The Government of Nepal
Ministry of Energy, Water Resources and Irrigation
Alternative Energy Promotion Centre (AEPC)
Making Renewable Energy Mainstream Supply in Nepal

IWMI International Water Management Institute

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

ICAR

Solar Water Pump Sizing Tool for Nepal

User Manual

December 2024

Authors

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Shilp Verma

IWMI-TATA Water Policy Program

SE4RL Solar Energy for Rural Livelihoods

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List of Abbreviations

AC	Alternating Current
AEPC	Alternative Energy Promotion Centre
DC	Direct Current
BoS	Balance of Systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbei
ICAR	Indian Council of Agricultural Research
IWMI	International Water Management Institute
LPCD	Liter Per Capita Per Day
MCB	Miniature Circuit Breaker
POSTED	Promotion of Solar Technologies for Economic Development
PV	Photovoltaics
RZWB	Root Zone Water Balance
SIP	Solar Irrigation Pumps
SPD	Surge Protection Device
VAT	Value Added Tax

1. Executive Summary

Solar water pumps have proved to be a means of water supply for drinking water, irrigation and other water needs. The Government of Nepal is promoting and supporting communities and individuals to fulfill their water needs utilising solar for pumping where it is best suited.

However, due to constrained technical human resources at the local level, often it is difficult to estimate the system cost and allocate an adequate budget for implementation. An inadequate budget may result in either project not being implemented or implemented in phases – leading to delays. As a solution, a Microsoft Excel-based tool is developed to assist the initial project development stage to estimate the system capacity and cost. The tool is targeted at users in Nepal who develop or fund solar water pumping projects such as the government, non-profits and private companies. The tool has been designed for two applications: drinking water and irrigation.

Jointly developed by GIZ, Indian Council of Agricultural Research (ICAR) and the International Water Management Institute (IWMI) with inputs from various experts throughout its development, the tool has followed the design philosophy of simplicity and user-friendliness. This tool builds on earlier work done in India for the Ministry of New and Renewable Energy (MNRE), Government of India, by the IWMI, ICAR and Borlaug Institute for South Asia (BISA), with support from GIZ. The tool developed in India helped users identify suitable solar water pumps based on water requirements for irrigation. With a similar philosophy, the tool developed for Nepal also requires a few key inputs from the user, upon which it generates a 3-page report highlighting the key system parameters and project costs that the user can refer to for budget estimates.

The tool presents a series of pages navigable through buttons that guide the user to the end report. It features a built-in crop water requirement tool (for irrigation) and a drinking water estimation method to determine the daily water requirement. It asks users only the key site information which can be obtained from the applicant without having to conduct a site survey.

Based on the user inputs, the tool estimates the capacity and quantities of components and uses the price database to obtain the system cost.

The report generated includes the key system features, general single-line diagram and the system costs i.e. bill of quantity. The report also features the annual energy that the solar water pumping system is anticipated to consume and the surplus energy that is available for multi-use planning. Finally, the report also features a what-if scenario, where the system capacity and cost are displayed for different cases of reduced daily water requirement. This helps the user optimise the water requirement in view of any budget or other project constraints.

The use of this tool must be limited to the initial planning phase only (pre-feasibility). It is not designed to be deployed for detailed designing of solar irrigation and drinking water systems. It is envisioned that this quick-sizing tool assists all levels of the government in planning solar water pumping projects, supporting the critical process of budgeting and financial planning.

2. Introduction

The Alternative Energy Promotion Centre (AEPC) has implemented over 3,600 solar drinking water and irrigation pumps by 2023. In addition, provincial and local governments have also been supporting these systems.

According to IWMI's rapid assessment report (2020) on AEPC's subsidy delivery mechanism for solar irrigation pumps (SIPs), the requirement for energy mix demands self-produced and green energy, and socio-political circumstances may still drive demands for SIPs at least for the next 7-10 years[1].

Recognising the potential of solar water pumps to reliably fulfil the water needs of communities and individuals in Nepal, this tool has been developed to support its initial planning phase. The demand for a simple user-friendly tool arose from interactions with local governments in west Nepal where they struggled to estimate the capacity and cost of solar water pumping projects to allocate an adequate for further assessments and implementation.

This was due to a lack of technical know-how in the local governments or a lack of technical human resources. Without adequate budget allocation, the projects would either not be implemented, or would be implemented in phases – leading to delays (Figure 1). This is where the tool is positioned as a solution.

GIZ's Promotion of Solar Technologies for Economic Development (POSTED) project, Indian Council of Agricultural Research (ICAR) and the International Water Management Institute (IWMI) joined hands to develop a quick sizing tool that all levels of the government can use for planning solar water pumping systems. The complementarity of the institutions aligned as GIZ's POSTED brought in expertise in the technical design of solar water pumping systems and ICAR & IWMI brought in expertise in the calculation of crop water requirements.

The design philosophy for the tool is simplicity and user-friendly. This also means that the tool is not made for detailed design, which requires a much rigorous design and costing procedure; for example, site survey, community engagement and detailed feasibility studies.

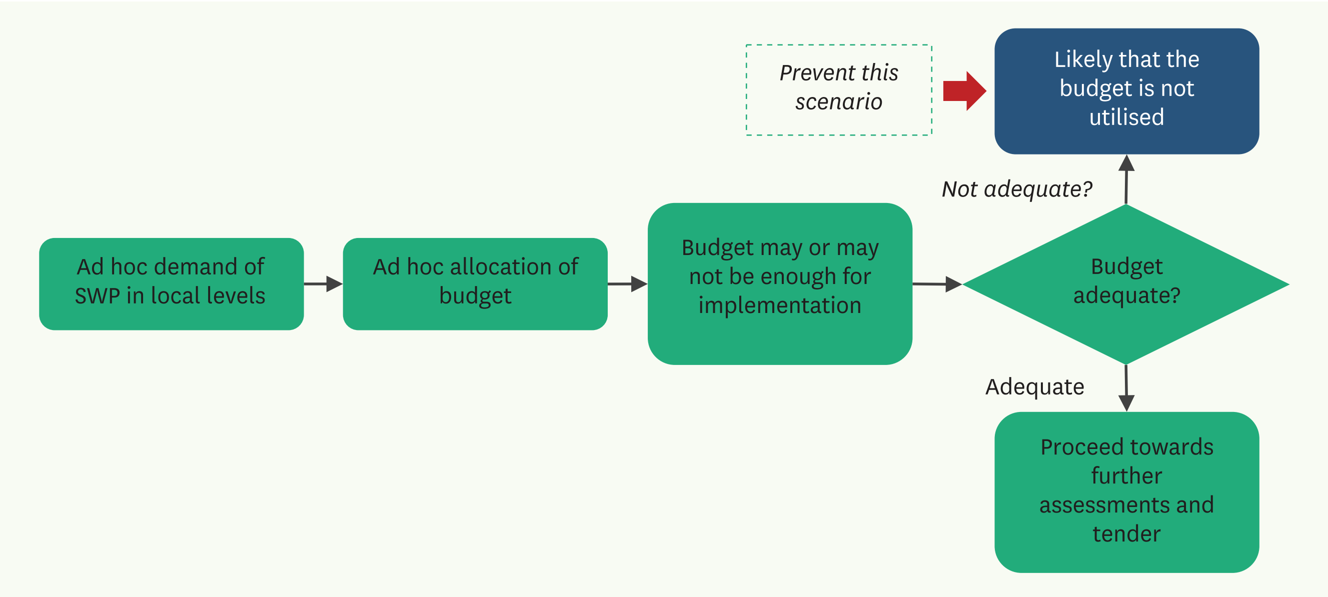


Figure 1: Problem identification and objective of the tool

[1] Pandey, V.P., Kafle, K., Upreti, L., Mukherji, A., Shrestha, G. and Khadka. M. 2020. A rapid assessment of AEPC's subsidy delivery mechanism for Solar Irrigation Pumps (SIPs) in Nepal. Report submitted by IWMI to AEPC, 40p, Colombo: International Water Management Institute (IWMI). Available online: https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/02_Rapid_Assess_2_AEPC_Final_15052020.pdf

Rather, the quick sizing tool only asks for key information about the site (without having to conduct a site survey) and can generate a report highlighting the key system features and project costs that the user can refer to for budget estimates.

The decision to make this a Microsoft Excel-based tool is because of the wide familiarity of the software which is used by every government official and professional. This reduces the learning curve concerning the software. Furthermore, being an Excel-based tool, it is offline and easier for users to transfer the tool from one computer to another. Similarly, given that the tool will be available for download, the users can always download the original version and save a copy to their local computer.

The tool that was built for India served as the foundation for the irrigation water requirement calculations which was adapted for Nepal. This linkage between Nepal's GIZ team and India's IWMI and ICAR team highlights south-south learning where knowledge materials and expertise complement to achieve region-contextualised solutions. The tool, throughout its development, received inputs from various experts.

The development began with a workshop (in June 2023) where the objectives and features of the tool were presented to experts from the government, private sector, researchers and development partners. The inputs were gathered revolving around the desired features, limitations and applications of the tool. After the prototype was developed, the workings of the tool were demonstrated in IWMI's Global Forum in April 2024 to a similar set of experts. A round of feedback was collected, after which the draft tool was prepared for user-group testing. For user-group testing, the GIZ team demonstrated the tool to local and provincial government officials in the Sudurpaschim (far west) and Koshi (far east) provinces[2] of Nepal. The tool was distributed to a set of government officials to be used. Further feedback was collected on the tool about its user-friendliness and practical use in planning solar water pumping projects for the government. Based on the inputs, the tool was finalised.

This user manual walks through the following major sections:

(i) The general architecture of the tool,

(ii) Understanding limitations of the tool, and,

(iii) Step-by-step procedure on its use and logic.

2.1 Architecture of the Tool

The architecture of the tool can be explained in four parts (Figure 2):

(i) **Basic input parameters:** In the beginning sections of the tool, the user is required to input key parameters of the project such as applicant information, water application, crop details (for irrigation), population (for drinking water), water lifting head and basic site information.

(ii) **Estimation of design parameters:** Based on the user inputs, the tool computes the key design parameters such as pump discharge and the total dynamic head.

(iii) **Design estimate:** Upon calculating the design parameters, the tool computes the design estimate which includes the capacity of components of the solar water pumping system. The components that make up the bill of quantity include:

a. **Major components:** Solar panels, inverter and pump.

b. **Balance of systems:** All other components required to complete the system to make it functional (for example, cables, pipe fittings, protection equipment, etc.).

(iv) **3-page design summary report:** The output of the tool is a 3-page design summary report which highlights the key system features, system costs, general single-line diagram and a breakdown of the bill of quantity.

[2] The POSTED (Promotion of Solar Technologies for Economic Development) project implemented by GIZ is focused in Sudurpaschim and Koshi provinces.

