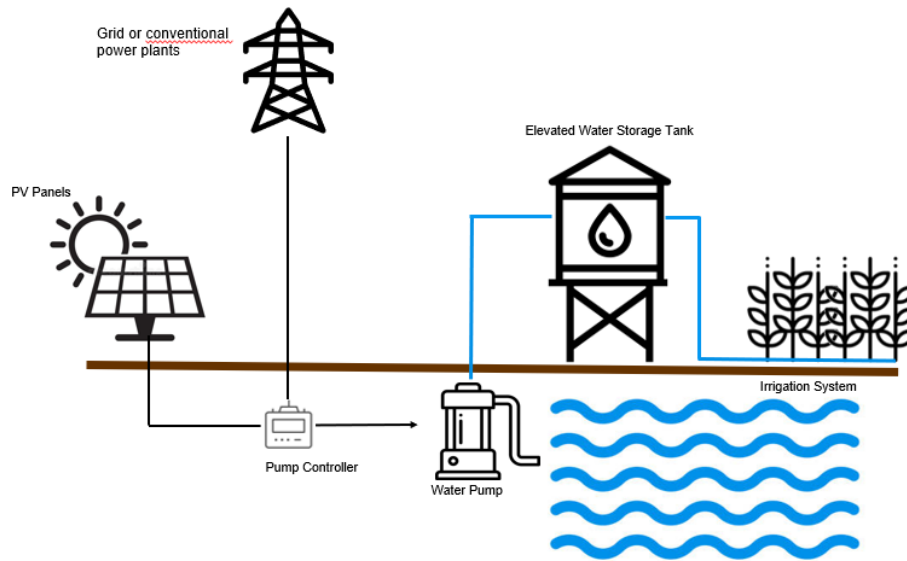


Figure 6-4 - Schematic of Hybrid Configuration

6.2.5. Battery Requirements

Principally, a battery can be attached to any of the above presented system configurations to increase system flexibility and hours of operation. Naturally, it would require additional CAPEX investments for the battery components and increase PV capacity (for cases where electricity purchase from grid is not an option). In addition, adequate storage and cooling of the battery system needs to be ensured to avoid damages or deterioration of battery life. Since SPIS systems can primarily run during sunshine hours, the value addition by inclusion of batteries is marginal and needs to be critically analysed from a technical as well as financial perspective.

A diesel generator is similar to batteries, in that it allows the farmers to use the water pumps even when there is no sunshine. In existing irrigation systems, it is common that a diesel generator is already present and can be integrated with the new solar system as a back-up option.

The following illustrations provide a conceptual overview of how such systems could look like if battery storage were to be included.

Direct pumping: Inclusion of batteries would installation of addition PV capacities so that during day time both the pump can be operated and the battery charged. Availability of battery storage would enable the farmers to run the pump for longer hours and be more flexible in terms of the time of use.

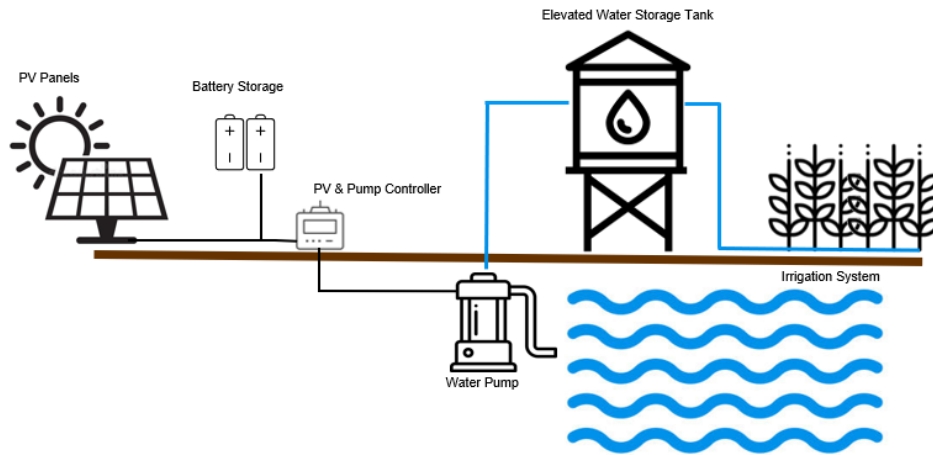


Figure 6-5 - Schematic of Direct Pumping Configuration with Battery Storage

Multi-use systems: Similar to direct pumping, additional PV capacity would be required. Availability of battery would furthermore allow operation of productive use equipment quite flexibly. Still if the systems are expected to run during evening hours, considerable battery capacities might be required, driving the cost upwards very quickly.

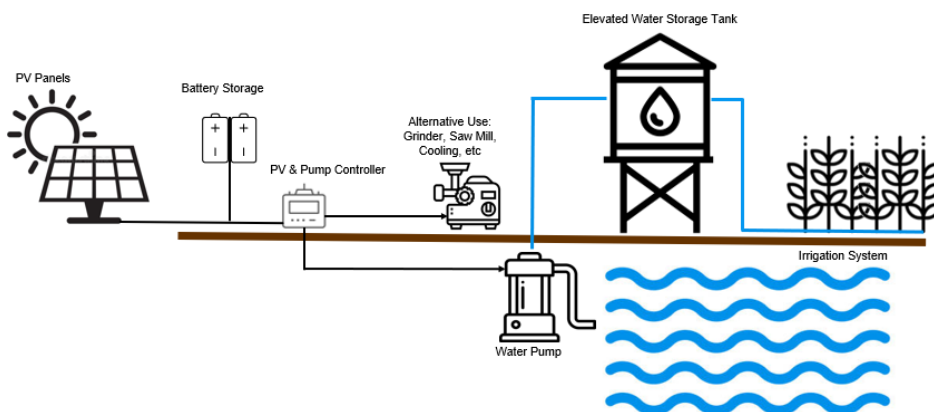


Figure 6-6 - Schematic of Multi-Use Configuration with Battery Storage

Mini-Grid: It is fairly common for Mini-Grids to include some level of battery storage anyway. Therefore, this configuration would be considered normal and availability of battery storage would not increase the costs for the pumping system significantly. One critical aspect to consider here would be that the operating times of the pump should not be left uncontrolled. Otherwise, it could lead to excess use of the battery outside sun-shine hours (e.g., if farmers decide to irrigate field early in the morning or during night hours). Such a situation would not only erode the benefit of connecting the pumping system to the Mini-Grid as an anchor day-time load, but would also eat up precious battery capacity intended for evening use of the other consumers.

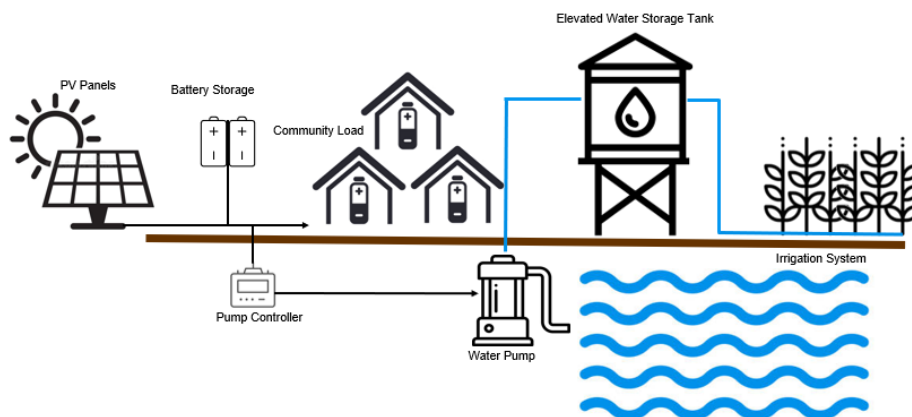


Figure 6-7 - Schematic of Mini Grid Configuration with Battery Storage

Hybrid systems: Inclusion of battery storage in hybrid systems can actually be beneficial if the operating requirements are favourable. This means that if electricity purchase from the grid can be ensured at a fairly low price, it can provide the system an opportunity to store this grid electricity whenever it is supplied and the pump can be operated independently as needed. Such a configuration would not require any additional PV capacity. In ideal cases, the PV capacity can also be reduced since even if the grid supply is available during day time (which would otherwise overlap with PV generation), it can be stored in battery and used flexibly when PV generation is low (e.g., early mornings or later afternoons). However, to determine overall system viability detailed techno-economic assessment should still be done to decide on a case-by-case basis.

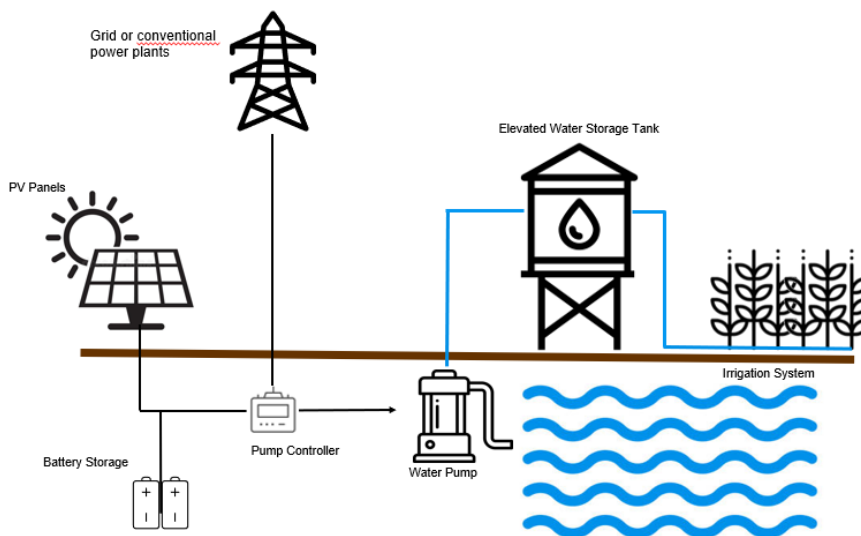


Figure 6-8 - Schematic of Hybrid Configuration with Battery Storage

6.3. Financing and Payment Options for Nationwide Roll-out

Depending on local context and prevailing practices different models are possible for ownership, financing and payment for the SPIS infrastructure. They are briefly presented below.

6.3.1. Ownership and service models

a. Farmers own the system

Under this model, the SPIS is handed over to the farmers either completely free of charge or against an equity contribution. They are themselves responsible for its operation and maintenance. Such systems are seldom found

in practice due to barriers to finance for bringing in the required equity contributions. In addition, they lack the technical capacities to operate and maintain the systems adequately. However, for the pilot scheme at Bong Mines, this would be the model proposed, since the SPIS is to be used as a training platform

b. Operator owns the system and sell water to farmers

A service provider invests in the SPIS and establishes contracts with the farmers for provision of water against an agreed tariff. The service provider is the owner of the SPIS infrastructure and is responsible for O&M and replacements, should any issues arise. The risk is primarily with the service provider who is dependent on the farmers purchasing sufficient water at agreed prices. Farmers would typically still have the option of reverting to alternative sources (e.g. diesel pumps), if they are not satisfied with the SPIS or find the fees to high.

c. Project developer hires an operator for running the system

Under this model, a project developer invests in the system, hires a local operator (individual or company) for O&M and sells water to the farmers. The earnings of the operator could be tied to minimum performance hours of the SPIS ensuring their commitment to adequate O&M and handling on site. Farmers again buy water against a fee. The project developer is primarily an investor and does not need to establish elaborate local presence to run operations and maintain the systems

6.3.2. Capital Financing

a. Grant

Most SPIS still require 50% or more CAPEX funding as grant to achieve financially viable systems. The grants could either be tied to business models of individual projects (e.g., to achieve required ROI or tariffs) or provided on a uniform basis (e.g., kW installed or X% of total CAPEX). This is the option proposed for the pilot scheme at Bong Mines, with the full cost of the SPIS infrastructure funded by CTCN.

b. Equity

This is the contribution of the eventual owners of the system. Typically, equity ranges between 10-20% for SPIS based on worldwide experience. However, higher equity may be demanded depending on contexts to ensure that the equity investor is fully committed to the sustainability of the systems.

c. Debt

The remaining financing needs to be raised as debt. Where possible, local financing is preferable since it protects the project and investor against FOREX fluctuations. However, local financing is often challenging in the context of SPIS since traditional banks don't usually offer financing products for such systems without sufficient collateral. Availability of micro-finance institutions and/or other impact lending agencies can help to ease the situation.

6.3.3. Payment options

a. Water as a service

Farmers pay a pre-agreed lump sum amount per month to use water as needed. This maybe suitable where water consumption is unpredictable.

Advantages:

- Farmers benefit from the flexibility of using as much water as needed against a fixed cost.
- Operator/Service provider benefits from guaranteed income per month/season from the system irrespective of water sales.

Disadvantages:

- Farmers need to pay monthly/seasonal service fees even in months/seasons where they don't need water.
- Farmers may be tempted to use as much water as possible since they don't have any incremental costs. This may reduce life of the system (early depletion of water resource, inefficient irrigation, early depletion of pump life).

- Operator does not have incentive to maintain system to highest standards since sales are not linked to water supplied. Sub-standard systems would provide less water to farmers. Equipment life may also be compromised if the operator is not the owner of the systems.

b. Post-paid metering

Farmers pay at the end of the month/season for the quantity of water they have used. Mechanisms for monitoring and metering water supply need to be established and transparency needs to be ensured to avoid theft or fraud.

Advantages:

- Farmers can flexibly use as much water as needed and pay for only what they consume
- Operator/Service provide have incentive to maintain system to high standards to maximize sales.

Disadvantages:

- Operator does not have a guaranteed source of income and is dependent on the monthly/seasonal consumption of water by the farmers.
- Post-paid metering exposes the operator/service provider to risks of defaults and delays on payments.
- Farmers are dependent on the transparency of the metering mechanism since they only receive the bill at the end of the month/season.

c. Pay As You Go (Pre-paid)

Farmers pay in upfront for the water they intend to purchase. Mechanisms for monitoring and metering water supply need to be established and transparency needs to be ensured to avoid theft or fraud.

