Training Resources for Solar Water Pump Testing
Part 1

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Introduction

Since 2019, VeraSol has been developing technical resources related to SWP testing in partnership with Schatz Energy Research Center. These resources include:

- Global LEAP Solar Water Pump Test Method , which describes laboratory testing procedures for measuring and evaluating energy performance, quality, and durability evaluation; as well as

- SWP Durability Research Memo, which identifies the common durability issues observed from the testing process and recommendations for how to enhance pump durability.

To further expand the technical resources for SWPs, the VeraSol team has developed a series of training documents for testing facilities and technicians interested in learning more about SWP testing. The documents include standard operating procedures (SOPs) for performing tests based on the Global LEAP test method.

Version	Date	Summary
1.0	8/26/22	First draft of this procedure

Scope / Field of Application

Several safety factors are involved with testing solar water pumps (SWPs) that must be reviewed and understood by each tester before testing or working on the test bench. Safety hazards outlined in this SOP are predominantly in relation to human and environmental health. Note that there may be other safety hazards observed in specific sets of circumstances that are not mentioned in this document. If a tester observes safety hazards, the Lab Manager should be notified before moving forward.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customised by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

- **SWP**- solar water pump
- **SOP**- standard operating procedure
- **DAQ**- data acquisition

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client as needed.

Materials Required

- *Shop towels and bucket; OR oil filter to separate water from oil*
- *Fire extinguisher*
- *Safety glasses*
- *Disposable gloves*

Pre-Test Preparation

Read *SWP Test Bench Instruction Manual*

Procedures

Read this SOP prior to conducting any performance testing on SWPs, performing any calibration or maintenance procedures, or handling any of the equipment or parts on the SWP test bench. Note that

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test-specific safety hazards and protocols are described in their specific SOP; this SOP details general safety hazards and protocols associated with testing SWPs.

General testing requirements
Before a tester conducts any testing, the following requirements must be met:
- Tester has been fully trained and approved to test by Lab Manager
- Tester has read this SOP, the SOP for the test they are going to conduct, and any preliminary procedural SOPs
- Tester has read/ is familiar with the *SWP Test Bench Instruction Manual* and familiar with the SWP test bench itself
  - Tester understands the test bench limitations and proper use/ care of it
- Tester demonstrates competency in hands-on electrical wiring, use of basic tools, and pressurised systems
- Tester has discussed any safety hazards observed prior to testing with the Lab Manager

Intake safety before testing
Before testing begins, the intake and visual screening procedures must be completed, which are outlined in the *2 SWP Intake and Visual Screening* SOP. During this process, look for physical safety hazards on the pump and its components that should be noted in the test report and possibly discussed with the Lab Manager prior to testing.

Some safety hazards may include:
- Visual damage to the SWP body and/or its components
- Loosened electrical wires
- Leaked oil from the pump's motor enclosure
- Missing necessary parts or pieces
- Missing information regarding the installation and use of the SWP system
- Poor construction/ manufacturing that could cause a hazard, like improper soldering, sharp edges, etc.

General electrical safety while testing
During testing, there are several safety protocols that must always be followed. The list below may not be inclusive of every case-by-case scenario:
- Before any wiring on the test bench is done (before, during, and after testing), *always* ensure the following are true:
  - The Chroma solar array simulator unit is turned OFF. You must press the physical power button on the unit itself to do this, and the screen on the front of the Chroma will be blank when it is powered off.
  - All DAQ equipment are unplugged and turned OFF.
    - Note that high voltages are not expected with the DAQ equipment; however, safety is highly prioritized, so removing this risk is best practice.
    - Also note that all of the DAQ equipment should be plugged into a power strip so that it is easy to plug in/ turn on and unplug/ turn off DAQ equipment.

- o Review all installation documents for the specific pump under test before wiring it to the test bench. If there is not adequate instructions or installation documents provided, the Lab Manager should be notified so that they can reach out to the manufacturer before testing.
  - o Always double check wiring after it has been done; if wiring is done incorrectly for a SWP, then powering it may cause damage or a safety hazard.
- Ensure the Chroma is turned OFF when testing is complete and/or when the tester must leave the test bench unattended temporarily.
- Use the 16A fuse, wired between the Chroma and the Controller or SWP, whenever possible as an extra safety precaution. This fuse will trip and open the circuit if 16A is breached.

Figure 1. 16A Fuse connecting electrical circuit or SWP testing.

- Ensure to review the lab's SWP testing input power limitations prior to testing a pump to ensure the rated specifications of the pump don't exceed any of them. See some of the most relevant testing limitations below.
  - o Note that the testing limitations should be saved in a test lab's records (such as on the testing computer) and shall be updated if any circumstances change.

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Testing Limitations				TEST LIMIT
PV POWER INPUT				
Equipment	limit	units	Notes	
Chroma	4.16	kW		*2.4 kW*
PV array- Alternative test method	2.4	kW	And we are limited by the season. This limitation is based on configuration and space mainly. There may be some flexibility in certain circumstances.	
HEAD/TEST BENCH PRESSURE				
	limit	units	Notes	
manual ball valve	600	psi	--	*200 psi/ 140 meters of head*
automatic ball valve	1000	psi	This piece is deemed unnecessary for testing; however, it is still integrated into the test bench.	
Large flow meter	250	psi	--	
Small flow meter	250	psi	--	(to ensure we don't trigger safety valve)
PVC network	300-600	psi		
maximum pressure safety valve	250	psi	--	
PHYSICAL PUMP SIZE				
	limit	units	Notes	
testing tanks	1000	gal	For larger submersible pumps, we have a 1000 gal water tank.	**
FLOW RATE				
	limit range	units	Notes	
Large flow meter	6-93/22-353	GPM/lpm	--	*5-350 lpm*
Low flow meter	1.25-9.5/4.7-35	GPM/lpm	--	

Figure 2. Testing limitations of conditions and equipment set up outlined in the *SWP Instruction Manual*

- If a SWP includes an external controller, ensure that its front cover is fully closed before testing and after it is wired up.
  - This helps protect the tester in cases of possible over-voltage/ over-current that could cause damage and a safety hazard
- The test bench has polycarbonate shielding installed just over where the laptop sits so that it is separating the tester's face and from all of the electrical equipment during testing. This shield is shatter-proof and may protect the tester should over-voltage or over-current may damage equipment and pose a safety hazard to the tester.
- It is recommended that the tester have all wiring double checked by the Lab Manager prior to testing.
- SWPs under test should be grounded when testing to protect the tester. More details may be found in the *3 SWP Testing Set up* SOP.
  - Often, pumps include a green ground electrical lead, which should be connected to either the pump controller and then to the grounding screw terminal connected to the Chroma grounded OR be connected directly to the grounding in the test bench if no external controller is included.
  - If a SWP does not include a green grounding electrical lead, then physically clip the test bench's grounding to the pump body.
- Take care not to expose electrical components/ electrical wires to water.
  - When connecting a SWP to the test bench for testing, ensure its electrical leads, are not exposed to water. This can be achieved in various different ways:
    - Ensuring exposed electrical leads have connections within waterproof terminal block.

- Making sure that all electrical connections threatened by water exposure are made physically far away from the water source, if possible.
- Directing non-water-proof junction box enclosures so that they are facing away from the water source.
  - o Never touch or try to reconnect electrical wires while equipment and/or Chroma is turned ON.
- Specific testing safety protocol may be found in each test's SOP.

Other Safety
- Ensure the pressure limit of the test bench is not surpassed, which is stated in the test bench limitations table shown in the section above.
  - o SWPs that need to be tested at heads where the simulated pressure exceeds the test bench limitations, the client must be contacted and made aware of this, and the SWP will only be tested to the maximum limit of the test bench.
  - o Scheduled test bench maintenance must be followed, as outlined in the *10 SWP Calibration and Maintenance* SOP, to ensure parts of the test bench are not compromised with age and are replaced/ maintained on the specified intervals.
  - o If the pressure of the test bench is surpassed during testing, this could compromise the safety of the testers and the functionality of the electrical testing equipment.
  - o There is a high-pressure safety valve in-line with the PVC network on the test bench that will release water if the system reaches the over-pressure limit, which reduces the risk of harm. Ensure the opening of this device is always facing a direction that is aiming outdoors and not towards anything that should not be exposed to water.

Figure 3. High pressure safety valve- output facing in a direction outward from the electrical equipment.
- Disposing of SWP parts after testing may pose as an environmental safety risk.

     o Ensure that all parts are categorized and recycled appropriately, and that all hydraulic oil in the motor enclosure either gets delivered or picked up as toxic waste. Until hydraulic oil is properly disposed of, it must be kept in a container with a lid that is labeled as hazardous waste.
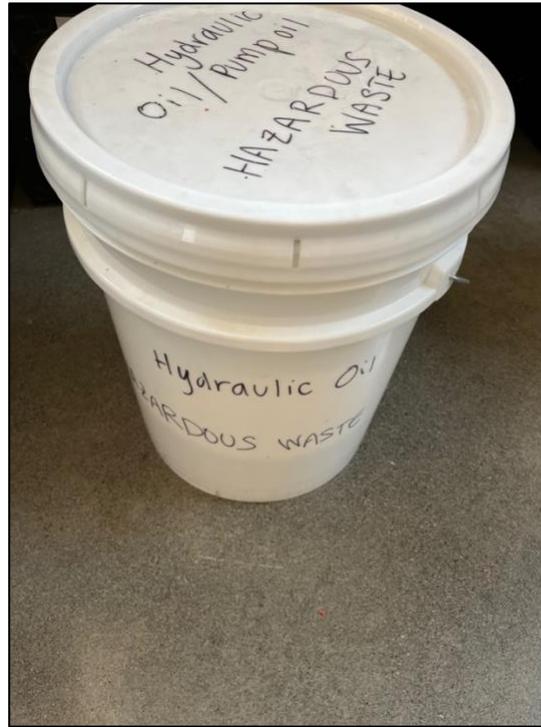
Figure 4. Five-gallon bucket containing old SWP oil, labeled as "toxic/ hazardous waste" and will be disposed of through a toxic waste facility.

- Ensure the tester knows how to properly use all shop tools that will be used during testing. For instance, during the internal inspection, sometimes there is a use for power tools, various wrenches, a vise, and more. Follow all safety protocols for working in the shop with these tools. If there is a power tool or other shop tool needed and the tester has not been trained on using it, consult with the Lab Manager to schedule a training.
- It is best practice to always wash your hands with soap after handling a SWP that has leaked oil or after performing an internal inspection of a SWP.

Leaked oil disposal- Environmental Safety

Some SWPs have been observed to leak hydraulic oil into the source water during testing. Not only should this be well-documented in the product test report as both a human health and environmental hazard, but it should also be disposed in an environmentally-conscious and safe way.

Figure 5. Oil leaked from a SWP in the source water during testing.

It is recommended to invest in or build a filter to separate the water from oil to have on-hand at the test lab. A filter paired with myco-filtration techniques and water testing is the best option for handling this contaminated water. If a test lab does not have a filter for this, after testing, the tester may use shop towels to sweep across the surface of the water (most likely where most of the visible oil is) to try to collect oil absorbed into the towel. This process should happen over again until the oil in the water is significantly less visible. The shop towels might be accepted at a hazardous waste management site; or they can be thrown into the garbage. The rest of the water surface should be scooped via 5-gallon bucket and dumped down the sink drain since this water is treated at the wastewater treatment plant OR disposed of in a grassy area, as it can be properly broken down biologically. *Note: water contaminated with oil that can be visibly observed should never be dumped down the sewer drain, as this is not treated water.*

<u>**Safety materials**</u>

- A tester should always know where the following safety items are nearby when testing and how to use them when a safety hazard is noticed (such as the following):
    o Fire extinguisher

Figure 6. Fire extinguisher affixed to a wall near the SWP test set up

- o First aid kit
- o First aid wool blanket
- o Electrical panelboard shut-off switch to the Chroma
- o Safety goggles and safety face shields
- o Disposable gloves

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Version	Date	Summary
1.1	08/25/22	Added to draft procedure
1.0	12/28/21	first draft of this SOP

Scope / Field of Application

Upon receiving a new product for testing, intake and visual screening procedures must be carried out, which include labelling all components received, taking photographs of the solar water pump (SWP) and any components that are included with it, taking measurements, and recording any observations and all manufacturers' ratings in the test report template. The procedure is discussed in detail in this document.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customised by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP – solar water pump

SOP – standard operating procedure

Responsibilities

SWP Tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *A camera (must be able to produce non-blurry and legible images)*
- *A laminated grid (32" x 32", grid markings at 1cm intervals)*
- *Meter stick (to measure pump component dimensions)*
- *Screwdriver, Allen wrench, miscellaneous common tools to open easily accessible compartments on the pump or controller*

Procedure

Intake

When a SWP arrives, it is helpful to open the SWP reporting template on a computer nearby so that you may fill out important information in the *Title Page* and *Visual Screening* tabs as you go.

1. Upon arrival of a SWP to the lab, be sure to inform the Lab Manager before beginning the intake process to set an expected timeline for testing.

2. Before starting the intake or visual screening process, it is important to create proper file structure and organization:

   a. Start by creating a new folder with the pump name and date that the pump was received. As an example, for a pump called SunflowAC4 that was received at the lab on 15 August 2022, it would have a folder that looks like this:
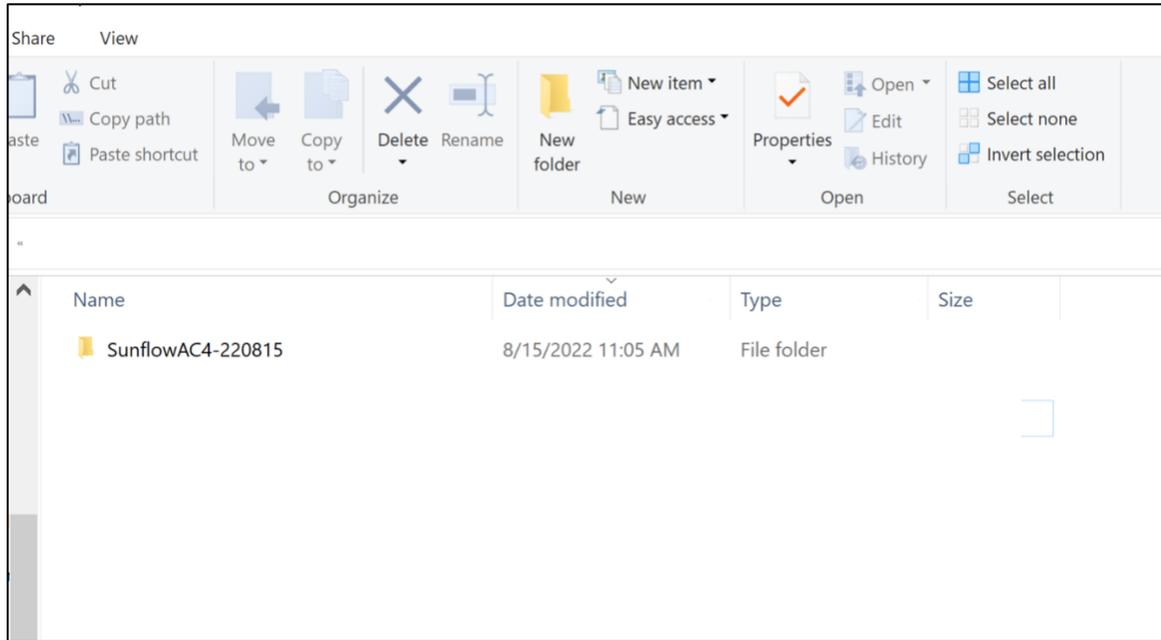
Figure 1: Main testing folder for SWP testing.

   b. Within the testing folder, there should be a series of subfolders for each of the tests that require a separate data analysis spreadsheet from the main reporting spreadsheet as seen in Figure 2.

   c. The reporting template should stay in the main testing folder outside of any of the subfolders as seen in Figure 2.
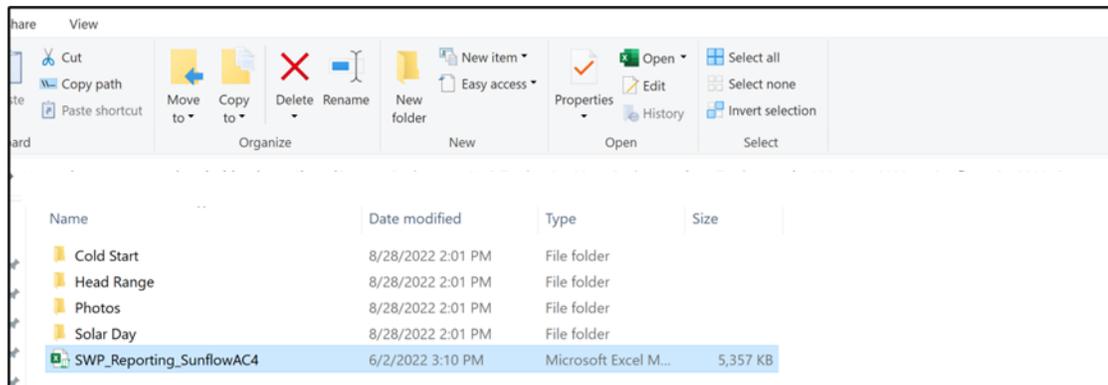
Figure 2: Testing subfolders for each new pump.

   d. Within each of the subfolders, the respective testing template should be copied from the "Testing_Template" folder to the relevant subfolder and then renamed from

"Template" to the pump name.
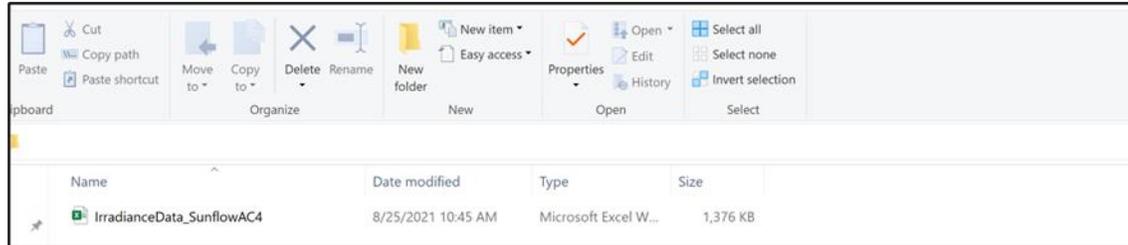
Figure 3: Testing template copied into the test subfolder.

    e. Once the file structure is created, open the *Reporting* template in the main folder and begin the intake and visual screening.

3. Begin the intake process by observing the package. Take pictures of the packaging and any labels or markings. Be sure to note any serial or model numbers on the packaging as well as any brand labelling.
    a. If there is a serial number located on the product packaging, note it in the *Title Page* tab, shown below in Figure 4.
    b. If there is any damage to the package that may have been sustained during shipping, be sure to take pictures and report it to the Lab Manager.

4. Remove the components from the packaging and note how many samples were received (this is typically 1 or 2 samples).

5. If more than one sample is received, choose one sample to begin photographing and removing from the package.

6. Note all the components included with the SWP in the *Title Page* tab of the reporting template shown below in Figure 4.

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Figure 4: Title page tab of the SWP reporting template

7. Review all manufacturer included information- this includes the user manual, packaging, warranty card, ratings on the pump, the manufacturer or distributor's website, and information provided directly to the lab. This information will be useful throughout the intake process and can help fill in some of the information located in the first section of the *Title Page* shown above in Figure 4.

8. Layout all included components on the laminated grid and take a photo of the entire SWP kit, this will go in the *Title Page* tab in the "Product Photo(s)" section. See example below:

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Figure 5: Title page section for the overall product photo with all included components

9. After taking the overall photo of all included components, take more detailed pictures of the components individually on the grid. This includes:
    a. All sides of the controller and, if easily accessible via standard tools such as screwdriver or Allen wrench, the internal parts of the controller.
    b. All pages of the user manual and warranty card, if included, in such a way to ensure that text is readable in the photo.
    c. All sides of the SWP. Including one clear image of the entire SWP itself on the grid to be used as the product image on the VeraSol Database.
    d. All sides of the PV panel, if included.
    e. Any label(s) (ensure that the labels are also readable in the photo). Some key places to check for labelling are:
        i. On the component (on the front of the pump or side of controller)
        ii. On the electrical cables
        iii. Inside of a component (i.e. a wiring diagram on the back of the face plate on a controller).
        iv. On the back of a PV module (if included).
    f. Any accessories or components.

NOTE: If all components can't fit into one photo for the *Title Page,* it is OK to include multiple photos of the components separately laid out on the grid.

10. Note any model or serial number on any of the components on the *Title Page*.
11. If there are multiple samples received, label each of the samples and their included components as [SubmittingEntity]-[ModelNumber]-[SampleNumber]. For example: SolarCompany-Sunshine124-01
    a. Refer to step 13 in the Visual Screening section below for more detail on how the submitting entity is defined.

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Visual Screening

The visual screening process will require aggregating information from the user manual, packaging, ratings on the pump, the manufacturer or distributor's website, and information provided directly to the lab from CLASP or from the manufacturer.

1. The *Visual Screening* tab is located directly next to the *Title Page* tab in the SWP reporting template. The *Visual Screening* process follows these general guidelines:
   a. Anything in a yellow or blue cell is a user inputted value that should be filled out if relevant.
      i. The boxes in yellow require a unique description or value while the boxes in blue require a selection from a dropdown menu of options.
   b. If a parameter is not relevant to a certain pump, it can be left blank. There are some parameters that will not be known until testing/internal inspection, so leave those blank until the information is known.
      i. If the information is not present or not able to be determined through internal inspection or testing (i.e. IP ratings, rated current, wire gauge, etc.) then fill in the cell with "--". See Figure 6 below for an example.
   c. The source of information should be filled in for any value or description. If there are multiple sources of information, fill in the most consumer-facing one. For example, if the pump power rating is rated on the pump label and the website as 500W, fill in 500W and note the source of information as "On Pump".
      i. If there are conflicting ratings, record the most consumer-facing one, but note the conflict in the comments section. The consumer-facing rating is typically ordered in by when the user encounters the rating in the process of opening and examining the product. For example, if both the packaging and the controller label have a rating listed for nominal power, the packaging would be considered more consumer-facing. For reference, the ranking from most consumer-facing to least consumer-facings are as following: packaging, user manual (or other physical documents), component labels/nameplates, website, and information provided directly to lab from manufacturer.
      ii. Some of the "Source of Information" boxes are white and filled in with the source "Measured". This is for parameters that are required to be measured directly by the person performing the visual screening, not acquired from any included materials.
   d. There is a comment section at the end of each section which should be used to note any discrepancies, vague or irrelevant information, missing key information, or anything else noteworthy.
2. The first section is the ***Pump Visual Screening*** where you need to fill in any information regarding the pump itself.
   a. If the pump has an integrated controller, fill in the information here, and note in the comments that there is an integrated charge controller.
3. Start by filling in the Pump model number or unique name, then fill in the value of any known parameter in the center column and note the source of information in the right column as seen below:

Figure 6: Pump section of the Visual Screening tab

4. The next section is the ***Controller Visual Screening*** which is where any information regarding separate charge controllers or inverters will go.
5. This section is very similar to the "Pump Visual Screening" above and should be filled out in a similar manner.
   a. If a parameter or section is not applicable, enter "--" or leave blank.
6. A sub-section of the "Controller Visual Screening" is the ***Controller inspection / functionality test*** where the user should note any indicators or lights on the

inverter/controller and how they are interpreted as well as answer some functionality questions. There is also a section to include both internal and external photos of the controller.

    a. If the indicator information is not provided in a user manual or other documentation, then the lab technician should fill in with their observation or interpretation after testing.

    b. The functionality section should be filled out after testing the pump and determining whether the controller functioned properly.

    c. For the workmanship section- this refers to both internal and external controller workmanship so the controller should be opened to assess this.

        i. Most of the time, the controller can be opened easily with common tools. However, if the controller cannot be opened without damage, do not open it until the testing is complete.

Controller inspection / functionality test

Category	Parameter (name of indicator)	Description	
Indicators	Power	███████████████████	
	MPPT		
	Well		
	Tank		

Category	Parameter	[yes/no]	Comments
Functionality	Do all buttons/switches function?	Yes	--
	Do all ports function?	--	There are no ports on the controller.
	Do all indicators function?	Yes	--
	Does the remote monitoring work?	--	There is no remote monitoring feature.
Workmanship	Are there any poor solder joints?	No	--
	Are there any wiring deficiencies?	No	--
	Are all internal components properly secured?	Yes	--
	Are there any battery-related deficiencies?	N/A	--
	Are there any safety concerns?	No	--
Overall controller comments:	The controller is robust and well made. No safety or electrical deficiencies were observed.		