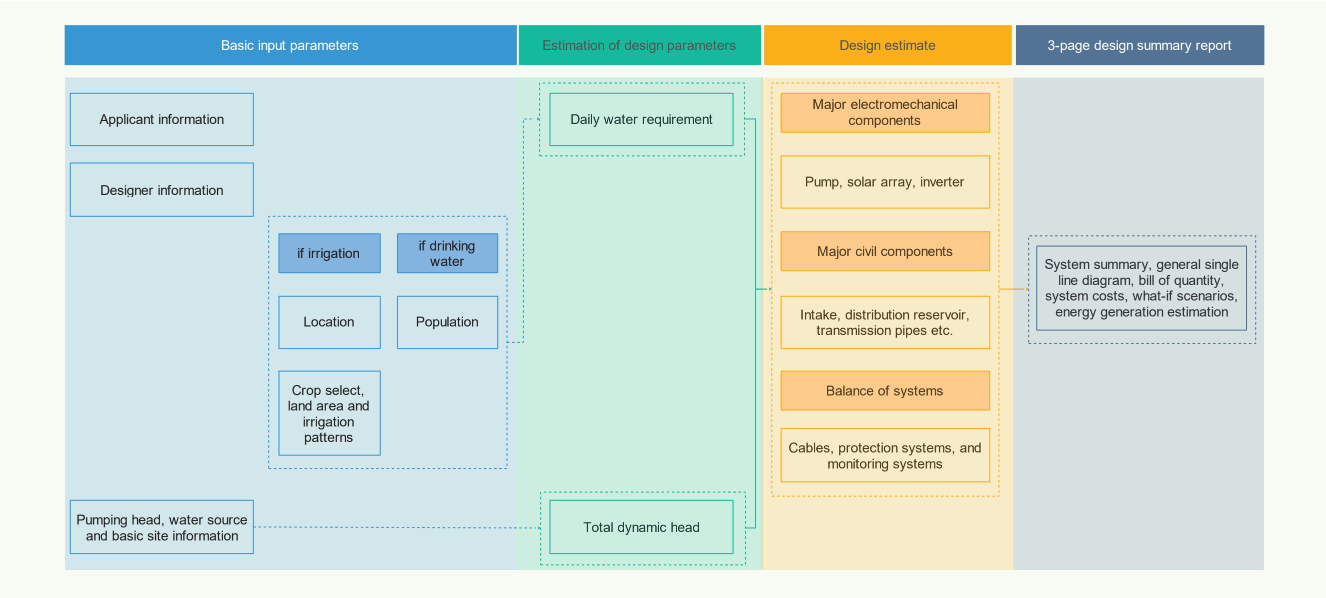


Figure 2: Architecture of the tool

2.2 Limitations of the Tool

The user must be aware of the limitations of the tool while using it. The following describes each of the limitations:

Applicable for pre-feasibility design estimate	The tool serves as a basic sizing tool to estimate the cost of the solar water pumping system. It shall not be used for detailed design.
AC pumping systems only	The selection of a pump is only based on AC pumps. No DC pumps are included in the database. This is because, for a quick sizing tool, the selection of AC pumps shall suffice for the purpose.
30 HP is the maximum single-stage pump size available	The maximum pump size available for single-stage pumping is 30 HP. If the pump size exceeds 30 HP, double-stage pumping is proposed.
60 HP is the maximum double-stage pump size available	The maximum pump size available for double-stage pumping is 60 HP i.e. double of the maximum single-stage pump size.
Maximum cut-off head for single-stage pumping is 200 m	The maximum cut-off head for single-stage pumping is 200 m. If the total dynamic head is above 200 m, a double-stage pumping is proposed regardless of the pump size.
Civil infrastructure is limited to the transmission side only	The civil infrastructure (for example, water pipes, fittings, anchor blocks, etc.) is included for the water transmission side only i.e. from the water source to the distribution reservoir. The tool does not include components on the water distribution side because this is highly specific to site conditions. For example, for drinking water systems, it is difficult to estimate the length of water distribution pipes without understanding the distribution of households in the community.

2.3 Troubleshooting

For the tool to function properly, macros must be enabled. Without macro, the tool will not be able to compute the solar water pump sizing and generate a report. For example, the tool has built-in climate data which is used to calculate the crop water requirement, but can only be accessed if the macro is enabled. After the first download, the macro-related settings of the computer may prevent the macros from running. Refer to the following cases and instructions on how to resolve the issue.

Case 1: When opening the Excel file, always click on 'Enable Editing' (Figure 3)

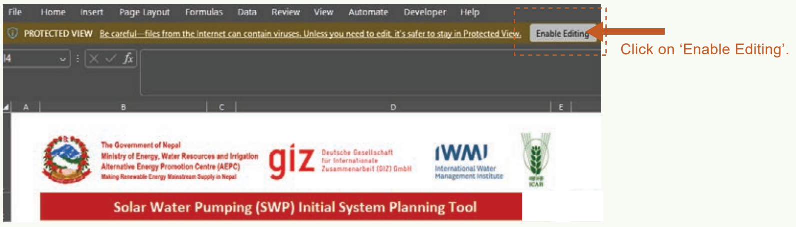


Figure 3: 'Enable Editing' prompt

Case 2: After the first download, a red tab on 'Security Risk' may be displayed. Follow the procedures in Figure 4.

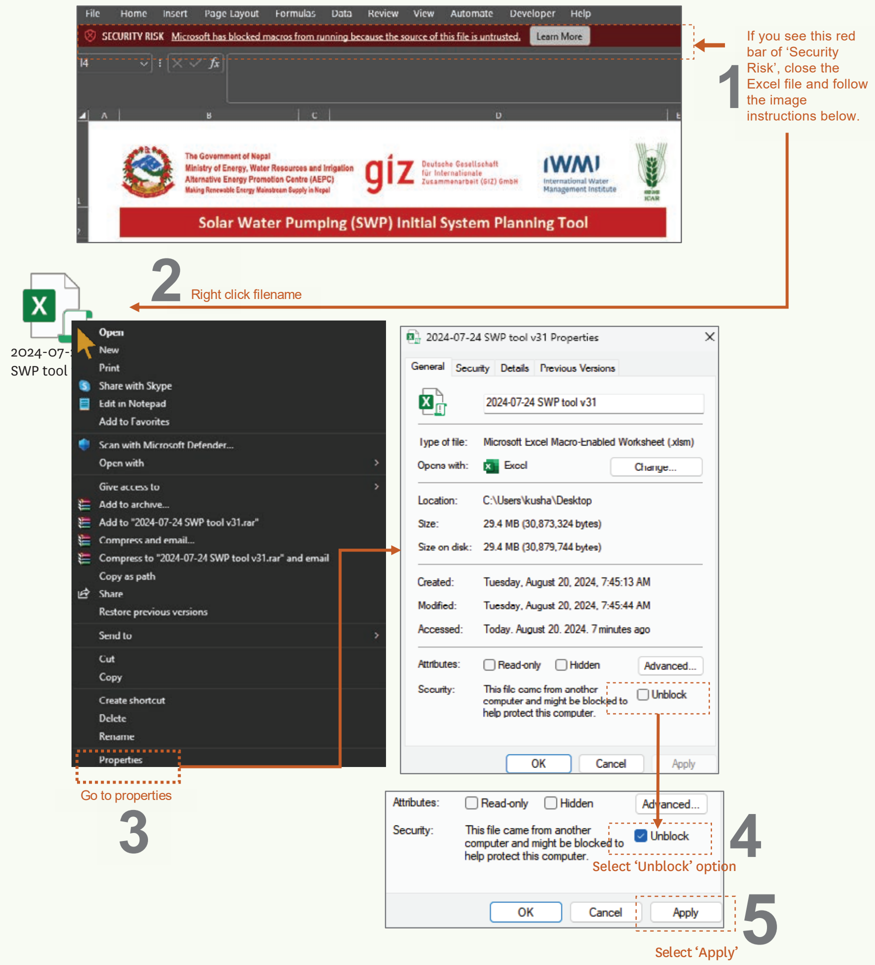


Figure 4: 'Security Risk' prompt

3. Data Inputs

The data inputs of the tool have been selected considering only the key inputs required by the user to generate a design estimate.

For ease, the cells have been colour-coded as follows:

Light Pink	User input
Dark Sage	Dropdown option
Light Silver	Linked cell (not to be edited)

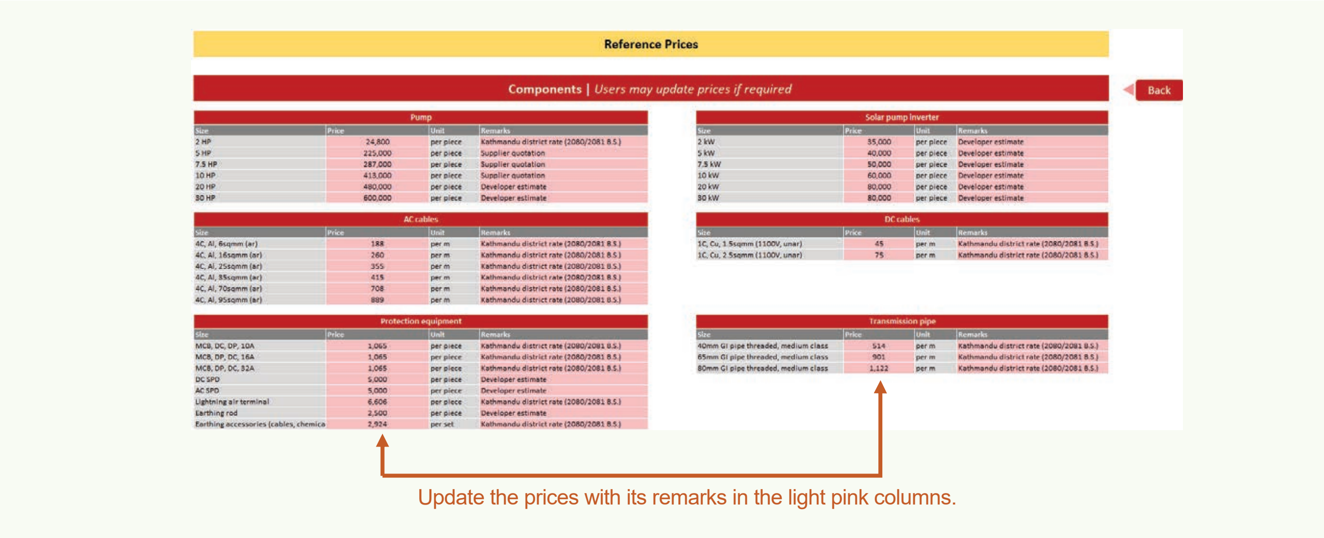
3.1 Price list

The start page of the tool describes the objective, limitations and the organisations involved in its development.

Users already versed with the tool can begin the quick sizing by clicking on the 'Start' button (Figure 5).

For first-time users and periodic updates, the price list button is given which takes the user to the price page (Figure 6). The prices of components need to be updated the first time by the user to adapt the tool to its region and for the accuracy of the results. After updating the price, it may need an update periodically when the user deems that the market prices of components have achieved a significant difference. After the prices have been updated, the user can go back to the first '1. Read Me' page and 'Start' the sizing.

Figure 5: '1. Read Me' page



Reference Prices

Components | *Users may update prices if required*

Back

Pump			
Size	Price	Unit	Remarks
2 HP	24,800	per piece	Kathmandu district rate (2080/2081 B.S.)
5 HP	225,000	per piece	Supplier quotation
7.5 HP	287,000	per piece	Supplier quotation
10 HP	413,000	per piece	Supplier quotation
20 HP	480,000	per piece	Developer estimate
30 HP	600,000	per piece	Developer estimate

Solar pump inverter			
Size	Price	Unit	Remarks
2 kW	35,000	per piece	Developer estimate
5 kW	40,000	per piece	Developer estimate
7.5 kW	50,000	per piece	Developer estimate
10 kW	60,000	per piece	Developer estimate
20 kW	80,000	per piece	Developer estimate
30 kW	80,000	per piece	Developer estimate

AC cables			
Size	Price	Unit	Remarks
4C, Al, 6sqmm (ar)	188	per m	Kathmandu district rate (2080/2081 B.S.)
4C, Al, 16sqmm (ar)	260	per m	Kathmandu district rate (2080/2081 B.S.)
4C, Al, 25sqmm (ar)	355	per m	Kathmandu district rate (2080/2081 B.S.)
4C, Al, 35sqmm (ar)	415	per m	Kathmandu district rate (2080/2081 B.S.)
4C, Al, 70sqmm (ar)	708	per m	Kathmandu district rate (2080/2081 B.S.)
4C, Al, 95sqmm (ar)	889	per m	Kathmandu district rate (2080/2081 B.S.)