Advantages:

- Farmers can flexibly use as much water as needed and pay for only what they consume
- Operator/Service provide have incentive to maintain system to high standards to maximize sales.
- Operator/service provider reduce their risk of defaults and payment delays

Disadvantages:

- Operator does not have a guaranteed source of income and is dependent on the monthly/seasonal consumption of water by the farmers.

6.3.4. Nationwide Upscaling

With respect to upscaling of the initiative across Liberia, the above presented options will need to be carefully analysed in the light of the pilot system experience, local dynamics and the overall characteristics of the sector. The following constraints and considerations should be taken into account:

- Most existing successful donor programmes are grant based, with no sustainable financing solution to scale and increase the reach of SPIS technologies
- Most smallholder farmers are unable to meet lenders requirements for creditworthiness.

In this backdrop, some key considerations include (but not limited to):

- Understanding of the financial boundary conditions for farmers (ability to pay, willingness to pay, financial capacity for investments, operational expenses)
- Preferred mode of payments (pay as you go, monthly fee, metered, etc.)
- Possible modes of payment and credit facilities that may need to be provided to bridge unforeseen periods of low revenues
- Existing terms and conditions of loans being provided by financial institutions
- Availability and intention to develop new financial products for SPIS market
- Risks and challenges for financial institutions associated with financial stability of smallholder farmers
- Possible role of NGOs, either as system providers, operators, etc.
- Availability of other market players to function as aggregators or system operators, etc.

- Initial expectations on tariff, investment returns, risk premiums and guarantees
- Possible structuring of blended finance and possible levels of equity, debt, and grant financing scenarios

While it is expected that initial systems will need to be heavily subsidized on CAPEX, sufficient measures must be introduced to ensure long term sustainability of the systems. This would require at OPEX and other maintenance costs are recovered via an adequate payment and collection system. From a perspective of promoting private investments, Pay As You Go systems could perhaps prove to be more beneficial since it would provide much needed payment guarantees to investors and motivate the farmers to also ensure efficient use of the purchased water. The mechanisms for measuring supplied water and for carrying out the financial transactions would need to be further explored based on the final site selection and locally available technologies.

6.4. Options to Improve / Adapt to Gender and Youth Needs

Vital to the implementation of the CTCN Upscaling Lowland Rice Production pilot project through improved solar powered irrigation practices, is how the project also aims at addressing the existing power relations, social dynamics and adapting to gender-based labour division in the traditional agriculture practices in Liberia and managing risks associated with women and youth inequalities. The goal is to integrate best practices, which accounts for positive effect and outcomes in inclusive and participatory initiative at the community level.

Detrimental to the outcome of this pilot is the failure to recognize and adapt the significant roles of women and youth, which are most times stratified by traditional norms and values. The approach is not intended to undermine the traditional norms and values in the selected communities, but to strengthen equal access and opportunities for both women and youth participation.

In order to determine an in-depth understanding on how the project will enhance the livelihood prospect of local farmers, and how gender-based division of labour tends to influence the agriculture patterns, the project will focus on the participation of women and youth, ranging from the composition of the Stakeholder Working Group and other key stakeholders' participation. The participation of women, men and youth in particular will help to make the intervention more workable, thereby focusing on specific needs of women and youth throughout the implementation.

In the areas visited to date and selected for the pilot scheme, women's and youth participation in the farmer-based organisations has been significant (over 50%), a figure which clearly indicates the vital roles of women and youth in smallholder farming. The participation of women and youth will continue to be documented throughout the project and their influence on the outcome of the pilot determined.

7. Conclusions & Recommendations

7.1. Pilot Site Selection

Following the initial reconnaissance site visits to Bong and Lofa counties, and the agreement to focus on Bong County for the pilot scheme, the Water Resources Expert, Gender Expert and Rice Production Expert made further visits to a number of proposed sites in Bong County, including Palala, Balama, Sargeant Kollie Town (SKT) and a number of sites in Bong Mines. Data was collected on the key characteristics of these sites in order to make an assessment of their suitability for the pilot scheme, including:

- Availability of suitable water sources:
 - Surface water; river and existing storage (dam/reservoir)
 - Groundwater
- Existence of lowland rice cultivated areas (~10ha), with potential for increased yields, cropping intensity and/or diversity of crops (i.e. areas out of command for gravity fed irrigation)
- Suitability of soil types (i.e. limited iron toxicity) and adequate drainage for rice production
- Community interest/motivation in new technologies and improved cultural practices
- Labour availability and organisation, particularly for equipment security
- Land ownership issues
- Location with respect to milling facilities and markets for inputs (i.e. seeds and agro-chemicals) and produce
- Site access from Monrovia and other parts of the country for construction logistics, demonstration workshop or meetings etc.

Underlying many of the selection criteria, a key factor related to cost, since CTCN only provide a limited budget for procurement of equipment and also the target was for affordability to a wide range of smallholder farmers. This influenced the selection, as follows:

- Perennial surface water sources were preferred, as dams and boreholes would be expensive (although existing boreholes were considered)
- The land/fields and pipeline routes should all be owned by the community (or under long-term agreement)
- Farm plots should be level and farmers experienced in growing rice
- Preferably impermeable soils, to reduce deep percolation losses and minimise the size of pumps and PV panels
- The community must commit to providing labour for implementation and security, and have an established Farmer Based Organisation through which to manage their contribution
- Close to milling facilities and markets, and accessible during the rains for implementation and training.

Based on the data collected and assessed by the Team, not all the selection criteria could be achieved, but the site at Bong Mines A was identified as the best and proposed as the most suitable for the pilot scheme. This assessment was presented to and agreed at a meeting of the SWG at the end of May 2022 (See Appendix B). The scoring matrix is shown in Table 7-1, indicating that there was no clear favourite, but despite shortcomings regarding water resources and soils, it was agreed to progress with this site for the pilot scheme. This decision was subject to completion of the soils analysis, which was subsequently undertaken at a laboratory in Ghana, but did not raise any unforeseen issues regarding the chemical or physical composition of the soil.

Table 7-1 - Site Selection Matrix

Criteria	Site					Comments/Justification for scoring
	Palala	Balama	SKT	Bong Mines A	Bong Mines B	
Availability of suitable water sources:						
<ul style="list-style-type: none"> Surface water; river and existing storage (dam/reservoir) 	1	2	3	3	4	Bong Mines - Most significant available surface water resources SKT - Dam used by CARI and AfricaRice project Palala - Unknown water source, not visible
<ul style="list-style-type: none"> Groundwater 	1	2	2	1	1	Bong Mines - Limited groundwater availability SKT potential for shallow well Balama & Palala - Unknown
Existing lowland rice cultivated areas, with potential for increased yields, cropping intensity and/or diversity of crops (i.e. areas out of command for gravity fed irrigation) ~10ha	3	3	4	4	4	Bong Mines - Existing rainfed rice growing area, vegetables in the dry season SKT - Lowland area growing rainfed rice Palala & Balama - Lowland areas, long thin sites
Suitable soil types (i.e. limited iron toxicity) and adequate drainage	3	3	3	2	2	SKT, Palala, Balama - Silt deposits, unknown characteristics Bong Mines - Silty soils, low water holding capacity, potential toxicity
Community interest/motivation in new technologies and cultural practices	1	3	2	3	3	Bong Mines - Significant membership and enthusiasm, FAO training in SRI Balama & SKT - Enthusiastic chairman, limited membership, poor JICA trials Palala - Little enthusiasm shown by chairman
Labour availability and organisation, particularly for equipment security	2	3	2	3	3	SKT predominantly women members, adjacent buildings for storage Palala - Larger group, but details unknown Balama - Pump would be located next to busy road
No land ownership issues	3	4	3	4	2	SKT land granted to co-operative, adjacent to CARI/AfricaRice project to 2023 Palala - Unknown, but assumed granted to the co-operative Bong Mines - Land owned by Dr Suba
Location with respect to milling facilities and markets for inputs (i.e. seeds and agro-chemicals) and produce	3	3	4	4	4	SKT close to Gbarnga, JICA, AfricaRice and CARI facilities Palala - Further away from Gbarnga Bong Mines closely located to Monrovia
Good site access from Monrovia and other parts of the country for construction logistics, demonstration workshop or meetings etc	3	3	4	4	3	SKT simplest and cheapest SPIS system, close to research facilities as demo Bong Mines Site B more costly to install system than Site A due to longer pipe delivery
Total	20	26	27	28	26	



Figure 7-1 - Selected Site - Bong Mines A

Following agreement of the proposed pilot scheme site with the SWG, members of the Team revisited the site at Bong Mines A to re-confirm the selection criteria and scoring, and analyse various cropping pattern and varieties suited to the particular site. They also met with a larger group of farmers and stakeholders to further outline the proposals for the pilot scheme and initiate a process of engagement that will continue through to the end of the TA (See Appendix C). This workshop was conducted on 3rd June, 2022, with more than 50 farmers and representatives from the areas around Bong Mine Dam 3, of which approximately 50% were women. These stakeholders were very interested in bringing the pilot scheme to their area and expressed their full support for the project, in particular their commitment to providing labour during the implementation and security for the SPIS equipment and infrastructure, once installed.

The data collected from Bong Mines A and other related information regarding the site and the pilot scheme were also discussed with FAO, who expressed their interest to extend support to the pilot scheme at Bong Mines, where they have already been actively providing training to farmers in SRI techniques.

The Team also had a positive interaction with BRAC International, a leading non-profit organisation with a mission to empower people and communities in situations of poverty, illiteracy, disease, and social injustice. Currently, BRAC works with more than 2000 rice farmers in Liberia and specifically produces and tests rice varieties to suit local conditions. BRAC indicated that they would be willing to provide support to the pilot scheme farmers at Bong mine, in particular for the guaranteed supply of good quality rice seed and other agro inputs.

7.2. Configuration Selection

As described earlier in this report and summarised in the presentation in Appendix B, the SPIS configuration options were outlined at a workshop to the SWG members. The key components of the Electrical, Irrigation and Agriculture Systems were described and the options most applicable to Liberia and the pilot scheme at Bong Mines were discussed, with the key points summarised below:

- Electrical system:
 - SPIS is more suitable where the limited energy generated can efficiently supply small volumes of water at low pressure

- Mini-Grids or Hybrid systems feeding the national grid are not suitable⁷
- Considering the context of Bongo Mines, a Standalone system is the preferred option, where the main components will be the solar panels, solar pumps and controllers, to supply the water distribution layout and irrigation method.
- Start with the simplest system; direct pumping with possibility to add alternative (productive) uses in the future (e.g. rice milling).
- Irrigation system:
 - Rice prefers flooded conditions (not overhead or drip) and permeable soils will require more water
 - Short piped supply routes and small changes in elevation, with no need for elevated storage, favours direct pumping at low head, with distribution by gravity through fields and unlined channels
 - Available budget for equipment and installation limits pilot to small area of rice production, but potentially larger area for vegetables.
 - Research opportunity should be maximised with a split scheme; partly flood, for rice, and partly drip, for vegetables.
- Agricultural system:
 - Cropping pattern:
 - 1st season: Rice (April-August) - Rainfed conditions
 - 2nd season: Rice (September-January) - Residual moisture, together with supplemental irrigation
 - 3rd season: Vegetable (February-April), including okra, cucumber, cowpea and chillies.
 - Rice varieties Suakako 8 and Nerica L19 are recommended as lowland varieties which are commonly cultivated across Liberia and recommended by Africa Rice and CARI
 - Transplanting, Weeding, Mechanisation etc
 - Organic manures and fertilizers
 - Restricted usage of Herbicides and Pesticides.

The SPIS configuration choice is dependent on multiple factors, including:

- Available Water Resources – Volumes, location and pumping head
- Soils, Crop/Variety choice and Agricultural Production Processes - Farm water/input requirements
- Climate (Sunshine, Rainfall, Temperature & Wind) - Power generation and crop evapotranspiration
- Other potential energy uses
- Farmer's skills
- Budget.

A matrix of technologies and functions was developed to aid the assessment of options most suited to the pilot scheme site and ranked according to cost, complexity (cost of O&M) and resource (water) efficiency, as shown in the following Table.

⁷ **Minigrids** are not considered since the site is more than 2 km away from the closest community. In order to operate a simpler and less expensive system, it is desired to work only in Low Voltage, and LV lines of more than 1 km are not ideal from a technical perspective due to voltage drop increases and other grid stability purposes. **Hybrid** systems that combine the national grid supply with solar PV offers room for cost savings, but the nearest network point is not close to the Bongo Mines site and even the mine electrical infrastructure is 30 years old and has been inactive for many years, so this option is also not considered.