Picture(s) of Controller- External and Internal

Figure 7: Controller functionality and workmanship section

7. The next section is the ***PV Module Visual Screening*** where the tester should fill out any PV

module related information.
  a. Many SWP's do not include a PV module with the samples, so if that's the case then use this section to fill out information about the recommended PV module specifications and note in the comments that the parameters listed are for a recommended PV module, not an included one.
  b. In the comment box "Configuration Description" include any information about the arrangement of the included or recommended solar panels. For example, say "The user manual recommends using four 250W (48V each) solar panels with two in series and the two strands in parallel for a total power of 1000W and 96V."

8. A sub-section of the PV Visual Screening is the ***PV inspection / functionality test,*** where there are several functionality and workmanship questions. This section only pertains to PV modules that were included and sent to the lab with the samples. Leave blank if PV modules were not included in the shipment to the test lab.

9. Input pictures or screenshots (if information was provided digitally or online) into the "Picture(s) of PV module related information" entry. This can include pictures from the user manual, PV label, website, controller label, packaging, or manufacturer provided information.

10. At the end of the "PV Visual Screening", the tester needs to fill in the ***Overall PV module rating*** using the following rating scheme:
  a. *Good* = No workmanship or functionality deficiencies observed
  b. *Satisfactory* = Small or insignificant workmanship deficiencies were observed such as slight scratches, very few missing screws/ adhesives, or small deformities, but these issues did not affect functionality of the product.
  c. *Needs improvement* = Many workmanship issues were observed such as deep or substantial scratches or numerous missing screws that either did not affect the overall functionality of the product or resulted in minor functionality issues, or minor functionality issues were observed such as broken indicator lights.
  d. *Poor* = Many or significant workmanship issues were observed that affected the overall functionality of the product or may contribute to significant safety hazards.
  e. *Undetermined* = The PV module was not included.

11. The next section is ***Visual Screening- Overall External Qualitative Assessment*** where the tester will rate the entire visual screening for all of the included components to this point using the following rating scheme:
  a. *Good* = No workmanship or functionality deficiencies observed
  b. *Satisfactory* = Small or insignificant workmanship deficiencies were observed such as slight scratches, very few missing screws/ adhesives, or small deformities, but these issues did not affect functionality of the product.
  c. *Needs improvement* = Many workmanship issues were observed such as deep or substantial scratches or numerous missing screws that either did not affect the overall functionality of the product or resulted in minor functionality issues, or minor functionality issues were observed such as broken indicator lights.
  d. *Poor* = Many or significant workmanship issues were observed that affected the overall functionality of the product or may contribute to significant safety hazards.

12. The next section is the ***Pump internal inspection / functionality test*** which is meant to be

filled out during and after testing. The functionality will be evaluated during the testing process and the workmanship/internal inspection should be evaluated after all testing has been completed, refer to the *9 SWP Internal Inspection* SOP for more details on how to perform the internal inspection and fill the results into this section.

13. Next is the ***Documentation Available*** section where information regarding the company, manufacturer, and submitting entity are entered. Note the difference between these three categories:

    a. Submitting entity – whoever arranged for sampling/ sending the SWP to the test lab. Whoever submitted the SWP for testing. Note that this may not always be the company/ manufacturer; however, it can be in some cases.

    b. Company – this is the entity that is selling the SWP and where the sampling takes place. The company may not always be the same as the manufacturer; for instance, some SWPs are rebranded by a distributor or company. The company's name should be on the user manual or on a component label.

    c. Manufacturer – this is the entity that manufactured the SWP. This might not be the same as the company. The manufacturer's model numbers may be printed on the pump and might not match the model number/ identifying information added by the company.

14. Next is the ***User or Operation Manual*** section. In this section, the tester will evaluate any included user or operational manual either included with the pump or provided digitally. The tester should fill in "Yes", "No", or "N/A" in response to whether the user manual includes the information on the left. The comment section on the right of the section should specify the wording or graphic in the user manual that pertains to the information. See Figure 8 for an example:

4	User or Operation Manual			
	Topic	**Does the user's manual include graphics and/or language describing the following:**	**[yes/no]**	**Comments**
	PV Operation	do not damage the back of the PV module	No	--
		how to connect PV module to unit	No	--
		maximum distance between PV array and controller or pump	No	--
		face PV module surface toward the sun	Yes	The user manual states to "angle the PV towards the sun at all times".
	Installation	any required pre-use steps described (fully charge battery, insert supplied fuse, if applicable)	Yes	The user manual states to fully submerge pump and turn controller off before supplying power.
		any instructions on how to prime the pump before use (if applicable)	No	--
		instructions for wire termination or connection during installation, if applicable	Yes	The user manual has a detailed wiring diagram for the pump and controller.
		how to make all required permanent connections	No	There were no permanent connections required to be made by the user.
		keep away from fire	No	--
		install securely	Yes	The user manual states to ensure that all parts are securely fastened before use.
		controller location requirements	No	--
		install by company that sells the SWP and/or trained technicians (and if so, if technician training documentation or other detailed installation	No	--
		temperature restrictions	Yes	The user manual states to the keep the pump in cool water at all times.
		instructions regarding wire or cable connections (e.g. warnings to prevent shorting connections, directions on stripping the wires and instructions to securely screw down the wires	Yes	There are instruction not to short wires.
		dry run warnings	Yes	--
		other warnings	Yes	The user manual states to not use the pump with non-water liquids.
		minimum water level above the pump	No	--
		minimum water level above the bottom of the borehole	Yes	The user manual says to keep one meter of water below the pump.
		liquid requirements	Yes	The user manual states to not use the pump in dirty water.
		pump placement or orientation	No	
		instructions on how to set up remote monitoring	N/A	

Figure 8: Example of the User or Operation Manual section of the visual screening.

15. The "User or Operation Manual" also includes a rating system as follows:
    a. *Good* = all necessary info is clearly provided so that the consumer can set up and use the product based on the provided information.
    b. *Satisfactory* = some information may reference older products or other information may be missing or confusing, but the consumer can set up the product based on the provided information
    c. *Needs improvement* = additional information is required for a consumer to set up the product
    d. *Poor* = there is no user manual, or the user manual provided references a completely different product

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16. The final section is the ***Warranty*** section where any information regarding the provided warranty is entered including the source, duration, and description.
17. The warranty also needs to be rated as:
    a. *Good* = describes what is covered by the warranty, the length of warranty, and how to access the warranty provided
    b. *Satisfactory*= what is covered by warranty and length are explained, but how to access the warranty is missing
    c. *Needs improvement* = a warranty is provided, but there is conflicting or missing information on either what is covered by it, the length of the warranty, and how to access the warranty provided.
    d. *Poor*= there is no warranty information provided.

After completing the Title Page and Visual Screening tabs, remove all background color from the cells (*i.e. the yellow and blue color)*.

Be sure that all photos taken during the visual screening are transferred to the "Photos" subfolder in the main testing folder.

Be sure to revisit this tab after testing is complete to verify the validity of the ratings or descriptions. For example, if the pump was rated as a centrifugal pump, but during the internal inspection it was discovered that the pump was helical rotor, then the "Pump Type" should be changed, and a comment should be left to describe the discrepancy. In addition to "Pump Type" there are a few other items that need to be filled in/ compared with ratings after testing has completed:

- Inrush current
- Functionality of controller and pump
- Internal inspection and comparison to ratings

Reference Procedures

This procedure references IEC 62257-9-5: 2018, Annex F: Visual Screening.

Version	Date	Summary
1.0	8/26/22	Initial drafting of document

Scope / Field of Application

After following the initial *2 SWP Intake and Visual Screening* SOP, the solar water pump (SWP) should be wired and attached to the test bench to carry out the testing procedures. The procedure for wiring a pump to the test bench is unique to each pump, and the tester should make sure they are comfortable and familiar with the requirements of each individual pump before attempting to wire and test.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP- solar water pump

SOP- standard operating procedure

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *SWP test bench*
- *Screwdrivers- various sizes*
- *PVC adapters*
- *Hose clamps*
- *Plumbers tape*
- *Vice grip*
- *(maybe) alligator clip grounding adapter*

Pre-Test Preparation

Ensure the user manual and all instructions have already been read to ensure all wiring and other connections are correct. Read all instructions available regarding pre-testing steps. If there are any additional materials or manufacturer-provided information, ensure that has also been reviewed. If there are any questions regarding discrepancies in the available information, or something needs clarity, discuss further with the Lab Manager.

Before this test is carried out, the following SOPs must be read, and procedures carried out (if applicable) for the pump under test:

- *SWP Test Bench Instruction Manual*
- *1 SWP Testing Safety*
- *2 SWP Intake and Visual Screening* SOP

Ensure all safety trainings have been provided to operate the test bench.

Procedure

Ensure that all steps in the preceding section, "Pre-Test Preparation," have been completed.

1. Bring the pump, and any included pump-specific installation equipment, into the testing area and to the test bench.
2. If you are going to start testing after wiring the SWP up to the test bench, then follow steps 3-4 below. This will be the testing set up for every test that requires the test bench.
   a. Note that in almost every testing case, the SWP should be tested outdoors, weather-permitting. Spilling can occur during testing, and so testing these appliances indoors is usually inappropriate.
3. Move the mobile test bench outside to the designated testing area.
4. If the computer and/or Chroma is exposed to the sun, provide shade by hanging a towel or moving something in between the sun and the Chroma or laptop (note: do not block output fans in the back of the Chroma).

Figure 1. Outdoor testing set up

Wiring the SWP

5. **Before any wiring or work is done to the test bench, ensure the DAQ equipment is not plugged into AC power and that the Chroma is turned OFF. No equipment should be ON (except the laptop, if needed).**
6. Check the wiring of the test bench and make sure all permanent connections are in place before wiring up the pump and that nothing looks out of place.
    a. The Chroma has two labeled output wires (positive and negative) that come up from behind the bench and connect to two screw terminals affixed to din railing on the test bench surface. Note that there is also a ground wire (shown as the yellow/ green wire in the photo below on the far left) that connects to the grounding of the Chroma, which should always be connected to the SWP under test (explained below in this procedure).
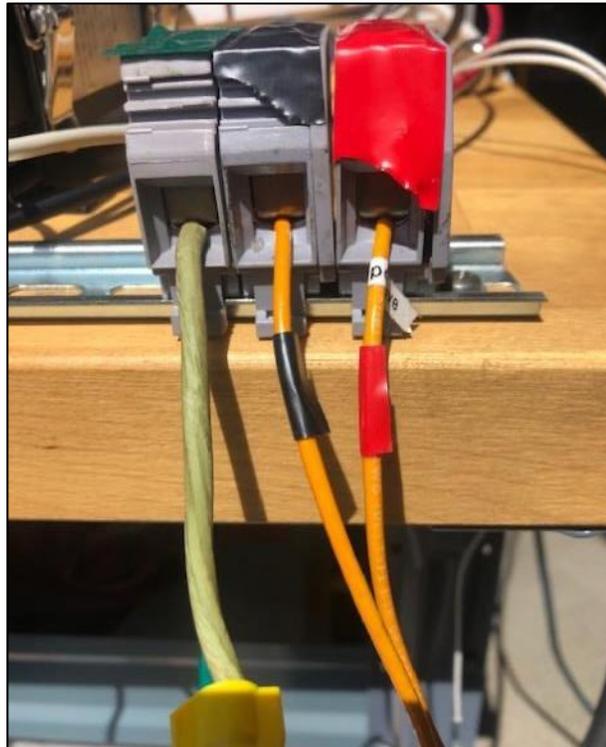
Figure 2. Terminal blocks holding power leads and grounding lead from Chroma

    b. Labeled red and black extender wires should be connected to the other end of the positive and negative chroma output leads via the screw terminal block, and the other ends should be fed into the DAQ equipment, which will connect via a 16A fuse.
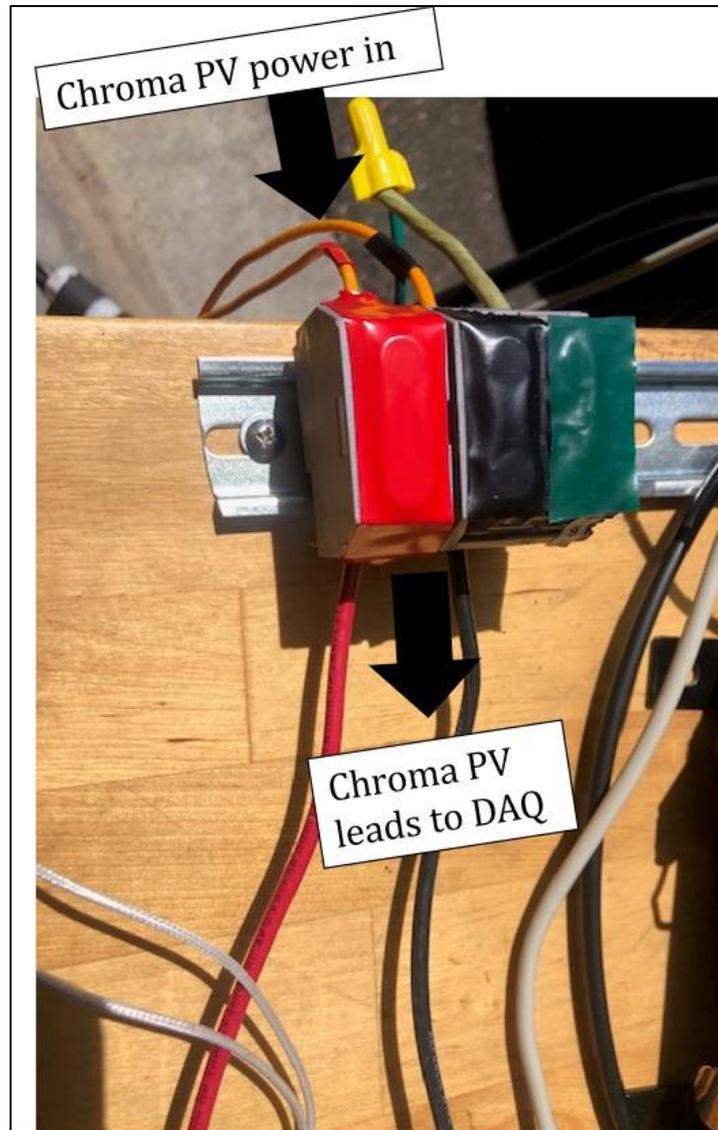
Figure 3. Terminal blocks attaching Chroma (PV power in) to the DAQ and SWP.

    i. Ensure that the red/ positive extension wire is fed through the current transducer affixed to the DIN rail before being connected to the LINE "+" end of the 16A fuse block along with the positive lead coming from the DAQ (Omega input lead). The negative extension lead should NOT be fed through the transducer with the positive, but instead be directly connected to the LINE "-" end of the 16A fuse along with the negative lead coming from the DAQ (Omega input lead).

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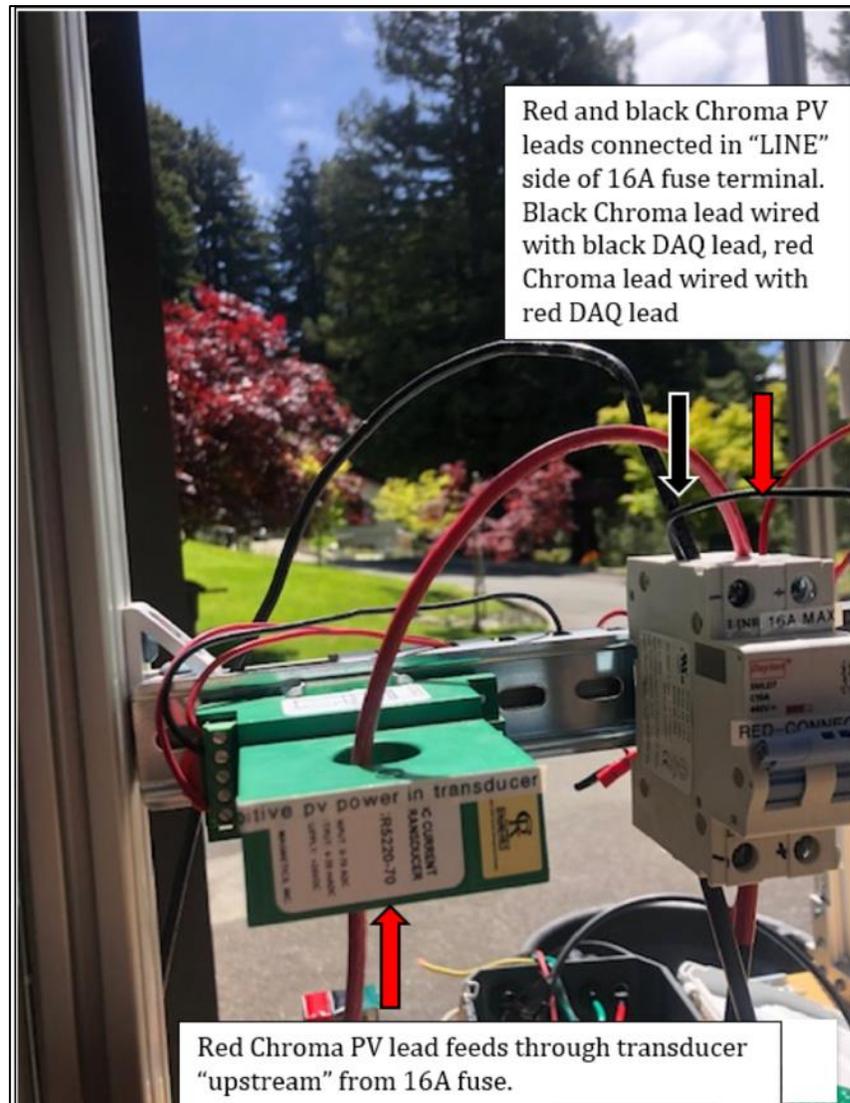
Figure 4. Chroma leads connection to the DAQ via 16A Fuse
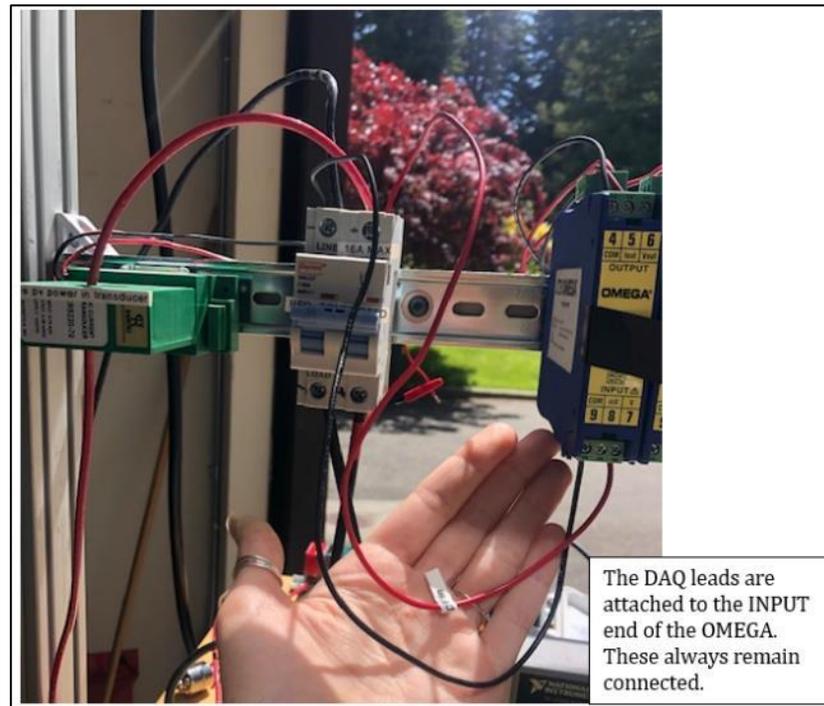
Figure 5. DAQ leads attached to Chroma via 16A fuse

      c. On the LOAD end (bottom) of the 16A fuse, there shouldn't be anything connected yet. This is where the pump and/or controller will be connected to.

7. After checking that the Chroma is properly connected to the DAQ and LINE input end of the 16A fuse, then you will want to wire up the controller and/or pump.

8. **If the pump has an external controller**:
   a. If possible, fix the external controller above the DAQ equipment and computer onto the t-slotted railing frame using hex screws and t-nuts. If there is no clear way to connect the controller in that way, then setting it on the benchtop is OK.
      i. Affixing the controller to the railing is only suggested because it's easier to read any codes (including error codes, running codes, etc.) that might appear on the controller during testing, but it's not necessary. See the figure below to see where to affix the controller, if possible (in yellow).
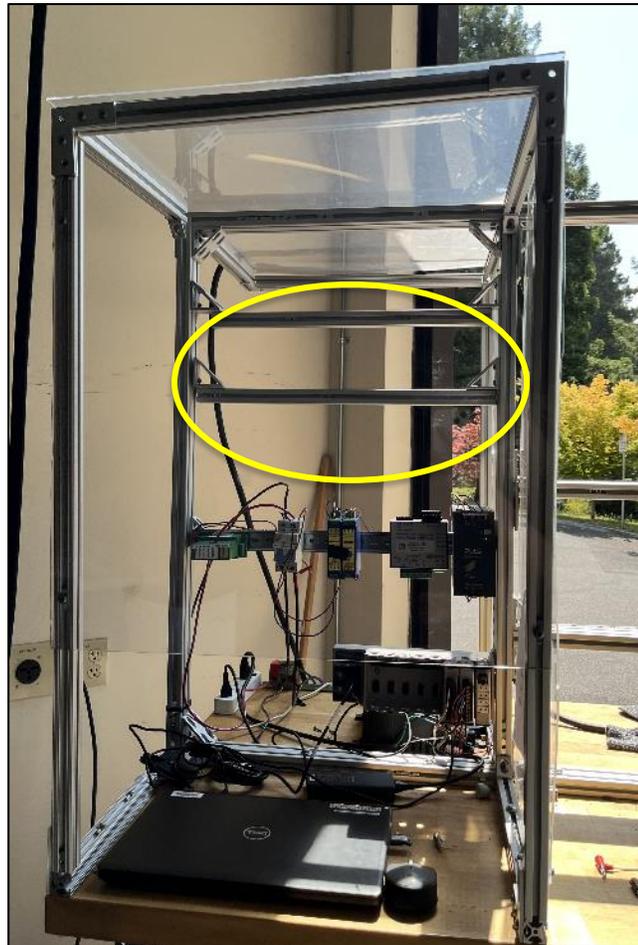
Figure 6. Double t-slotted framing installed to mount external controllers on, if possible (in yellow circle)

b. Connect the controller's PV input connection spot to the DAQ, generally using 13AWG wires (unless rated). Ensure you use one black and one red lead to differentiate between negative and positive. Mostly all external controllers have a two-input connection for the PV inputs, one positive and one negative.

    i. Follow all instructions provided to make the electrical connections within the controller for its input.

    ii. Sometimes, custom adapters might need to be configured or purchased by the testers in order to make sound electrical connections; however, oftentimes, controllers will have common plugs (like MC4 connectors) and screw terminals to easily attach electrical leads to the input power source (Chroma in this case).

    iii. **Appendix A: Common Controller/ Pump Connections** provides several common electrical connections that have been observed in tested external controllers.

c. If the controller is not expected to draw more than 16A, then include the 16A fuse in-line with the electrical input circuit, and attach the other ends of the black and red leads you've just connected to the controller to the 16A fuse LOAD side (shown in

the photo below).

    i. Note that the 16A fuse may be bypassed and a simple terminal block may be used in its place if the controller is expected to draw more than 16A during testing.
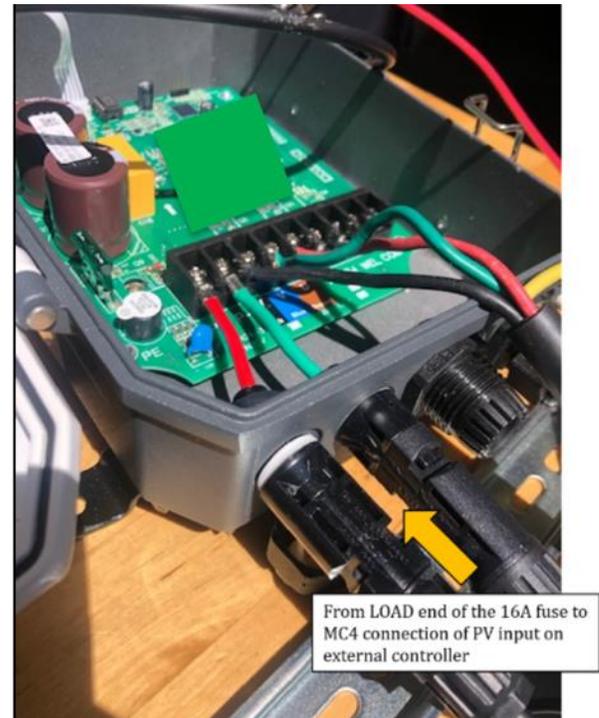
Figure 7. Connecting external controller to DAQ and Chroma

  d. After the PV-side (input) is connected, work on connecting the pump to the controller ("pump-side"/ output).