DC cables			
Size	Price	Unit	Remarks
1C, Cu, 1.5sqmm (1100V, unar)	45	per m	Kathmandu district rate (2080/2081 B.S.)
1C, Cu, 2.5sqmm (1100V, unar)	75	per m	Kathmandu district rate (2080/2081 B.S.)

Protection equipment			
Size	Price	Unit	Remarks
MCB, DC, DP, 10A	1,065	per piece	Kathmandu district rate (2080/2081 B.S.)
MCB, DP, DC, 16A	1,065	per piece	Kathmandu district rate (2080/2081 B.S.)
MCB, DP, DC, 32A	1,065	per piece	Kathmandu district rate (2080/2081 B.S.)
DC SPD	5,000	per piece	Developer estimate
AC SPD	5,000	per piece	Developer estimate
Lightning air terminal	6,606	per piece	Kathmandu district rate (2080/2081 B.S.)
Earthing rod	2,500	per piece	Developer estimate
Earthing accessories (cables, chemica	2,924	per set	Kathmandu district rate (2080/2081 B.S.)

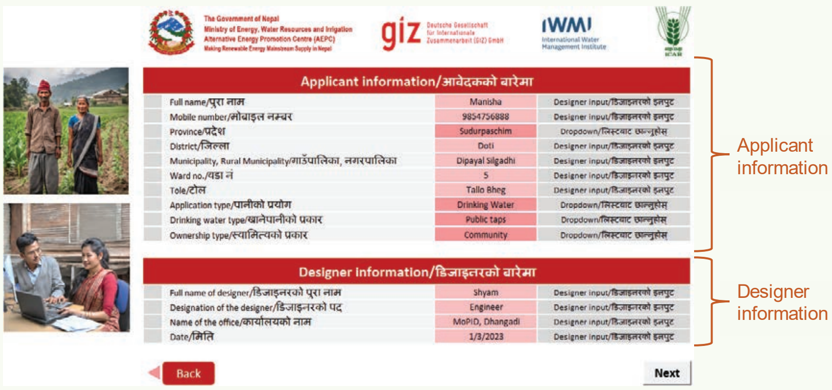
Transmission pipe			
Size	Price	Unit	Remarks
40mm GI pipe threaded, medium class	514	per m	Kathmandu district rate (2080/2081 B.S.)
65mm GI pipe threaded, medium class	901	per m	Kathmandu district rate (2080/2081 B.S.)
80mm GI pipe threaded, medium class	1,122	per m	Kathmandu district rate (2080/2081 B.S.)

Figure 6: 'Reference Prices' update page

3.2 Applicant and designer information

The first step of the design tool is the applicant and designer information in the '2. Applicant' sheet (Figure 7).

Applicant information	The applicant information section records the details of the applicant for whom the solar water pumping system is being designed. It records the name, mobile number, province, district, municipality, ward, tole, application type and the ownership type. The selection of application type is important because this updates the successive steps of the tool based on parameters required for irrigation or drinking water.
Designer information	The designer information section records the details of the designer who is using the tool. This is required in case any user of the tool would like to update the data inputs or would like to refer to the original designer in the future. It records the name, designation, office and the date.



Applicant information/आवेदकको बारेमा		
Full name/पुरा नाम	Manisha	Designer input/डिजाइनरको इनपुट
Mobile number/मोबाइल नम्बर	9854756888	Designer input/डिजाइनरको इनपुट
Province/प्रदेश	Sudurpaschim	Dropdown/लिस्टबाट छान्नुहोस्
District/जिल्ला	Doti	Designer input/डिजाइनरको इनपुट
Municipality, Rural Municipality/गाउँपालिका, नगरपालिका	Dipayal Silgadhi	Designer input/डिजाइनरको इनपुट
Ward no./वडा नं	5	Designer input/डिजाइनरको इनपुट
Tole/टोल	Tallo Bheg	Designer input/डिजाइनरको इनपुट
Application type/पानीको प्रयोग	Drinking Water	Dropdown/लिस्टबाट छान्नुहोस्
Drinking water type/खानेपानीको प्रकार	Public taps	Dropdown/लिस्टबाट छान्नुहोस्
Ownership type/स्वामित्वको प्रकार	Community	Dropdown/लिस्टबाट छान्नुहोस्

Designer information/डिजाइनरको बारेमा		
Full name of designer/डिजाइनरको पुरा नाम	Shyam	Designer input/डिजाइनरको इनपुट
Designation of the designer/डिजाइनरको पद	Engineer	Designer input/डिजाइनरको इनपुट
Name of the office/कार्यालयको नाम	MoPID, Dhangadi	Designer input/डिजाइनरको इनपुट
Date/मिति	1/3/2023	Designer input/डिजाइनरको इनपुट

Figure 7: '2. Applicant' page

3.3 Location

Note: This input is applicable only for irrigation.

If the application type 'Irrigation' is selected on the first page, the next page carries the user to the project location page. The map of Nepal is arranged in a grid with latitude and longitude in the left and top axes (Figure 8). Based on the selection of the project location cell, the tool retrieves the soil, temperature and rainfall data which is used to calculate the water requirement for irrigation.

The user must select the cell where the project is located, click on 'Load Climate Data' and click 'OK'. The tool may take a few seconds to retrieve the climate data, after which, the next page on 'Cropping System Details' is displayed.

Important:

- Do not click on cells outside of the map boundary OR in the black cells, or else an error will pop up. The black cells are those for which the soil data is not available. Choose the nearest adjacent cell instead.

- The user cannot input the latitude and longitude values in the cells above the climate data chart. The latitude & longitude values and the chart are updated based on the selected project location from the boundary map and displayed for reference only.

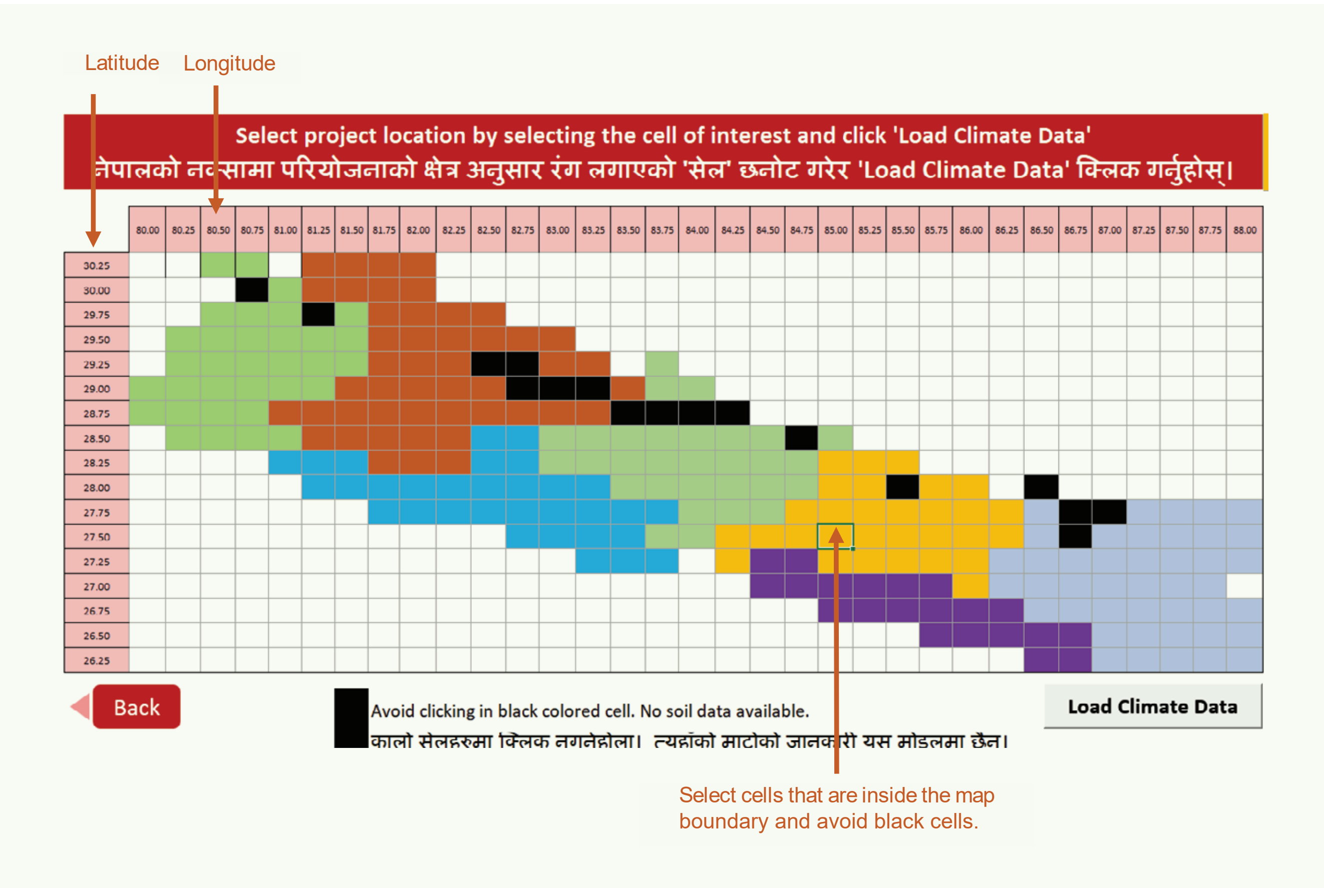


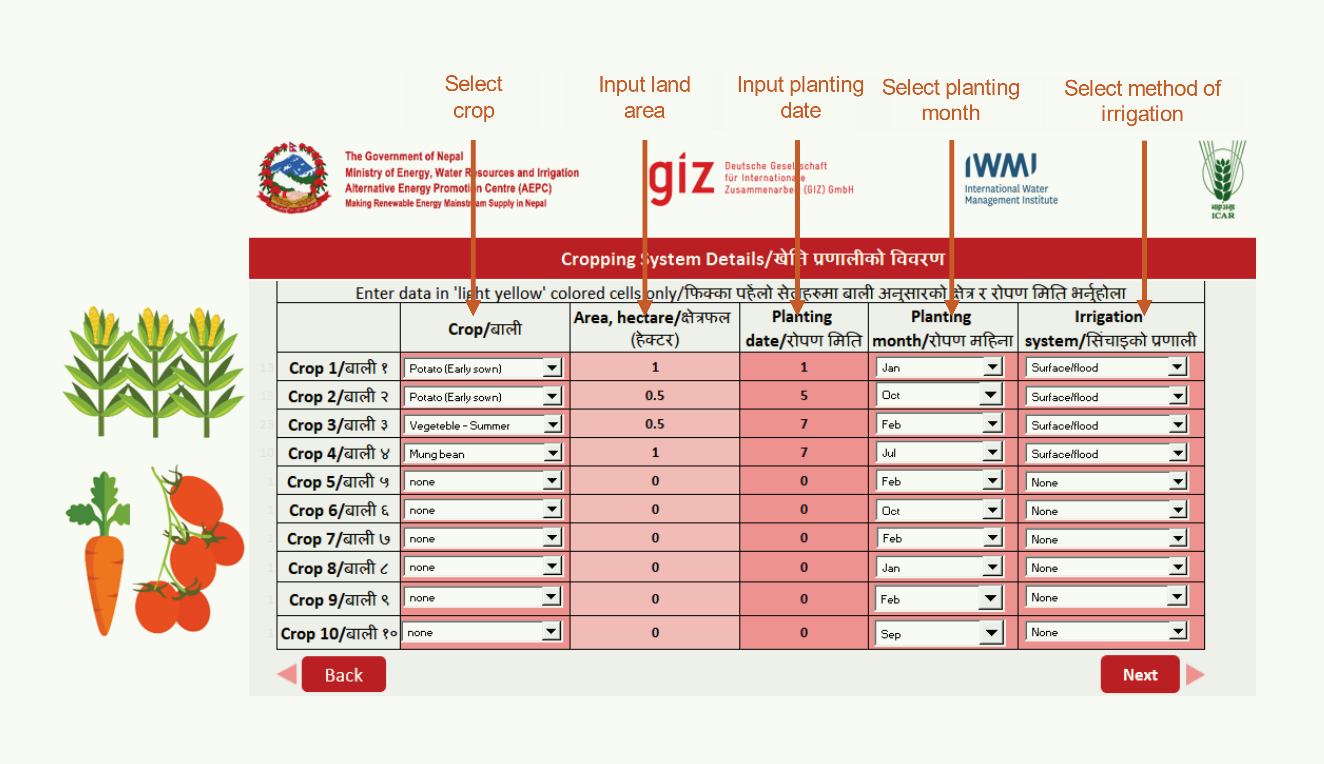
Figure 8: '3. Location' page

3.4 Cropping system details

Note: This input is applicable only for irrigation.