Table 7-2 - Configuration Selection Matrix

Technology Options		Functions													Comments						
		Energy source	Energy storage	Controls	Monitoring	Alternative uses (Milling etc)	Domestic uses	Pump water	Store water	Distribute water	Irrigate plants	Water Management	Weed Management	Nutrient Management		GAZ / yield enhancement	Adaptability	Staple food production	Farm/family income generation		
Electrical Systems	PV panels	Fixed	✓	1																More susceptible to theft	
		Moveable	✓	2																	Expensive and additional complexity for maintenance
		Tracking	✓	3																	Simple, effective, efficient
	Controls	Internet of Things	✓		1	2															Complexity
		Standalone	✓		1	3															Simple and easy
	Connectivity	Mini-grid	✓		2	2	2														Expensive and distant from communities
		Hybrid	✓		3	1	1														Expensive and distant from national grid infrastructure
		No storage	✓	0																	Cheaper and simpler, but doesn't allow electrical supply outside of sunshine hours
	Energy storage supply	Batteries	✓																		Guaranteed power supply but expensive
		Lead Acid Battery	✓	1																	Allows to supply electricity outside sunshine hours. Cheaper but shorter life time than lithium
		Lithium Ion Battery	✓	2																	Allows to supply electricity outside sunshine hours. Expensive but longer life time than lead acid
	Pumps	Direct Cables	✓	3																	
Fixed speed		✓						1												Advantageous in solar pump installation	
Variable speed		✓						2													
Submerged		✓						1												Advantageous due to zero (0) NPSH	
Irrigation Systems	Water storage	Natural River, Lake, Pond	✓						1											Simple, good water storage capacity, cheapest option	
		Dam & Reservoir	✓						2											Large water storage capacity, but expensive to build	
		Elevated tank	✓						3											Expensive per cu m, subject to damage	
	Conveyance & Distribution	Pipes	✓						1	1											Least losses, but expensive, greater control and accurate measurement of water
		Canals	✓						3	3											High losses and more expensive to build and maintain, if lined, difficult to monitor and control
	Irrigation	Mix	✓						2	2											
		Surface/Flood	✓						1	4											Simple, farmer-friendly, best for paddy, least efficient usage of water
		Sprinkler	✓						3	2											More efficient compared to surface, subject to evaporation loss, needs pressurised system, good for vegetables
		Drip	✓						2	1											Most efficient, expensive, technically complex, more susceptible to damage and theft
	Filtration	Sub-surface	✓						4	3											Highly dependent on soil profile and land preparation, expensive
		Broadcasting fertilisers	✓						2	3											Required to limit blockages in drip irrigation, expensive
		Fertiliser application	✓							1											Farmer-friendly, inexpensive
	Herbicide application	Fertigation	✓							2											Highly technical, suited for pressurised irrigation
		Broadcasting	✓							1											Farmer-friendly, inexpensive
	Agricultural Systems (SRI)	Crop	Rice	✓														1	1		Becoming staple food, good marketability, higher returns and in-line with GoL policy
Vegetables			✓															3	2	Seasonal, storage problems	
Maize			✓															2	3	Less remunerative crop, seasonal	
Variety		Suakako 8	✓																1		Good for lowland condition Liberia, resistant to iron toxicity
		NERICA L19	✓																1		Good for lowland condition Liberia, resistant to iron toxicity
SRI practices		Transplanting	✓																	1	Transplanting young seedlings before tiller formation is the key for SRI, results in healthier plants and higher yield
		Broadcasting/Random seeding	✓																	9	Uneven germination and lower yields
		Spacing	✓																	2	More productive tillers, Square planting ease the mechanical weeding
		Manual weeding	✓								2									5	Improper weeding, expensive, time-consuming for available labourer
		Mechanical weeding	✓								1									3	Low cost technology, trampled weeds used as compost
		Chemical Herbicides	✓								3									8	Expensive, limited by availability of right chemicals at right time, environmental concerns
Bio-fertiliser		Leaf Colour Chart	✓																	4	Minor cost technology, providing needs-based Nitrogen application
		Chemical Fertiliser	✓																	7	Expensive, limited by availability of right chemicals at right time, environmental concerns
		Bio-fertiliser	✓																	6	Use of manure and composts from other agricultural activities
Watering		Flooded paddy	✓								2	2	1								Wastage of more water, reduced numbers of ear bearing tillers
	AW&D	✓								1	1	2								Improved water use efficiency, more tiller formation	

Key to symbols:
 ✓ Best value option
 ✓ Simplest, low maintenance option
 ✓ Most resource (water) efficient option

Based on this assessment and the discussions, the simplest configuration was agreed, as shown in the following Figures, with the electronics compatible with more complex configurations, such as being energised through a back-up diesel generator or being able to supply to alternative (productive) uses such as rice milling, although this is only recommended if the pumping capacity is not compromised.

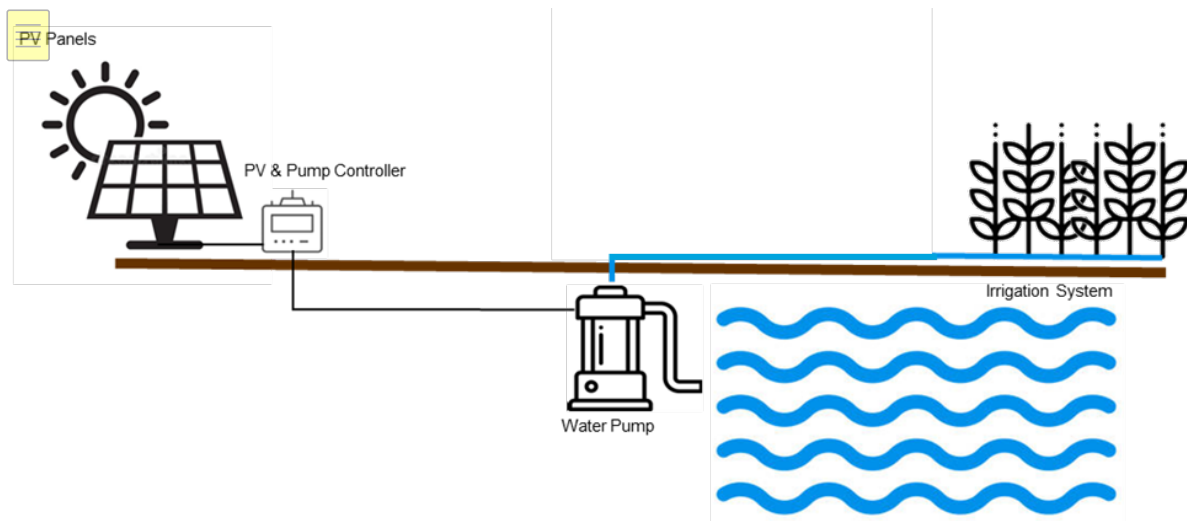


Figure 7-2 - Selected SPIS Configuration - Direct Pumping, No Storage, Surface Irrigation

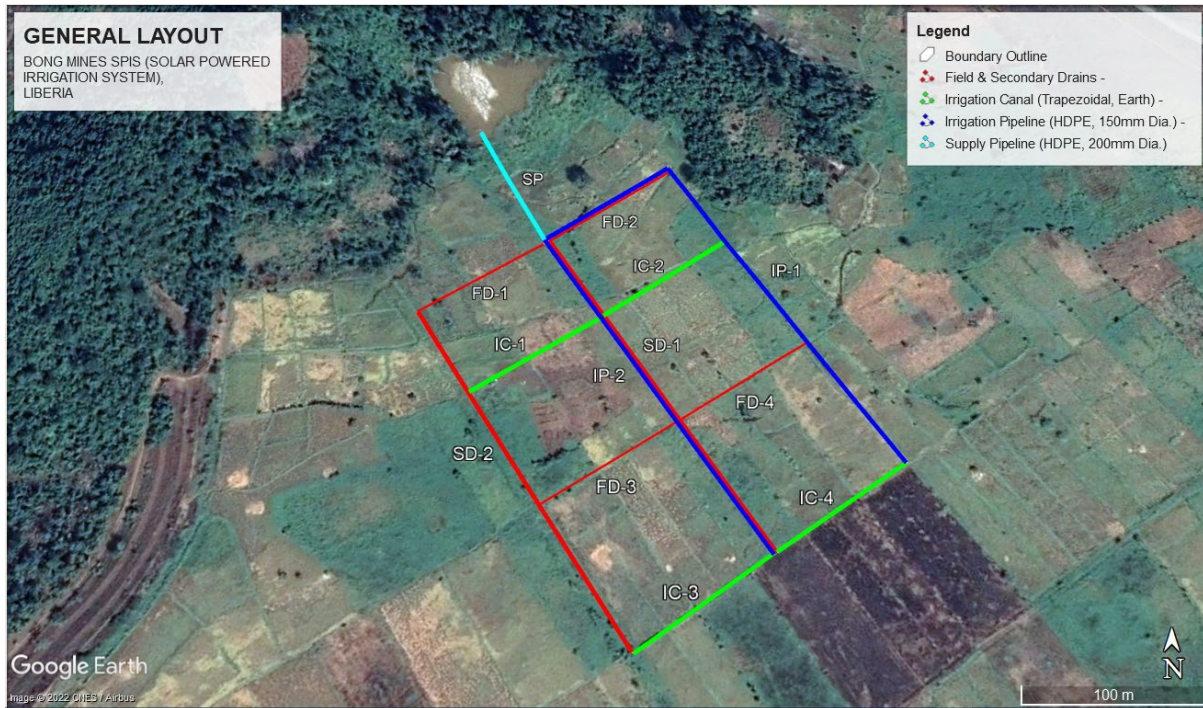


Figure 7-3 - Selected SPIS Configuration - Outline Irrigation and Field Layout

Farmers will need to take ownership of the farming activities at the scheme, both during implementation and operation, and will be responsible for the inputs required for rice production; although it is hoped that for the initial seasons these will be met with assistance from organisations such as FAO and BRAC.

Under the TA, “learning-by-doing” workshops will be conducted with the farmers and Municipal and National Officers on the various technological options and methods of monitoring and evaluation, to maximise the lessons learnt from the scheme.

8. Appendices

Appendix A - Fact Sheets

INSERT FACT SHEETS



Upscaling Lowland Rice
Production to Improve
Food Security through
Improved Solar Powered
Irrigation Practices
AFCIA 2021000017



UN
environment
programme



CTCN
UN Climate Technology Centre & Network
UNFCCC Technology Mechanism



Contact

Ministry of Agriculture

Environmental Protection Agency of Liberia



Solar Powered Irrigation Systems

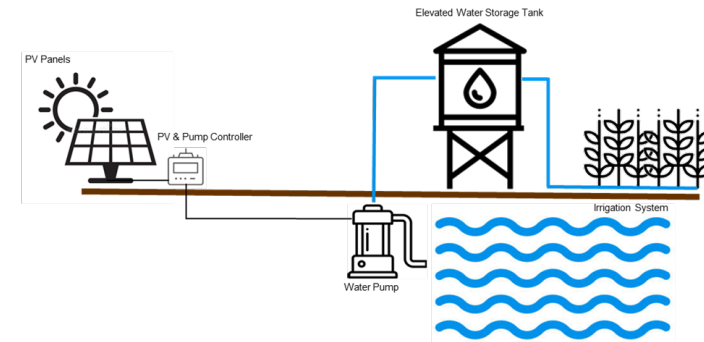


Constraints in Liberia:

- Drought stresses, low soil fertility, erosion of soil and weed competition.
- Poor drainage and iron toxicity in undeveloped swamps.
- Lack of small farm equipment, especially for post harvest operations.

Opportunities:

- Managing reliable irrigation systems and using resource efficient technologies like Solar Powered Irrigation Systems (SPIS).
- Implementing Systems of Rice Intensification (SRI); new varieties and crop management practices and improving water, fertilizer and soil management.



Rice Farming in Liberia:

- Approximately 55 % of rural Liberian households are food insecure.
- Smallholder and subsistence agriculture provides the main livelihood for 48.9 % of the workforce.
- Liberia imports up to 60 % of its staple food; Rice.
- Existing rice cultivation is generally a single, rainfed crop.
- Most agricultural activities are done manually, with little use of fertilizer or herbicides.
- Limited access to appropriate tools and equipment.
- Current yields <2t/ha



Key Components of SPIS

Electrical System:

- Photovoltaic (Solar) Panels
- Controller
- Solar Pump

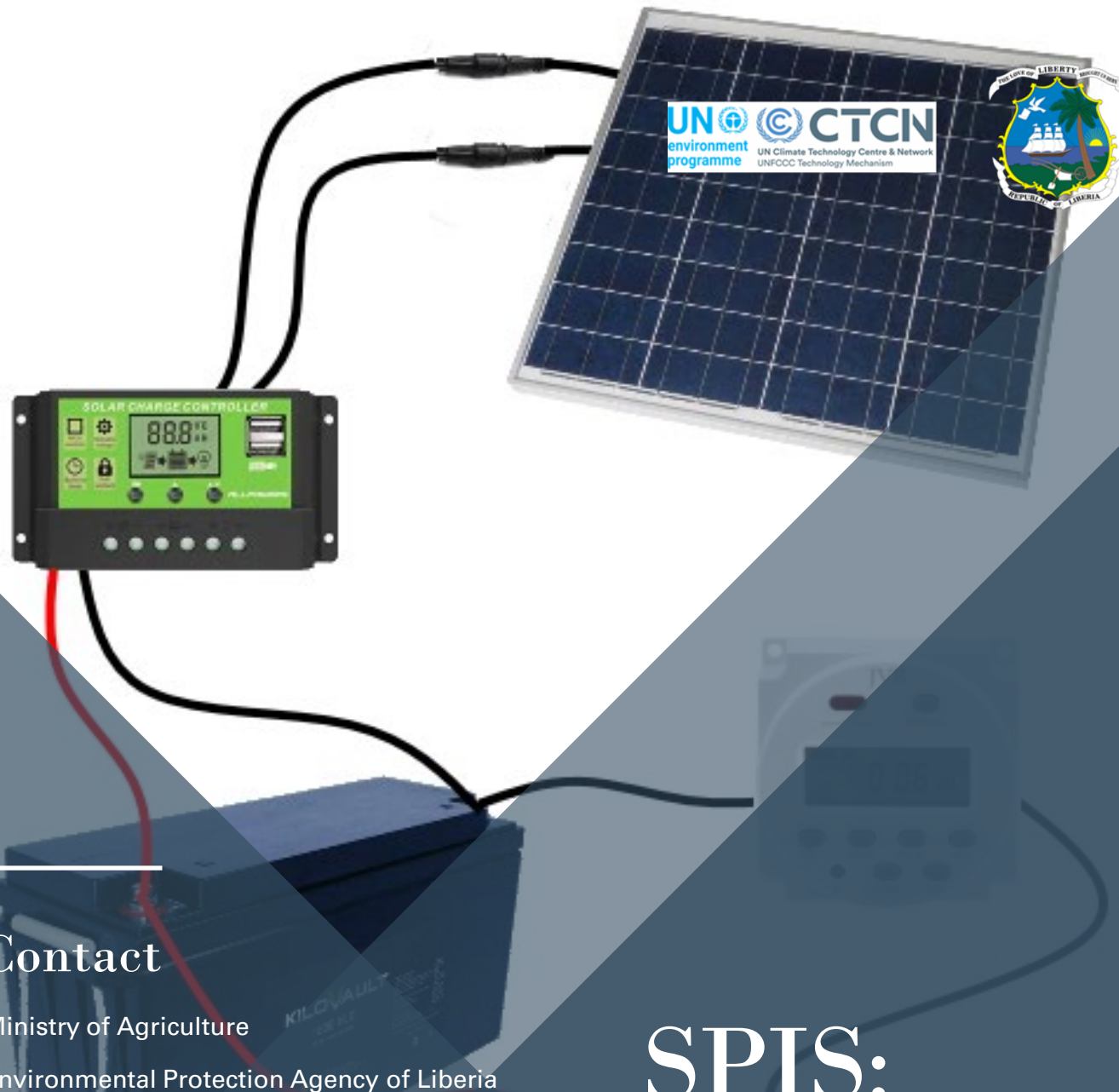
Irrigation System:

- Storage
- Distribution
- Application method

Agricultural Production System:

- Crop/Variety
- Agricultural inputs
- SRI methods

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SPIS: Electrical Systems



Configurations/Options:

- Stand Alone: Simple and Cheaper
- Multi-Use Systems: Other uses need to be compatible with pump requirements
 - Milling 💧🔧
- Mini-Grid: Expensive, community must be close to water source. \$\$
- Batteries: Allow to pump outside sunshine hours, but add complexity and cost



Photovoltaic (Solar) Panels:

- Panels
 - Without Mounting (Cheapest but theft is a risk)
 - Fixed Mounting – Simple and Safe
 - Sunlight Tracking – Complete and Expensive \$\$\$ 💧🔧

Controllers:

- MPPT – allows to maximise power output from panels 💧💧

Solar Pumps:

- Submersible 💧💧🔧 \$\$\$
- Surface Mounted \$



Recommendations:

- Although there are many potential configurations, a stand-alone system is recommended for simplicity and cost efficiency reasons.
- Other uses such as rice milling can be explored in the future once the pilot is running.
- Mini-grid option requires a community to be close to the water source.
- Battery Storage would allow to pump water outside of sunshine hours, but brings in extra costs and more operation complexity.
- Submersible pumps is recommended to protect against theft and optimise efficiency, but it should be run from a shallow pool to ensure water is clean and avoid pump damage.



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Production to Improve
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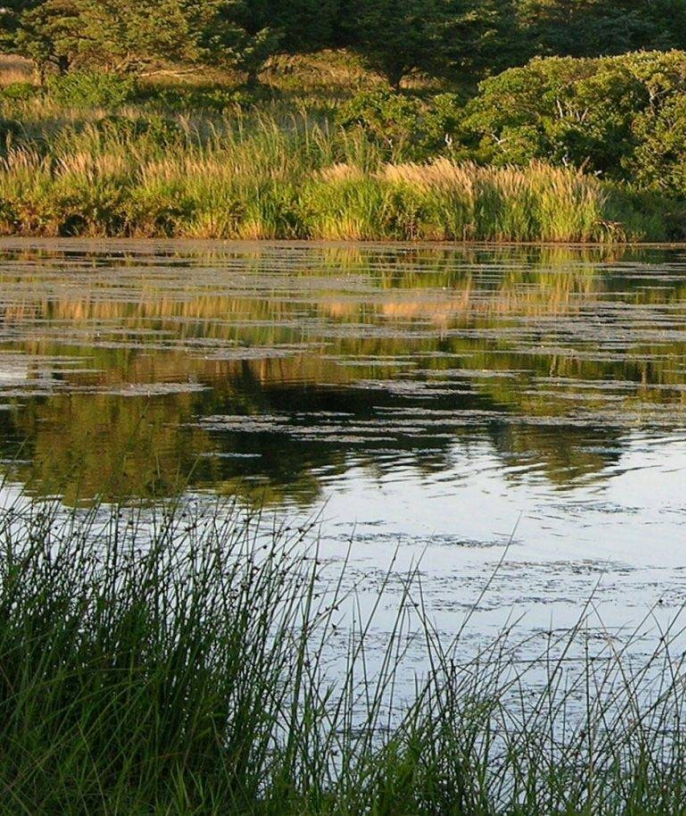
Contact

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SPIS: Irrigation Systems



Field Application Methods:

- Flood/Surface irrigation: \$ 🔧
 - Basin/Border
 - Furrow
- Overhead irrigation 🔧
- Drip irrigation 💧
- Sub-surface

Other Options:

- Night-Time Irrigation 💧
- Fertigation/Herbigation 💧
- Automatic Controls



Traditional Sprinkler System



Drip/Trickle System

Water Source/Storage:

- Natural pond/Existing Reservoir - Cheapest and simplest \$ 🔧 💧
- Dam reservoir/Dugout - High capital cost of construction 💧
- Elevated tank storage - For low pressure/low volume systems. 💧

Supply/Distribution:

- Pressurised rigid/flexible pipes (uPVC/HDPE) 💧
- Flexible hose \$ 🔧 💧
- Open channel (Lined or unlined) - Permeable soils lead to significant losses in unlined channels \$ 🔧



Conclusions:

- SPIS is more suited to irrigation techniques where the limited energy can efficiently supply smaller volumes of water at lower pressures
- Rice prefers flooded conditions (large water consumption), which will need the SPIS to supply large volumes at low head
- Alternate Wetting and Drying can be trialed with drip application methods
- Depending on the available budget for equipment and installation, SPIS can irrigate small areas of paddy fields for rice, or furrows or drip irrigation systems for vegetables.

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SPIS:
System of Rice
Intensification



Further details of SRI:

- Careful land preparation; 1st and 2nd ploughing, leveling and raking, with good drainage channels
- Preference for compost or farmyard manure to inorganic fertilizers, to promote microbial activity
- Nutrient-rich and un-flooded nurseries, close to the fields for quick planting
- Seedlings transplanted singly with their roots intact and seed sac attached
- Use of Leaf Colour Chart to manage needs-based Nitrogen application
- Frequent weeding in both directions between plants
- Root zone kept moist, not submerged, irrigating between 25-50mm.



What is the SRI method?

A method developed in Madagascar, characterised by five key components:

- Transplanting younger seedlings to reduce shock
- Wider spacing of plants so their roots grow larger
- Alternate Wetting and Drying for soil aeration during the vegetative stage
- Improved weed management, using small machinery
- Improved nutrient management through the addition of organic matter and fertilisers.



Recommendations:

- Cropping pattern:
 - 1st crop: Rice (Apr-Aug) - Rainfed
 - 2nd crop: Rice (Sept-Jan) - Irrigated
 - 3rd crop: Vegetable (Feb-Apr)
- Rice varieties Suakako 8 and Nerica L19
- 100 m² nursery for 1 ha main field (70% soil, 20% organic manure, 10% rice hull)
- Single transplanting at 2nd/3rd leaf stage (8-15 days)
- Spacing generally 25x25cm (or 20x20cm for shorter duration varieties)
- Alternate Wetting and Drying (AWD) the fields every 7-10 days
- Early 1st weeding and a 2nd weeding 15-20 days later, using mechanical tools.

Upscaling Lowland Rice
Production to Improve
Food Security through
Improved Solar Powered
Irrigation Practices
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SPIS:
Costs and Finance
Options



Capital Financing:

- **Grant:** Commonly partially funded (>50%) and tied to a Business Model.
- **Equity:** Minimum investment (10-20 %) ensures full commitment and improves sustainability of the systems.
- **Debt:** Remaining financing from loans from local lenders to avoid forex risks.

Payment Options:

- **Water as a service:** Farmers pay a pre-agreed lump sum per month.
- **Post-paid metering:** Farmers pay for the amount of water used at the end of the month.
- **Pay-as-you-irrigate:** Farmers pay in upfront for the water they intend to use.



Ownership/Service models:

- **Farmer-owned**
 - + Farmers' sense of ownership makes them responsible for O&M.
 - Farmers rarely have the required equity to purchase a system and often lack technical knowledge to operate it.
- **Operator-owned**
 - + Farmers pay for water, to cover the cost of O&M, but can decide to use other means if fees are too high.
 - The system might become unviable if too few farmers pay the water fees.
- **Developer-owned**
 - + Developer hires an operator, with no need to establish a local presence.
 - Operation may cease if too few farmers pay the water fees.



Conclusions:

- The pilot system implemented under the project is farmer-owned, but available for demonstration by the Ministry and other interested parties.
 - The capital cost of an SPIS to irrigate rice is approximately US\$ 7,500 per ha¹ and can save approximately US\$ \$600 /ha/year in fuel costs, compared to diesel powered pumps, and also save around 1,000 kg CO₂/ha/year.
1. For upscaling to a national programme in Liberia, the simplest and cheapest configurations have been selected.
 2. Suitable payment methods, such as pay-as-you-irrigate, credit facilities, and market maturity must play an essential role to achieve significant scalability.

Appendix B – Record of Stakeholder Working Group Workshop (31 May 2022): Presentation and Minutes

Attendance:

Present in the room:

- Oliver Taylor
- Robert Bimba
- Olivia David
- Fatumata Dolley
- Zipporah Page
- Dr Akintayo
- Halala Kokulo
- Pandian Balamurugan
- Sanco Lysander

Online:

- Nadege Trocellier
- James Dolo
- Rajendra Uprety
- George Oboli
- Imran Muhammad
- Mohammed V Kamara
- Fireflies.ai Notebook (This person did not identify themselves during the meeting)

Minutes

A copy of the presentation is shown below and a recording of the meeting is also available at the following link:

https://caresgroup-my.sharepoint.com/:v:/r/personal/oliver_taylor_cares-group_com/Documents/Recordings/Meeting-20220530_164845-Meeting%20Recording.mp4?csf=1&web=1&e=KDgZcA

The key aims and agreements from the meeting were as follows:

- **Site selection of best site in Bong County:** It was agreed to accept the findings in the presentation, with Bong Mines Site A ranked first, SKT ranked second and Bong Mines Site B ranked 3rd. Assuming there are no significant differences in the expected results of soil analyses for Bong Mines, the proposed site for the pilot scheme will be planned for Bong Mines Site A.
- **SPIS Configuration Options:** It was agreed that the electrical systems should be simple and robust, with the potential in the control electronics to utilise additional power in the future for other uses, such as rice milling. Regarding the irrigation methods to apply water to the fields, it was agreed that direct pumping to field channels and surface/flood irrigation was the most appropriate for the cultivation of rice, following SRI techniques, and would be the most easily acceptable to the farmers in the area. The proposed cropping pattern for the scheme was discussed as Rice (Wet season)-Rice (Dry)-Vegetables(Dry, depending on available water resources).
- **Next steps:** There was much discussion regarding the significant issues of farmer participation and security. A stakeholder engagement meeting with the district agriculture officers, co-operative and farmer members at the Bong Mines Site A will be held on Friday 3rd June to present the selection and outline of the SPIS pilot scheme to be installed. This meeting is open to other members of the SWG wish to attend.



Technical Assistance for Upscaling Lowland Rice Production to Improve Food Security through Improved Solar Powered Irrigation Practices in Liberia

Stakeholder Working Group Meeting

30 May 2022

Agenda

- Welcome and introductions
- Update on the progress of pilot site selection
- Discussion of SPIS Configuration Options
- Progress and programme / Next steps
- AOB



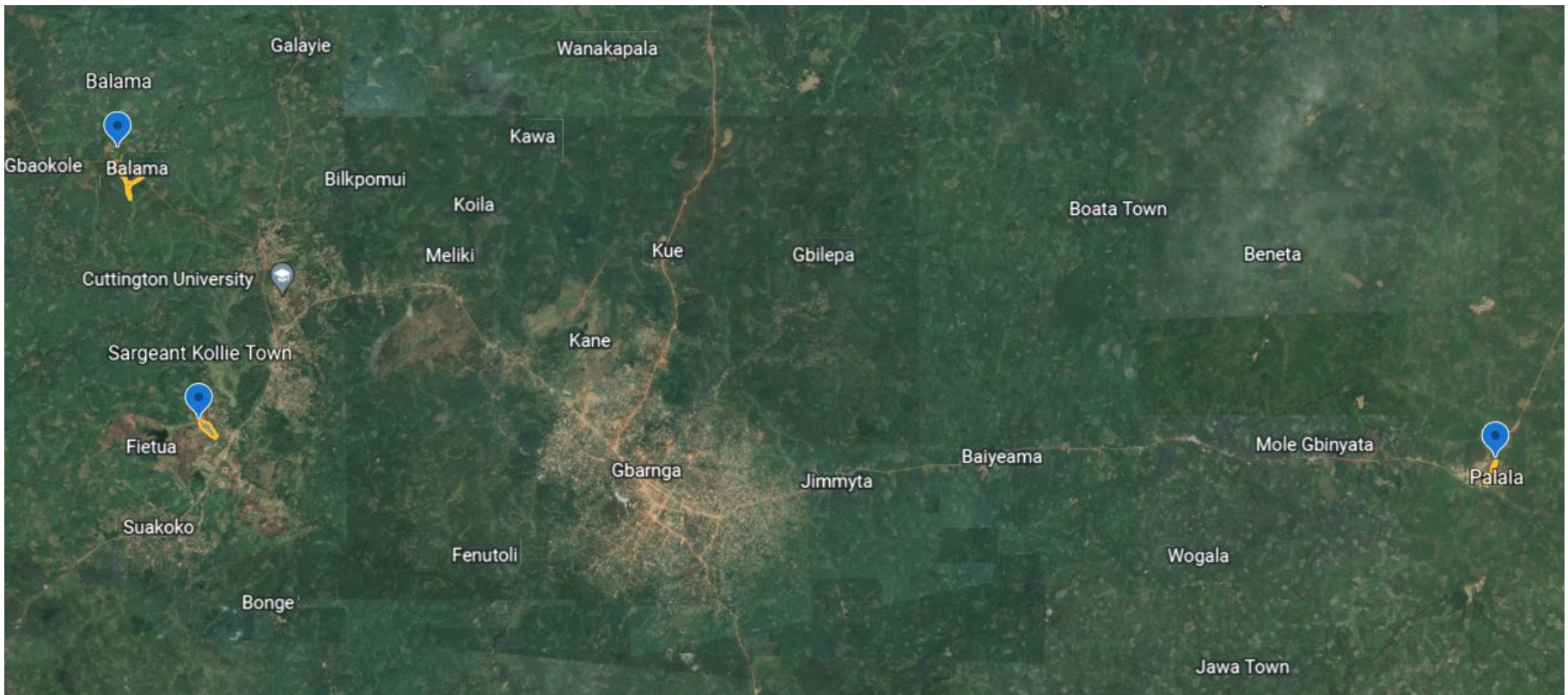
Welcome and Introductions

SWG Member	Organization / Role
Robert Bimba (Chair)	CHAP, Executive Director / RICOWAS Project In-Country Contact
Fatumata Dolleh (Co-Chair)	Gender Focus Representative at National Rice Federation of Liberia (NFRL)
Mohammed Kamara	Agriculture Infrastructure Investment Company (AIICO), CEO
Dr. James Dolo	Central Agricultural Research Institute (CARI), Researcher / Plant Breeder
Dr. Akintayo Inoussa	AfricaRice Center, Liberia, Country Director
Olivia K. David	Liberia Land Authority, Gender Coordinator
Anthony Kullie	Ministry of Mines and Energy: Director, Liberian Hydrological Service
Moses Gbanyan	Ministry of Agriculture: Region Agriculture Coordinator (RAC)
Mariatou Njie	FAO Representative in Liberia
Zipporah Page	CARI Researcher