    i. Note that many separate controllers have a three-phase output for the pump; some only have two.

  e. The pump will be tested at a distance from the controller, DAQ equipment, and Chroma; therefore, a power extension cable is used between the pump and controller.

  f. First connect the pump leads to one end of the extension cable using either a spring terminal box or WAGOs (ensure to keep these electrical connections on the test bench and not close to the water tank if possible). The extension cable has four leads, which should be enough for the pump. If there are any spare leads on the extension cable not being used, they may be taped off with electrical tape.
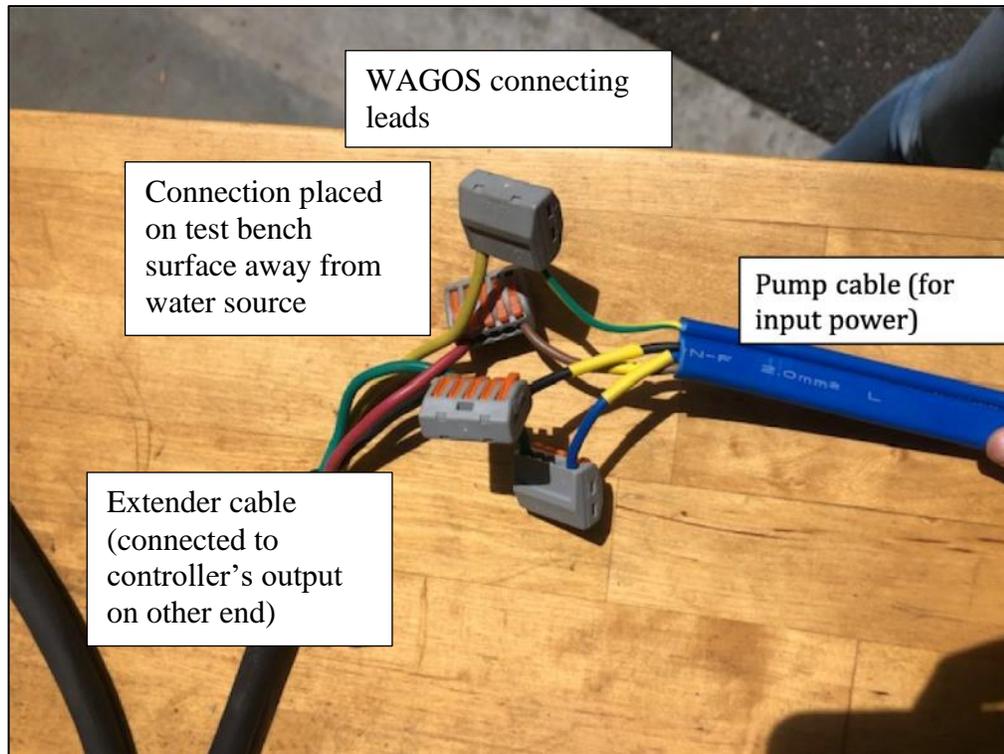
Figure 8. Connecting pump input power leads to extender cable to connect to the controller

g. Once attached to the pump power leads, follow the extension cable over to the external controller.
    i. Follow the instructions on how to connect the extension cable leads in the controller. Often, controllers have screw terminals or other common connection types for output terminals.
    ii. There are examples in **Appendix A: Common Controller/ Pump Connections** of some example controller connections. Ensure to double check that the correct lead of the extension cable is connected to the correct terminal in the controller; the colors of electrical leads might not match on the extender cable to the pump leads, so be aware of this.

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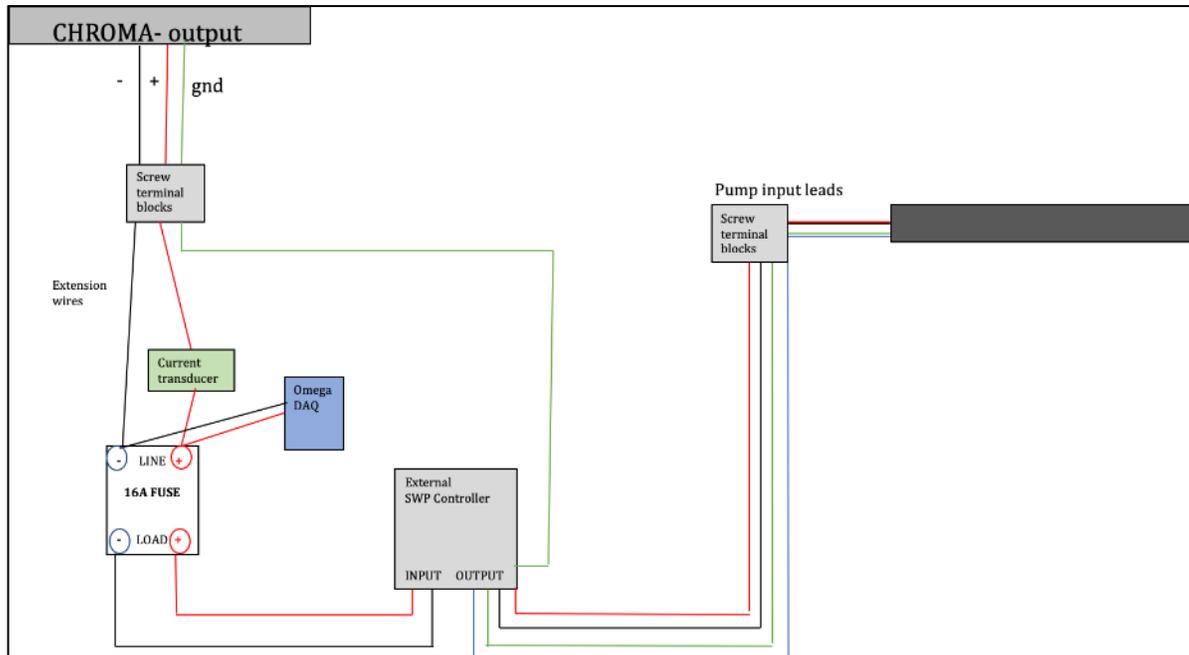
Figure 9. Overview of wiring scheme for pumps with external controllers
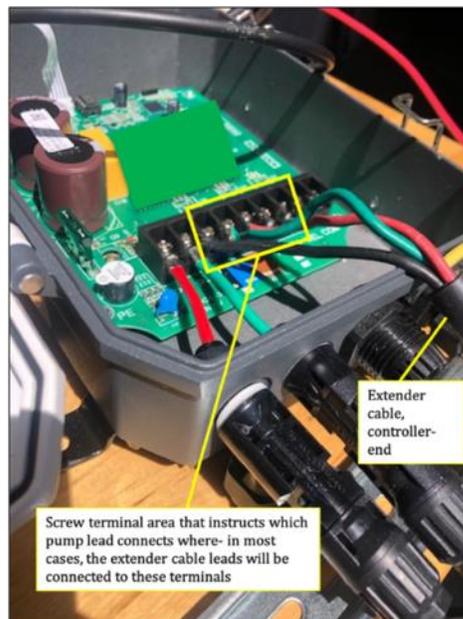
Figure 10. External controller internal screw terminals to connect to pump input leads

9. **If the pump has an integrated controller or no controller**:
    a. In this case, the pump is likely meant to be connected directly to the solar output, but check the manual to ensure that it is being connected correctly.
    b. For pumps without an external controller, the pump leads will be connected to the extender cable leads, just as explained in step 6g. and 6h. Instead of the other end of the extender leads attaching to a controller, they will be attached directly to the 16A fuse to the LOAD output end (see image below). In most of these cases, the extender

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cable may only utilize three of the four possible conductors between the Chroma and the SWP (positive lead, negative lead, and grounding).
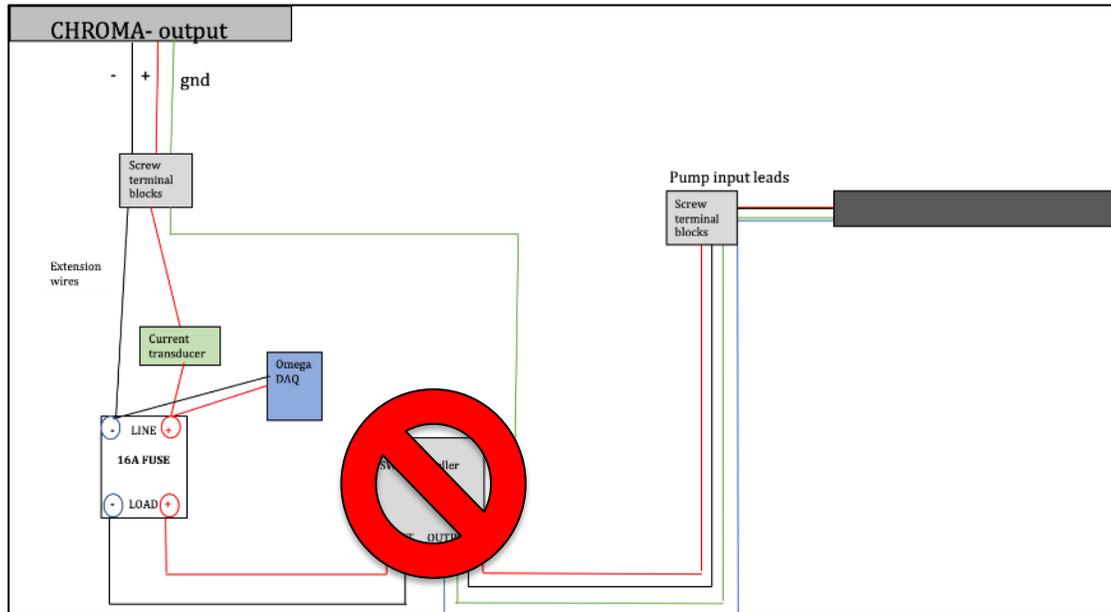
Figure 11. SWP without an external controller wiring schematic

10. **Note: if a SWP is advertised as including a controller but the samples that arrive at your test lab do not include a controller, then request for the included controller to be sent. Don't test the SWP without the controller if a controller should be used.**

11. **Make sure to always ground the SWP being tested.** There are several different options for grounding a SWP depending on its design. Always follow manufacturer instructions for how to ground the SWP, if possible. Choose one of the following options to ensure safe grounding:

   a. If the SWP has an electrical grounding lead:

      i. Identify which lead is meant to be grounded; this normally can be achieved by reviewing consumer-facing documents included with the SWP. Usually, the ground lead is green or yellow with a green stripe.

Figure 12. SWP input power leads, with a grounding lead that is yellow with a green stripe (pointed at by a white arrow)

ii. You may connect the grounding lead to the normal extender cable, and follow it back to attach to either a grounding connection in the external controller, if applicable, or connect it to the other opening of the screw terminal block that the Chroma grounding is also attached to (Figure 2).
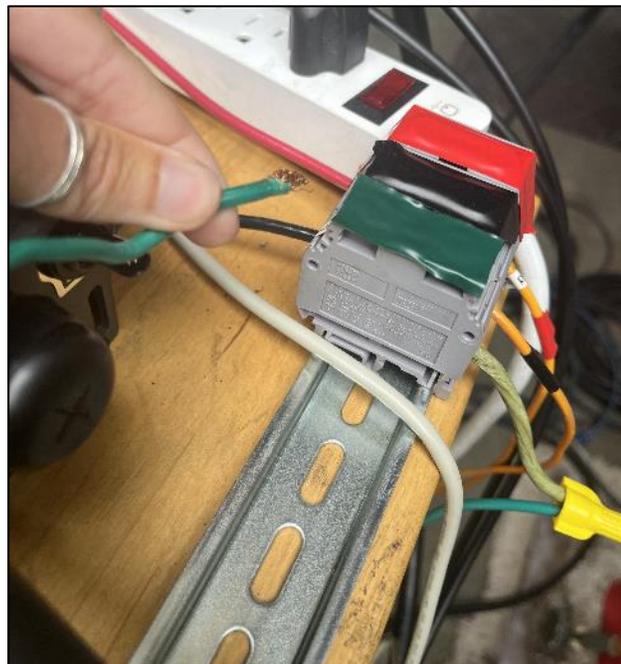
Figure 13. Extender cable grounding lead from the SWP being connected to the screw terminal shared with the Chroma grounding lead.

b. If the SWP does not have a grounding lead included, then an alligator grounding

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adapter might need to be configured so that the grounding can be attached to the pump body. Ensure it is attached to a part of the pump body that will not be submerged in the water during testing (near the outlet may be the best option).

    c. The alligator clip adapter should be connected to the extender cable that will attach to the Chroma grounding screw terminal block

Figure 14. Alligator grounding adapter with grounding lead on other side.

Figure 15. Alligator clip connected to the pump body on one side; the other side, connected to the extender cable that connects to the Chroma grounding screw terminal box.

12. After wiring up the SWP, always, review the user manual, component label, and manufacture provided information to ensure wiring is done correctly both on the pump-side and PV-side of the controller and/or pump.

PVC connections

13. After the SWP is properly wired up to the test bench, its outlet needs to be hooked up to the test bench, and its inlet needs to be placed (note: sometimes, adapters are needed for the inlet of the pump as well, in order to fit with the test set up).

14. The test bench's PVC network has an inlet hosing that is ¾" in diameter, which is always static, so each SWP has to be fitted to the test bench in order for secure connection; this is the reason why it is useful to have stock of PVC adapters of all different sizes on-hand.

    a. Note that not only expansion/ reducing adapters may be needed, but also adapters that

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have thread-to-barb connection types so that the threaded end can connect to the PVC threading of the pump's outlet, and the barbed end can be connected to the hosing of the test bench inlet via an adjustable hose clamp.

15. Assess the size of the pump's outlet: each pump's outlet is different, and there is always a possibility that the lab does not have the right size of adapter(s) to make a secure connection. Look through the storage of adapters to find one (or several) that could connect the SWP outlet to the inlet of the test bench.
    a. Note: if there are no viable options in the lab's storage container of adapters, notify the Lab Manager so that a purchase can be made for the specific SWP under test.
    b. There may be several adapters that are needed. For instance, if the SWP outlet is ½" in diameter, a ½" PVC nipple will be needed, along with an expansion adapter and a ¾" thread-to-barb adapter to connect it to the ¾" hosing of the test bench inlet.
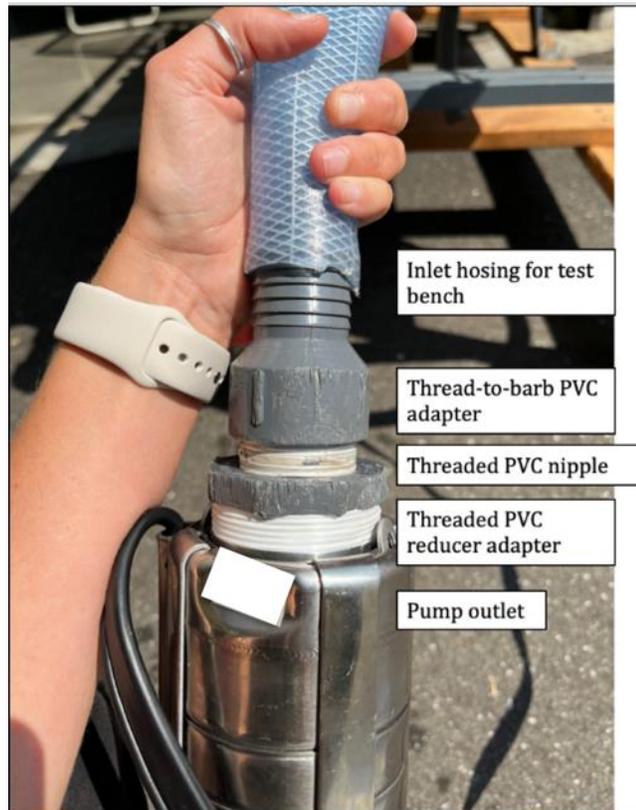
Figure 16. PVC adapters for pump outlet

16. Once the correct adapters are found/ acquired to connect the pump to the test bench, connect all adapters to the pump's outlet, and fit the barbed end into the test bench's inlet hosing. Tighten down the adjustable hose clamps to secure this connection.
    a. For every threaded PVC connection, ensure to always apply plumbers' tape to prevent water leakage (if needed, you may reference the *SWP Test Bench Instruction Manual* for resources on how to apply this properly).
        i. Notice the photo above how there is plumbers tape applied for each threaded connection of PVC adapters.

17. Note that for surface pumps, sometimes an additional adapter(s) and hosing will need to be affixed to the inlet-side to allow for the inlet to reach the source water from the placement of the pump.

Figure 17. surface pump needing PVC adapters and hosing for both its inlet and outlet.

Other Steps

18. After the wiring and PVC connections are made, fill the water trough with clean, cool water. The water trough is set on a furniture dolly and can be maneuvered around, but it's best to move it to right below the test bench inlet.

    a. *Note that if the empty water trough is filled with debris before testing, brush it out to remove debris before filling it with water. Debris can damage the flow meters during testing.*

19. If the SWP under test is submersible, position the pump so that its body is in the trough and intake screen is below the water several inches (sometimes more in some cases) so that no air is sucked into the pump during testing. You may decide to fill the trough with more water to ensure the intake screen is positioned adequately below the water surface.

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Figure 18. Submersible pump with its intake screen fully under water.

20. If the SWP is a surface pump, position it so that it's sitting on the ground or on a stool next to the water trough and its intake hosing end is positioned under the water's surface (See Figure 16). For surface pumps, they need to be primed before testing- see the *4 SWP Cold Start and Inrush Current* SOP for instructions on priming SWPs.
21. Ensure the test bench *outlet* hosing is also underwater in the trough; otherwise, when the pump is started, water will pump out onto the ground.
22. Lastly, walk through all information provided for the pump, and make sure all connections look correct. It's also good practice to tighten all adjustable hose clamps included in the set up once more before testing using a flathead screwdriver.

Appendix A: Common Controller/ Pump Connections

In the photo below, there are screw terminals within the external controller for P+/P- (PV input, positive and negative), and for W,V,U (Pump input power leads). To make these connections, stripped electrical wire is needed to twist under the screws, and a screwdriver can be used to tighten and clamp down on the leads.

Figure 19. Screw terminals for PV input and for SWP power output within external controller.

In the next photo, the P+/P- input connections are screw-terminals-to-MC4 connections. It's useful to have MC4-to-stripped electrical wire adapters on-hand, so those could be used in this case to connect the controller to the DAQ; the MC4 connectors would snap in-place at the controller entrance, and the other end of stripped wire would be clamped in the screw terminals of the 16A fuse. If, however, the MC4 adapters were not available, then the ring lugs currently clamped down in the screw terminals of P+ and P- in the controller could be removed, and stripped wire could be used here in place of the MC4 connection.
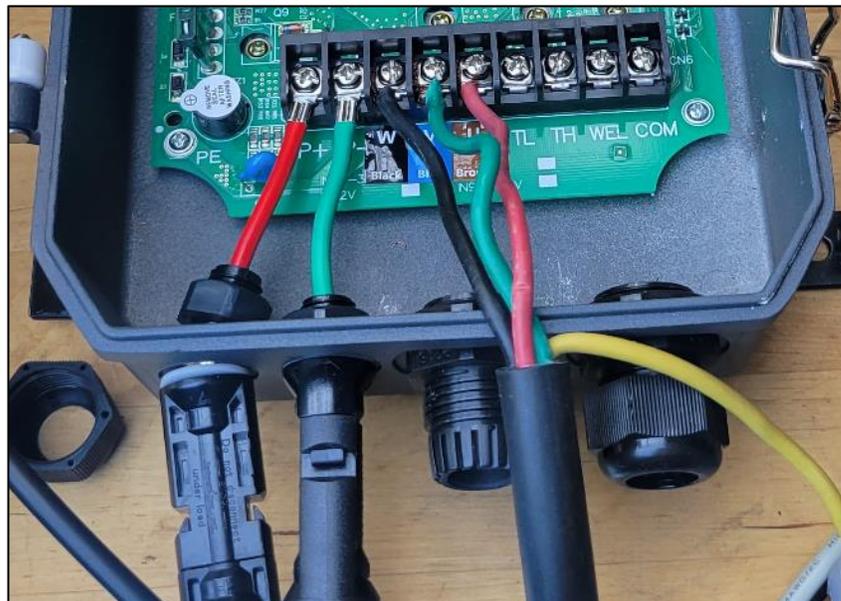
Figure 20. Screw terminals for SWP output, and MC4 connectors for PV input of external controller.

In the figure below, this surface pump does not have an external controller, so the pump was wired up directly to the DAQ. The tester had to make custom ring lug-to-wire connectors to ensure a secure electrical connection.

Figure 21. Ring lug adapters custom-made for this SWP power input connections.

The figure below shows another example of an external controller with MC4 input power connectors.

Figure 22. MC4 connectors for PV input of this external controller.

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SWP Cold Start Test and Inrush Current Measurement

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Version	Date	Summary
1.0	08/29/2022	Initial drafting of document

Scope / Field of Application

After a solar water pump has been wired to the test bench and is ready to be tested, the first two performance tests to perform are the Cold Start Test and inrush current measurement. These procedures are defined in the Global LEAP Solar Water Pump Test Method, Version 2, section 3.6.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

Inrush current- Directly after supplying a pump with input power, there may be a sudden electrical inflow current to the pump that is significantly greater than the rated pump current. This greater current is defined as inrush current and only occurs within the few first moments after power is supplied to the pump.

Cold start- the lowest input power that allows the pump to turn on and provide flow. This is used to assess at what point in the day a pump in the field would turn on in a defined set of conditions.

SWP- solar water pump

SOP- standard operating procedure

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *SWP Test Bench*
- *EX830 clamp meter*

Pre-Test Preparation

Before this test is carried out, the following SOPs must be read and procedures carried out (if applicable) for the pump under test:
- *SWP Test Bench Instruction Manual*
- *1 SWP Testing Safety* SOP
- *2 SWP Intake and Visual Screening* SOP

- *3 SWP Testing Set Up* SOP
- Steps 1-31 in the *6 SWP Solar Day* SOP must have been carried out to calculate the required simulated irradiance steps and ensure the Chroma and LabView have been set up correctly for the SWP under test.
- *4 SWP Cold Start and Inrush* SOP (this SOP must be reviewed prior to testing, and especially if this procedure has been updated since the last time the tester has tested)

If the pump under test is a surface pump, it must be primed prior to this test, which will be mentioned in the Cold Start procedure, below.

Ensure all safety trainings have been provided to operate the test bench.

Procedure

Cold Start Test

1. The Chroma should be set up with power input steps, which were determined in steps 1-31 of the *6 SWP Solar Day Test* SOP.
2. If the pump does not require priming (such as submersible pumps), skip this step and go to step 3. If the pump under test is a surface pump, it must be primed using the following steps:
    a. Read in an irradiance step in the Chroma software that is higher than what you expect the pump will be able to turn on at (at a simulated head of 0m). Generally, 700 W/m2 or 800 W/m2 are reliable steps to choose for this (note: only use these irradiance step inputs for the priming process).
    b. Ensure you have either a cup or bottle of water or a hose that's turned on resting next to the pump.
    c. Ensure the high flow ball valve on the test bench is fully open and the surface pump is next to the water (it's intake hose can be in the water as well).
        i. You may use a second tester to help make this transition easier; if so, the second tester will be next to the pump holding the pump's intake hose and a cup or bottle of clean, cool water (or a hose that is on).
    d. Click on *IV Run* OFF▶ in the Chroma software to turn the Chroma output on.
        i. If there is not a second tester, immediately go to the pump and start pouring water down its intake hose so that there is flow going straight to its intake; this is to facilitate creating a suction.

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Figure 1. Priming the surface pump by pouring water down it's intake hose.

    ii. Continue pouring water into the intake hose until the pump gains suction, and you'll immediately push the intake hose opening under the water surface in the testing trough so the pump doesn't dry run.

        i. Note that generally, when a pump has formed a suction, it will begin to make a different noise and you'll see the flow of water within the hose in between the pump's output and input of the test bench.