For irrigation, the next page carries the user to the cropping systems details page. The user shall provide the information regarding type of crops, land area, cropping pattern and method of irrigation.

The user can select up to ten crops. For each crop, inputs on the land area (in acres), planting date, planting month and method of irrigation are required. The daily water requirement for irrigation is calculated based on these data inputs.



	Crop/बाली	Area, hectare/क्षेत्रफल (हेक्टर)	Planting date/रोपण मिति	Planting month/रोपण महिना	Irrigation system/सिंचाइको प्रणाली
Crop 1/बाली १	Potato (Early sown)	1	1	Jan	Surface/flood
Crop 2/बाली २	Potato (Early sown)	0.5	5	Oct	Surface/flood
Crop 3/बाली ३	Vegeteble - Summer	0.5	7	Feb	Surface/flood
Crop 4/बाली ४	Mung bean	1	7	Jul	Surface/flood
Crop 5/बाली ५	none	0	0	Feb	None
Crop 6/बाली ६	none	0	0	Oct	None
Crop 7/बाली ७	none	0	0	Feb	None
Crop 8/बाली ८	none	0	0	Jan	None
Crop 9/बाली ९	none	0	0	Feb	None
Crop 10/बाली १०	none	0	0	Sep	None

Figure 9: ‘4. Crop select’ page

3.5 Design inputs

On the design inputs page, the user shall input a few technical information that is required for the estimation of electromechanical and civil components of the solar water pumping system. The data inputs are described as follows:

Irrigation	After the input provided in the ‘4. Crop select’ page, the ‘5. Design inputs’ page is displayed
Drinking water	After the Applicant and Designer Information page, the ‘5. Design inputs’ page is displayed.

Data inputs that are displayed for irrigation only (Figure 10)	
Number of days allocated for irrigation in a month	The 'number of days' of irrigation in a month determines the pump discharge capacity to meet the monthly irrigation requirements. For example, a higher number of days of irrigation in a month reduces the estimate of pump discharge. Similarly, a lower number of days of irrigation in a month increases the pump discharge capacity as the same quantity of water is to be applied over fewer days.

Data inputs that are displayed for drinking water only (Figure 11)	
Population	For drinking water, the population is the key determinant for the daily water requirement. Refer to Section 8 on how the daily water requirement for drinking water is calculated.
Is the water requirement known?	For drinking water, this option allows the user to either select the daily drinking water requirement calculated by the tool or use a user-defined value. The user shall choose either 'Yes' or 'No'.
Specify daily water requirement	If the user selects 'Yes' in the 'Is the water requirement known?' input, the user shall input the desired daily water requirement in litres per day.

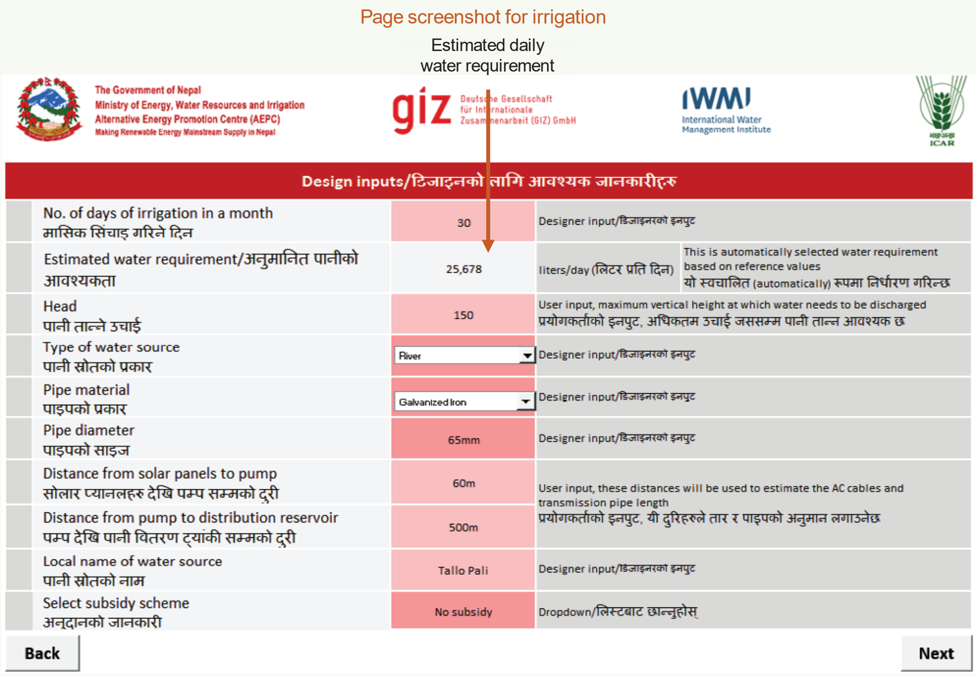
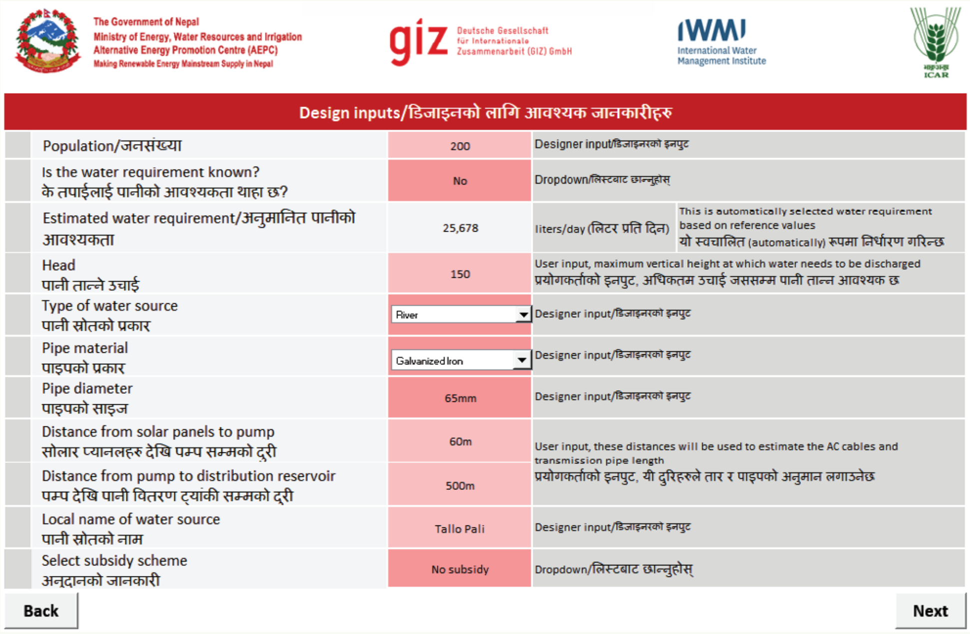


Figure 10: '5. Design inputs' page for irrigation

Common data inputs	
Head	The head is the vertical height between the water source and the highest point of the distribution reservoir.
Type of water source	The user shall select the type of water source with options ranging from tubewell, open well, stream, pond, river and tank/lake. The selection of the water source will update the additional head required to pump water from the source to the distribution reservoir.
Pipe material	The user shall select a pipe material which will be required to calculate the head loss.
Pipe diameter	The user shall select an estimated pipe diameter that can be used in the project. This will be required to calculate the head loss.
Distance from solar panels to pump	The user shall enter the estimated distance from the solar array to the pump. It is assumed that the controller is placed adjacent to the solar array. This distance is required to estimate the power cable to the pump.
Distance from pump to distribution reservoir	The user shall enter the estimated distance from the pump to the distribution reservoir. This distance is required to estimate the length of the water transmission pipe.
Local name of water source	The user shall enter the name of the water source (if any). This will help the user to identify the water source locally in later stages.
Select subsidy scheme	The user can select the subsidy scheme of the project. There are three options to choose from: (i) No subsidy, (ii) User-defined subsidy and (iii) AEPC scheme. Based on the selection, the percentage (%) of the total project cost is split into subsidy and applicant contribution amounts. No subsidy: In this case, only the total project cost is displayed in the report. User-defined subsidy: In this case, the user shall enter the subsidy as a percentage of the total project cost. The subsidy amount is then displayed in the report. AEPC scheme: In this case, the tool takes a 60% subsidy of the total project cost for irrigation application and a 90% subsidy for drinking water application in alignment with the AEPC's Renewable Energy Subsidy Delivery Mechanism 2022. The subsidy amount and the applicant's contribution are displayed in the report.

Page screenshot for drinking water



Population/जनसंख्या	200	Designer input/डिजाइनरको इनपुट
Is the water requirement known? के तपाईलाई पानीको आवश्यकता थाहा छ?	No	Dropdown/लिस्टबाट छान्नुहोस्
Estimated water requirement/अनुमानित पानीको आवश्यकता	25,678	liters/day (लिटर प्रति दिन) This is automatically selected water requirement based on reference values यो स्वचालित (automatically) रूपमा निर्धारण गरिन्छ
Head पानी तान्ने उचाई	150	User input, maximum vertical height at which water needs to be discharged प्रयोगकर्ताको इनपुट, अधिकतम उचाई जससम्म पानी तान्न आवश्यक छ
Type of water source पानी स्रोतको प्रकार	River	Designer input/डिजाइनरको इनपुट
Pipe material पाइपको प्रकार	Galvanized Iron	Designer input/डिजाइनरको इनपुट
Pipe diameter पाइपको साइज	65mm	Designer input/डिजाइनरको इनपुट
Distance from solar panels to pump सोलार प्यानलहरु देखि पम्प सम्मको दूरी	60m	User input, these distances will be used to estimate the AC cables and transmission pipe length प्रयोगकर्ताको इनपुट, यी दुरिहरुले तार र पाइपको अनुमान लगाउनेछ
Distance from pump to distribution reservoir पम्प देखि पानी वितरण ट्यांकी सम्मको दूरी	500m	
Local name of water source पानी स्रोतको नाम	Tallo Pali	Designer input/डिजाइनरको इनपुट
Select subsidy scheme अनुदानको जानकारी	No subsidy	Dropdown/लिस्टबाट छान्नुहोस्

Back Next

Figure 11: '5. Design inputs' page for drinking water

Note: After pressing the ‘Next’ button, it may take a few seconds for the next page to be displayed. This is because the tool is computing the design estimate based on the data inputs. A ‘Computing. Please wait…’ message is displayed adjacent to the ‘Next’ button.