CARES/INTee Team, CTCN, MoA and EPA



Bong County - Gbarnga



Three sites within the vicinity of AfricaRice, CARI and JICA project offices

Gbarnga - Palala



Size: 700 x 75 m, 3.5 ha

Membership: ~105 farmers

Limited interest

Water source: Wetland, no significant surface water resources

Gbarnga - Balama



Size: 1300 x 75 m, 9.5 ha

Membership: Interested and knowledgeable leadership

Water source: Wetland, very limited surface water resources.

Recent trials by JICA for dry season rice using small petrol driven pumps.

Gbarnga - SKT



Size: 600 x 125 m, 8.5 ha

Membership: Interested and knowledgeable leadership, limited membership (~20 active).

Water source: Wetland, reservoir with competing water demands (CARI, AfricaRice etc).

Potential for gravity supply to head of scheme area.

Gbarnga - SKT

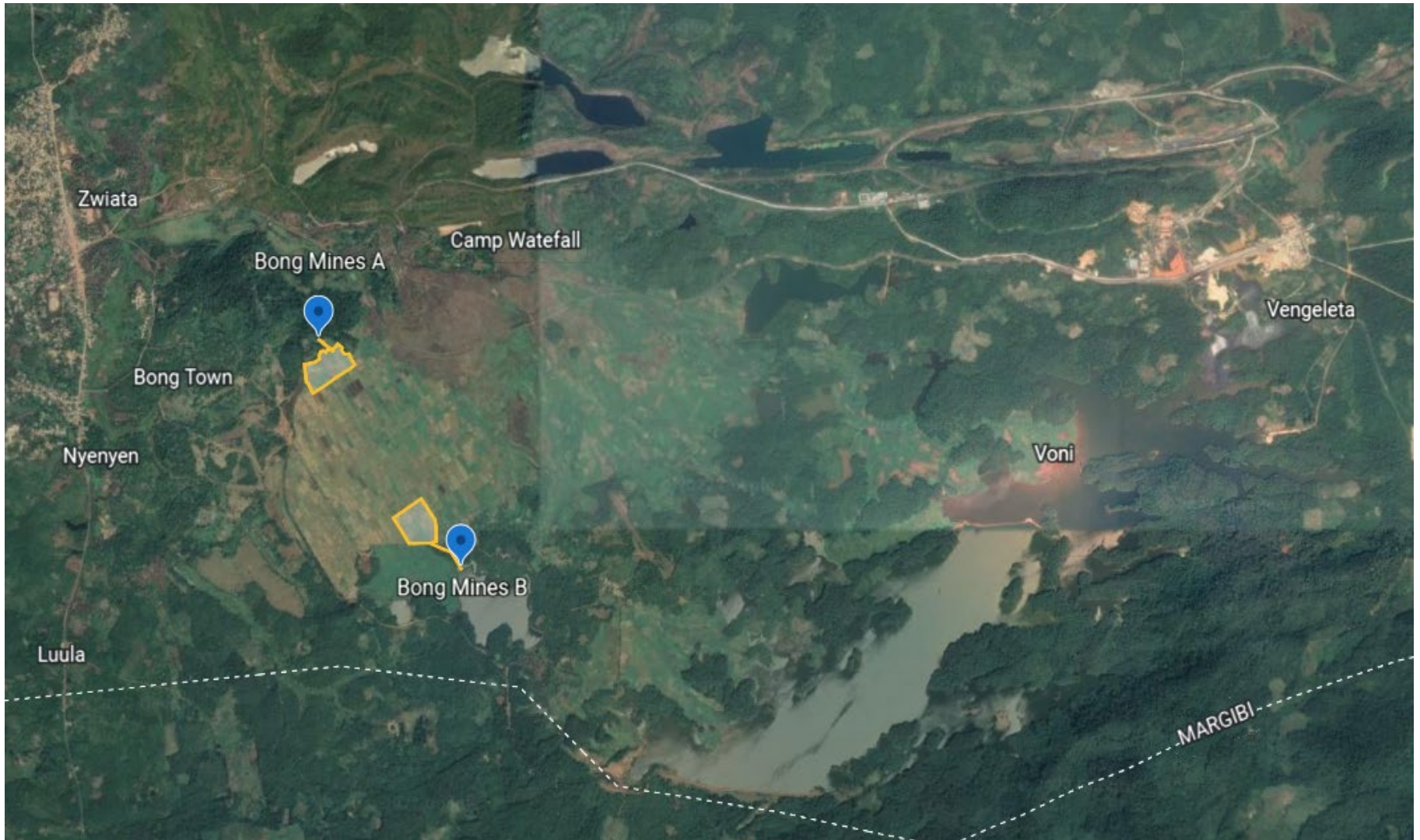


800m gravity supply to head of scheme area.

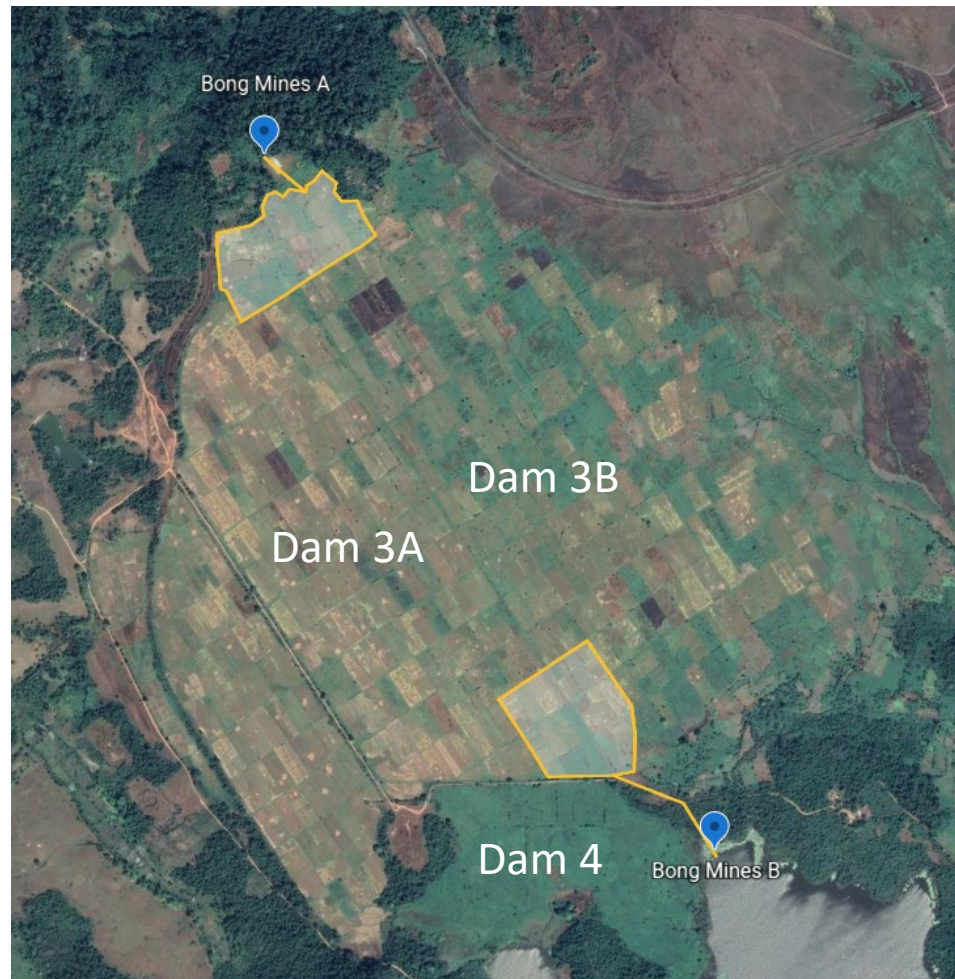
Collection sump structure required for solar pumping to raise water to fields.

Recent trials by JICA for dry season rice using small petrol driven pumps.

Bong Mines - Overview



Bong Mines – Identified Sites



Bong Mines – Site A



Size: 400 x 200 m, 7.5 ha

Membership: Part of the Fuamah District Multipurpose Cooperative, Dam 3A and 3B areas

Water source: Limited surface water resources, available throughout the dry season.

Soils have high organic content in top surface, predominantly silt/sand with low water holding capacity.

Pumping distance ~125m

Bong Mines – Site B



Size: 300 x 250 m, 7.5 ha

Membership: Part of the Fuamah District Multipurpose Cooperative, Dam 3A and 3B areas

Water source: Significant surface water resources, available throughout the dry season.

Soils have high organic content in top surface, predominantly silt/sand with low water holding capacity.

Pumping distance ~350m

Access via private land, Crossing of drainage channels.

Pilot Site Selection Criteria

Criteria	Palala	Balama	SKT	Bong Mines A	Bong Mines B	Comments/Justification for scoring
Availability of suitable water sources:						
•Surface water; river and existing storage (dam/reservoir)	1	2	3	3	4	Bong Mines - Most significant available surface water resources SKT - Dam used by CARI and AfricaRice project Palala - Unknown water source, not visible
•Groundwater	1	2	2	1	1	Bong Mines - Limited groundwater availability SKT potential for shallow well Balama & Palala - Unknown
Existing lowland rice cultivated areas, with potential for increased yields, cropping intensity and/or diversity of crops (i.e. areas out of command for gravity fed irrigation) ~10ha	3	3	4	4	4	Bong Mines - Existing rainfed rice growing area, vegetables in the dry season SKT - Lowland area growing rainfed rice Palala & Balama - Lowland areas, long thin sites
Suitable soil types (i.e. limited iron toxicity) and adequate drainage	3	3	3	2	2	SKT, Palala, Balama - Silt deposits, unknown characteristics Bong Mines - Silty soils, low water holding capacity, potential toxicity
Community interest/motivation in new technologies and cultural practices	1	3	2	3	3	Bong Mines - Significant membership and enthusiasm, FAO training in SRI Balama & SKT - Enthusiastic chairman, limited membership, poor JICA trials Palala - Little enthusiasm shown by chairman
Labour availability and organisation, particularly for equipment security	2	3	2	3	3	SKT predominantly women members, adjacent buildings for storage Palala - Larger group, but details unknown Balama - Pump would be located next to busy road
No land ownership issues	3	4	3	4	2	SKT land granted to co-operative, adjacent to CARI/AfricaRice project to 2023 Palala - Unknown, but assumed granted to the co-operative Bong Mines - Land owned by Dr Suba
Location with respect to milling facilities and markets for inputs (i.e. seeds and agro-chemicals) and produce	3	3	4	4	4	SKT close to Gbarnga, JICA, AfricaRice and CARI facilities Palala - Further away from Gbarnga Bong Mines closely located to Monrovia
Good site access from Monrovia and other parts of the country for construction logistics, demonstration workshop or meetings etc	3	3	4	4	3	SKT simplest and cheapest SPIS system, close to research facilities as demo Bong Mines Site B more costly to install system than Site A due to longer pipe delivery
Total	20	26	27	28	26	

SPIS Configuration Options

Electrical System



The Solar Panel



The Controller



The Solar Pump

Irrigation System



Storage



Distribution



Application

Agriculture System



Crop/Variety



Inputs usage



SRI methods

Configuration choices depend on multiple factors, including:

- **Available Water Resources** – Volumes, location and pumping head
- **Soils, Crop/Variety Choice and Agricultural Production Processes** - Farm water/input requirements
- **Climate** (Sunshine, Rainfall, Temperature & Wind) - Power generation and crop evapotranspiration
- **Other potential energy uses**
- **Farmer's skills and Budget.**

SPIS Configuration Options – Electrical System



The Solar Panel



The Controller



The Solar Pump

Configuration aspects include:

- PV panels
- Mounting structures
- Controller (Usually Maximum Power Point Tracking MPPT)
- Pump (DC or AC, variable motor speed and pump volume)
- Monitoring system (Volume, Timer etc)
- Alternative energy uses (Rice mill etc)
- Batteries
- Mini-Grids and Hybrid systems

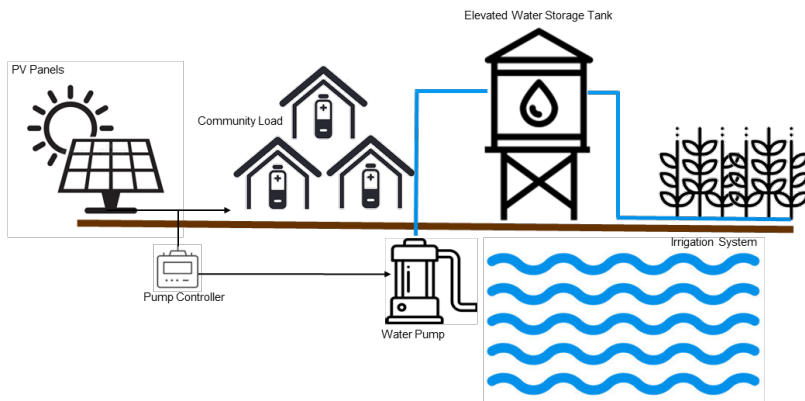
Conclusions/Recommendations for SPIS Pilot Scheme:

- Mini-Grid / Hybrid systems not suitable
- Suggested to start with basic standalone system with possibility to add alternative (productive) use, probably rice milling
- Land assessment for suitability of mounting PV structure
- Security of assets ? Fencing ?