Figure 2. Creating suction by immediately submerging the pump's inlet hose under the source water after it begins to develop some suction.

    e. Let the pump run with the intake hose in the water trough for a few minutes to ensure the suction is well-established and air bubbles are flushed out of the test bench piping network prior to testing.

        i. If the pump has a difficult time gaining suction, check that there are no kinks in the outlet hosing (such as the kink shown in Figure 2).

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    f.   Click the [IV Run OFF] in the software to turn the Chroma output off.

    g.   Now that the suction has been established, it will remain as long as the pump's intake hose remains under the water surface during all testing that day. If the pump's intake hose is removed from the water, the suction will need to be re-established again the next time the pump is used/ tested.

3. You may arbitrarily choose any low irradiance step to check whether or not the pump will turn on with its power input.

    a.   Depending on the pump, the tester may decide to start at the lowest possible irradiance step, 50 W/m2. Although, oftentimes, the tester may decide to start at 200 W/m2 or 300 W/m2. (Note: the 700/800 W/m2 suggested in step 2 above were only for priming the pump).

4. Ensure the high flow ball valve is fully open to have the lowest pressure in the test bench as possible (0m of head).

5. Read in the chosen low step to first run with the pump, then click on [IV Run OFF] in the Chroma software to turn the Chroma output on.

6. Observe the flow rate measurements in real-time in the LabView display to check for any flow above 1 lpm.

7. If there is no flow, turn off the Chroma output by clicking [IV Run OFF] in the Chroma software. You'll need to go back up to step 3 and choose another low irradiance input step that is **higher** than the one previously attempted.

    a.   For instance, if you tried 100 W/m2, you might try 150 W/m2 or 200 W/m2 on the next attempt.

8. If there IS flow above 1 lpm and you are not simulating the 50 W/m2 (the lowest point you can attempt), then turn off the Chroma output and go back to step 3 to choose another low irradiance input step that is **lower** than the previous step attempted.

9. If the flow is under 30 lpm, switch to the low flow ball valve by opening the low flow ball valve and then slowly fully closing the high flow ball valve.

10. Continue to repeat steps 3-8 until you've found the lowest irradiance step that allows the pump to pump water. Each irradiance step possible is incremented in 50 W/m2, and generally, this cold start step is under 500 W/m2 (not always the case though).

11. Once you have found the cold start irradiance step, record what the irradiance step was determined in the SWP test report for that pump under the "Cold Start" section and record the raw data for flow, input voltage, input current, and pressure over the course of two minutes by opening a data file in LabView.
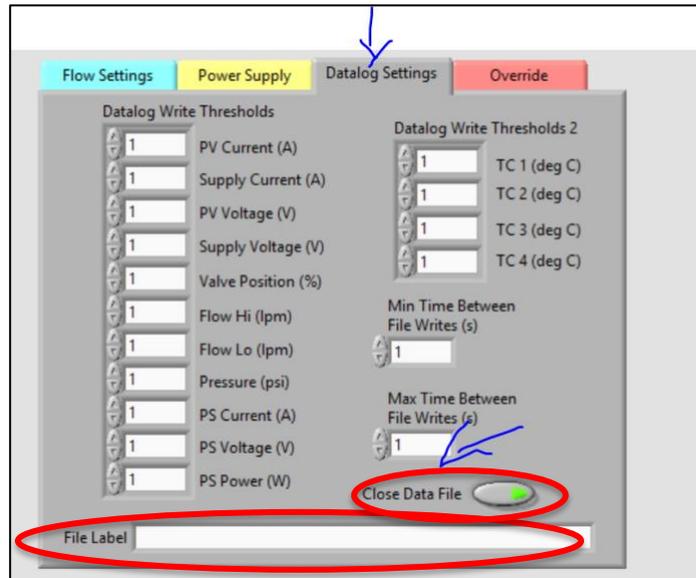
a. In LabView, navigate to the *Datalog Settings* tab on the right
b. Click on the slider button next to "Close Data File" if it is currently open and green. It should turn red when closed.
c. Enter "<pumpname>-coldstart" in the "File Label" field.
d. Click the same slider button again to "Open Data File" and it should turn green.
e. Keep the data file open recording all measured data for two minutes, and then close it and find the raw data to save in the pump's testing folder.

12. Turn the Chroma output off; you are done with the test.

Analysis and Reporting

1. After this test is done, all raw data should be copied and pasted (as values) into the *ColdStart* spreadsheet template for this product, which should be saved in a known place. The template should be copied into the product testing folder on your computer and renamed.

2. Open the *rawdata* tab in the spreadsheet to copy and paste all cold start raw data over to the right of the table with the yellow cells. Then, copy the raw data columns for voltage, current, flow, and pressure to paste into the yellow highlighted columns on the left.

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Figure 3. *rawdata* **tab in the Cold Start testing template**

3. The average values of each yellow column will then be automatically pulled into the *Test Results* tab. Navigate to this tab and fill out all of the yellow cells. The white cells should auto-populate with the measured and calculated results.

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4. Open up the test report spreadsheet for the product under test and navigate to the *Test Results* tab. Scroll down and find the section for the Cold Start test, and paste the results from the Cold Start template into the test report in this section.
   a. Add any comments about the test if any notable observations were made.

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Figure 4. "Cold start test" section in the test report template

Inrush Current Measurement

1. After the Cold Start Test has been completed, the Inrush Current can be measured before other tests have been started.
2. Sometimes, this test is easiest to be done with two testers.
3. Ensure the high flow ball valve is fully open and low flow ball valve is closed on the test bench so that there is no added pressure.
4. Take the EX830 clamp meter and clamp it around either the positive or negative Chroma lead. Note: do not clamp it around both leads at a given time; otherwise, the current won't be able to be read.

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Figure 5. Clamp meter around output lead of Chroma
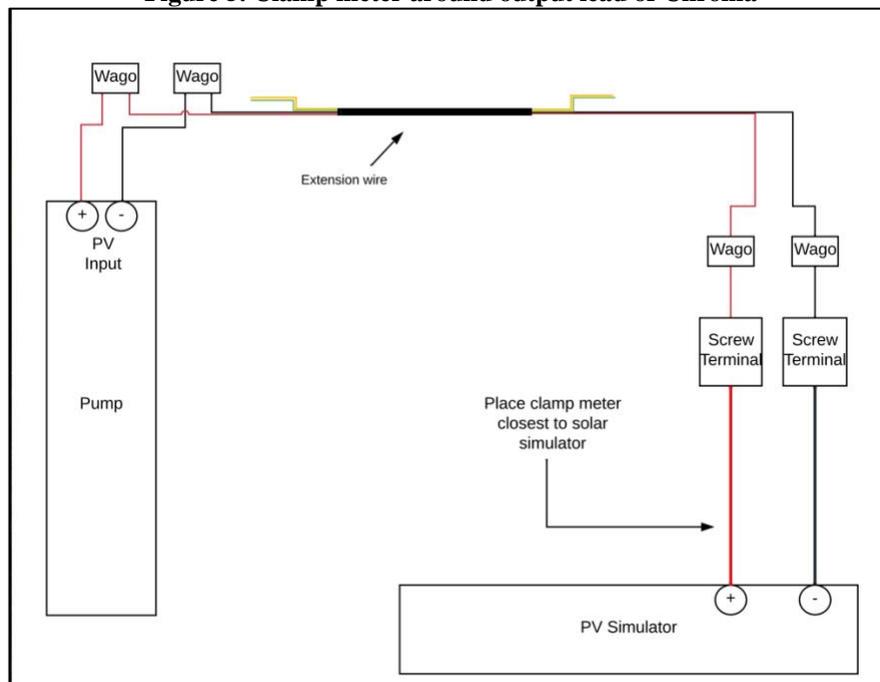
Figure 6. Clamp meter applied around Chroma lead, DC pump
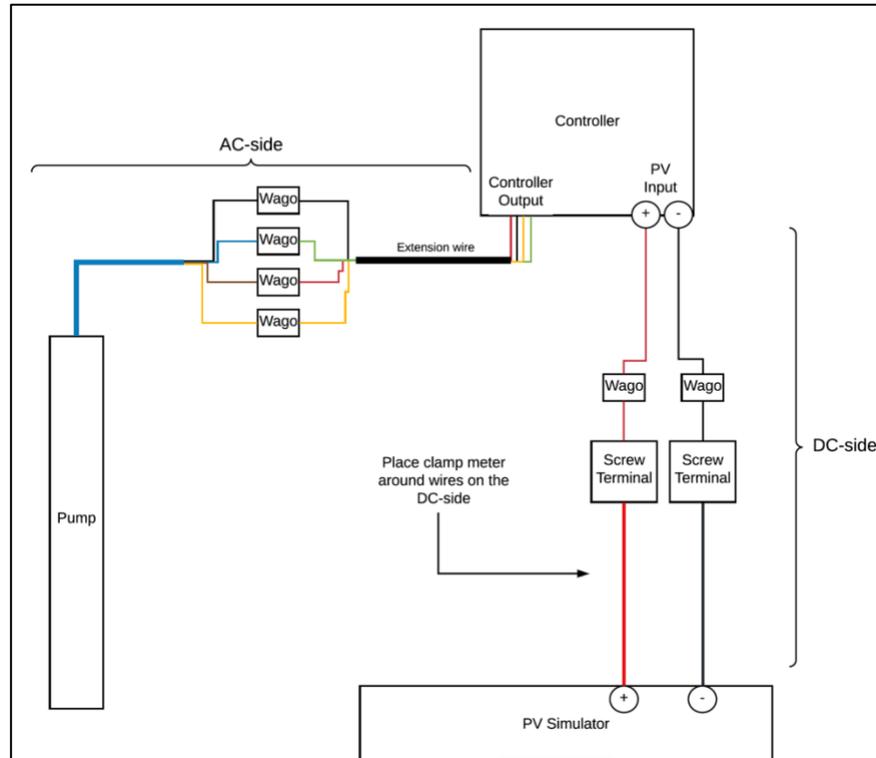
Figure 7. Clamp meter applied on the DC-side of the pump kit set up for AC pumps

5. While the clamp is around one of the Chroma leads, use the "Peak Hold" function on the EX830 to measure inrush current
    a. Turn the clamp meter on, switch to the A_{DC} position (DC amperage)

    b. Allow time to stabilize (5-10 seconds)
    c. Press and hold PEAK button until "CAL" appears in the display- this is "zeroing" out the device in the selected range.

     d. Press the PEAK button and Pmax will display
     e. The display will update each time a higher positive peak occurs

6. While the clamp is on this PEAK setting, have another tester turn on the Chroma at the cold start irradiance step (determined in the last procedure).

7. Write down the peak current, which should be reached within the first few seconds of turning on the Chroma.

8. If the peak current is within 10% of the current setpoint, repeat steps 1-5 but clamping around the other power lead from the Chroma (for instance, if you initially clamped around the positive lead, this time, clamp around the negative lead) and see if the peak value is higher in this configuration. Record this measurement 3-5 times and use the average as the reported value.

     a. To determine whether or not the inrush current should be measured again around another power lead from the Chroma, compare the measurement with the Imp input set on the Chroma during this test. If the inrush current is lower than or equal to the Imp set on the Chroma, then try performing the test again on the other power lead.

9. Record the average of the 3-5 repetitions from the configuration that resulted in the highest current in the "Visual Screening" section of the test report for the product tested.

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Figure 8. *Visual Screening* **tab of the test report, where inrush current measurement is recorded.**

10. Turn the Chroma output off; nothing needs to be recorded in LabView for this test.

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Version	Date	Summary
1.0	8/30/22	Initial version of this SOP.

Scope / Field of Application

This SOP outlines how to perform and analyze results from the Head Range Test, specified in the Global LEAP Solar Water Pump Test Method (Version 2), section 3.7. This procedure references *IEC 62253: H-Q Characterizations (5.3.3).*

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP – solar water pump

SOP – standard operating procedure

Wire-to-water efficiency – the efficiency between the hydraulic power generated by the pump and the PV power input

Useful operating head range – head range that corresponds to the head at maximum flow and the head at which the flow is decreased by 50%

Simulated solar irradiance - amount of solar power in watts available per m^2 of area at a given time, which is simulated by a solar array simulator in most cases during solar water pump testing.

Head (m) – The vertical distance water may be lifted by a pump from the surface of the source water to the delivery point. This metric is usually specified in meters. Note that during testing, head is simulated by controlling the pressure in the pump's outlet hose; pressure and head are directly correlated in relation to SWPs.

Hydraulic power- Power converted by a motor to the flow of a liquid over a vertical distance

SSR – sum of squared residuals is a technique used in regression analysis to measure the variance between the measured data point and the value calculated from the best fit model. In the context of this test, the SSR is the objective cell that is minimized during the data analysis.

DAQ – Data Acquisition system, the DAQ is the part of the SWP test bench that reads in data from the various equipment and reports the values into the LabView.

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test

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results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *SWP test bench*

Pre-Test Preparation

Ensure all safety trainings have been provided to operate the test bench, and that the *1 SWP Testing Safety* SOP and the *SWP Test Bench Instruction Manual* have been read.

Before this test is carried out, the following SOPs must be read and procedures carried out (if applicable) for the pump under test:
- *SWP Test Bench Instruction Manual*
- *1 SWP Testing Safety*
- *2 SWP Intake and Visual Screening*
- *3 SWP Testing Set up*
- Steps 1-31 in the *6 SWP Solar Day SOP* must have been carried out to calculate the required simulated irradiance steps and ensure the Chroma and LabView have been set up correctly for the SWP under test.
- *5 SWP Head Range SOP* (this SOP must be reviewed prior to testing, and especially if this procedure has been updated since the last time the tester has tested)

Ensure all safety trainings have been provided to operate the test bench.

Also before this test is started, open the *HeadRange* spreadsheet which should be saved in the pumps testing folder after being copied from the testing template folder; review the *Instructions* tab and fill in the metadata in the *TestResults* tab.
- Fill in the date, tester, pump name, and simulated PV power.
- The head range test is meant to be carried out at a simulated solar irradiance input of 700 W/m^2 , and the specific simulated power point will be different for each pump's PV specifications. The specific simulated PV power will be determined in and copied from the *IrradianceData* spreadsheet, as shown below.

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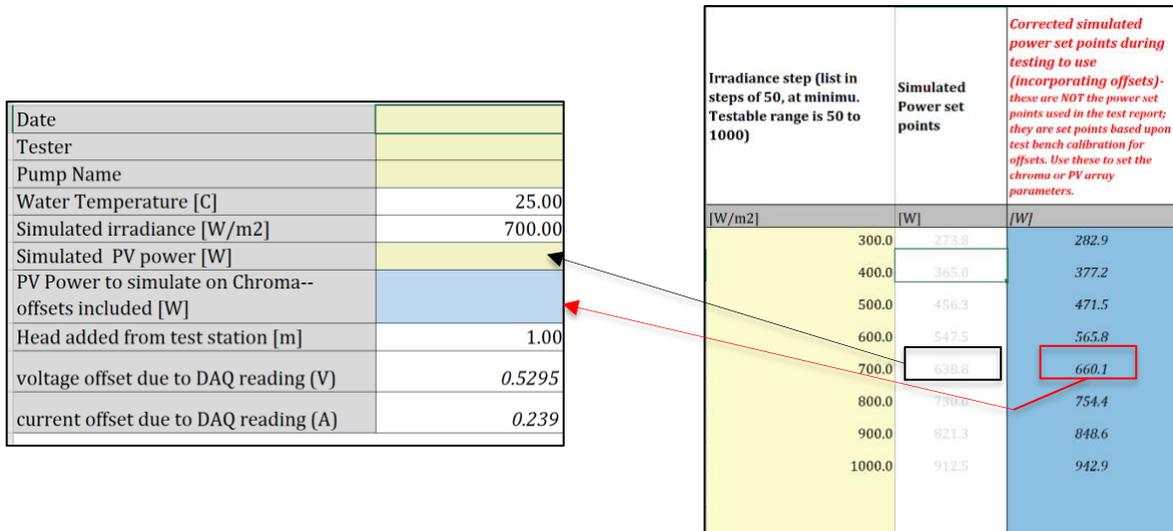
Figure 1. (On the left) The *Test Results* tab in the *HeadRange* spreadsheet; (on the right) the *Inputs* tab in the *IrradianceData* spreadsheet and the calculated 700 W/m2 value.

- o Normally, if the nominal pump head was provided to the test lab, the Solar Day Test is performed before the Head Range Test.
- o If the manufacturer did not provide or rate the nominal head (also commonly called working head) in any consumer-facing materials OR the pump was determined not able to function properly at the rated nominal head, **then the Head Range test must be performed prior to the Solar Day test** in order to determine what head to simulate for the Solar Day test, which is described in the instructions below in the *Determining Head at Max Efficiency for Solar Day Test* section.

Confirm all wiring and test bench set-up is correct by following the Testing Set Up SOP (*1 SWP Testing Set Up* SOP) prior to testing and verifying the following:

- The pump and controller are wired up properly to the test bench DAQ and to the Chroma
- The tank is filled to an appropriate amount with clean, cool, debris-free water
- The pump is either submerged in the water (if submersible) or ready to be primed (if surface) and its outlet is connected to the test bench's inlet hose securely.
- The test bench output hose is submerged in the water trough.
- The high-flow ball valve in the test bench pipe network is full open and the low-flow leg of the network is closed off so that water will only flow through the high-flow leg.

In the Chroma software, open the IV files that correspond to the pump currently under test and read in the IV file that corresponds to the 700W/m^2 set point; note that should have already been programmed in following steps 1-31 in the *6 SWP Solar Day* SOP, which may be referenced for this step.

Procedure

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1. Determine the set points to test for the head range.
   a. The pump should run through at least five different head setpoints and up to ten.
   b. These are typically in intervals of 5 or 10 meters depending on the rated head ranges and the testers discretion.
      i. For example, if a pump's maximum head is rated at 100 m, it would make sense to go in 10 m intervals from 0-100.
      ii. However, if a pumps maximum head is rated at 40m, then 5m intervals would be more appropriate for choosing set points.
   c. Ensure that the max set point does not exceed the overall system pressure capacity in psi. Our test bench should not exceed, for instance, more than approximately 180psi.
   d. The set points can be written down in the testing spreadsheet or on a piece of paper.
   e. Note, there will likely be instances where a pump does not perform up to its rated maximum. In this case, the set points can be adjusted during testing to reflect the true head range observed for the pump.
      i. For example, if a pump is rated for 40 meters of head, but during testing the pump only gets to ~25 meters of head before shutting off, then the tester will adjust their testing points with 25 meters of head as the maximum.
2. Once the head range set points are determined, the equivalent pressure for the test bench valve should be determined.
   a. To convert the head setpoint to the pressure set point for the test bench, subtract one meter to account for the natural one-meter head added from the test bench and convert to pounds per square inch (PSI). If the set point is an even 5- or 10-meter interval, refer to the table below, where the PSI displayed in the third column is associated with the head including the test bench 1m adjustment:

Table 1. Head-Pressure conversion for test bench

Head (m) without test bench adjustment	Head (m) with test bench adjustment	PSI
5	4	5.688
10	9	12.798
15	14	19.908
20	19	27.017
25	24	34.127
30	29	41.237
35	34	48.347
40	39	55.457
45	44	62.567
50	49	69.677
55	54	76.786
60	59	83.896
65	64	91.006
70	69	98.116
75	74	105.226

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80	79	112.336
85	84	119.445
90	89	126.555
95	94	133.665
100	99	140.775
105	104	147.885
110	109	154.995
115	114	162.105
120	119	169.214
125	124	176.324
130	129	183.434

3. Turn the Chroma output ON to power the controller/pump by clicking on the *IV Run* button in the Chroma software display.
   a. For surface pumps, you generally will need to prime them before they are able to start pumping water if it's the first time using the pump during testing that day. This entails pouring water into the pump's inlet right after starting to power it, and then once it starts pumping, immediately placing it underwater. This will allow the pump to form suction for pumping water throughout the test and only needs to be done at the very beginning of testing, or whenever the pump's inlet is removed from the water.
      i. See the *4 SWP Cold Start and Inrush Current* SOP for instructions on how to properly prime a surface pump.
   b. For submersible pumps, there's generally not a pre-step needed for them to start pumping; just ensure that the intake screen of the pump is fully submersed in water.
4. The head range test should be performed starting at 0m of head (or fully open valve).
5. Allow the pump to turn on and stabilize at a constant flow.
   a. If the flow rate is less than 25lpm at 0m of head, switch the flow from the high flow pipe to the low flow pipe.
      i. Do this by fully opening the low flow valve while the high flow valve is open, then slowly close the high flow valve and redirect the flow into the low flow pipe.
      ii. The valve is open when the yellow handle is parallel to the pipe. The valve is closed when the yellow handle is perpendicular to the pipe.
      iii. **DO NOT** close the high flow valve without ensuring the low flow valve is open. If both valves are closed, it could build up pressure in the system and either cause the pump to stop pumping or cause damage to the pump, test bench, or both.
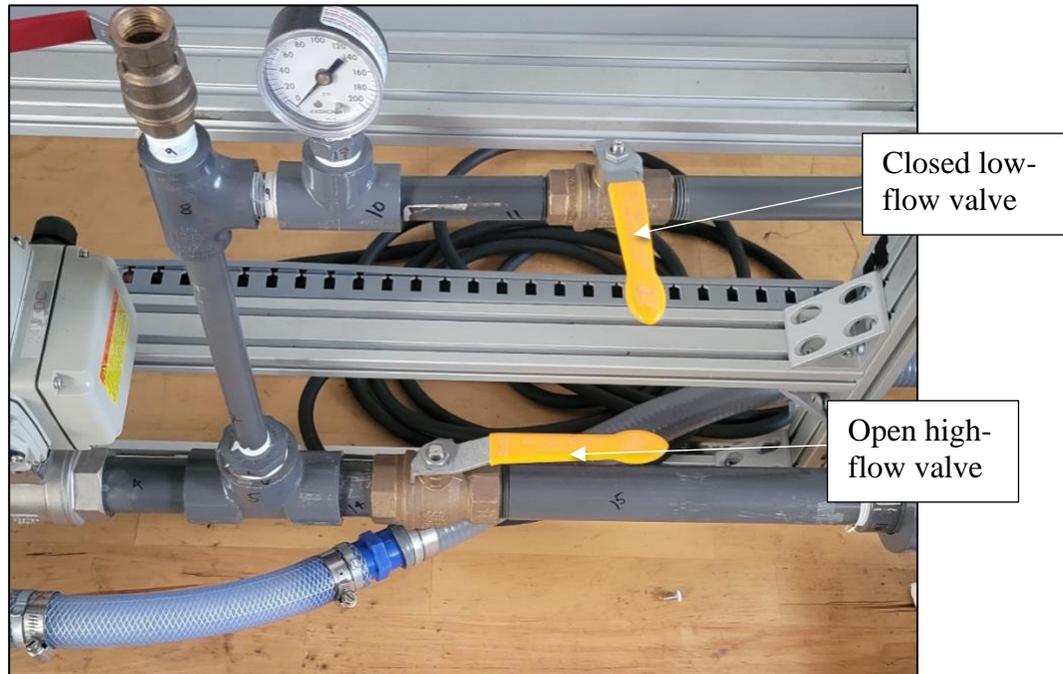
Figure 2: Open high flow valve and closed low flow valve on the test bench

6. Open the *Dialog Settings* tab in the LabView program and ensure that the data file is closed/ not currently being read currently (button is red near the file name). In the "File Label" box put the title of the data file using the following format: "PUMP-NAME-TEST-HEAD"

    a. For example, the first step of a pump called "SunflowAC4" would be "SunflowAC4-HeadRange-0m" or "SunflowAC4-HeadRange-allpoints" (depending on how you choose to write files, see step 13a for more information). See Figure 3 below:

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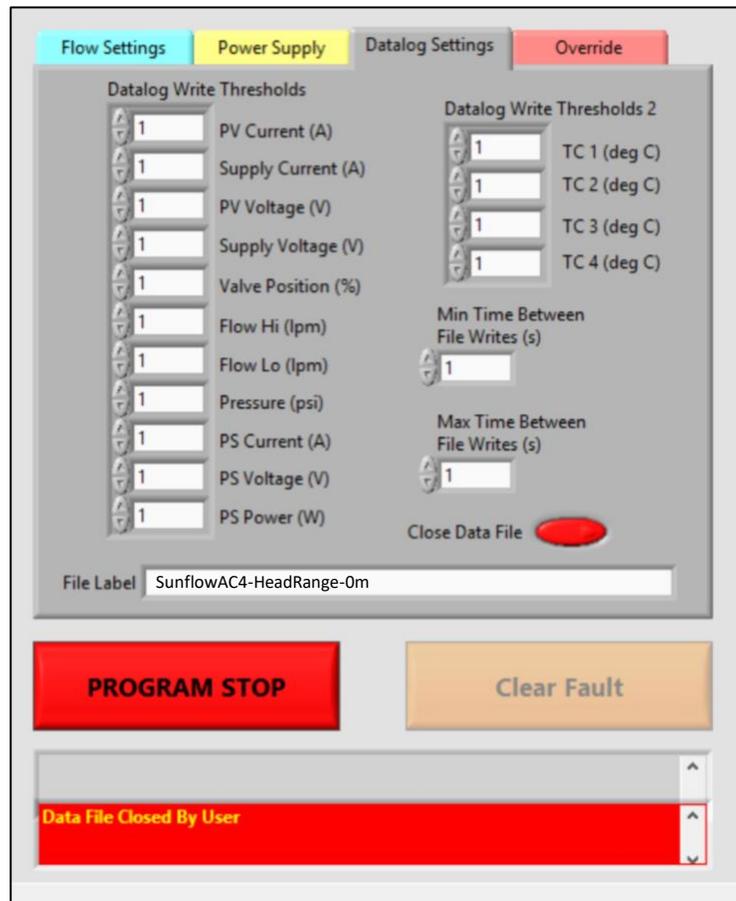
Figure 3: File label in LabView filled in for the head range test

7. Ensure that the valve (either high-flow or low-flow depending on the flow rate) is fully open and the other valve is completely closed. The pressure reading shown in LabView should be close to zero (refer to Figure 4). It is ok if the pressure is not very close to zero as some pumps with high flow rates will not be able to reach zero even with a fully open valve. If there is uncertainty about the pressure reading, reach out to the Lab Manager.
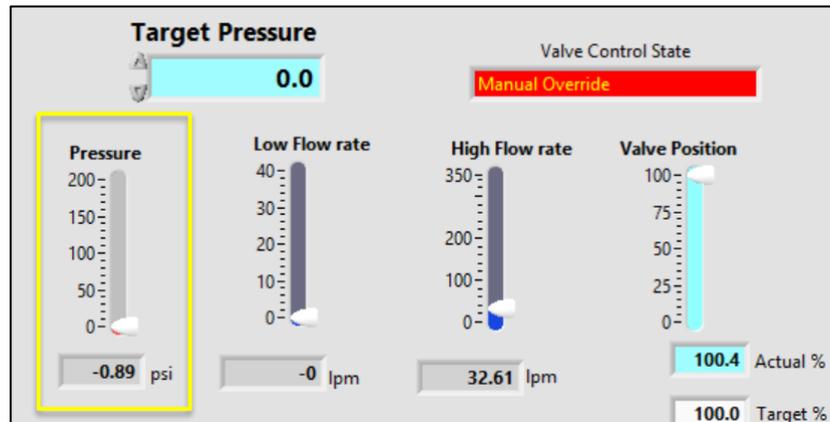
Figure 4: Example of pressure reading on LabView when there is no pressure on the system and only the high flow valve open.