3.6 Balance of Systems

The balance of systems (BoS) means all other items except the solar panels, controller and pump, that are required to complete the solar water pumping system.

The next page displays the BoS that has been automatically calculated by the tool. The user may choose to proceed with the default items and quantity or edit the BoS.

The following describes the items in the BoS:

Items which are always included in the bill of quantity	
DC cable length – array to inverter	The DC cable is calculated for solar array interwiring and connection to the inverter/controller. It is assumed that the inverter/controller is located adjacent to the solar array.
AC cable length – inverter to pump	The AC cable is calculated based on the input of the distance from the solar array to the pump with a design margin added i.e. 5% by default.
MCB – PV disconnector (protection)	Miniature Circuit Breakers (MCB) must be included to protect the system from overcurrent. Multiple MCBs are to be used for separate strings of the solar array.
DC SPD – array to inverter (protection)	DC Surge Protection Device (SPD) must be included to protect the system from high surge currents.
AC SPD – inverter to pump (protection)	AC Surge Protection Device (SPD) must be included to protect the system from high surge currents.
Controller box	The controller box must be included to house of the inverter, MCBs, DC & AC SPDs and other control equipment.
Lightning air terminal rod	The lightning air terminal must be included to protect the system against lightning strikes.
Earthing rod	The earthing rod must be included to properly ground the system.
Cable conduits	The cable conduits must be included to protect the power cables.

Additional items with the option to include to exclude from the bill of quantity (all selected by default)	
Remote monitoring unit	A remote monitoring unit enables the system to be monitored and controlled remotely.
Plumbing accessories	Plumbing accessories include check valves, pipe fittings (elbows, flange) etc.
Transmission pipe	The transmission pipe is the main length of the water transmission from the pump to the distribution reservoir. The length of the transmission pipe is calculated based on the input of the distance from the pump to the distribution reservoir.
Intake reservoir (stone masonry)	The intake reservoir is where the pump will be placed near or in the water source. The cost included by default is for stone masonry.
Distribution reservoir (stone masonry)	The distribution reservoir is the highest point of the system where the water will be pumped and stored. The cost included by default is for stone masonry.

If the user is satisfied with the default values, click the ‘Proceed with defaults’ button which will generate the report (Figure 12).

If the user wishes to edit the default values, click the ‘Edit items’ button.

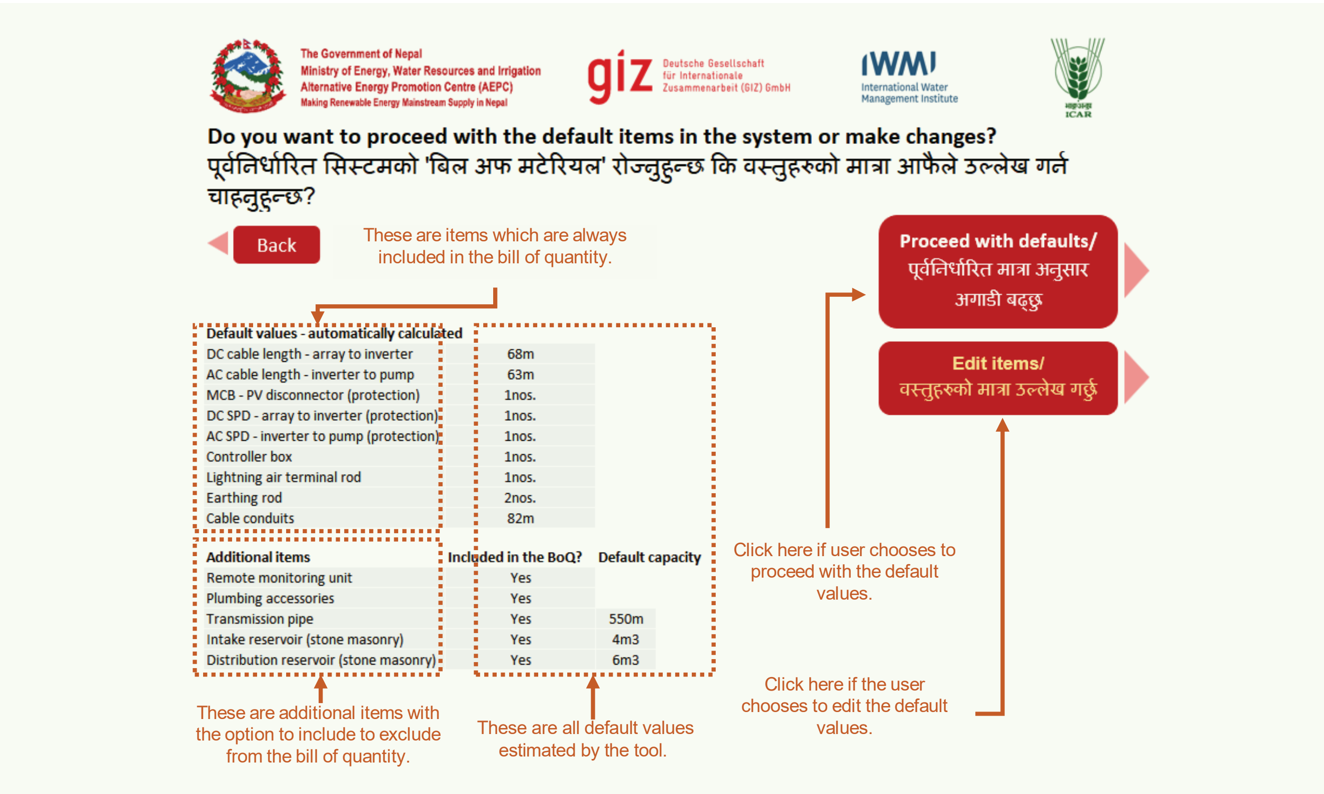


Figure 12: '6. BoS query' page

3.7 Edit Balance of Systems

Note: This page is displayed only if the 'Edit items' button is selected in the previous page 'BoS Query'.

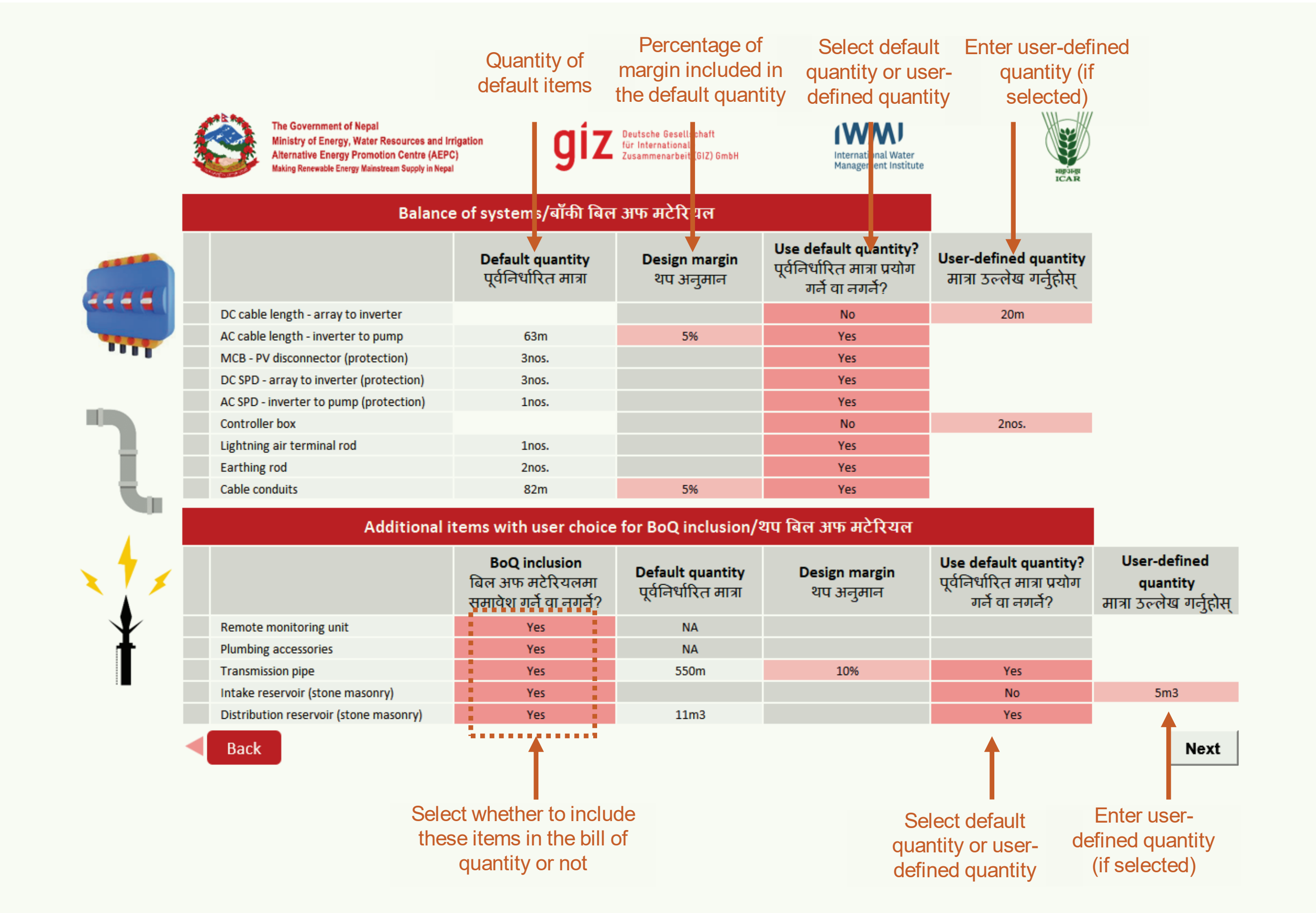
While the tool automatically estimates the BoS, the user can edit the BoS if desired. In the 'BoS' page, the user can view and edit the BoS (Figure 13).

The top section of the page titled 'Balance of Systems' lists items that must be included in the system. Here, the user can view the design margin (in percentage and where applicable) that has been included to calculate the default quantity of each item. If the user wishes to edit the default value, the user shall go to the 'Use default quantity?' column and select 'No'. Then the column titled 'User-defined quantity' is displayed, in which the user shall input their value.

The bottom section of the page titled 'Additional items with user choice for BoQ inclusion' lists items that can be removed from the bill of quantity altogether. If the user wishes to remove an item, select the option 'No' in the 'BoQ inclusion' column.

Similarly, the user can view the design margin (in percentage and where applicable) that has been included to calculate the default quantity of each item. If the user wishes to edit the default value, the user shall go to the 'Use default quantity?' column and select 'No'. Then the column titled 'User-defined quantity' is displayed, in which the user shall input their value.

Note: After pressing the 'Next' button, it may take a few seconds for the next page to be displayed. This is because the tool is computing the design estimate based on the quantity edits. A 'Computing. Please wait...' message is displayed adjacent to the 'Next' button.