Electrical System

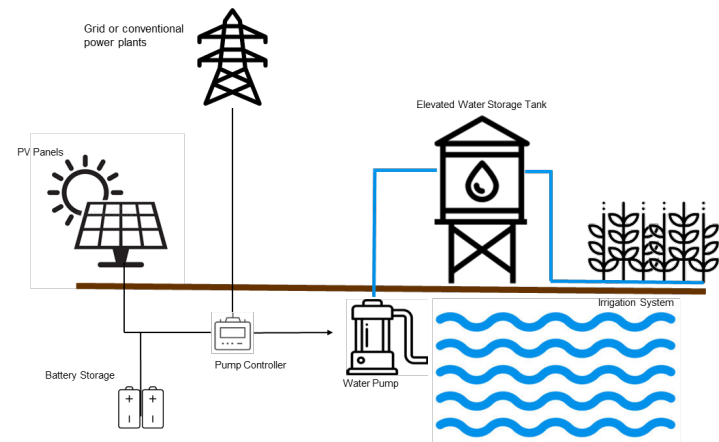
Mini-Grid

Not suitable
(Far away from community,
more than 2 km)



Hybrid

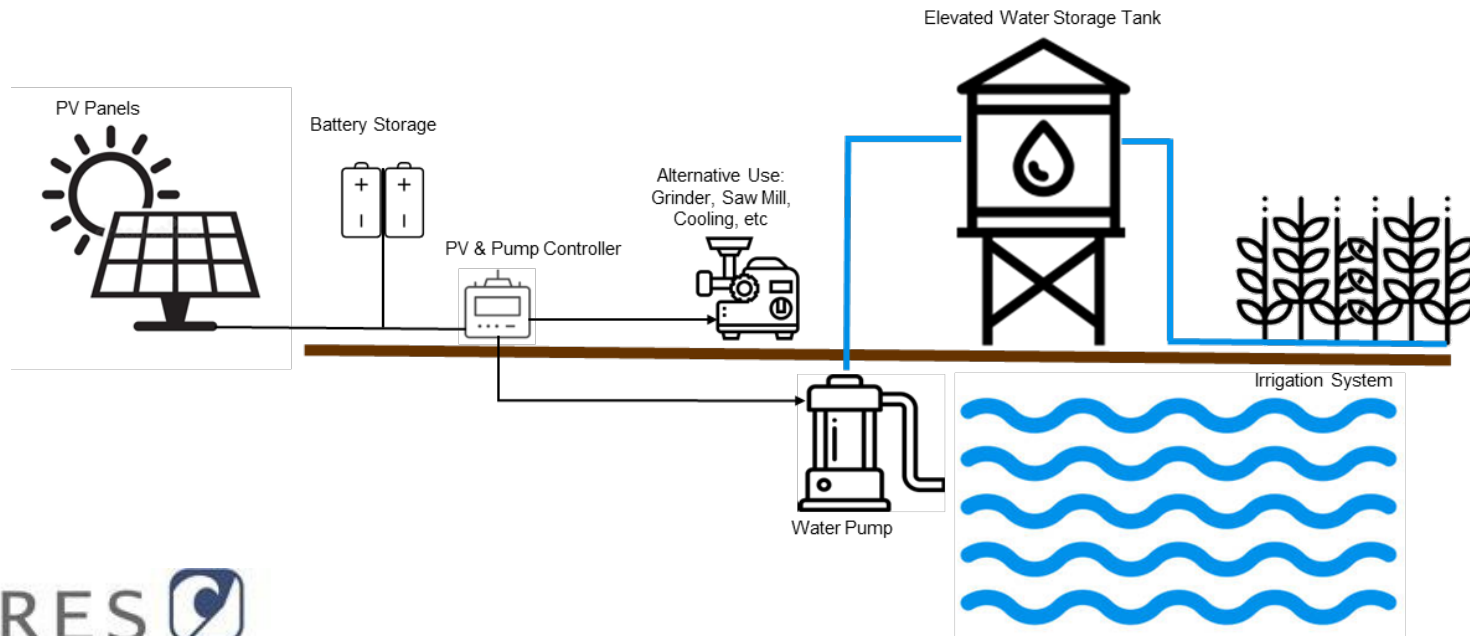
Not suitable
(Far away from grid,
30 years old inactive network)



Electrical System

Standalone System

- **Storage tank:** Irrigation frequency vs active pumping hours
- **Battery:** Cost vs additional benefit ?
- **Diesel generator:** Fuel supply ? Diesel costs ?
- **Alternative uses:** Value addition by milling rice vs compromise on pumping capacity?



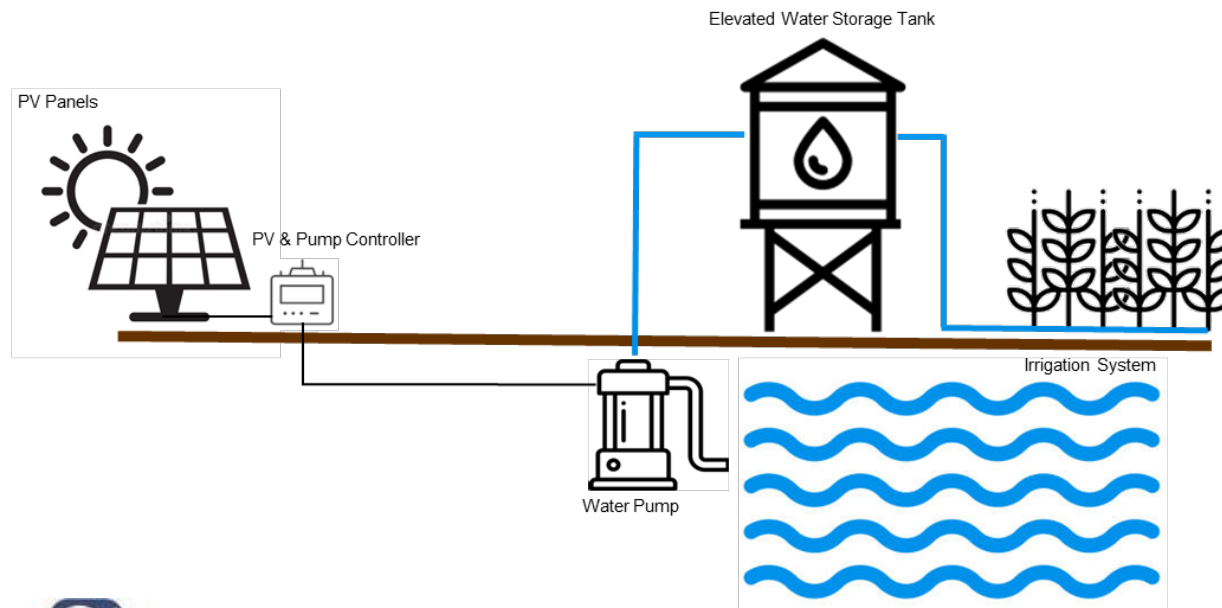
Electrical System

Recommendation:

Start with basic system with option to add alternative (productive) use like rice milling

Standalone System

Electronics should allow for this future adaptation



SPIS Configuration Options – Irrigation System



Storage



Distribution



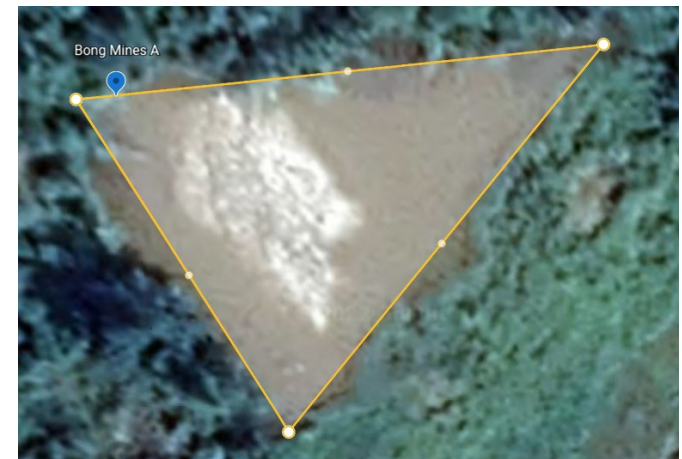
Application

Water storage options:

- Natural pond/Existing Reservoir - Cheapest and simplest
- Dam reservoir/Dugout - High capital cost of construction
- Elevated tank storage - For low pressure delivery systems

Bong Mines Site A:

- Minimum 1,200 m³



Irrigation System



Storage



Distribution



Application

Supply and distribution options:

- Pressurised rigid/flexible pipes (uPVC/HDPE)
- Flexible hose
- Open channel (Lined or unlined)



Field Water Application Methods:

- Flood/Surface irrigation:



Paddy or Furrow

- Overhead irrigation:



- Drip irrigation:



Irrigation System

Conclusions:

- SPIS is more suited to irrigation techniques where the limited energy can efficiently supply smaller volumes of water at lower pressures
- Rice prefers flooded conditions (large water consumption), but can also trial drip application
- Permeable soils lead to significant losses in unlined channels and fields
- SPIS system will need to supply large volumes at low head
- Available budget for equipment and installation limits pilot scheme to small area of paddy fields for rice, furrows or drip irrigation system for vegetables.

Recommendations for SPIS Pilot Scheme:

- Maximise research with split scheme; partly flood, partly drip, partly rice, partly vegetables
- Utilise existing natural pond/reservoir for storage (with elevated tank in fields for drip areas)
- Direct pumping; piped water delivery with short supply route and small change in elevation
- Distribution by unlined field channels to fields (with surface pipes and drip lines).

SPIS Configuration Options – Agriculture System



Crop/Variety



Inputs usage



SRI methods

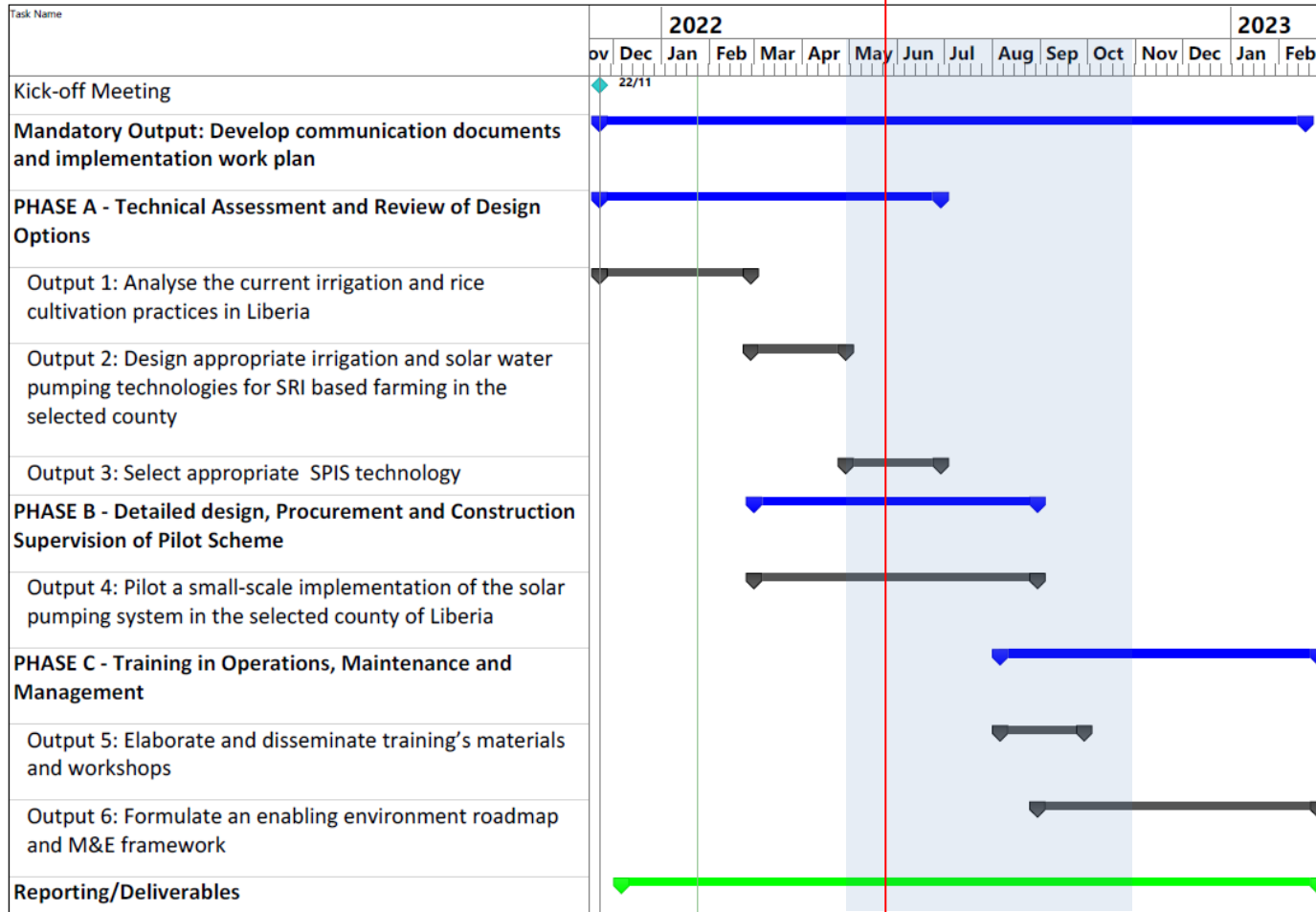
Configuration aspects include:

- Crop choices/Cropping pattern (Rice or vegetables?)
- 1st, 2nd and 3rd season?
- Organic manures and Fertilizers
- Herbicides and Pesticides (Restricted usage)
- Transplanting, Weeding, Mechanisation etc

Conclusions/Recommendations for SPIS Pilot Scheme:

- Rice – Rice –Rice (Complex)
- Rice – Rice – Pulses
- Rice – Rice – Vegetables
- Rice – Rice – Maize
- Rice – Rice
- Rice – Vegetables
- Rice – Maize
- ?