8. Start the data recording by pressing the "Close Data File" button (the button should have a green arrow when the file is opened) and allow the file to read in about 2 minutes of data.
9. Once finished, close the data file and move to the next point.
    a. Note that you may keep the data file open the entire time while performing this test; in other words, you would be writing data to one big data file instead of multiple data files organized by simulated head. If this is the case, you will need to sort through the data to separate and organize based on simulated head steps during the analysis part of the test.

Figure 5: Closing a data file after data has been collected.

10. For simulating the next head step, slowly close the valve while paying close attention to the pressure gauge in LabView (shown in Figure 4). The pressure gauge will be fluctuating, but ideally, the tester should aim to have the fluctuations around (above and below) the set point, if possible.
11. If writing to multiple files for this test, rename the data file in the *Dialog Settings* in LabView to the new set point and start recording data. You may skip this step if writing to one big data file.
12. The file in the "Pump Tester" folder will include the title from LabView within the file, but the overall file name will be "PumpTester_[date]_[file number]. It is good practice to rename the file to match the LabView title before starting the next point. You may also copy the datafile to the SWP test folder after closing each data file during testing.
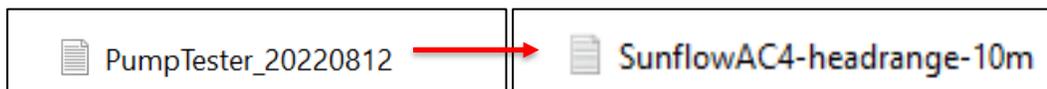
Figure 6: Rename the file name to match the LabView title.

13. Repeat steps 10-12 for each pressure setpoint.
14. The maximum head is defined as the point just below the pressure at which the pump can no longer produce greater than 1 lpm of flow. When this happens, either the pressure will start to decrease until just above 1 lpm, or, the pump will shut off if its max pressure is surpassed and the tester will need to decrease pressure until the pump turns back on and work their way

back up to just below the shut-off pressure. This pressure will likely not be one of the defined set points and rather be a pressure in between setpoints.

15. After all of the possible set points are completed, move the raw data file(s) from the "pump tester" folder to the pump's testing folder.
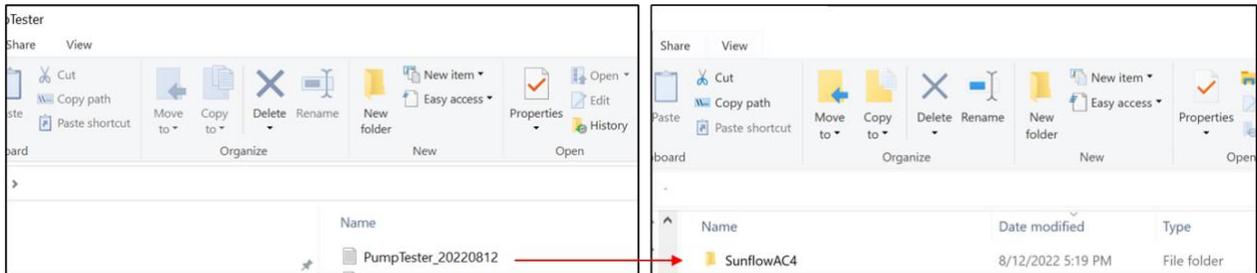
Figure 7: How to transfer raw data files from the raw data folder to the testing folder

Data Analysis

The objective of the Head Range test spreadsheet is to take in the series of points measured during testing, to average the two minutes of data for each setpoint, and to fit two different polynomial curves to the dataset to accurately interpolate the performance of the pump in between the tested points. This is accomplished using Excel's "Solver" feature, which minimizes or maximizes the value of an objective cell by changing a set of other, dependent cells. In this case, the objective cell is the sum of square residuals between the calculated values and the actual measured values. Solver works to minimize the sum of the square residuals ("objective cell") by running through a series of iterations of adjusting the coefficients in the polynomial ("variable cells"), which has the goal of fitting the best line to the dataset.

The *HeadRange* spreadsheet consists of four tabs named *Instructions*, *Test Results*, *Calculations*, and *Data Analysis*, and ten tabs that are numbered 1-10. The ten numbered tabs are for data entry and averaging. Other than the data entry tabs, the *Test Results* and *Calculations* tabs also require user input.

There are also red cells throughout the spreadsheet that help to provide instruction and tips, so be sure to thoroughly read those in addition to the following this procedure.

16. Open the *HeadRange* spreadsheet and navigate to the green numbered tabs in the bottom of the spreadsheet; this is where the raw data measured from the LabView program will go. Make sure to enter the data in ascending order (from lowest to highest head) from left to right.

17. These green tabs can be renamed to indicate which set point they correlate to**, but do not delete the unused tabs**, because this may affect the formulas/calculations.

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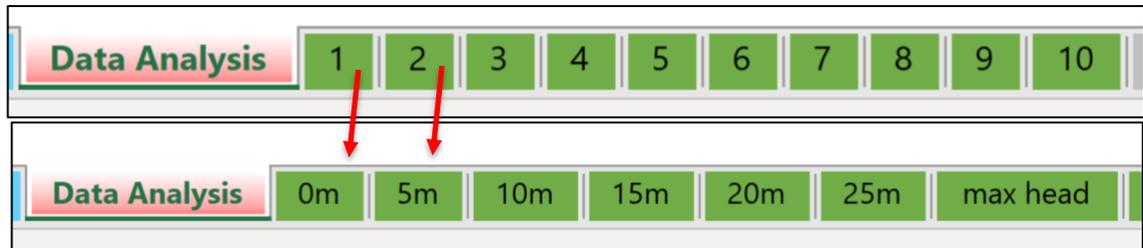
Figure 8: Raw data tabs in the head range spreadsheet renamed to reflect the actual tested points.

18. Open the raw data tab that correlates to the 0 meters of head point, and paste in the entire dataset from the raw data file into the green tab anywhere to the right of columns A:F.

    a. The LabView raw data files can be opened as a plain text file typically using the "Notepad" app. Once opened, click anywhere in the file and press "CTRL+A" to select the entire dataset, then "CTRL+C" to copy the selection. Then, within the *HeadRange* spreadsheet green tab, press "CTRL + V" in column I to paste the entire dataset.

    b. Note that if you used one data file, you will copy and paste all of the content into the first raw data tab; however, you will need to look through it to find the data for the 0m setpoint to pull over to columns A:F in the *HeadRange* spreadsheet, described in step 22 below.

19. In columns A:F, there are four columns that are highlighted yellow; these are titled "Current", "Voltage", "Flow", and "Pressure". Each of these columns require that these specific raw data points from the raw data file pasted to the right be copied and pasted into their column category, and then they are automatically averaged at the top in row 2.

Figure 9: This figure shows which raw data column needs to be transferred to the averaging columns.

20. Some important notes:

    a. There are two flow columns in the raw data: one for the low flow meter and one for the high flow meter. Make sure you paste the correct flow meter data into the "Flow"

column (col E). If using one large data file, the high flow may have changed to low flow for some of the higher pressure points, so be aware of this.

b. If there are any data points in the raw data that should not be used for the analysis (i.e. points not at the right pressure, points that were prior to the solar array simulator's output being turned on, transitional steps in between setpoints, etc.), be sure to remove them from the averages or select only the relevant data to be pasted into columns A:F.

Figure 10: Example of one large data file that contains all of the *HeadRange* test data and how to exclude the transitional data points.

21. After pasting the data from each setpoint into its corresponding green tab, then pasting the columns into the proper averaging column, the rest of the spreadsheet will grab the average values in row 2 for the calculations so make sure that those values are averaged correctly and represent the goal pressure step.

22. Navigate to the *Calculations* tab. In this tab, it is required to use the "Solver" feature in excel, which should be on the "Data" tab in the Excel toolbar.

a. If Solver is not on the "Data" tab in the toolbar, navigate to the "File" tab on the toolbar
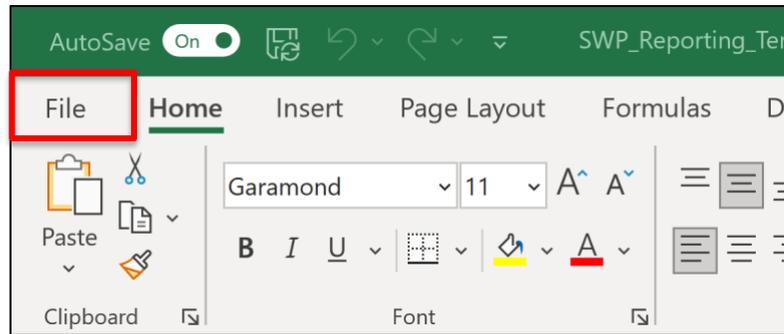
Figure 11: File tab on the excel toolbar.

b. In the "File" menu, select "More" then "Options"
c. In the "Options" menu, select "Add-ins"
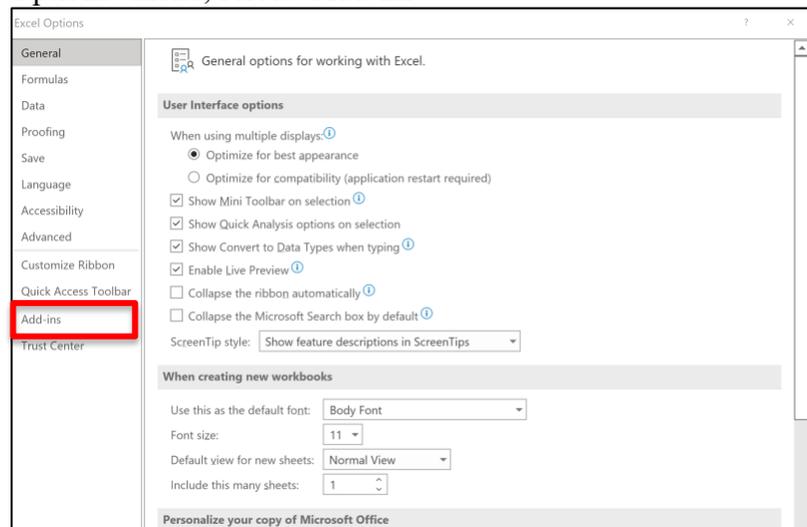
Figure 12: Options menu in excel.

d. In the "Add-ins" menu, select "Excel Add-ins" in the manage dropdown then press "Go…"
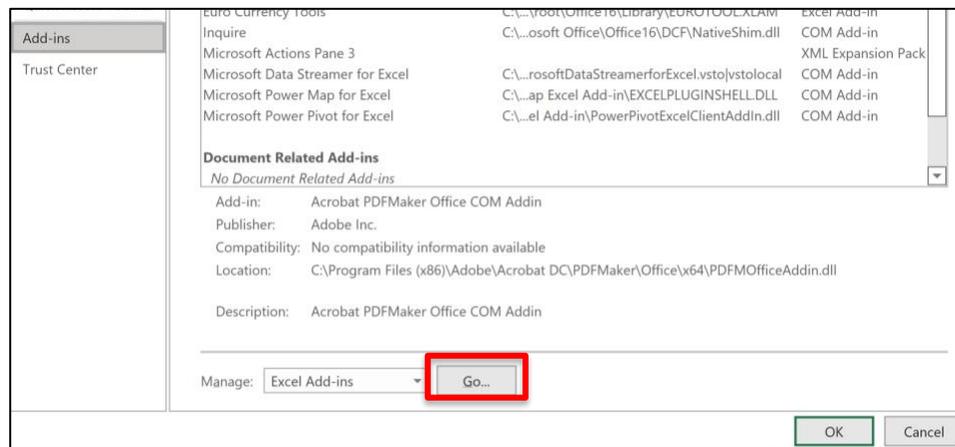
Figure 13: Add-ins menu within the options menu.

e. The select the check box by the "Solver Add-in" in the "Add-ins" menu then select "OK"
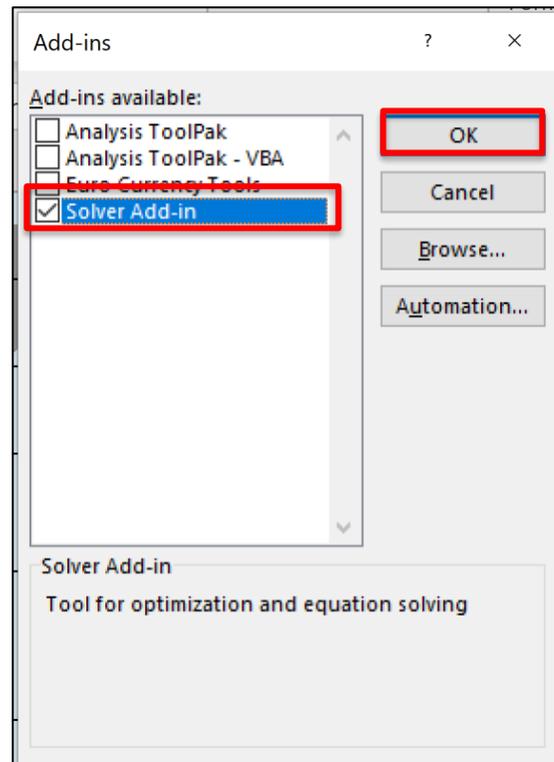
Figure 14: Selection menu to add Solver into excel.

23. There are two main sections to the *Calculations* tab: the efficiency curve and the flow curve. Each plot references the data in the corresponding table to the left, and both require Solver.

24. To start, locate the green cell under the efficiency curve table labeled "sum of squared residuals – OBJECTIVE". Verify that this cell is summing all the relevant cells above it (see Figure below). Note that the formula in the green cell may need to be manually changed depending on how many setpoints were used for this test; the blue reference cell for the formula may be adjusted so that it only incudes the points with tested data included.

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Figure 15: Objective cell summing the squared residuals of all the relevant data points

25. Then, navigate to Solver and set the objective to the green cell labeled "Objective", and set the variable cells to the blue cells below the table labeled "Variable cells". See the figure below; the objective cell is indicated in the red highlighted box, and the variable cells are indicated in the yellow highlighted box.
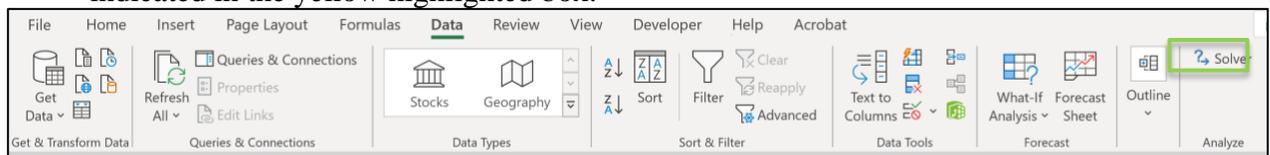
Figure 16**: Which cells correspond to the objective and variable cells in the solver algorithm.**

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26. Press "Solve" to start the solving process. This could take 10-30s to run. Once a solution has been found, run solver again another 2-3 times until the variable cells are unchanging, and the objective cell is a very small number.

27. Repeat steps 24-26 as described but for the flow curve and corresponding flow table, changing the objective cell from D19 to T19 and the variable cells from B26:B29 to P26:P28.

28. Once the Solver process is complete for both graphs and tables:

    a. Check the objective cells (D19 and T19) values to make sure they are less than an order of magnitude of about 10^1. If they are higher than 10^1, follow the steps in the *Troubleshooting* section below.

    b. Check the "Calculated Efficiency" values in column C and the "Calculated Flow" values in column S to verify that the values seem reasonable (non-negative and similar to the measured values). If the values are significantly different or negative, follow the steps in the *Troubleshooting* section below.

    c. Check the variable cell values (B26:B29 and P26:P28) and compare them to their respective graph's trendline equation. The values of a, b, c, and d (or just a, b, and c for the flow curve) should be similar to the coefficients of the trendline equation. If they are not similar and the trendline appears to fit the data well, follow the steps in the *Troubleshooting* section below.
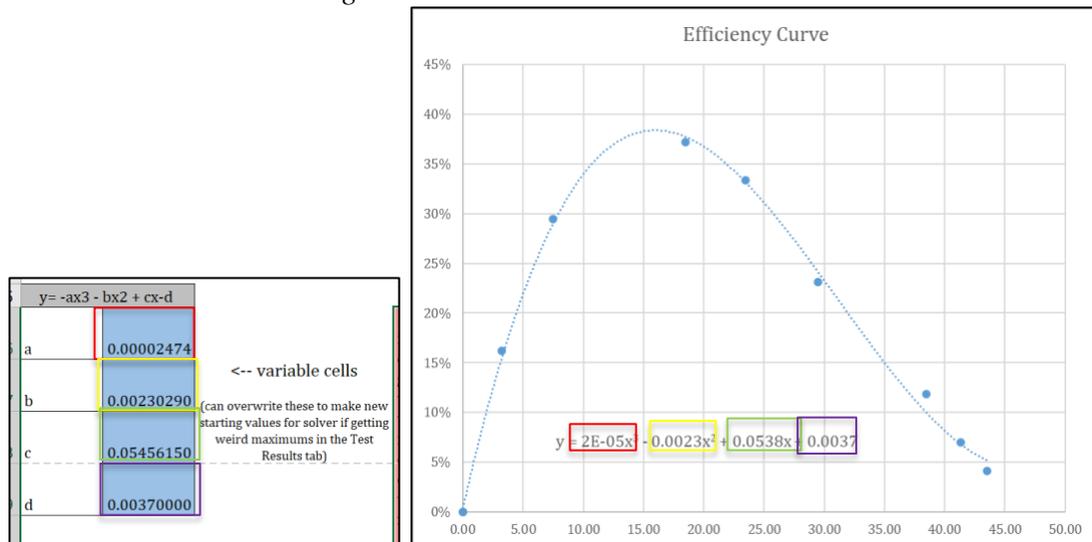
Figure 17: Comparing trendline equation to variable cells to verify that they are similar.

29. Navigate to the *Test Results tab* on the *HeadRange* spreadsheet and check the main test results table (shown in Figure 18) to ensure the values here make sense as well.

    a. Verify that the formulas in the four cells to the right of the main table (column I through L) are including the entire column of relevant data and excluding any cell with errors indicated by "#VALUE!" or "#DIV/0!"

    b. Make sure that the flow curve includes all the relevant data from the main test results table. The orange line should represent the wire-to-water efficiency vs. flow, while the blue line should represent the head vs. flow. This can be verified and changed by double clicking the line in the graph and adjusting the blue and purple selection until it covers the relevant data and excludes the non-relevant points:

Set Point	Available PV power [W]	Measured PV power [W]	Head [m]	Flow [lpm]	wire to water efficiency [%]	Hydraulic Power [W]
0	600	571	0.0	115.4	0%	
1	600	571	4.9	106.5	15%	85.5
2	600	570	11.1	90.4	29%	164.2
3	600	570	20.6	62.3	37%	209.5
4	600	569	30.7	35.4	31%	177.9
5	600	569	40.4	22.3	26%	147.3
6	600	570	49.9	10.4	15%	84.8
7	600	568	55.0	5.6	9%	50.3
8	600	568	59.3	2.5	4%	24.3
9	600	#DIV/0!	#VALUE!	#VALUE!	--	#VALUE!
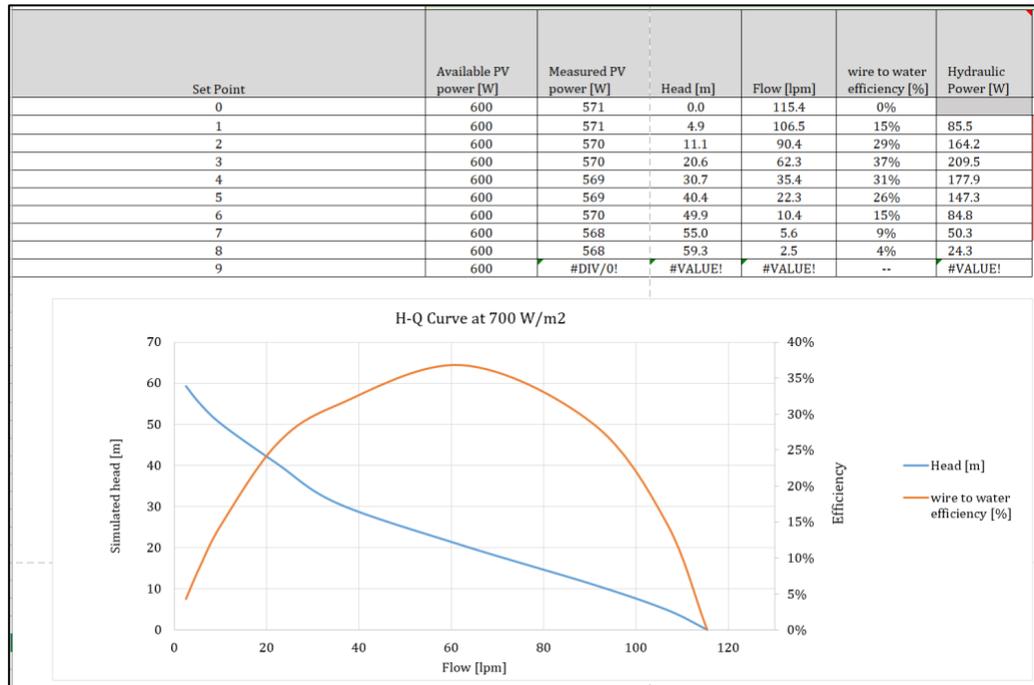
Figure 18: How to select the data displayed in the flow graph on the "Test Results" tab.

  i. After changing or editing the data in this way, check the graph to verify that the legend on the right still displays the correct titles. If the legend on the right says "Series 1" or "Series 2", right click the graph, press "Select Data…", click on the series that needs to be changed, then click "Edit". Then, in box titled "Series Name" type the proper title for the series (either "Wire-to-water efficiency" or "Head (m)"
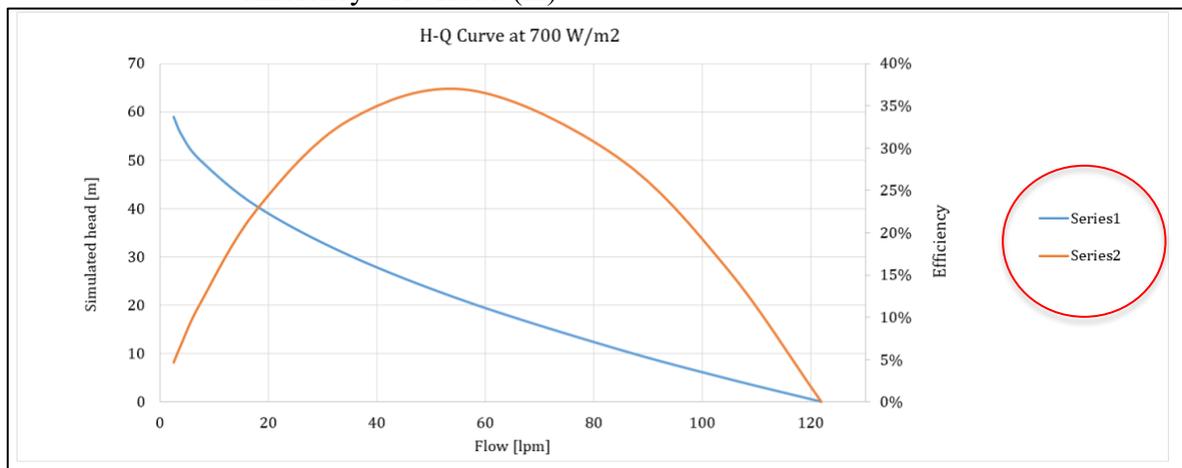
Figure 19: Improper legend on the *HeadRange* spreadsheet.