Balance of systems/बाँकी बिल अफ मटेरियल

	Default quantity पूर्वनिर्धारित मात्रा	Design margin थप अनुमान	Use default quantity? पूर्वनिर्धारित मात्रा प्रयोग गर्ने वा नगर्ने?	User-defined quantity मात्रा उल्लेख गर्नुहोस्
DC cable length - array to inverter			No	20m
AC cable length - inverter to pump	63m	5%	Yes	
MCB - PV disconnector (protection)	3nos.		Yes	
DC SPD - array to inverter (protection)	3nos.		Yes	
AC SPD - inverter to pump (protection)	1nos.		Yes	
Controller box			No	2nos.
Lightning air terminal rod	1nos.		Yes	
Earthing rod	2nos.		Yes	
Cable conduits	82m	5%	Yes	

Additional items with user choice for BoQ inclusion/थप बिल अफ मटेरियल

	BoQ inclusion बिल अफ मटेरियलमा समावेश गर्ने वा नगर्ने?	Default quantity पूर्वनिर्धारित मात्रा	Design margin थप अनुमान	Use default quantity? पूर्वनिर्धारित मात्रा प्रयोग गर्ने वा नगर्ने?	User-defined quantity मात्रा उल्लेख गर्नुहोस्
Remote monitoring unit	Yes	NA			
Plumbing accessories	Yes	NA			
Transmission pipe	Yes	550m	10%	Yes	
Intake reservoir (stone masonry)	Yes			No	5m3
Distribution reservoir (stone masonry)	Yes	11m3		Yes	

Figure 13: '7. BoS' page

4. Report

After completion of the data inputs, a 3-page report is generated (Figure 14, Figure 15). The report includes details of the estimated system size and project costs.

The report is intended to be the outcome of the tool which can be exported/printed. The following table describes the information contained in the report.

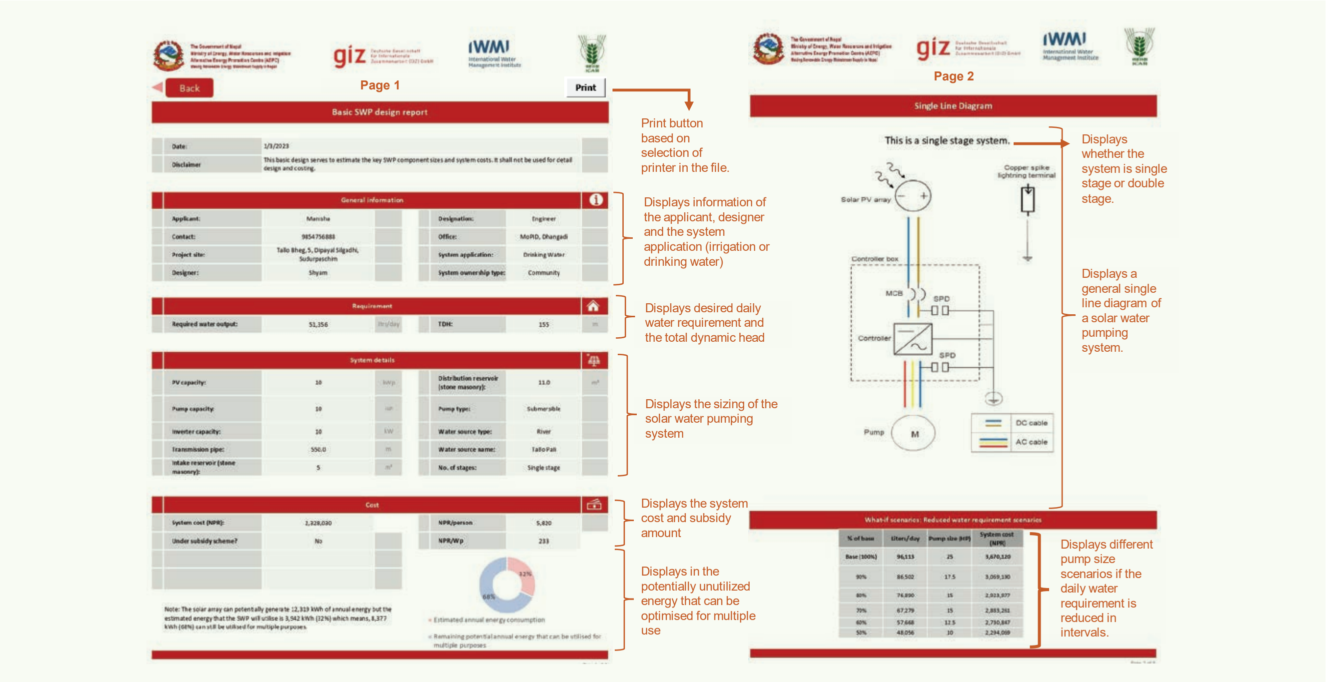


Figure 14: '8. Report' page 1 and 2

Figure 15: '8. Report' page 3

PAGE 1	
Feature	**Description**
General information	This displays the information of the applicant, designer, system application (irrigation or drinking water) and the system ownership type.
Requirement	This displays the desired daily water requirement and the total dynamic head.
System details	**This displays the sizing of the solar water pumping system:** • Solar array (PV) capacity • Pump capacity • Inverter capacity • Transmission pipe length • Intake reservoir size (if selected) • Distribution reservoir size (if selected) • Pump type • Water source type • Water source name
Cost	This displays the system cost and subsidy amount. **The system cost is also displayed in per-unit values, namely:** • NPR per acre: system cost divided by the total land area (for irrigation only) • NPR per person: system cost divided by the total population (for drinking water) • NPR per Wp: system cost divided by the solar array capacity • The per-unit values help compare the cost of the system with other designs.
Energy utilisation	A note is displayed at the bottom of the first page describing (i) the total energy that the system can generate annually, (ii) the estimated energy that will be utilised by the solar water pumping system and (iii) the remaining utilised energy that can be utilised for multiple purposes and encourages the user to plan for maximum use of available energy. The annual energy utilised for the solar water pumping system is estimated with a fixed percentage i.e. 32% based on the capacity utilisation factor calculated from phone surveys conducted by IWMI in 2021[3].

[3] Shrestha, S., Gnawali, S.M. and Mukherji, A. 2023. Grid-connected solar irrigation in Nepal: Exploring opportunities and identifying hurdles. Issue Brief Series No. 06, Colombo: International Water Management Institute (IWMI).
Available online: https://solar.iwmi.org/wp-content/uploads/sites/43/2023/11/issue-brief-06-1.pdf

PAGE 2

Feature	Description
Single-stage or double-stage system	On top of the single-line diagram, information is displayed stating whether the system is single-stage or double-stage.
Single Line Diagram	A general single-line diagram of a solar water pumping system is displayed to help the user and the reader of the report get a sense of the arrangement of the components of the system. Note: This single-line diagram is only a general figure and does not represent all the quantities included in the bill of quantity.
What-if scenarios	The what-if scenario presents the different pump sizes and system cost scenarios if the daily water requirement is reduced in intervals. The baseline (desired daily water requirement) represents 100%, after which, the what-if scenario is run for 90%, 80%, 70%, 60% and 50% of the baseline water requirement. For each scenario, the pump size and the system cost are displayed. This allows the user to see how the project cost varies if the daily water requirement is reduced, which may help in optimising the system and meeting a desired budget or other project constraints.

PAGE 3

Feature	Description
Bill of quantity	The bill of quantity tabulates the breakdown of the project cost which is required for transparency and decision making to include or exclude optional system components.

5. Water Requirement and Dynamic Head

Irrigation water requirements are governed by the type of crop, climate and soils of the region. The tool estimates irrigation water requirements using the combined approach of crop evapotranspiration and a soil water balance. Reference crop evapotranspiration (ETr) is estimated using Penman-Monteith method (Evapotranspiration-based Irrigation Requirement (ETIR) subroutine) and root zone water balance is simulated using Root Zone Water Balance (RZWB) subroutine. The tool works out crop evapotranspiration (ETc), effective rainfall (Pe), and irrigation water requirement (Ir) for each crop in the selected cropping sequences over a 10-year period (2009-2018) at a daily timestep. The detailed procedure is outlined in the following sections.

The PMET subroutine

The tool uses PMET subroutine to compute daily reference evapotranspiration (ETr) using FAO-56 Penman-Minteith method which is then converted into Crop Evapotranspiration (ETc) using crop coefficients (Kc) for different crop growth stages (Allen et al., 2005)[4]. Daily maximum and minimum temperature, latitude and altitude of the grid point (or location) are inputs to the PMET module. Other input parameters to PM method viz. humidity, radiation, wind speed are estimated using the inbuilt functions as specified in FAO-56 (Allen et al., 1998)[5] and (Zotarelli et al., 2010)[6]. FAO-56 method has been selected as it closely approximates grass ET_o at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$$

The ET_o is estimated as;
Where,
ET_o= reference evapotranspiration (mm day^{-1}),
R_n= net radiation at the crop surface (MJ m^{-2} day^{-1}),
G= soil heat flux density (MJ m^{-2} day^{-1}),
T= air temperature at 2 m height (°C),
u_2= wind speed at 2 m height (m s^{-1}),
e_s= saturation vapour pressure (kPa),
e_a= actual vapour pressure (kPa),
$(e_s - e_a)$= saturation vapour pressure deficit (kPa),
Δ= slope vapour pressure curve (kPa °C^{-1}),
G= psychrometric constant (kPa °C^{-1}).
The ET_C at daily time step is obtained by multiplying the ET_o with K_c.

$$ET_c = ET_o * K_c$$

Daily values of ET_c are then aggregated to get the monthly ET_{cm} values of a crop for each calendar month as;

$$ET_{cm} = \sum_{j=1}^{n} ETo_j \times Kc_j$$

Where, ET_{cm} is the monthly ET_c of month m, and ETo_J is the reference evapotranspiration on jth day of the month and *n* is total number of days in a month.

Irrigation water requirement of the crops is obtained after adjusting the estimated ET_c for effective rainfall and efficiency of system of water application selected for each plot. In this tool, the Soil Conservation Service effective rainfall estimation method developed by the United States Department of Agriculture (USDA-SCS method) is used to assess the effective rainfall. In the tool, the month implies the calendar month of the year. Based on sowing and harvesting dates, the SIPS tool makes necessary adjustments in P_e to consider only those days of the starting and end months

[4] Allen, R.G., Walter, I.A., Elliott, R.L., Howell, T.A., Itenfisu, D., Jensen, M.E., and Snyder, R.L. 2005. The ASCE Standardized Reference Evapotranspiration Equation. Am. Soc. of Civil Eng., Reston, VA.

[5] Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. 1998. Crop evapotranspiration – guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper #56, Rome: Food and Agriculture Organization of the United Nations (FAO).