Progress and programme



Wet Season

Select site and technology: June 2022

Install equipment: August 2022

Training/Learning

Planning national roll-out

Project completion: February/March 2023

Next steps

Output 3: Select appropriate SPIS technology

- **SPIS Configurations Report** and fact sheets on appropriate technologies (2-3 recommended options and cost estimates, **Activity 3.1, 3.2. 3.3 & 4.1**)
- **Activity 3.4:** Stakeholders' meeting to present configuration to farmers (3rd June)

Output 4: Pilot a small-scale implementation of the solar pumping system in the selected county of Liberia

- **Activity 4.2:** Plan the implementation of the pilot project
- **Activity 4.3:** Organize an online meeting to discuss the logistics and implementation of the pilot
- **Activity 4.4:** Route the technology to the selected area
- **Activity 4.5:** Implement the small-scale project in the pilot area.



Appendix C – Record of Stakeholder Meeting at Bong Mines (3 June 2022)

The farmer's workshop was conducted in the selected site of Dam 3, Bong mine on 3rd June, 2022. In general, the response for the meeting was good with appreciable numbers of participants.

The minutes of the meeting as follows,

1. Self introduction by all participants
2. There were 47 participants, including the leader of the community and a representative from MOA, two participants from CARES. More than 50 percent of the farmers were women.
3. Some hard copies of SWG presentation held at Monrovia were distributed to the lead farmers.
4. The session was started with emphasizing the importance, need and objective of the project title and the lowland is preferred to go with this project.
5. CARES field visit on various counties and the sites with various parameters were discussed and the substantiation of the Dam 3 site selection with various parameters like water resources, suitability of the land, soil type, interest of the community was discussed. The farmers are highly satisfied with site selection
6. Various options of SPIS technology pertaining to Electrical, Irrigation and Agricultural options were elaborated in detail, with detailed illustration and diagrams.
7. Discussed about the various components of SRI and its implication on yield maximization and double cropping options like rice-rice and rice-veg. Few farmers responded for rice-veg options because of the ready market
8. CARES intervention to link the farmers with service providers like BRAC and other agencies for the collaboration were discussed
9. The security issues, provision of security to the installed materials, the ownership, continuous support from all the farmers up to the end of the cropping cycle were pointed out and agreed by them, with seven people volunteering to share security shifts for the equipment and agreement to build a shelter for the guards.
10. Finally, the most important aspect of What CARES give farmers and what not. Farmers /the community should take care of their own farming cost including inputs and should deploy labour force for any civil and installation work whenever needed. CARES install the SPIS and conducts technical session on SPIS and SRI on need basis / as when require.
11. A further meeting was scheduled for the following Sunday, when there was further discussion around the security issue and the commitment to begin clearing of the site when the site for the installation is identified.

Names of Farmers Attending the Farmers' Engagement Meeting Held on June 3, 2022 Dam 3 Bong Mines, Bong County				
No.	Names	Position	Sex	Contact
1	James G. Wonnie	Secretary	M	775169687
2	Garsonid K. Watson	MoA	M	778625911
3	Francis F. Tamba	Farmer	M	775753195
4	John Hinnah	Farmer	M	776205406
5	Hawa Jibbah	Farmer	F	886448815
6	Theresa Konoh	Farmer	F	776867171
7	Ruth Fokoe	Farmer	F	776031670
8	Jenson A. Jallah	Farmer	M	886584584
9	Johnson N. Kamanda	Farmer	M	880430355
10	Tamba Dennis	Farmer	M	778643892
11	Pst. James Tamba	Farmer	M	770273002
12	John Fayiah	Farmer	M	555917357
13	Annie Koryee	Farmer	F	775682999
14	Cecelia Sahr	Farmer	F	778837122
15	Nancy James	Farmer	F	776031670
16	Blessing Titus	Farmer	F	770946009
17	Tewa korkorma	Farmer	F	776304137
18	Musu Kemesie	Farmer	F	776564534
19	Sumo Kpehe	Farmer	M	881417589
20	Edward Sahr	Farmer	M	555127711
21	Siah Ngegbah	Farmer	F	N/A
22	Hana Gollay	Farmer	F	776043387
23	Nancy G. Padmore	Farmer	F	775263513
24	Lucy Toe	Farmer	F	775165859
25	Abdulai Passaway	Farmer	M	778328953
26	Martha Sumo	Farmer	F	N/A
27	Yongo Eric	Farmer	F	N/A
28	Alakemenie Wennie	Farmer	M	N/A
29	Esther George	Farmer	F	N/A
30	Sylvester S. B. Gboyah	Farmer	M	886857109
31	Gbolo Sylvester	Farmer	F	775969084
32	Jackson Dolo	Farmer	M	N/A
33	Morris Dennis	Farmer	M	N/A
34	Siah Kendema	Farmer	F	N/A
35	Fatu David	Farmer	F	N/A
36	Mary Tengbeh	Farmer	F	N/A
37	Siah James	Farmer	F	N/A
38	Sahr James	Farmer	M	N/A
39	Eric Kolliemeolyne	Farmer	M	770361665
40	Krubo Reeds	Farmer	F	776455164
41	Janet Kollie	Farmer	F	886856454
42	Annie David	Farmer	F	N/A
43	Satta Taylor	Farmer	F	N/A
44	Nenkpeh Mulbah	Farmer	F	N/A
45	Abu Sam	Farmer	M	77527272183
46	Krubo Kokulo	Farmer	F	777584555
47	Solomon Sahr	Farmer	M	N/A



Appendix D – FAO CropWat Calculations

1. RICE-1

MONTHLY ETO PENMAN-MONTEITH DATA

File:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-1_JUN-Mid-OCT_PD-1st Jul\SUAKOKO.pem

Country: Liberia_BONG MINES Station: SUAKOKO

Altitude: 150 m. Latitude: 7.00 °N Longitude: 9.58 °W

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	18.7	31.5	69	78	5.3	15.9	3.50
February	17.7	32.6	64	78	5.5	17.1	3.86
March	18.1	32.5	66	78	5.4	17.7	3.98
April	19.0	32.3	68	78	5.2	17.5	3.93
May	19.7	31.5	74	95	4.6	16.1	3.69
June	19.3	30.2	72	164	3.6	14.2	3.69
July	19.5	28.7	78	199	2.6	12.9	3.32
August	18.1	27.5	76	199	2.2	12.6	3.25
September	19.6	29.5	68	164	2.7	13.5	3.64
October	20.5	30.5	80	112	4.3	15.4	3.42
November	21.2	30.5	82	112	5.1	15.8	3.41
December	19.7	31.1	78	78	4.2	14.0	3.08
Average	19.3	30.7	73	120	4.2	15.2	3.56

MONTHLY RAIN DATA

File:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-1_JUN-Mid-OCT_PD-1st Jul\SUAKOKO.crm

Station: SUAKOKO

Eff. rain method: USDA Soil Conservation Service formula:

$$\begin{aligned} \text{Peff} \text{ Peff} &= \text{Pmon} * (125 - 0.2 * \text{Pmon}) / 125 \text{ for } \text{Pmon} \leq 250 \text{ mm} \\ &= 125 + 0.1 * \text{Pmon} \text{ for } \text{Pmon} > 250 \text{ mm} \end{aligned}$$

	Rain mm	Eff rain mm
January	19.0	18.4
February	59.0	53.4
March	152.0	115.0
April	175.0	126.0
May	199.0	135.6
June	197.0	134.9
July	204.0	137.4
August	159.0	118.6
September	361.0	161.1
October	220.0	142.6
November	98.0	82.6
December	36.0	33.9
Total	1879.0	1259.6

RICE DATA

e:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-1_JUN-Mid-OCT_PD-1st Jul\Crop-1_RICE-1.

Crop Name: RICE-1 Transplanting date: 01/07 Harvest: 13/10

	Stage	nursery		landprep		growth stage			total	
				total	puddling	initial	develop	mid late		
Length (days)		30		20	10	20	25	35	25	135
Kc dry		0.70			0.30	0.50	-->	1.05	0.70	
Kc wet		1.20			1.05	1.10	-->	1.20	1.05	
Rooting depth (m)						0.10	-->	0.60	0.60	
Puddling depth (m)				0.40						
Nursery area (%)		10								
Critical depletion		0.20				0.20	-->	0.20	0.20	
Yield response f.						1.00		1.09	1.09	1.09
Cropheight (m)								1.00		

SOIL DATA

ile:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-1_JUN-Mid-OCT_PD-1st Jul\SANDY LOAM.SO

Soil name: SANDY LOAM General soil data:

Total available soil moisture (FC - WP)	140.0	mm/meter
Maximum rain infiltration rate	30	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion (as % TA)	0	%
Initial available soil moisture	140.0	mm/meter

Additional soil data for rice calculations:

Drainable porosity (SAT - FC)	20	%
Critical depletion for puddle cracking	0.50	mm/day
Water availability at planting	100	mm WD
Maximum waterdepth	100	mm

CROPPING PATTERN DATA

File: D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-1_JUN-Mid-OCT_PD-1st Jul\CROP_PAT.PAT

Cropping pattern name: BONG MINES IRRIG PRJ

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1	...JUN-Mid-OCT_PD-1s	RICE-1	01/07	13/10	100

CROP WATER REQUIREMENTS

ETo station: SUAKOKO Crop: RICE-1

Rain station: SUAKOKO Planting date: 01/07

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Nurs	1.20	0.44	4.4	45.0	0.0
Jun	2	Nurs/LPr	1.06	3.93	39.3	44.9	81.6
Jun	3	Nurs/LPr	1.06	3.79	37.9	45.2	181.4
Jul	1	Init	1.10	3.78	37.8	46.2	0.0
Jul	2	Init	1.10	3.65	36.5	46.8	0.0
Jul	3	Deve	1.12	3.68	40.5	44.4	0.0
Aug	1	Deve	1.15	3.75	37.5	39.7	0.0
Aug	2	Mid	1.17	3.80	38.0	36.6	1.4
Aug	3	Mid	1.17	3.96	43.6	42.3	1.3
Sep	1	Mid	1.17	4.11	41.1	50.9	0.0
Sep	2	Late	1.17	4.26	42.6	56.5	0.0
Sep	3	Late	1.12	4.00	40.0	53.5	0.0
Oct	1	Late	1.06	3.69	36.9	50.9	0.0
Oct	2	Late	1.02	3.47	10.4	14.8	0.0
					486.7	617.7	265.6

RICE IRRIGATION SCHEDULE

ETo station: SUAKOKO Crop: RICE-1 Planting date: 01/07
 Rain station: SUAKOKO Soil: SANDY LOAM Harvest date: 13/10

Yield red.: 0.0 % Rice scheduling options

Pre puddling:

Soaking depth on day 1 0.5 m

Timing Irrigate at 20 % depletion of Field Capacity Application

Refill soil moisture content to 100 % saturation

Puddling

Timing Irrigate at 0 mm waterdepth

Application Refill waterdepth to 50 mm

Growth stages

Timing Irrigate at 5 mm waterdepth

Application Refill waterdepth to 100 mm

Field efficiency 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.	SMNet	Gif	Loss
Depl.SA			mm	fract.	%	state	mm	mm	mm	mm	mm
11 Jun	-19	PrePu	0.0	1.00	100	Prep	0.0	1	81.4	0.0	80.0
21 Jun	-9	Puddl	0.0	1.00	100	Prep	1.5	0	128.6	0.0	78.6
25 Jun	-5	Puddl	0.0	1.00	100	OK	12.1	0	52.2	0.0	2.2
11 Aug	42	Dev	0.0	1.00	100	OK	3.1	0	100.4	0.0	0.4
13 Oct	End	End	0.0	1.00	0	OK	0.0	0			

Totals:

Total gross irrigation	517.9 mm	Total rainfall	980.1 mm		
Total net irrigation	362.5 mm	Effective rainfall		819.5 mm	
Total irrigation losses	0.0 mm	Total rain loss		160.6 mm	
Total percolation losses	556.1 mm				
Actual water use by crop	401.6 mm	Moist deficit at harvest		0.0 mm	
Potential water use by crop	401.6 mm	Actual irrigation requirement		-418. mm	
Efficiency irrigation schedule	100.0 %	Efficiency rain		83.6 %	
Deficiency irrigation schedule	0.0 %				

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	1.00	1.09	1.32	0.50	1.10	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

SCHEME SUPPLY

ETo station: SUAKOKO Cropping pattern: BONG MINES IRRIG PRJ

Rain station: SUAKOKO

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.0	0.0	0.0	0.0	0.0	262.9	0.0	2.7	0.0	0.0	0.0	0.0
deficit												
1. RICE-1												
Net scheme irr.req.												
in mm/day	0.0	0.0	0.0	0.0	0.0	8.8	0.0	0.1	0.0	0.0	0.0	0.0
in mm/month	0.0	0.0	0.0	0.0	0.0	262.9	0.0	2.7	0.0	0.0	0.0	0.0
in l/s/h	0.00	0.00	0.00	0.00	0.00	1.01	0.00	0.01	0.00	0.00	0.00	0.00
Irrigated area	0.0	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.0	0.0	0.0	0.0
(% of total area)												
Irr.req. for actual area	0.00	0.00	0.00	0.00	0.00	1.01	0.00	0.01	0.00	0.00	0.00	0.00
(l/s/h)												