30. After analyzing and checking the data, be sure to verify the results with the Lab Manager.

Reporting

1. After the data and results have been verified by the Lab Manager, the data should be entered into the *SWP_Reporting* spreadsheet in the *Test Results* tab.

2. Open both the *SWP_Reporting* and *HeadRange* spreadsheets and navigate to the *Test Results* tab of both.
3. In the reporting spreadsheet, the section for the head range test is called "Useful operating range per typical solar day (Head Range Test)" (See Figure 20 below).
4. In column A of the first and second table in the head range section of the reporting spreadsheet, enter the sample number used during this procedure (typically "1").
5. In the *HeadRange* spreadsheet, copy the values in row 14, columns I through L and paste them as values into the first table of the head range section of the reporting template starting from column B.
6. In column B of the second table, the value should be entered as "700" for all the rows of data.
7. In the *HeadRange* spreadsheet, select and copy the data in columns D through G and paste it into the table in the Reporting spreadsheet starting from column C.

Note: always use the "Paste as Values" option when pasting values from the testing spreadsheet into the reporting spreadsheet.
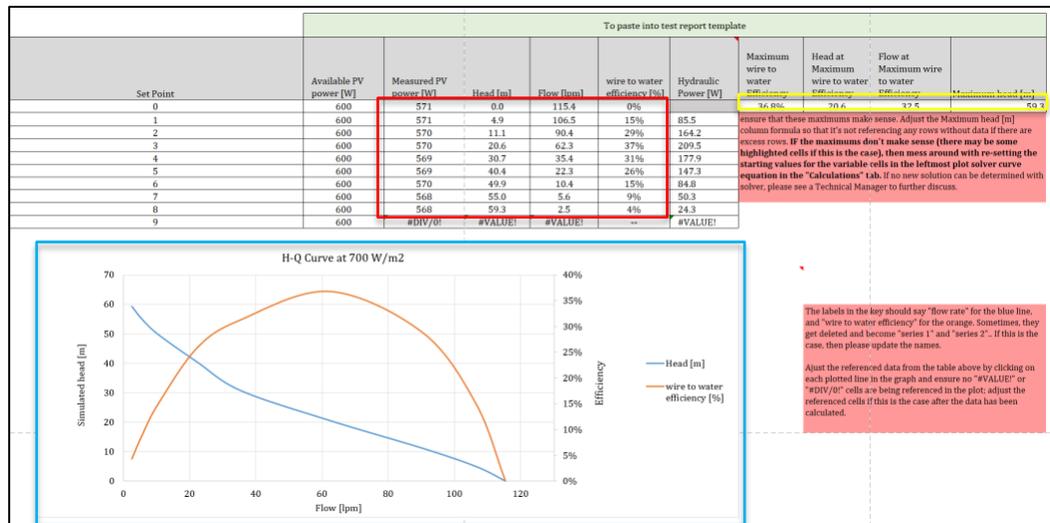
Figure 20: Section in the HeadRange spreadsheets to copy the data from.

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Useful operating range per typical solar day (Head Range Test)

Sample	Maximum wire to water efficiency [%]	Head at maximum efficiency [m]	Flow at maximum efficiency [lpm]	Maximum head [m]
1	37%	21	33	59

Sample	Simulated irradiance at maximum head [W/m2]	Available PV power [W]	Measured PV power [W]	Simulated head [m]	Measured flow [lpm]	Wire to water efficiency [%]
	700	600	571	0.00	115.4	0.0%
	700	600	571	4.91	106.5	15.0%
	700	600	570	11.1	90.4	28.8%
	700	600	570	20.6	62.3	36.8%
1	700	600	569	30.7	35.4	31.3%
	700	600	569	40.4	22.3	25.9%
	700	600	570	49.9	10.40	14.9%
	700	600	568	55.0	5.60	8.9%
	700	600	568	59.3	2.50	4.3%

Comments:

H-Q curve

Figure 21: The results from the HeadRange spreadsheet pasted into the reporting spreadsheet.

8. In the reporting spreadsheet, hide any rows that are not needed for displaying data, remove the background color from the cells.

Determining Head at Max Efficiency for Solar Day Test

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1. In cases where the nominal head is not provided by the manufacturer, it is recommended to use the head that corresponds to the *maximum wire-to-water efficiency* as calculated in the Head Range spreadsheet.
2. After completing all the <u>Data Analysis</u> steps, navigate to the *Test Results* tab in the *HeadRange* spreadsheet and note the value in cell J14, shown in Figure 22 in the yellow rectangle.

						Maximum wire to water Efficiency	Head at Maximum wire to water Efficiency	Flow at Maximum wire to water Efficiency	
Available PV power [W]	Measured PV power [W]	Head [m]	Flow [lpm]	wire to water efficiency [%]	Hydraulic Power [W]				Maximum head [m]
600	571	0.0	115.4	0%		36.8%	20.6	32.5	59.3
600	571	4.9	106.5	15%	85.5				
600	570	11.1	90.4	29%	164.2				
600	570	20.6	62.3	37%	209.5				
600	569	30.7	35.4	31%	177.9				
600	569	40.4	22.3	26%	147.3				
600	570	49.9	10.4	15%	84.8				
600	568	55.0	5.6	9%	50.3				
600	568	59.3	2.5	4%	24.3				
600	#DIV/0!	#VALUE!	#VALUE!	--	#VALUE!				

To paste into test report template

ensure that these maximums make sense. Adjust the Maximum head [m] column formula so that it's not referencing any rows without data if there are excess rows. **IF the maximums don't make sense (there may be some highlighted cells if this is the case), then mess around with re-setting the starting values for the variable cells in the leftmost plot solver curve equation in the "Calculations" tab.** If no new solution can be determined with solver, please see a Technical Manager to further discuss.

Figure 22: Head at maximum wire-to-water efficiency in the *HeadRange* spreadsheets

3. The *head at maximum wire-to-water efficiency* is the target head that should be used during the Solar Day test if a manufacturer rated or provided nominal head is not available. The value shown in Figure 22 should then be entered into the *IrradianceData* spreadsheet in cell B11 prior to performing the Solar Day test, if this is the case.

Troubleshooting

There are some common errors seen in the <u>Data Analysis</u> section of this procedure. A few of them will be addressed in this section.

1. In cases of poor line fit (i.e. negative calculated flow or efficiency, high SSR, different calculated and trendline coefficients) after using Solver on the two curves, there are two main causes to troubleshoot: signs of polynomial coefficients (i.e. positive or negative) and the values of coefficients.
   a. Verify that the signs in the formula in the "Calculated Flow" or " Calculated Efficiency" column are the same as the signs on the trendline shown on the graph.
   b. The example below is of a scenario where the trendline appears to fit the data quite well, but the objective cell (sum of square residuals) is too high, and the calculated flow is negative at high head values. In this example, the sign on the first coefficient is negative in the formula but positive on the graph. To solve this issue, the tester should edit the formula in the calculated flow column to match a new equation and delete the first negative sign and re-solve using Solver.

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$$=-(\$P\$26*R9\wedge2)-(\$P\$27*R9)+\$P\$28$$

Figure 23: The signs of the excel formula used the in the calculations compared to the signs of the trendline equation.

    c. There are a few steps to take if the values of the coefficients displayed in the variable cells do not align with the trendline displayed on the graph:
        i. Reset solver by plugging in the number "1" or some arbitrary number into the variable cells and resolve. Typically, when resetting the variable cells, solver will have to run at least 3 times to reconverge to a solution.
        ii. Manually type in the coefficients from the trendline equation into the variable cells and resolve. In some cases, the variable cells will reset to the previous values. In that case, check the signs of the formula as described in the previous step.

2. In some cases, the trendline does not fit the data well due to fluctuations in the pump's performance, outliers, etc. If this is the case, consult the Lab Manager to discuss possible solutions, which may include retesting or using a different line fitting technique to make sure the calculations are an accurate reflection of the pump's performance.

Reference Procedures

This procedure references IEC 62253: H-Q characterization (5.3.3).

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Version	Date	Summary
1.0	8/31/22	-first draft of this SOP

Scope / Field of Application

The Solar Day Test will determine the volume of water moved over a manufacturer-specified head for three defined solar days with the highest input power points associated with the specified PV array for the pump along with the maximum irradiance points defined for the three different solar days. The three solar days maximum irradiances are defined as 450 W/m2 for a low irradiance day, 700W/m2 for an average irradiance day, and 1000 W/m2 for a high irradiance day. SWP head is related to pressure, so the pressure associated with the required head for testing will be set on the test bench to simulate the given head for each simulated irradiance day. Input power will be simulated using a solar array simulator in most cases.

Note that descriptions throughout this SOP that are specific to the test bench and equipment described in the SWP Test Bench Instruction Manual may be adapted and customized by other test labs trained to the current Global LEAP SWP test methods if needed.

Definitions and Acronyms

SWP- solar water pump

SOP- standard operating procedure

Head (m)- The vertical distance water may be lifted by a pump from the surface of the source water to the delivery point. This metric is usually specified in meters. Note that during testing, head is simulated by controlling the pressure in the pump's outlet hose; pressure and head are directly correlated in relation to SWPs.

Nominal head (m) for solar day test- this is either the head specified by the manufacturer or the head determined during the Head Range Test to be when the SWP performed at maximum efficiency.

Inverter- A mechanism that transforms DC (direct current) into AC (alternating current).

Charge controller- A device that controls the power (either current or voltage) going into a pump from a power source. Most charge controllers can detect operational faults and signal this to the user.

Maximum Power Point Tracking (MPPT)- A charge controller algorithm that searches for the maximum power point along the PV array's IV curve in order to maximize the power utilized from the PV array.

Power-width Modulation (PWM)- A charge controller algorithm that uses an electronic switch to control the input PV voltage to the controller through the use of quick on-off phase cycling to consistently accept the best voltage input available.

Standard Testing Conditions (STC)- Testing conditions for PV modules defined as a cell temperature of 25 degrees Celsius at 1000 W/m2 and an airmass of 1.5. This is a standard in the solar industry to compare PV modules to one another.

Temperature Coefficient of Voc (%/°C)- Quantifies the inverse relationship between temperature and voltage of a PV module, often given in %/°C.

Solar Irradiance (W/m2)- Amount of solar power in watts available per m2 of area at a given time.

Voc- the maximum, possible voltage when the PV module is at open-circuit.

Vmax, Vmp- the voltage at the max power.

Isc- the short-circuit current, which is the maximum possible current for a PV module or array.

Imax, Imp- the current at the max power.

Typical Module Operating Temperature (TMOT)- Testing conditions for PV modules that are more realistic to conditions that most PV modules will be operating in. This is defined as a cell temperature of 50 degrees Celsius at 1000 W/m2 and an airmass of 1.5. The PV specifications within this set of conditions may be estimated using the rated power points at STC and the rated or assumed temperature coefficient of Voc.

Solar Day (hr)- Time over a day where there is solar irradiance above 0 W/m2.

Slew Rate (V/ms or A/ms)- Rate of change in voltage or current output over time (from Chroma in this case).

Program response time (ms)- time it takes for solar array simulator to respond to change in either output voltage or current.

Responsibilities

SWP tester- has read all relevant SOPs, has reviewed all relevant SWP testing information, and has carried out all pre-testing steps, if applicable. The SWP tester has discussed with the Lab Manager if there is any conflicting or missing information or safety hazards observed. This person may also perform SWP testing equipment calibrations, maintenance, and checks, if approved.

Lab Manager- performs tests and equipment calibrations, maintenance, and checks, reviews test results, and provides input as needed. Also, may communicate directly with the client, as needed.

Materials Required

- *SWP test bench*

Pre-Test Preparation

Before this test is carried out, the following SOPs must be read and procedures carried out (if applicable) for the pump under test:
- *SWP Test Bench Instruction Manual*
- *1 SWP Testing Safety*
- *2 SWP Intake and Visual Screening*
- *3 SWP Testing Set up*
- *4 SWP Cold Start and Inrush*
- *6 SWP Solar Day Test* (this SOP must be reviewed prior to testing, and especially if this procedure has been updated since the last time the tester has tested)

The SWP (and controller, if applicable) must have been set up on the test bench as according to the user manual/ information provided by the manufacturer, and the following information especially should have been determined and noted:
- Solar PV array configuration used for the SWP input
  - Specifically: *Pmax, Voc, Isc, Vmp, Imp*
  - If applicable: temperature coefficient of the PV module(s) advertised
- Nominal vertical head for the Solar Day Test (m)
- Any testing limitations of the pump or pre-use steps, if applicable

Note that the input power characteristics may be submitted with the pump by the company, which should be the power points used during this test. If this information isn't available, input power may be oftentimes determined simply by the max input ratings listed on the SWP/ controller and/or user manual/ packaging. If there is no information regarding the PV array configuration but there are max input ratings listed on the controller (or SWP when an external controller is not included), these max ratings for voltage and current may be interpreted as input Voc and Isc for testing purposes.

If the following required information was not included in the shipment of SWP samples for testing and cannot be found online, then the company may need to be contacted to confirm the input power points, desired vertical head to be used for testing, and any other necessary information needed to test the pump. Similarly, if there are significant discrepancies, the company may need to be contacted to decipher which values should be used for testing. If the company is not being responsive, let the Lab Manager know and let the company know that their test results may be delayed.

Also note that normally, if the nominal pump head was provided to the test lab, the Solar Day Test is performed before the Head Range Test. If the manufacturer did not provide or rate the nominal head (also commonly called working head) in any consumer-facing materials OR the pump was determined not able to function properly at the rated nominal head, **then the Head Range test must be performed prior to the Solar Day test** in order to determine what head to simulate for the Solar

Day test, which is described in the instructions in the *5 SWP Head Range* SOP in the *Determining Head at Max Efficiency for Solar Day Test* section.

Ensure all safety trainings have been provided to operate the test bench.

Procedure

Spreadsheet inputs

1. Open up the *IrradianceData* test template spreadsheet; review the *Instructions* tab and then move onto the blue *Inputs* tab to begin.
2. In this spreadsheet, there are notes in light red cells that are helpful instructions and guidance. All yellow cells are entry cells for the user; the blue and white cells contain calculations and should generally not be overwritten.
3. Start on Table 1 by filling in the following information:
   a. PV temperature coefficient (if applicable; otherwise, use assumed Toc's listed to the right in the spreadsheet)
   b. Pmax at STC (W), usually listed on back of PV module or specified by manufacturer or user manual
   c. Vmax- either specified in documentation or provided by manufacturer
   d. Imax (sometimes calculated from knowing Pmax and Vmax: Pmax/Vmax=Imax)
   e. system cost (without PV module)- this should be provided by the client and should include the pump, the controller (if included with the system), and any included accessories.
      i. Note: sometimes, only the full retail cost (PV included) is known. For cases like this, calculate how much the PV should cost based upon the assumed value of $0.81/ W and the maximum power rating of the PV module, and enter in the cost with the PV module price estimate subtracted out.
   f. simulated head (m)- this should be specified by the manufacturer OR determined by the Head Range Test
      i. note that this is not always the same value as the maximum rated head
      ii. the simulated head should be determined by the manufacturer and is in relation to the head at which the pump functions with the highest efficiency.
      iii. If this needs to be determined by the Head Range Test (if unavailable from the manufacturer or the given value won't allow the pump to function at 700 W/m2, then follow the steps in the 5 SWP Head Range SOP and perform that test before this Solar Day Test.
   g. Ensure that the "Voltage offset for the DAQ measurements (V)" and the "Current offset for the DAQ measurements (A)" are up to date. These are the offsets that are factored into all voltage and current measurements on the DAQ and are determined by an annual in-house calibration of the DAQ. The most up-to-date offsets should be saved in a known location on a test lab computer or server.

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h. Check the Vmax and Pmax in blue in the Figure below that include the offsets for each; ensure they make sense. In general, these values should be slightly higher than the calculated TMOT values.

TABLE 1. Initial inputs		
Inputs		**notes**
PV temperature coefficient (%/ · C)	-0.35%	This means that for every 1 degree Celsius , the PV panel will decrease in efficiency by this percentage. If the temperature coeff isn't provided, use the Table to the right to assume a value for this calculation.
Pmax at STC (W)	188	--
Vmax	24	V
Imax	7.8	A
FOB cost	500.0	WITHOUT the PV module (if possible)
Retail Cost	$ 900	*note, this is the cost WITHOUT the PV module. IF retail price is given (instead of FOB), overwrite formula to the left in col. B and input retail cost provided.
Simulated head [m]	25	
vertical distance added by the test bench	1	changed if the test set up is changed or using a different test bench. This accounts for the vertical distance from the surface of the source water up to the inlet to the test bench pipe network.
$/W	0.81	CLASP guidance
PV module cost	$ 152.28	delete if PV modules are already included in system cost
STC Temperature (degrees C)	25	--
TMOT temperature (degrees C)	50	--
change in temperature (degrees C)	25	--
efficiency loss from STC to TMOT (%)	-9%	--
Vmax, calculated (50 degrees C) (V)	21.90	Calculated. Use this to input into test report template.
Imax, calculated (50 degrees C) (A)	7.83	Calculated. Use this to input into test report template.
PTMOT, calculated (50 degrees C) (W)	171.55	Calculated. Use this to input into test report template.
Vmax, calculated (50 degrees C) (V), **with offset**	22.80	Use this when testing. Still be aware if the Voc based on this Vmp will exceed system or product capabilities and make adjustments when possible so that these boundaries are not exceeded. This value not to be added to test report.
PTMOT, calculated (50 degrees C) (W), **with offsets**	183.84	Use this when testing- this will be the simulated max power in the Chroma. This value not to be added to test report.
Voltage offset for the DAQ measurements (V)	0.9000	*These shouldn't be changed often unless more than 6 months has gone since using the test bench by or the DAQ has been updated. Ensure these match the other testing templates and the most recently saved calibration spreadsheet for the DAQ voltage and current offsets (copy and paste these values in from the dAQ current/voltage calibration spreadsheet) .*
Current offset for the DAQ measurements (A)	0.230	

Figure 1. Table 1 in the *IrradianceData* spreadsheet.

4. Then, move onto Table 2 to fill in the irradiance steps to test for the Irradiance day test. These steps should range anywhere from 50 to 1000 W/m2 (no more, no less) and should be entered in intervals of 50 W/m2.
   a. Usually, the minimum step will be determined during testing; however, for setting up the test in the spreadsheet prior to powering the SWP, a minimum irradiance should be entered into the table and checked during the test later.
      i. A good place to start for the lowest simulated irradiance could be the cold start irradiance determined in the *4 SWP Cold Start and Inrush SOP*.
         1. Note that the Cold Start irradiance step will not always be the minimum irradiance this test will start at, because frequently, SWPs cannot sustain the nominal head at this irradiance.
   b. You will test SWP at each listed simulated irradiance listed in Table 2 at the provided static pressure (associated with the head) as long as the pump can provide at least 1lpm of flow.

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    i.   Note that if the SWP cannot provide at least 1lpm of flow at any irradiance step during testing, it will not be included in the test results, and the irradiance step should be removed from Table 2.

TABLE 2. Flow measurements				Below, fill in the yellow cells with data from testing, which should also be copied/ pasted in the RawData# tabs to the right		
Irradiance step (list in steps of 50, at minimu. Testable range is 50 to 1000)	Simulated Power set points	*Corrected simulated power set points during testing to use (incorporating offsets)- these are NOT the power set points used in the test report; they are set points based upon test bench calibration for offsets. Use these to set the chroma or PV array parameters.*	Adjusted Flow	Flow	Measured supplied PV power	Pressure
[W/m2]	[W]	*[W]*	flow (lpm)	Q flow (lpm)	Power (W)	pressure (psig)
			--			
			--			
			--			
			--			
			--			
			--			
			--			
			--			
			--			
			--			
			--			

Figure 2. Table 2 in the *IrradianceData* spreadsheet.

5.   As you enter each irradiance step in the first column, you'll notice that the second and third columns start to populate. The second column populates with the simulated power set points associated with each irradiance step and the provided PV power. However, because the DAQ has measurement drift and must be annually in-house calibrated, the calibration offset measurements must be factored into the simulated power input for each step, so the blue column (column three) shows the actual power inputs that are required for each irradiance step with the calibration offsets factored in. The actual power inputs are what should be referenced when programming into the Chroma solar array simulator to power the SWP during testing (steps outlined below).

TABLE 2. Flow measurements				Below, fill in the yellow cells with data from testing, which should also be copied/ pasted in the RawData# tabs to the right			
Irradiance step (list in steps of 50, at minimu. Testable range is 50 to 1000)	**Simulated Power set points**	*Corrected simulated power set points during testing to use (incorporating offsets)- these are NOT the power set points used in the test report; they are set points based upon test bench calibration for offsets. Use these to set the chroma or PV array parameters.*	**Adjusted Flow**	**Flow**	**Measured supplied PV power**	**Pressure**	
[W/m2]	[W]	*[W]*	flow (lpm)	Q flow (lpm)	Power (W)	pressure (psig)	
50.0	8.6	*9.2*	--				
200.0	34.3	*36.8*	--				
400.0	68.6	*73.5*	--				
500.0	85.8	*91.9*	--				
600.0	102.9	*110.3*	--				
700.0	120.1	*128.7*	--				
800.0	137.2	*147.1*	--				
850.0	145.8	*156.3*	--				
900.0	154.4	*165.5*	--				
950.0	163.0	*174.7*	--				
1000.0	171.6	*183.8*	--				

Figure 3. Use the blue corrected simulated power points for input into the Chroma.

6. The other four columns will be filled out during the test; instructions are below in this SOP.

LabView Set up

7. A LabView program is used for recording all data points collected during testing.
7. First, log into the testing computer/ laptop designated for SWP testing; this computer should have a place on the SWP test bench so it can remain connected to the DAQ equipment and the Chroma.
8. It might make sense to have the DAQ equipment, the laptop charging cable, and the multi-USB port adapter (connected to the DAQ NI chassis and the Chroma communication cable- reference the *SWP Test Bench Instruction Manual* to see what this unit looks like) plugged into a power strip, and plugged into the laptop. The power strip should be unplugged when testing is not in-progress and during the testing set up.

9. Open LabView on the testing computer
10. Select "Open Existing" and then scroll down the list of all of the projects created in LabView to open "Pump Bench Main v1.vi" (this may be renamed, if desired).