[6] Zotarelli, L., Dukes, M.D., Romero, C.C., Migliaccio, K.W., and Morgan, K.T. 2010. Step-by-Step Calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method), IFAS Extension, University of Florida, Florida, available online: http://edis.ifas.ufl.edu.

which are part of the crop growing period, so that the P_e of the start and end months is not overestimated. The effective rainfall is calculated as;

$$P_{em} = P_m \times (125 - 0.2 \times P_m)/125 \qquad \text{for } P<250 \text{ mm}$$

$$P_{em} = 125 + 0.1 \times P_m \qquad \text{for } P>250 \text{ mm}$$

Where, P_{em} is the effective rainfall (mm) of m[th] month (mm) and P_m is the Total rainfall (mm) of m[th] month (mm). Irrigation water requirement of a month (I_{rm}) is the portion of the monthly crop evapotranspiration (ET_{cm}) that is in excess of monthly (P_{em}). The monthly irrigation water requirement of the crop is then estimated as;

$$Ir_m = ET_{cm} - P_{em} \qquad \text{if } Pe_m < ET_{cm}$$

$$I_{rm} = 0 \qquad \text{if } P_{em} > ET_{cm}$$

The irrigation requirement obtained using the above equations is the net irrigation water requirement of the crops. The gross irrigation water requirement (I_{rg}) is estimated considering the irrigation efficiencies of the respective irrigation methods in each plot. In the tool, the irrigation efficiencies (IE) of surface, sprinkler and drip systems are considered as 45, 75 and 90%, respectively. The gross irrigation water requirement is converted into volumetric units by multiplying the I_{rmg} of each plot with the area of the respective plots.

$$I_{rmg} = \frac{I_{rm}}{IE}$$

$$V_{mg} = \sum_{j=1}^{j=K} \frac{I_{rmgj} \times A_j}{4000}$$

Where, K is the number of plots considered in the command area of the solar pumping system, I_{rmgj} is the monthly gross irrigation water requirement of j^{th} plot (mm), **A**j is the area of the j^{th} plot (acre). The online version of the toll has no limitations on number of plots but in the excel version, number of plots are limited to 10. Factor 4000 is added in the denominator of above equation to convert the crop water requirement in the units of litre per month.

The RZWB subroutine

The RZWB subroutine simulates the root zone water balance on a daily timestep, accounting for inflow and outflow processes within the root zone. To solve the water balance equation for specific crop and soil combinations, daily values of crop evapotranspiration (ET_c) are obtained from the PMET subroutine, as outlined previously. Soil properties such as saturation percentage (SP), field capacity (FC), wilting point (WP), and maximum deep percolation rate (DP_m) are retrieved from the gridded soil database for each grid point. Additionally, the initial soil water content is a crucial input for the model; the RZWB subroutine allows users to set the initial soil moisture either at field capacity or at a user-specified value before the growing period begins.

The simulation starts with the computation of 'total water' (TW) which is the total inflow of water in the modelling domain. Mathematically, it is the sum of 'residual soil water' carried forward from the previous day and 'rainfall + irrigation' of the present day. This is the total inflow into the system which will be distributed among different outflow components as the simulation period progresses. Conceptually, TW represents the soil water storage, ponded water, potential runoff and deep percolation on a particular day (Figure 16). Note that the model assumes that lateral inflows are balanced by outflows and there is no upward flux from a shallow water table.

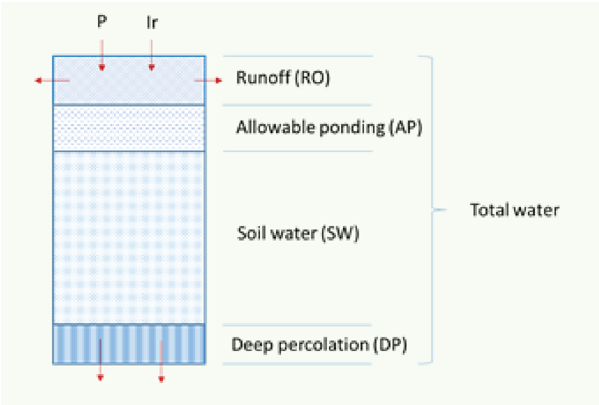


Figure: 16 Conceptual representation of total water on ith day within the crop growing period

On the first day of the crop growing period, the simulation starts with the total water as a sum of initial moisture content (MC_i), rainfall (P_i) and irrigation (I_{ri}) on day-1 (i^{th} day). Using the water balance approach, the residual soil water *(RSW)* on i^{th} day is estimated considering the *ET, RO* and *DP* on i^{th} day as follows:

$$TW_i = MC_i + (P_i + I_{ri})$$

$$RSW_i = TW_i - (ETc_i + RO_i + DP_i)$$

The residual moisture content on i^{th} day is carried forward to next day *(i+1)*, and the total water on $(i+1)^{th}$ day is estimated considering the P and I_r on $(i+1)^{th}$ day. The residual soil water on $(i+1)^{th}$ day is then obtained after accounting for the ETc, RO and DP estimates of $(i+1)^{th}$ day.

$$TW_{(i+1)} = RSW_i + \left(P_{(i+1)} + Ir_{(i+1)}\right)$$

$$RSW_{(i+1)} = TW_{(i+1)} - \left(ET_{c(i+1)} + RO_{(i+1)} + DP_{(i+1)}\right)$$

Deep percolation and runoff

If the RSW is more than *FC*, the system is programmed to deduct excess soil moisture towards DP as per the following conditions. The logic here is, if the residual soil moisture on a particular day is not enough for deep percolation to occur at maximum deep percolation rate *(DP_m)*, then the excess moisture above FC should be accounted for towards deep percolation loss. If the *RSW* is in excess of *FC* + DP_m, then the deep percolation on that day should occur at the maximum deep percolation rate of the soil.

$DP = DP_m$ if $(RSW - FC) > (FC + DP_m)$

$DP = RSW - FC$ if $RSW > FC$ and $RSW < FC + DP_m$

$DP = 0$ if $RSW < FC$

If the *RSW* is more than *SP*, the system is programmed to deduct excess soil moisture towards *RO* as per the following conditions.

$RO = RSW_{(i+1)} - SP$ if $RSW_{(i+1)} > SP$

$RO = 0$ if $RSW_{(i+1)} < SP$

Runoff from Paddy fields: In the case of crops like paddy, where fields are generally bunded, the height of bunds may vary from 5-15 cm.

If the selected crop is paddy, then the default value of *AP* is set to 10cm however, the *RZWB* subroutine has an option to input the user-specified depth of bund (allowable ponding, *AP*).

$RO = RSW - (SP + AP)$ if $RSW > (SP + AP)$

$RO = 0$ if $RSW < (SP + AP)$

5.1 Irrigation Water Requirement

In the *RZWB* subroutine of the SIPS tool, if the moisture content carried forward from the previous day *(RSM_i)* is below the critical limit *(CL)*, an equivalent amount of irrigation to bring back the soil moisture level to field capacity is considered as the irrigation requirement. The default value of the critical moisture limit (Management Allowed Deficit, MAD) is set at 50% of the available water (50% MAD). Available water is the amount of water present between *FC* and *WP* of the soil.

$$CL = 0.5 \times (FC - WP)$$

$I_{r(i+1)} = FC - RSM_i$ if $RSM_i < (WP + CL)$

$I_{r(i+1)} = 0$ if $RSM_i \geq (WP + CL)$

The irrigation requirement obtained using the above equations is the 'net irrigation requirement' of the crops. The gross irrigation water requirement is estimated considering the irrigation efficiency *(IE)* of the respective irrigation methods in each plot. In the tool, the irrigation efficiencies of surface, sprinkler and drip systems are considered as 45, 75 and 90%, respectively.

$$I_{rmg} = \sum_{i=1}^{n} \frac{Ir_i}{IE}$$

Where, I_{rmg} is the gross irrigation water requirement of m^{th} month (mm) and *n* is the number of irrigation events in the calendar month under consideration, I_{ri} is the net irrigation water requirement of the i^{th} irrigation event in m^{th} month (mm).

The monthly gross irrigation water requirement of a crop is estimated as the sum of the daily irrigation water requirements of all the crops within a calendar month. The total amount of water applied during each irrigation event of the calendar month is summed to get the monthly irrigation water requirement. In the tool, the month implies the calendar month of the year. The gross irrigation water requirement is converted into volumetric units by multiplying the I_{rmg} of each plot with the area of the respective plots. Volumetric irrigation water requirement for each calendar month *m* is calculated as;

$$V_{mg} = \sum_{j=1}^{j=K} \frac{I_{rmgj} \times A_j}{4000}$$

Where, *K* is the number of plots considered in the command area of the solar pumping system, I_{rmg} is the monthly gross irrigation water requirement of j^{th} plot (mm), A_j is the area of the j^{th} plot (acre). The online version of the tool has no limitations on the number of plots but in the Excel version, the number of plots is limited to 10. Factor 4000 is added in the denominator of the above equation to convert the crop water requirement to the units of a litre per month.

Net system discharge

The number of days available for irrigation each month is a crucial factor in determining pump discharge. This availability is influenced by various elements, including solar radiation, system maintenance, and potential unforeseen breakdowns. Additionally, farmers cannot dedicate every day of the month to irrigation. A greater number of operational days within a month will reduce discharge requirements, allowing for a smaller pump size.

To ensure that the chosen pump can meet water demands throughout the year, the month with the highest irrigation requirement is used to determine the system's discharge capacity. From the array of monthly values, the maximum irrigation water requirement (Vmax) is selected for calculating system discharge as follows:

$$V_{max} = Max(V_{mg}) \text{ .... m=1(January) to m=12 (December)}$$

The design discharge of the solar pumping system is estimated as;

$$Q_s = \frac{V_{max}}{N \times 4.5 \times 3600}$$

Where, Q_s is the design discharge of the solar pumping system (l/sec), V_{max} is the maximum monthly gross irrigation requirement *(l)* and is the user-specified value of number of days available for irrigation in a month. Note that the number of days available for irrigation in a month is the same for all months. Both the Excel as well as online versions do not allow users to enter a different number of days of operation for different months. The factor (6x3600) is added in the denominator to convert the discharge in the unit of l/day to l/s.In the tool, the duration of pump operation a day is fixed at 4.5 hrs.

5.2 Drinking Water Requirement

The drinking water requirement is calculated based on the input of the population and the type of tap connection. There are three options for the tap connections: (i) Fully plumbed connection, (ii) Yard connection and (iii) Public taps.

Taking references from Design Guidelines of Urban Water Supply and Sanitation (Sector) Project[7] and Kathmandu Valley Wastewater Management Project – Dhobighat[8], the liter per capita per day (lpcd) are as follows:

[7] GoN. 2021. Urban Water Supply and Sanitation (Sector) Project: Design Guidelines. Kathmandu: Department of Water Supply and Sewerage Management, Ministry of Water Supply, Government of Nepal (GoN).

[8] GoN. 2018. Initial Environmental Examination, NEP: Kathmandu Valley Wastewater Management Project – Dhobighat. Prepared by: Project Implementation Directorate (PID), Kathmandu Upatyaka Khanepani Limited, Ministry of Water Supply, Government of Nepal for the Asian Development Bank (ADB). Available online: https://kuklpid.org.np/Content/Upload/document/safeguard/0B80F3F2-FBA0-48A9-9BAE-C14BD126313A.PDF

1. Fully plumbed connection: 135 lpcd
2. Yard connection: 70 lpcd
3. Public taps: 45 lpcd

The following parameters are used:

- Daily water requirement (W)
- Margin (M)
- Annual growth of population (G)
- Number of years of projection (Y)

The formula used to determine the daily water requirement is:

$$DWR = P * W * (1 + M) * (1 + G)^{Y}$$

Where,

DWR is the average daily water requirement used for pump sizing
P is the current population
W is the daily water requirement per person
M is the percentage of margin/contingency for daily water requirement per person
G is the percentage of annual population growth
Y is the number of years of the project

5.3 Dynamic Head

The total dynamic head is one of the key values that is calculated which represents the sum of the water lifting head (user input), geodetic head, and head loss due to friction.

The total dynamic head is calculated based on user inputs about the pumping water level, the distance of the field from the water source and the diameter of the conveyance pipe being used to carry water from the water source to the field. The geodetic head refers to the actual physical difference in height between the pumping water level at the water source and the highest point of the discharge. In estimating the geodetic head, the tool considers the elevation of the tube well head at the ground surface as the discharge point while in the case of other water sources elevation of the delivery side of the pump is considered as the point of discharge.