2. RICE-2

MONTHLY ETO PENMAN-MONTEITH DATA

File:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-2_Mid-OCT-FEB_PD-15th Nov\SUAKOKO.pem

Country: Liberia_BONG MINES Station: SUAKOKO

Altitude: 150 m. Latitude: 7.00 °N Longitude: 9.58 °W

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	18.7	31.5	69	78	5.3	15.9	3.50
February	17.7	32.6	64	78	5.5	17.1	3.86
March	18.1	32.5	66	78	5.4	17.7	3.98
April	19.0	32.3	68	78	5.2	17.5	3.93
May	19.7	31.5	74	95	4.6	16.1	3.69
June	19.3	30.2	72	164	3.6	14.2	3.69
July	19.5	28.7	78	199	2.6	12.9	3.32
August	18.1	27.5	76	199	2.2	12.6	3.25
September	19.6	29.5	68	164	2.7	13.5	3.64
October	20.5	30.5	80	112	4.3	15.4	3.42
November	21.2	30.5	82	112	5.1	15.8	3.41
December	19.7	31.1	78	78	4.2	14.0	3.08
Average	19.3	30.7	73	120	4.2	15.2	3.56

MONTHLY RAIN DATA

File:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-2_Mid-OCT-FEB_PD-15th Nov\SUAKOKO.crm

Station: SUAKOKO

Eff. rain method: USDA Soil Conservation Service formula:

$$P_{eff} = \begin{cases} P_{mon} * (125 - 0.2 * P_{mon}) / 125 & \text{for } P_{mon} \leq 250 \text{ mm} \\ 125 + 0.1 * P_{mon} & \text{for } P_{mon} > 250 \text{ mm} \end{cases}$$

	Rain mm	Eff rain mm
January	19.0	18.4
February	59.0	53.4
March	152.0	115.0
April	175.0	126.0
May	199.0	135.6
June	197.0	134.9
July	204.0	137.4
August	159.0	118.6
September	361.0	161.1
October	220.0	142.6
November	98.0	82.6
December	36.0	33.9
Total	1879.0	1259.6

RICE DATA

e:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-2_Mid-OCT-FEB_PD-15th Nov\Crop-2_RICE-2.

Crop Name: RICE-2 Transplanting date: 15/11 Harvest: 27/02

	Stage	nursery	landprep		initial	growth stage		total	
			total	puddling		develop	mid late		
Length (days)		30	20	10	20	25	35	25	135
Kc dry		0.70		0.30	0.50	-->	1.05	0.70	
Kc wet		1.20		1.05	1.10	-->	1.20	1.05	
Rooting depth (m)					0.10	-->	0.60	0.60	
Puddling depth (m)			0.40						
Nursery area (%)		10							
Critical depletion		0.20			0.20	-->	0.20	0.20	
Yield response f.					1.00		1.09	1.09	1.09
Cropheight (m)							1.00		

SOIL DATA

le:

D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-2_Mid-OCT-FEB_PD-15th Nov\SANDY LOAM.S

Soil name: SANDY LOAM General soil data:

Total available soil moisture (FC - WP)	140.0	mm/meter
Maximum rain infiltration rate	30	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion (as % TA)	0	%
Initial available soil moisture	140.0	mm/meter

Additional soil data for rice calculations:

Drainable porosity (SAT - FC)	20	%
Critical depletion for puddle cracking	0.50	mm/day
Water availability at planting	100	mm WD
Maximum waterdepth	100	mm

CROPPING PATTERN DATA

file: D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-2_Mid-OCT-FEB_PD-15th Nov\CROP_PAT.PA

Cropping pattern name: BONG MINES IRRIG PRJ

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1	...d-OCT-FEB_PD-15th	RICE-2	15/11	27/02	100

CROP WATER REQUIREMENTS

ETo station: SUAKOKO Crop: RICE-2
 Rain station: SUAKOKO Planting date: 15/11

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	2	Nurs	1.20	0.41	2.1	24.7	0.0
Oct	3	Nurs/LPr	1.13	2.17	23.9	42.2	80.9
Nov	1	Nurs/LPr	1.06	3.63	36.3	33.9	191.5
Nov	2	Init	1.09	3.70	37.0	27.0	10.0
Nov	3	Init	1.10	3.63	36.3	21.8	14.5
Dec	1	Deve	1.11	3.53	35.3	15.7	19.6
Dec	2	Deve	1.13	3.48	34.8	9.8	25.1
Dec	3	Mid	1.16	3.72	40.9	8.6	32.4
Jan	1	Mid	1.16	3.91	39.1	6.3	32.8
Jan	2	Mid	1.16	4.07	40.7	3.8	36.9
Jan	3	Mid	1.16	4.21	46.3	8.5	37.9
Feb	1	Late	1.14	4.28	42.8	13.1	29.7
Feb	2	Late	1.09	4.21	42.1	16.6	25.5
Feb	3	Late	1.05	4.07	28.5	20.8	4.7
						486.2	541.5

RICE IRRIGATION SCHEDULE

ETo station: SUAKOKO Crop: RICE-2 Planting date: 15/11
 Rain station: SUAKOKO Soil: SANDY LOAM Harvest date: 27/02

Yield red.: 0.0 % Rice scheduling options
 Pre puddling:
 Soaking depth on day 1 0.5 m
 Timing Irrigate at 20 % depletion of Field Capacity Application
 Refill soil moisture content to 100 % saturation

Puddling
 Timing Irrigate at 0 mm waterdepth
 Application Refill waterdepth to 50 mm

Growth stages
 Timing Irrigate at 5 mm waterdepth
 Application Refill waterdepth to 100 mm

Field efficiency 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Puddl state	Percol. mm	Depl. mm	SMNet mm	Gif mm	Loss mm	Depl. SA mm
26 Oct	-19	PrePu	0.0	1.00	100	Prep	0.0	1	81.3	0.0	80.0	
5 Nov	-9	Puddl	0.0	1.00	100	Prep	2.9	0	126.2	0.0	76.2	
9 Nov	-5	Puddl	0.0	1.00	100	OK	12.1	0	62.4	0.0	12.4	
16 Nov	2	Init	0.0	1.00	100	OK	3.1	0	99.2	0.0	-0.8	
5 Dec	21	Dev	0.0	1.00	100	OK	3.1	0	95.1	0.0	-4.9	
22 Dec	38	Dev	0.0	1.00	100	OK	3.1	0	96.2	0.0	-3.8	
6 Jan	53	Mid	0.0	1.00	100	OK	3.1	0	96.0	0.0	-4.0	
20 Jan	67	Mid	0.0	1.00	100	OK	3.1	0	96.2	0.0	-3.8	
5 Feb	83	End	0.0	1.00	100	OK	3.1	0	101.7	0.0	1.7	
22 Feb	100	End	0.0	1.00	100	OK	3.1	0	100.5	0.0	0.5	
27 Feb	End	End	0.0	1.00	0	OK	0.0	0				

Totals:

Total gross irrigation 1364.0 mm Total rainfall 241.9 mm

Total net irrigation	954.8 mm	Effective rainfall	203.2 mm
Total irrigation losses	0.0 mm	Total rain loss	38.8 mm
Total percolation losses	541.1 mm		
Actual water use by crop	404.9 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	404.9 mm	Actual irrigation requirement	201.8 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	84.0 %
Deficiency irrigation schedule	0.0 %		

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	1.00	1.09	1.32	0.50	1.10	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

SCHEME SUPPLY

ETo station: SUAKOKO Cropping pattern: BONG MINES IRRIG PRJ

Rain station: SUAKOKO

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit											
1. RICE-2 107.6	59.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.9	216.0	77.0
Net scheme irr.req.											
in mm/day 3.5	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	7.2	2.5
in mm/month 107.6	59.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.9	216.0	77.0
in l/s/h 0.40	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.83	0.29
Irrigated area	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0
(% of total area)											
Irr.req. for actual area	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.83	0.29
0.40 (l/s/h)											

3. VEGETABLES

MONTHLY ETO PENMAN-MONTEITH DATA

(File: D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-3_MAR-MAY_PD-1st Mar\SUAKOKO.pem)

Country: Liberia_BONG MINES Station: SUAKOKO
 Altitude: 150 m. Latitude: 7.00 °N Longitude: 9.58 °W

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	18.7	31.5	69	78	5.3	15.9	3.50
February	17.7	32.6	64	78	5.5	17.1	3.86
March	18.1	32.5	66	78	5.4	17.7	3.98
April	19.0	32.3	68	78	5.2	17.5	3.93
May	19.7	31.5	74	95	4.6	16.1	3.69
June	19.3	30.2	72	164	3.6	14.2	3.69
July	19.5	28.7	78	199	2.6	12.9	3.32
August	18.1	27.5	76	199	2.2	12.6	3.25
September	19.6	29.5	68	164	2.7	13.5	3.64
October	20.5	30.5	80	112	4.3	15.4	3.42
November	21.2	30.5	82	112	5.1	15.8	3.41
December	19.7	31.1	78	78	4.2	14.0	3.08
Average	19.3	30.7	73	120	4.2	15.2	3.56

MONTHLY RAIN DATA

(File: D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-3_MAR-MAY_PD-1st Mar\SUAKOKO.crm)

Station: SUAKOKO

Eff. rain method: USDA Soil Conservation Service formula:

$$P_{eff} = P_{mon} * (125 - 0.2 * P_{mon}) / 125 \quad \text{for } P_{mon} \leq 250 \text{ mm}$$

$$P_{eff} = 125 + 0.1 * P_{mon} \quad \text{for } P_{mon} > 250 \text{ mm}$$

	Rain mm	Eff rain mm
January	19.0	18.4
February	59.0	53.4
March	152.0	115.0
April	175.0	126.0
May	199.0	135.6
June	197.0	134.9
July	204.0	137.4
August	159.0	118.6
September	361.0	161.1
October	220.0	142.6
November	98.0	82.6
December	36.0	33.9
Total	1879.0	1259.6

DRY CROP DATA

File: D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-3_MAR-MAY_PD-1st Mar\CROP-3_VEGETABLES.

Crop Name:	CROP-3_Vegetables	Planting date:	01/03	Harvest:	29/05
Stage	initial	develop	mid	late	total
Length (days)	15	30	30	15	90
Kc Values	0.70	-->	1.05	0.95	
Rooting depth (m)	0.25	-->	0.60	0.60	
Critical depletion	0.30	-->	0.45	0.50	
Yield response f.	0.80	0.40	1.20	1.00	1.00
Cropheight (m)			0.30		

SOIL DATA

(File: D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-3_MAR-MAY_PD-1st Mar\SANDY LOAM.SOI)

Soil name: SANDY LOAM

General soil data:

Total available soil moisture (FC - WP)	140.0	mm/meter
Maximum rain infiltration rate	30	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion (as % TA	0	%
Initial available soil moisture	140.0	mm/meter

CROPPING PATTERN DATA

(File: D:\ANTHONY_Current\CONSULTANCY_PRIVATE\CARES_Ghana\CTCN_Liberia\B_CROP-3_MAR-MAY_PD-1st Mar\CROP_PAT.PAT)

Cropping pattern name: BONG MINES IRRG PRJ

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1	...AY_PD-1st Mar\CRO	CROP-3_Vegetables	01/03	29/05	100

CROP WATER REQUIREMENTS

ETo station: SUAKOKO Crop: CROP-3_Vegetables
 Rain station: SUAKOKO Planting date: 01/03

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Mar	1	Init	0.70	2.76	27.6	33.1	0.0
Mar	2	Deve	0.72	2.85	28.5	40.7	0.0
Mar	3	Deve	0.82	3.25	35.7	41.1	0.0
Apr	1	Deve	0.93	3.68	36.8	40.8	0.0
Apr	2	Mid	1.02	4.01	40.1	42.0	0.0
Apr	3	Mid	1.02	3.95	39.5	43.1	0.0
May	1	Mid	1.02	3.87	38.7	44.4	0.0
May	2	Late	1.01	3.73	37.3	45.7	0.0
May	3	Late	0.95	3.50	31.5	37.2	0.0
					315.7	368.0	0.0

CROP IRRIGATION SCHEDULE

ETo station: SUAKOKO Crop: CROP-3_Vegetables Planting date: 01/03
 Rain station: SUAKOKO Soil: SANDY LOAM Harvest date: 29/05

Yield red.: 0.0 %

Crop scheduling options

Timing: Irrig
 ate at 100 %
 depletion
 Application: Refil
 l to 100 % of field
 capacity Field eff.
 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr	IrrDeficit	Loss	Gr. Irr	Flow
							mm	mm	mm	mm	l/s/ha
12 Mar	12	Init	0.0	1.00	100	35	16.7	0.0	0.0	23.9	0.23
29 May	End	End	0.0	1.00	0	8					

Totals:

Total gross irrigation	23.9 mm	Total rainfall	525.9 mm
Total net irrigation	16.7 mm	Effective rainfall	288.5 mm
Total irrigation losses	0.0 mm	Total rain loss	237.5 mm
Actual water use by crop	312.2 mm	Moist deficit at harvest	7.0 mm
Potential water use by crop	312.2 mm	Actual irrigation requirement	23.7 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	54.9 %
Deficiency irrigation schedule	0.0 %		

Yield reductions:

Stagelabel	A	B	C	D	Season
Reductions in ETc	0.0	0.0	0.0	0.0	0.0 %
Yield response factor	0.80	0.40	1.20	1.00	1.00
Yield reduction	0.0	0.0	0.0	0.0	0.0 %
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0 %

SCHEME SUPPLY

ETo station: SUAKOKO

Cropping pattern: BONG MINES IRRG PRJ Rain station:
SUAKOKO

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1. CROP-3_Vegetables												
Net scheme irr.req. in mm/day	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
in mm/month	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
in l/s/h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated area (% of total area)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irr.req. for actual area (l/s/h)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00