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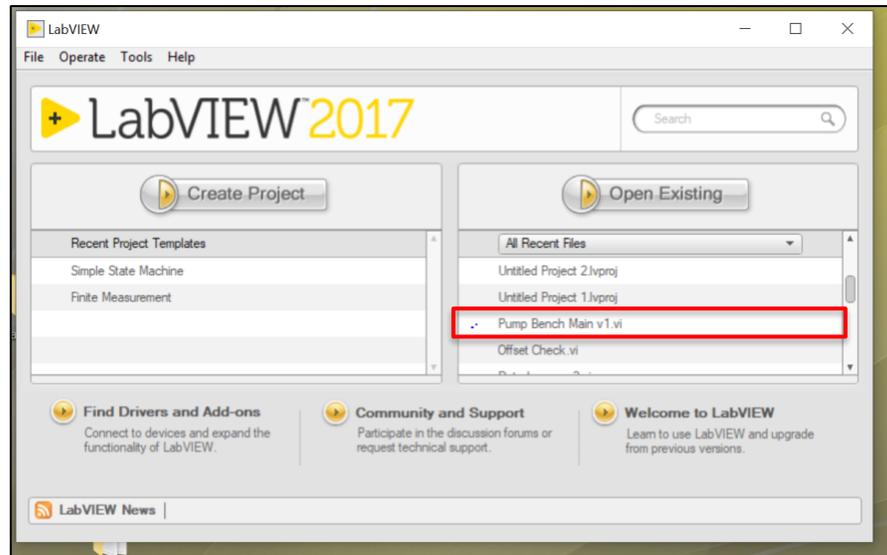
Figure 4. Use the Pump Bench main v.1 for the LabView program for SWP testing.

11. To start the program and "wake up" all of the communicative equipment, click on the right arrow on the top of the LabView Front Panel in the toolbar. The arrow should turn black and have motion indicators when clicked/ started the program.
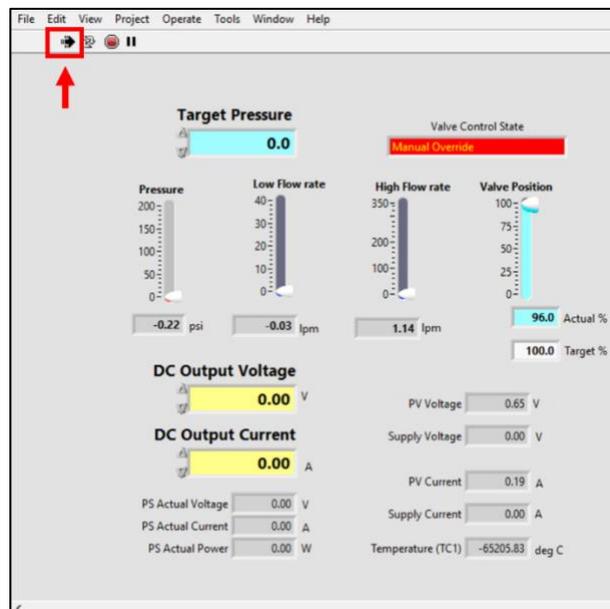
Figure 5. Press the arrow in LabView screen in the upper left corner to start the program.

12. There are a few adjustments needing to be made in LabView before testing. Click on the red Override tab in the display to the right. Click the switch to turn Manual Override On (the switch should turn all red when activated) and ensure the Valve Setpoint is set at 100%. This is giving the power to adjust the pressure manually (by physically closing/ opening the ball valves in the system instead of automating this feature: it's been found better to do this manually during testing rather than automatically).

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Figure 6. Manual Override button is open in LabView screen by default upon opening the program.

Figure 7. Manual Override button closed manually before SWP testing is started.

13. Then, click on the grey Datalog Settings tab to the left of the Override tab. The Max Time Between File Writes (s) is default 60; change this value to 1. This is to shrink the gap in between each data point being recorded.

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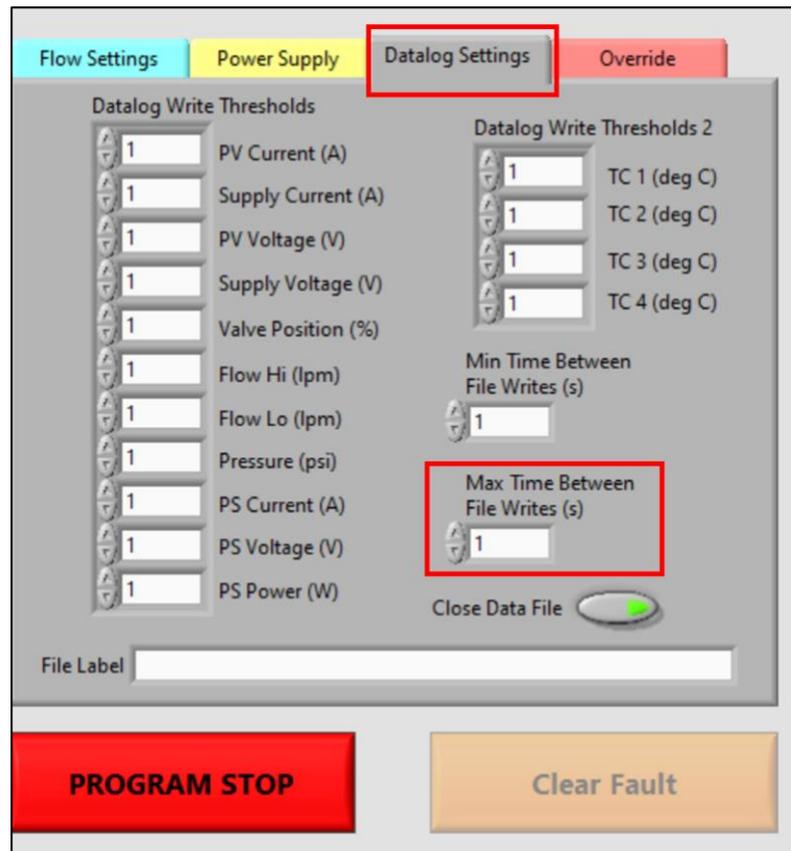
Figure 8. Datalog setting tab in LabView adjustments.

14. Click on the blue Flow Settings tab and adjust the Maximum Pressure Allowable depending on what kind of pressure will be tested with the specific SWP. For instance, if the SWP is going to be tested at 10 m, the associated pressure is 12.8 psi; so, set the maximum pressure allowable just above 12.8 psi; maybe set at 20m. However, if you are testing Head Range, higher pressures than 12.8 psi for this example pump may be used, so consider this. The program will give a fault sign if the max pressure is surpassed by the system; however, the test bench will continue to function properly.

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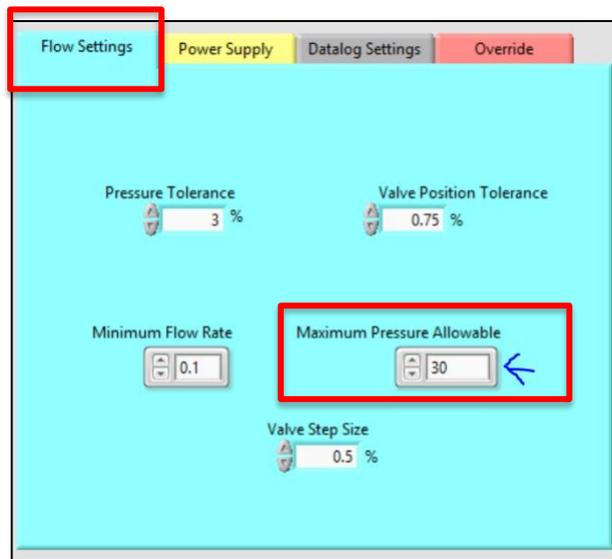
Figure 9. Flow settings tab in LabView adjustments.

15. Calculate the head you will be testing the SWP at for the Solar Day test (you should do this for the other tests, too). Calculate the vertical height (m) below what the setpoint is for head because the height of the test bench adds additional height to the controlled pressure-simulated head. For the example pump, specified at 10 m, 10m minus the vertical distance test bench adds (m) should actually be calculated, and that's the pressure that the test bench will be set to for testing at that meter. You may use this website: https://www.convertunits.com/from/meter+of+head/to/PSI
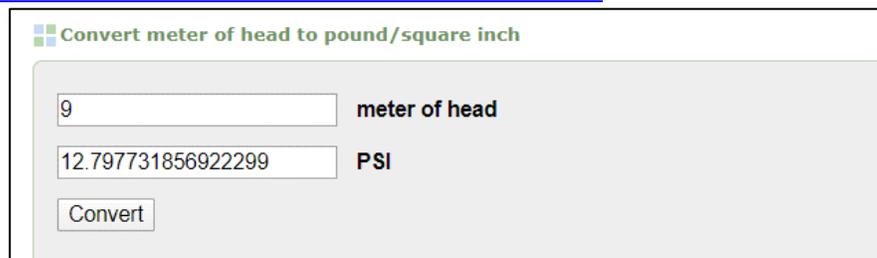
Figure 10. Meters of head to psi calculator.

Another option to look up pressures corresponding to vertical head set points is to consult Table 1 in the *5 SWP Head Range* SOP, which can also be posted on the SWP test bench next to the computer.

Create I-V Curve for each irradiance step in Chroma

16. Once you've calculated the irradiance step power points in the *IrradianceData* template and set up the LabView program, you may then input data onto the computer in the Chroma software to create the I-V curves that will be used for testing.

17. Turn the Chroma PV simulator ON by pressing the power button on the unit itself.

Figure 11. The Chroma unit OFF has a blank screen- press the button on the left of the screen to turn the unit on.

18. On the computer, click on the Chroma software to open up the program.

19. The software will open to the screen below. Click on "USB" on the slide bar for the interface since the PV simulator and the computer is connected via USB. Then click on "Communication Scan" on the top tool bar to ensure the computer recognizes the connection. Ensure that to the right of slide bar, it reads "USB" and next to it in grey, the recognized USB being used. If the screen looks like the picture below, you may then click "Set OK" to move onto the next step.

    a. Note that if the software does not recognize the USB input, double check that the USB dock on the test bench is plugged into the computer. Close out the software on the computer and re-open it to try to connect again.
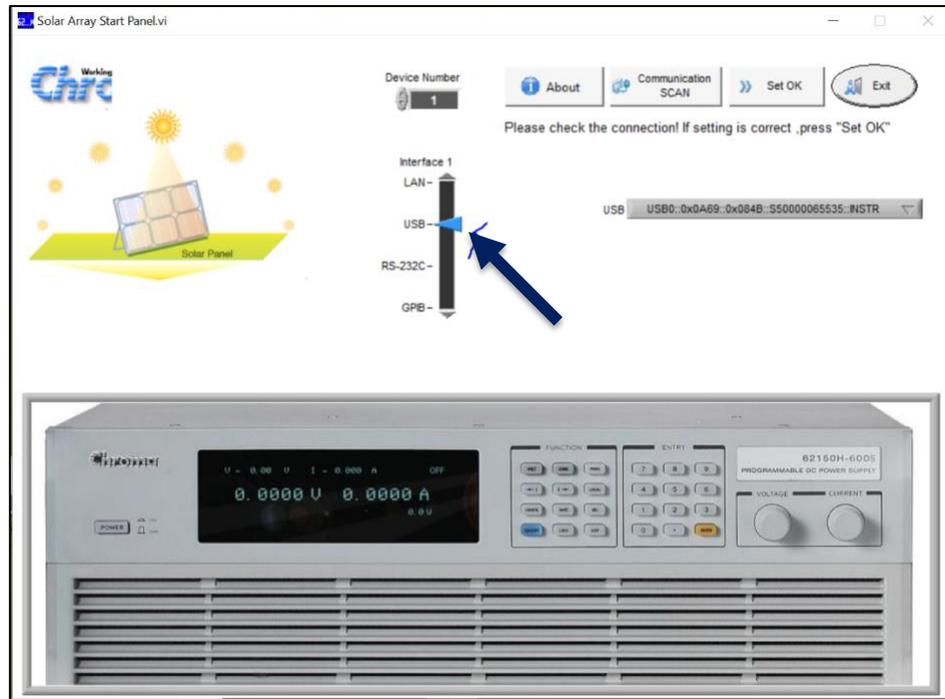
Figure 12. Slider to choose type of connection to laptop for Chroma software.

20. The next screen is the working display, where there will be an IV curve developed for each irradiance step. The red border in the figure below represents the output measurements based upon the input entered in the yellow bordered tables.
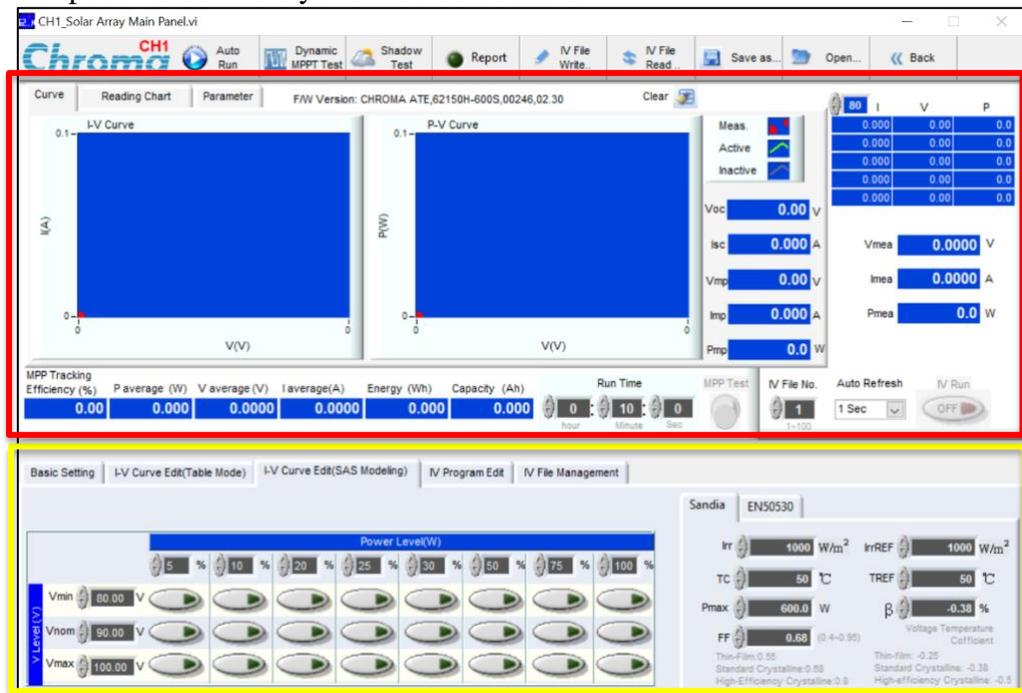
Figure 13. Chroma software window.

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21. Before entering in the IV curves, check back to the LabView to ensure that it's not specifying a PV input voltage and current significantly higher than zero (while the power input is actually zero).
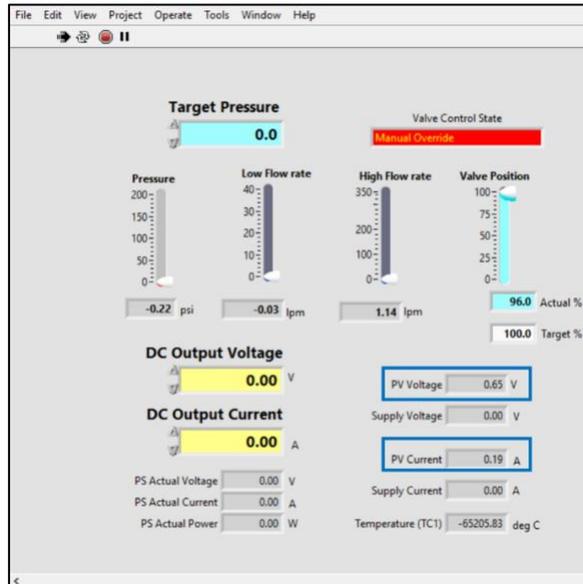
Figure 14. LabView window- where to read the input voltage and current during testing.

    a. If voltage or current are significantly more than zero, check to see if the values match the offsets in the testing spreadsheet. If not, consult with the Lab Manager so that the offsets can be rechecked/ rerecorded prior to testing following the *10 SWP Calibration and Maintenance* SOP.

22. First, take a look at the *IrradianceData* testing spreadsheet, and find the calculated Pmax (at TMOT, with offsets-from Step 1). Enter Pmax (at TMOT, with offsets) into the "Pmax" input box under the "Sandia tab" on the bottom right of the Chroma software screen.

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TABLE 1. Initial inputs		
Inputs		**notes**
PV temperature coefficient (%/° C)	-0.35%	This means that for every 1 degree Celsius , the PV panel will decrease in efficiency by this percentage. If the temperature coeff isn't provided, use the Table to the right to assume a value for this calculation.
Pmax at STC (W)	188	--
Vmax	24	V
Imax	7.8	A
FOB cost	500.0	WITHOUT the PV module (if possible)
Retail Cost	$ 900	*note, this is the cost WITHOUT the PV module. IF retail price is given (instead of FOB), overwrite formula to the left in col. B and input retail cost provided.
Simulated head [m]	25	
vertical distance added by the test bench	1	changed if the test set up is changed or using a different test bench. This accounts for the vertical distance from the surface of the source water up to the inlet to the test bench pipe network.
$/W	0.81	CLASP guidance
PV module cost	$ 152.28	delete if PV modules are already included in system cost
STC Temperature (degrees C)	25	--
TMOT temperature (degrees C)	50	--
change in temperature (degrees C)	25	--
efficiency loss from STC to TMOT (%)	-9%	--
Vmax, calculated (50 degrees C) (V)	21.90	Calculated. Use this to input into test report template.
Imax, calculated (50 degrees C) (A)	7.83	Calculated. Use this to input into test report template.
PTMOT, calculated (50 degrees C) (W)	171.55	Calculated. Use this to input into test report template.
Vmax, calculated (50 degrees C) (V), **with offset**	22.80	Use this when testing. Still be aware if the Voc based on this Vmp will exceed system or product capabilities and make adjustments when possible so that these boundaries are not exceeded. This value not to be added to test report
PTMOT, calculated (50 degrees C) (W), **with offsets**	183.84	Use this when testing- this will be the simulated max power in the Chroma. This value not to be added to test report
Voltage offset for the DAQ measurements (V)	0.9000	These shouldn't be changed often unless more than 6 months has gone since using the test bench by or the DAQ has been updated. Ensure these match the other testing templates and the most recently saved calibration spreadsheet for the DAQ voltage and current offsets (copy and paste these values in from the dAQ current/voltage calibration spreadsheet) .
Current offset for the DAQ measurements (A)	0.230	

Figure 15. Use the TMOT Pmp with offsets included for Chroma software input.
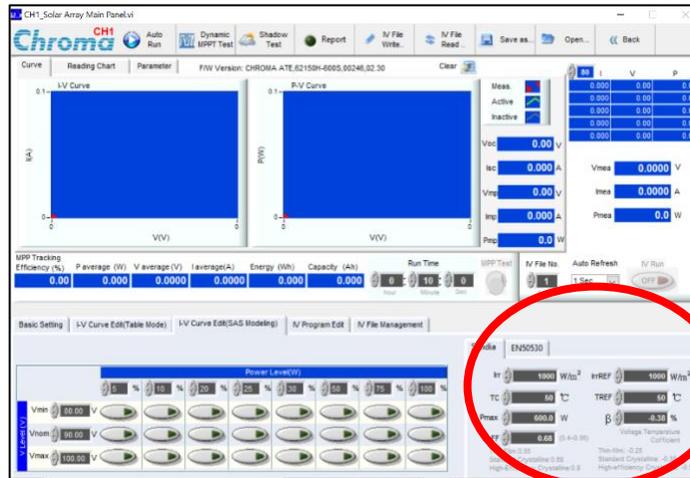
Figure 16. Programming PV input specs in the Chroma software.

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Figure 17. Pmax in the Chroma software should be Pmax at TMOT determined in the *IrradianceData* spreadsheet.

23. Sandia is a PV module performance model with the inputs indicated in the darker grey boxes in this tab. Follow this procedure on inputting values into this:

Table 1. Sandia inputs for programming PV into Chroma software

Parameter	Input Value
Irr	1000 (this should be default)
TC	50 (this should be default, TMOT temp)
Pmax	* enter in the TMOT Pmax from IrradianceData spreadsheet here*
FF	Keep at 0.68, default, unless manufacturer specifies type of PV cell material
IrrREF	1000 (this should be default)
TREF	50 (this should be default, TMOT temp)
B	-0.38 (keep at this default unless the manufacturer specifies the temperature coefficient for the advertised or included PV module(s))

24. Next, enter the maximum TMOT voltage (Vmax, with offsets), which is pulled from the *IrradianceData* spreadsheet from "Vmax, calculated (50 degrees C) (V), with offset (below) into the I-V Curve Edit (SAS modeling) tab table in the Chroma software in the "Vmax" row.

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TABLE 1. Initial inputs		
Inputs		**notes**
PV temperature coefficient (%/ · C)	-0.35%	This means that for every 1 degree Celsius , the PV panel will decrease in efficiency by this percentage. If the temperature coeff isn't provided, use the Table to the right to assume a value for this calculation.
Pmax at STC (W)	188	--
Vmax	24	V
Imax	7.8	A
FOB cost	500.0	WITHOUT the PV module (if possible)
Retail Cost	$ 900	*note, this is the cost WITHOUT the PV module. IF retail price is given (instead of FOB), overwrite formula to the left in col. B and input retail cost provided.
Simulated head [m]	25	
vertical distance added by the test bench	1	but changed if the test set up is changed or using a different test bench. This accounts for the vertical distance from the surface of the source water up to the inlet to the test bench pipe network.
$/W	0.81	CLASP guidance
PV module cost	$ 152.28	delete if PV modules are already included in system cost
STC Temperature (degrees C)	25	--
TMOT temperature (degrees C)	50	--
change in temperature (degrees C)	25	--
efficiency loss from STC to TMOT (%)	-9%	--
Vmax, calculated (50 degrees C) (V)	21.90	Calculated. Use this to input into test report template.
Imax, calculated (50 degrees C) (A)	7.83	Calculated. Use this to input into test report template.
PTMOT, calculated (50 degrees C) (W)	171.55	Calculated. Use this to input into test report template.
Vmax, calculated (50 degrees C) (V), **with offset**	22.80	Use this when testing. Still be aware if the Voc based on this Vmp will exceed system or product capabilities and make adjustments when possible so that these boundaries are not exceeded. This value not to be added to test report.
PTMOT, calculated (50 degrees C) (W), **with offsets**	183.84	Use this when testing- this will be the simulated max power in the Chroma. This value not to be added to test report.
Voltage offset for the DAQ measurements (V)	0.9000	These shouldn't be changed often unless more than 6 months has gone since using the test bench by or the DAQ has been updated. Ensure these match the other testing templates and the most recently saved calibration spreadsheet for the DAQ voltage and current offsets (copy and paste these values in from the dAQ current/voltage calibration spreadsheet) .
Current offset for the DAQ measurements (A)	0.230	

Figure 18. Table 1 in IrradianceData spreadsheet; use the Vmax with offset calculated for TMOT.
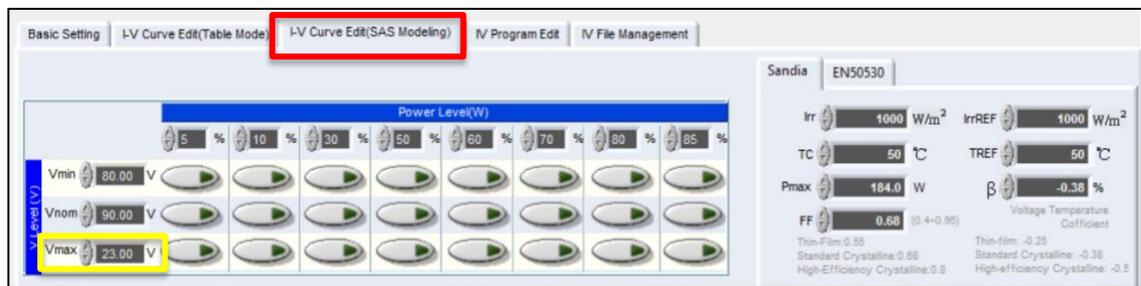
Figure 19. I-V Curve Edit tab in the Chroma Software, where I-V curves are programmed. Enter Vmax at TMOT into the last row.

25. Once Vmax is entered, navigate to percentage box in the first column of the table to create IV curves for each irradiance step.

    b. You will be referencing Table 2 in the *IrradianceData* testing spreadsheet for the next steps of entering in an IV curve for each irradiance step.

    c. Start with creating the IV curve for the lowest irradiance step. First, select the button at the bottom of the first column (green slider), to the right of the Vmax box in the Chroma software. You should see the IV curve on the graphs above as well as the set points Isc, Voc, Vmp, Imp, and Pmp filled out for the first irradiance step.