Friction head is the loss of head on account of friction in the pipes and fittings. The elevation head is the elevation difference between the delivery point at the water source and the highest point in the command area of the system.
The head required for the operation of an irrigation system (say, drip or sprinkler) is termed an operational head requirement. The total dynamic head is calculated as;

$$H_t = H_{geo} + H_f + H_o + H_e$$

Where, H_t is the total dynamic head requirement of the pumping system (m), H_{geo} is the geodetic head, H_f is the friction head loss in pipes and fittings, H_o is the operational head requirements for the irrigation system and H_e is the elevation head.

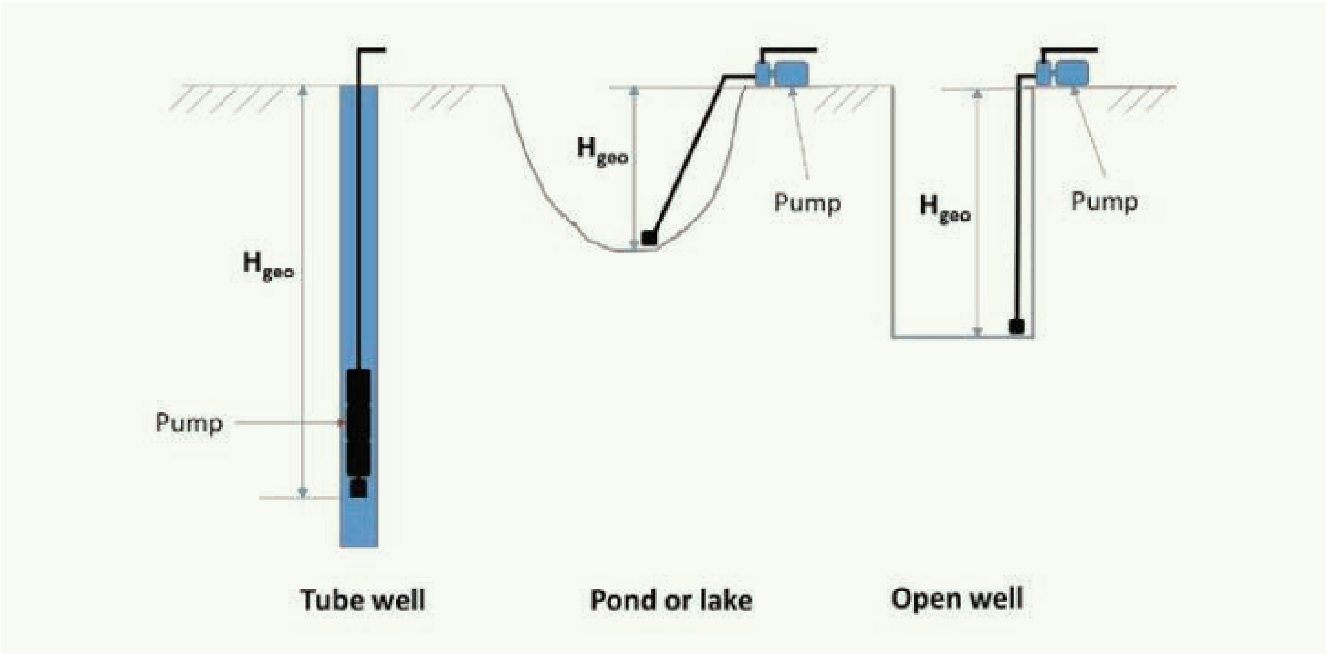


Figure 17: Computation of geodetic head for different water sources (Image obtained from IWMI India's solar irrigation pump sizing tool user manual[9])

Geodetic head

The geodetic head depends on the type of water source and the placement of the pump with respect to the pumping water level. In the case of streams, the geodetic head is the difference in elevation of the pump and the maximum possible lowest water level in the stream. If the water source is an open well, the depth of the open well is considered as the total geodetic head. If the water source is a tube well, 95% of the depth of the tube well is considered as the geodetic head. The geodetic head is limited to the maximum practical suction lift of the centrifugal pump (7.0 m) in the installations where pumps are placed at the ground surface (Table 1).

Table 1: Computation of geodetic head for different water sources

Water source	Condition	Geodetic head, m
Stream	Wl_{min} <7 m Wl_{min} >7 m	$H_{geo} = WL_{min}$ $H_{geo} = 7.0$
Open well	d_{ow} <7 m d_{ow} >7 m	$H_{geo} = d_{ow}$ $H_{geo} = 7.0$
Pond/late	d_p <7 m d_p >7 m	$H_{geo} = d_p$ $H_{geo} = 7.0$
Tube well	Submersible pump	$H_{geo} = 0.95 * d_{tw}$

[9] Mali, S.S., Shirsath, P.B., Verma, S. and Sikka, A.K. 2022. Solar Irrigation Pump (SIP) Sizing Tool: Beta Version User Manual. ICAR, IWMI, BISA and GIZ collaborative project. Colombo: International Water Management Institute (IWMI).
Available online: https://www.iwmi.org/tools/sip-sizing-tool/sip_sizing_manual.pdf

Where, WL_{min} is the minimum possible water level in the stream with respect to pump (m), d_{tw}, d_p and d_{ow} are the depths of tube well, pond and open well, respectively.

Friction head in pipes and fittings

Friction loss through the pipes is a function of water discharge (Q_s) and the diameter (D) of the pipeline. The tool accounts for the friction loss on the suction and delivery sides separately. User input is the diameters of the suction and delivery pipes and the distance of the field from the water source. The length of the suction side is assumed to be the same as that of the geodetic head.

$$H_f = H_s + H_d + H_{fit} + H_{syst}$$

Where, h_s is the friction loss on the suction side of the pump (m), h_d is the friction loss on the delivery side of the pump (m), h_{fit} is the friction loss in fittings and accessories and h_{syst} is the friction loss in irrigation system (applicable to pressurised irrigation systems only).

The friction loss in the suction (h_s) and delivery (h_d) sides of the pump is calculated using the Darcy Weisbach equation.

$$h_s = \frac{789{,}000 * L_s * Q_s^{1.75}}{D_s^{4.75}}$$

$$h_d = \frac{789{,}000 * L_d * Q_s^{1.75}}{D_d^{4.75}}$$

Where, L_s and L_d are the lengths of the pipes on the suction and delivery sides (m), Q_s is the water discharge (l/s) and D_s and D_d are the diameters of the suction and delivery pipes (mm).

The friction loss in fittings and accessories is reasonably assumed as 10% of the total friction loss in pipes.

$$h_{fit} = 0.1 * (h_s + h_d)$$

At the stage of pump selection, if the actual friction loss within the selected system (drip or sprinkler) is known, the user can directly input this value in the tool for calculation of the system head. If the water application systems are yet to be designed, but the choice of systems for each plot has been finalised then the friction loss within the water application system is based on some thumb rule and the friction loss in these systems is assumed as 10% of the operational heads of these systems.

$$h_{syst} = 0.1 * H_o$$

Where, h_{syst} is the frictional loss in the selected system of irrigation (m), H_o is the operational head of the selected water application system (m).

Operational head

Each irrigation system has its specific requirements for its operation to achieve higher application efficiencies. These head ranges often vary from 2 m in the case of gravity-fed systems to about 80 m in the case of rain guns. A variety of water application devices are available in the market with a wide range of operational head requirements. It is a bit difficult to generalise these ranges for its implementation in the tool. As in the case of frictional losses within the water application systems, here also user gets the option to input the actual operational requirement of the system or use the default value of the operational head for the selected water application method. The default system operational heads considered in the SIPS are presented in Table 2.

Table 2: Default values of the operational head of different systems

Irrigation method	Operational head (m)
Surface/flood	0
Drip or trickle	10
Micro-sprinklers	15
Sprinklers	25

Elevation head

The elevation head is the difference in the elevation of the highest point in the command and the elevation of the pump discharge point. The tool assumes that the land is flat and the default value of elevation is set equal to zero. However, users get an option to override the elevation head where they can input the actual elevation head obtained from field surveys or visual observations of biophysical conditions within the command area.

6. Pump Selection

After the data inputs are completed and the tool estimates the total dynamic head, the pump capacity is estimated based on the following methodology:

1 **The tool has 207 models of market-available pumps in its database.**

- The capacity of the pump ranges from 0.5 HP to 30 HP.
- The manufacturers taken for reference include Pedrollo, Pluga and Latteys.

For each pump, the type of pump (submersible/surface), its capacity (kW/HP) and pump curve (head vs. flow) have been recorded. Similarly, the efficiency of the pump at each operating point has been calculated.

2 **Based on the desired water flow (m³/hr) and the total dynamic head, the tool selects the pump according to the following criteria:**

- The desired water flow (m³/hr) and the total dynamic head is met,
- Pump efficiency must be at least 65% at the given operating point,
- Out of the options that meet the above two criteria, the pump with the lowest capacity is chosen.

3 **If there are no pumps that match the above selection method, the tool falls back to a theoretical estimation of the pump size. The following formula is used:**

$$\text{Hydralic Power, } P_H = \frac{q * p * g * h}{3.6 * 10^6}$$

$$\text{Shaft power, } P_s = \frac{P_H}{\eta}$$

Where,
q is the water flow rate
p is the density of water: 1,000 kg/m³
g is the acceleration due to gravity: 9.81 m/s²
h is the total dynamic head
n is the pump efficiency: 65%

After determining the pump capacity, the inverter capacity and the solar array size are matched to the horsepower (HP) of the pump.
The reason for matching the solar array size to the pump capacity in HP is that this allows for a 1.34 DC:AC ratio allowing margin for system losses.

6.1 Bill of Quantity

After determining the pump capacity, the bill of quantity (BoQ) is estimated, which includes
(i) electromechanical components,
(ii) civil components (water transmission and distribution reservoir only), and
(iii) installation & transportation.

Note: The civil components include items for water transmission and distribution reservoir only. Components for water distribution are not included because these are highly site-specific and require a detailed survey.

The tool has a pre-defined set of BoQ generated for the following ranges of pump capacities:

- 1 – 2 HP
- > 2 – 5 HP
- > 5 – 7.5 HP
- > 7.5 HP – 10 HP
- > 10 HP – 20 HP
- > 20 HP – 30 HP

Depending on the selected pump capacity, the tool extracts the respective pre-defined BoQ with its component quantities, general specifications and per-unit component weights[10]. The tool updates the number of components respective to the design (for example, updates the AC cable length based on the user input of the distance from the solar array to the pump).

It then calculates the system cost from the rates specified on the 'Price' page.

Notes:

- The cost of solar panels is tax exempted and no VAT is calculated for this item.
- A 5% contingency is included in the system cost.

6.2 What-If Scenarios

The report generates a what-if scenario of reduced water requirement scenarios (Figure 18).

% of base	Liters/ day	Pump size (HP)	System cost (NPR)
Base(100%)	**96,113**	**25**	**3,670,120**
90%	86,502	17.5	3,069,190
80%	76,890	15	2,923,977
70%	67,279	15	2,8883,261
60%	57,668	12.5	2,730,847
50%	48,056	10	2,294,069

Figure 18: What-if scenarios:Reduced water requirement scenarios

The what-if scenario presents the different pump sizes and system cost scenarios if the daily water requirement is reduced in intervals. The baseline (desired daily water requirement) represents 100%, after which, the what-if scenario is run for 90%, 80%, 70%, 60% and 50% of the baseline water requirement. For each scenario, the pump size and the system cost are displayed.

This allows the user to see how the system cost varies if the daily water requirement is reduced, which may help in optimising the system and meeting a desired budget or other project constraints.

[10] Component weight is used to calculate the transportation cost

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