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d. Enter in different percentages in the percentage input of the same column until you see the correct power associated with the lowest irradiance step appear in the listed set points above and to the right of this table in the chroma software.

    i. Note that the percentage is in reference to the maximum irradiance, which is 1000 W/m2. For example, 5% is 50 W/m2 and 50% is 500 W/m2, etc.

TABLE 2. Flow measurements				Below, fill in the yellow cells with data from testing, which should also be copied/ pasted in the RawData# tabs to the right		
Irradiance step (list in steps of 50, at minimu. Testable range is 50 to 1000)	Simulated Power set points	*Corrected simulated power set points during testing to use (incorporating offsets)- these are NOT the power set points used in the test report; they are set points based upon test bench calibration for offsets. Use these to set the chroma or PV array parameters.*	Adjusted Flow	Flow	Measured supplied PV power	Pressure
[W/m2]	[W]	[W]	flow (lpm)	Q flow (lpm)	Power (W)	pressure (psig)
50.0	8.6	9.2	--			
200.0	34.3	36.8	--			
400.0	68.6	73.5	--			
500.0	85.8	91.9	--			
600.0	102.9	110.3	--			
700.0	120.1	128.7	--			
800.0	137.2	147.1	--			
850.0	145.8	156.3	--			
900.0	154.4	165.5	--			
950.0	163.0	174.7	--			
1000.0	171.6	183.8	--			

Figure 20. Table 2 in *IrradianceData* spreadsheet- match the simulated irradiance step power setpoints entered into the Chroma software to the blue column values in this table.
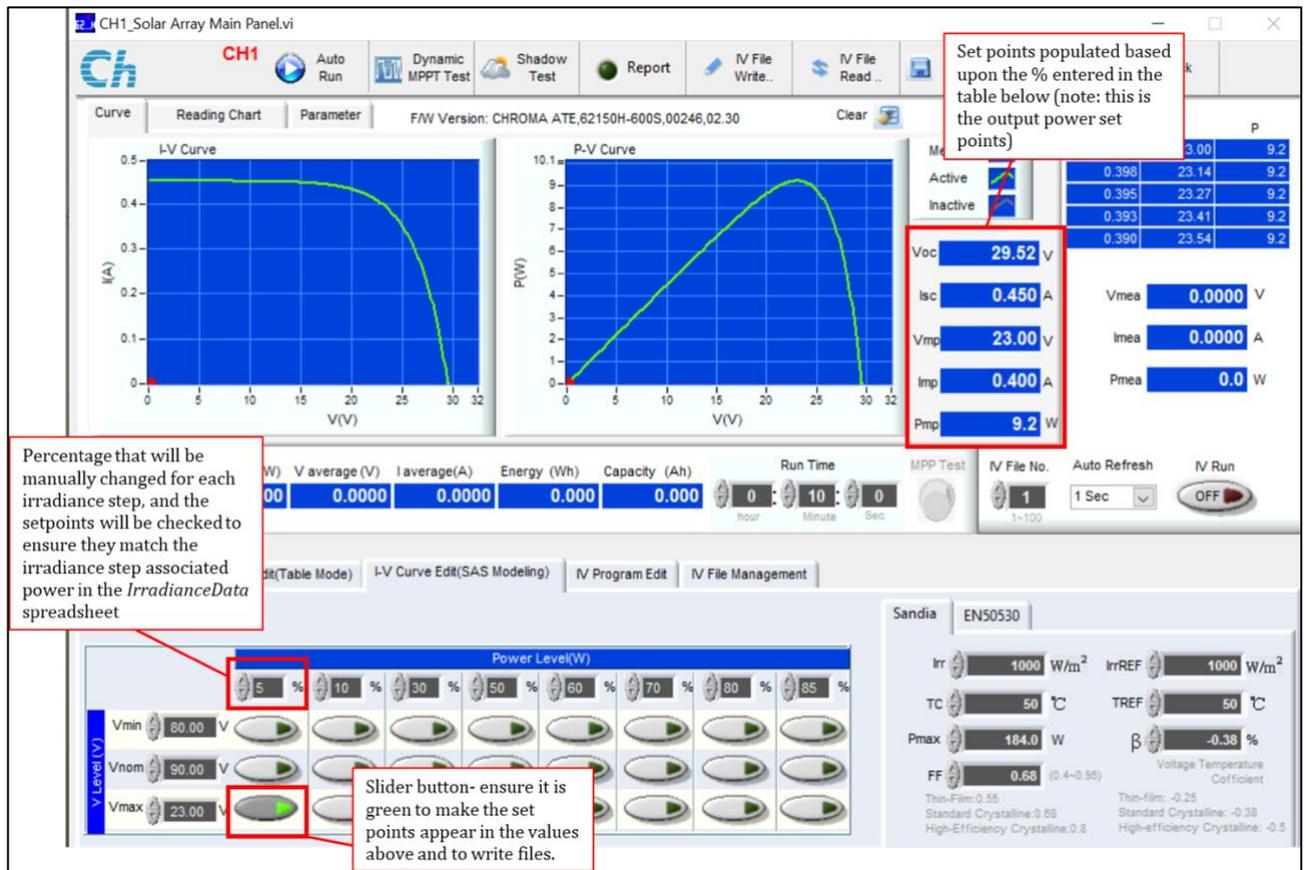
Figure 21. Chroma software window while creating an I-V curve for each simulated irradiance step defined in the *IrradianceData* spreadsheet.

  a. Notice in the example photos above the Pmp in the blue column in the *IrradianceData* spreadsheet for step 1, which is 9.2W, is being set in the Chroma software by adjusting the percentage field until the Pmp in the upper right-hand shows 9.2W to match the spreadsheet setpoint.

26. Verify with the *IrradianceData* spreadsheet that the power matches closely with the power calculated in the spreadsheet (the value that includes offsets). Also verify that the Isc and Voc shown in Chroma do not exceed the tolerances for the pump/controller. The figure below shows the Chroma software filled out based on pump-specific inputs.

  e. For example, for the example product entered above, 5% of the Vmax (23V) corresponds to a Pmax output of 9.2W in the Chroma software. You can double check that 9.2W corresponds to the 50W/m2 irradiance set point determined be the *IrradianceData* spreadsheet (in the red box in the figure above).

27. Once everything is verified and correct for the irradiance step, it is best practice to write each power step to a separate file in Chroma. Starting with "IV File No." at 1, click "IV File Write" at the top of the screen. That will write the data for that power step into a file so that it can be read in again if needed, without having to re-enter anything. Note that the green slider button in the table must be active in order for the data for that point to be written to a

file. ALWAYS check that the file being written is for the correct power input parameters associated with that step.
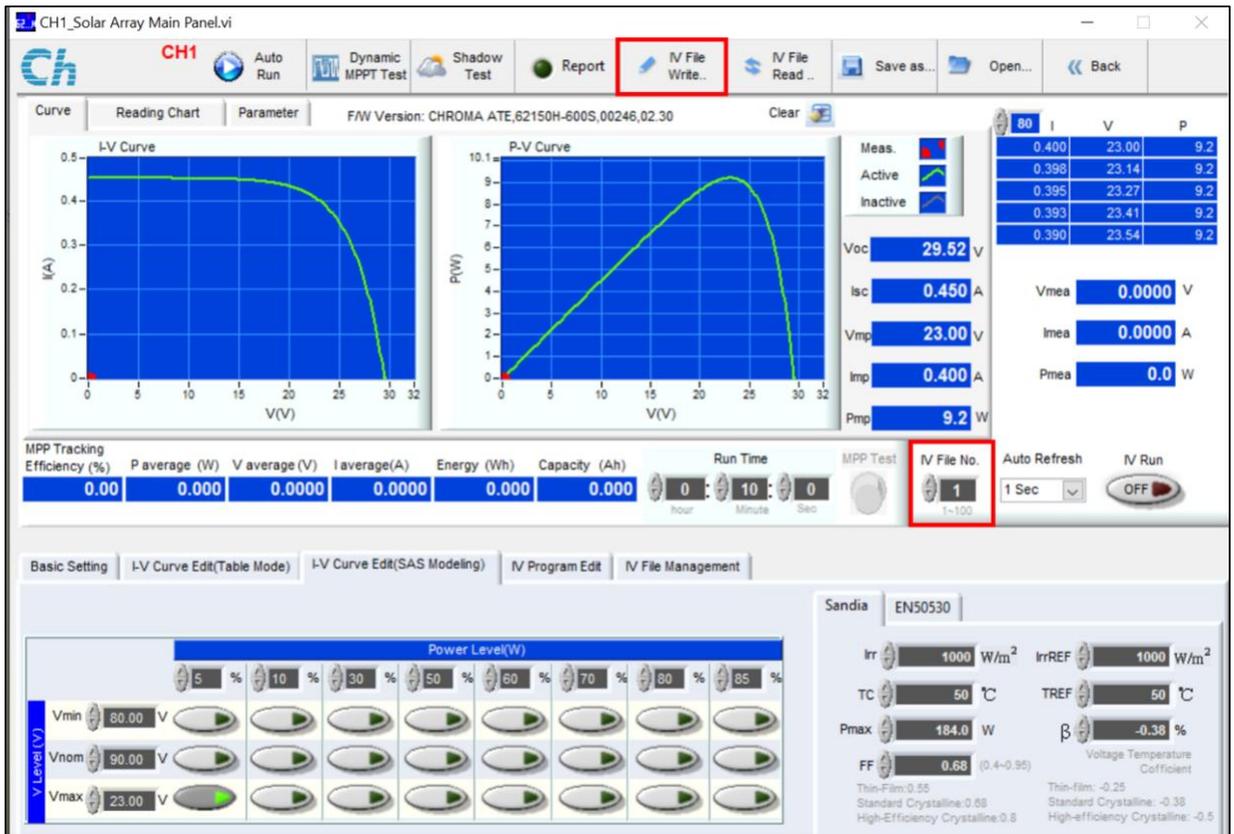
Figure 22. Writing each I-V curve data file once programmed in Chroma software.

28. Repeat steps 10-12 with each irradiance step from the lowest simulated irradiance step up to 1000 W/m². Be sure to change the "IV File No." by clicking on the "up" arrow right next to the "IV File No" input for each step so nothing gets overwritten (each file write is numbered, representing a separate IV curve written).
    f. As you go through each set point as determined in the *IrradianceData* spreadsheet, verify that the Isc, Voc, Vmp, Imp, and Pmp are within the proper range and that the Pmp matches the value calculated for that irradiance step (Table 2 in *IrradianceData* spreadsheet).
29. Once each power step is written to a separate file, its best practice to verify that the files were written correctly and that the values are accurate in the files. To do so, start with "IV File No." 1 and press "IV File Read" at the top of the screen. This will read in the data that was written out to IV File No. 1. Verify that the data is correct for that step and continue increasing the IV File No. and pressing "IV File Read" to verify each file's data.

Figure 23. Each written file may be read into the software again to use as the power input.

30. Now that each irradiance step is programmed into Chroma, the Solar Day test is ready to be performed.

31. To save the I-V curves you've just created, click on the "Save as…" button on the top, and you can name the file the name of the pump you are currently testing. That way, if you need to stop testing and pick back up, you won't have to re-create the I-V curves, but you could just click "Open" and select which file you'd like to open up that has been saved.

Figure 24. Save datafile in Chroma software for each SWP tested to easily use again.

Conducting the test

32. Normally, you will have already done the *4 SWP Cold Start and Inrush SOP* prior to starting this test, and you will have a better sense of which irradiance step to begin with. In general, you will want to start this test by working in the Chroma software to select *IV File No. 1* (or step 1 that you programmed into the Chroma corresponding to step 1 that you entered into the *IrradianceData* spreadsheet) and the selecting "IV File Read" so that this irradiance step is queued for when the Chroma output power is turned on.
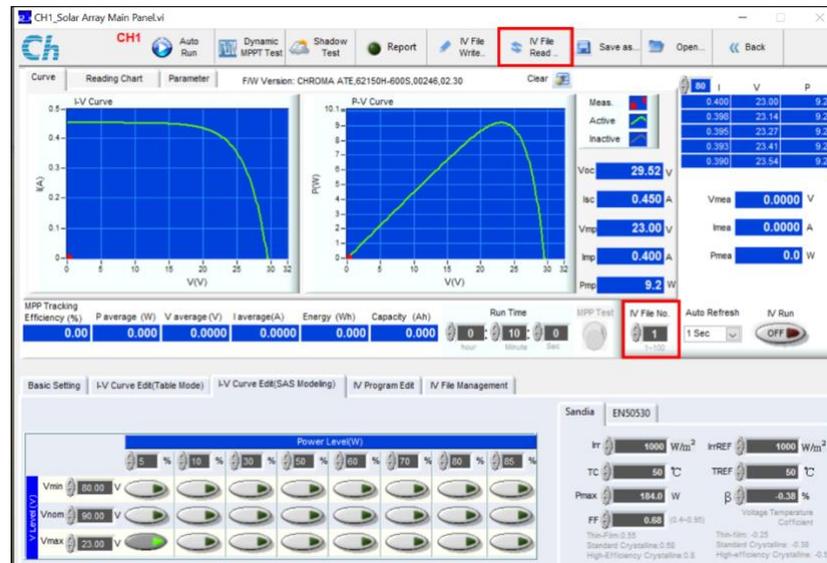
Figure 25. Read in file 1 first for testing.

33. Ensure that when you read in *IV File No. 1* (or step 1) that the voltage, current, and power values that populate in the software look correct. Specifically, ensure that:
    a. Voc and Isc look correct, and they are not exceeding the max voltage/ current inputs for the controller or pump (if controller is integrated or no controller is included)
    b. Vmp and Imp look correct, and they are not exceeding the max voltage/ current inputs for the controller
    c. Imp/Isc do not exceed the fuse switch installed on the test bench (which currently has a 16A maximum). If so, then you will need to rewire product to the test bench so that the fuse switch is bypassed in the circuit, or connect a higher amp fuse switch).
    d. Ensure that the Pmp is the same value that is calculated in Table 2 in the *IrradianceData* spreadsheet. For example, if the first step you will test correlates to the 50W/m2 step, then the power output of the chroma (Pmp in the software) must match the power calculated in the blue column in Table 2 in the *IrradianceData* spreadsheet (see photos in step 25 above).
34. Once you've read in step 1, **before you turn the output power of the Chroma output ON**, double check that:
    a. The pump and controller are wired up properly
    b. The pump is either in the water (if submersible) or ready to be primed (if surface)
    c. The water trough is full of clean, cool, debris-free water
    d. The high-flow ball valve in the test bench pipe network is full open and the low-flow leg of the network is closed off so that water will only flow through the high-flow leg.
    e. LabView is set up, and no files are currently open/ being read.
    f. The 16A Fuse switch is in its "up" position to allow for the circuit to be closed.

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g. The output hose of the test bench is positioned in the source water and that the pump is properly positioned.

35. Turn the Chroma output ON to power the controller/pump by clicking on the *IV Run* button

in the Chroma software display [IV Run OFF] (it should darken when the output is ON).

   a. For surface pumps, you generally will need to prime them before they are able to start pumping water. This entails pouring water into the pump's inlet right after starting to power it, and then once it starts pumping, immediately placing it underwater. This will allow the pump to form suction for pumping water throughout the test and only needs to be done at the very beginning of testing, or whenever the pump's inlet is removed from the water.

      i. Note that if the pump needs to be primed, this would typically be done at the simulated power step associated with 700 W/m^2 or 800 W/m^2 rather than the lowest step.

   b. For submersible pumps, there's generally not a pre-step needed for them to start pumping (unless specified); just ensure that the intake screen and intake area of the pump is fully submersed in water by at least a few inches to avoid intaking any air.

   c. Note: if the Cold Start Test already occurred immediately prior to this test, priming won't need to be done again if the pump's inlet was not removed from the water in between tests (for surface pumps).

36. Open up the LabView screen on the computer and see if there's any flow being measured.
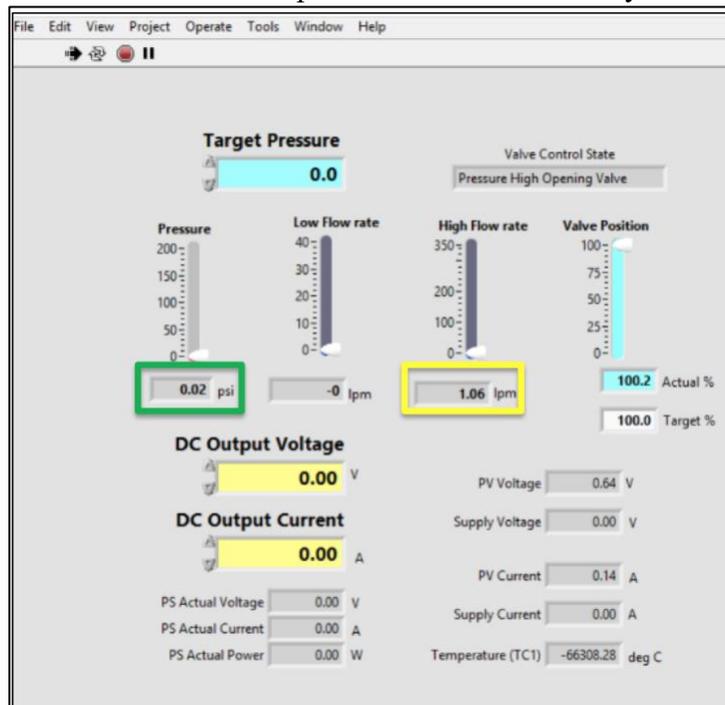
Figure 26. Look at measured pressure and flow in LabView window.

37. If there IS flow greater than 1 lpm, then calculate the system pressure required to simulate

the head specified by the manufacturer or determined in the Head Range Test, and start increasing the system pressure doing the following:

    a. Slowly, start closing the high flow ball valve while watching the pressure reading (in the green rectangle in the photo above) and High Flow rate measurements (in the yellow rectangle in the photo above) in LabView.

Figure 27. Slowly closing the high flow ball valve.

38. If there is NO flow (if the flow rate is less than 1 lpm), then you may turn off the Chroma's output by clicking on the same IV Run button, and then following steps 32-37 but at the next irradiance step (note in the Chroma software, you will have to read in the correct file number associated with the irradiance step IV curve originally entered and saved).

39. Once you determine the lowest irradiance step/ power input that allows for the pump to achieve flow over 1 lpm *at its simulated vertical head*, maintain that simulated head for 1-2 minutes as you write a file for testing data for that step in LabView.

    a. NOTE: before writing the test data to a file in LabView, ensure the correct ball valve is being utilized.

        i. For flows lower than 25 lpm being measured, transition to the low flow ball valve on the higher leg of the test bench. For flows 25 lpm and greater, use the high flow ball valve.

            1. To switch from the higher to lower flow ball valve leg, open the low flow valve while the high flow valve is already open. Then, slowly

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close the high flow valve, trying to maintain the flow at the lower value.

2. Do not move on to the next step until only one ball valve is open and the other is closed.
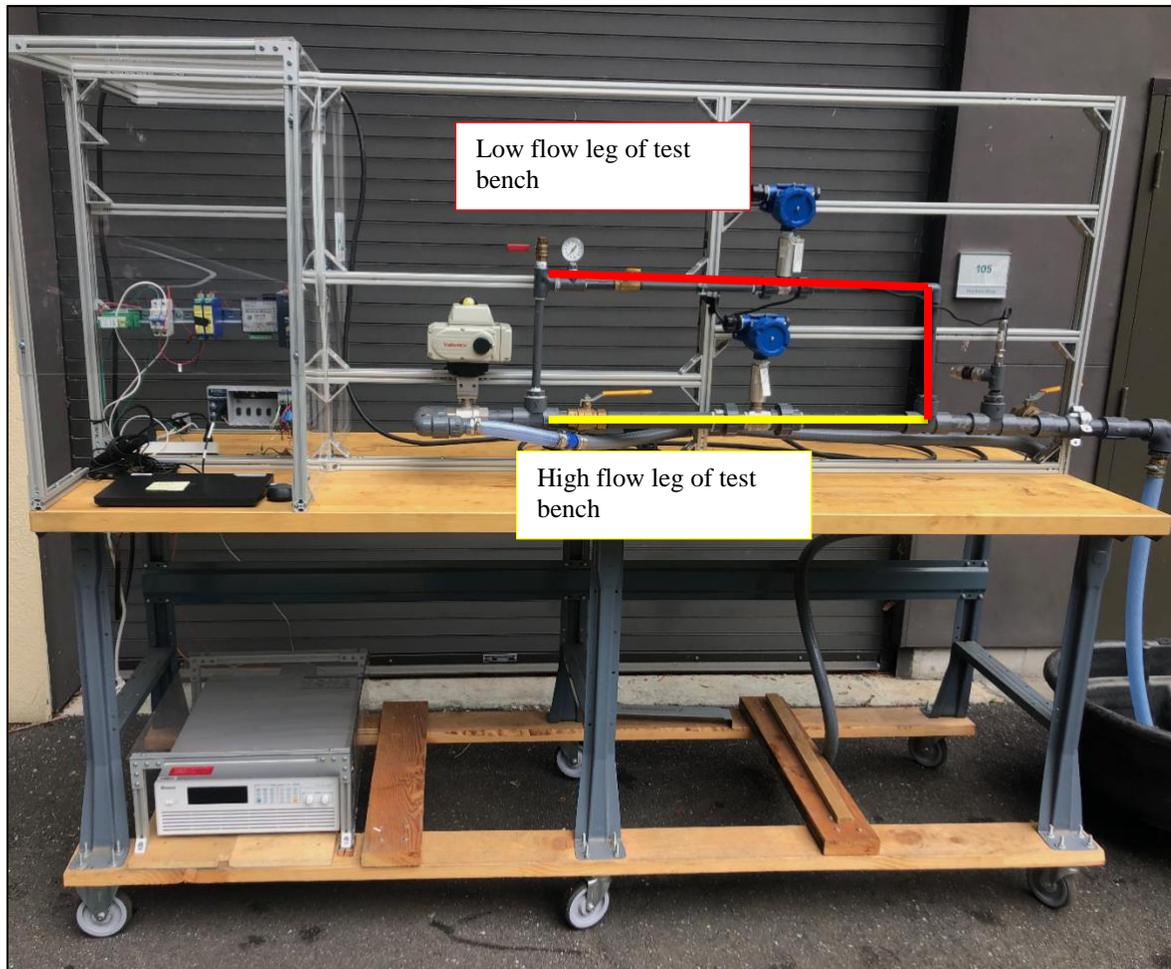
Figure 28. Test bench low flow and high flow legs, each with its own ball valve and flow meter; only one should be used at a time.

b. Navigate to the Datalog Settings tab in LabView. Ensure the data file is closed, indicated by the red slider button next to "Close Data File". Input the name of the data file you want to write for this irradiance step. It is best practice to use the following naming convention *<Pump name>- <Test>-< irradiance step>* (see figure below).
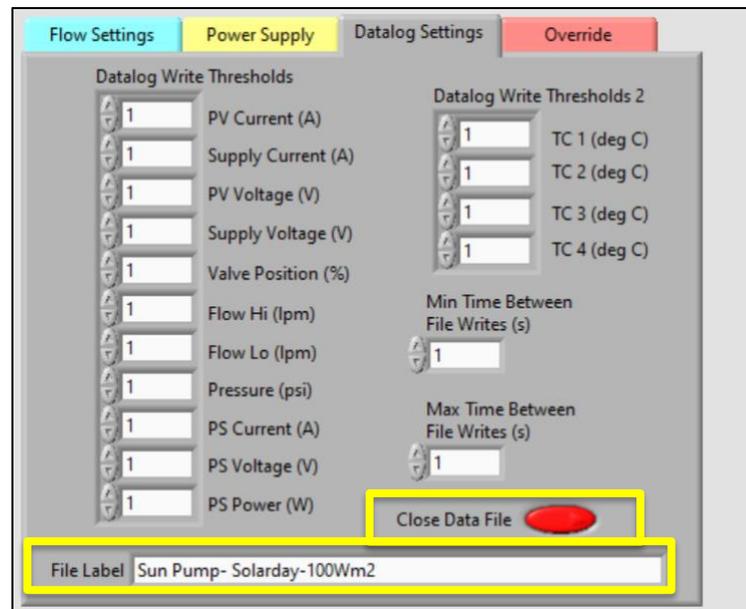
Figure 29. Input filename of raw data file while the data file button is closed in LabView.
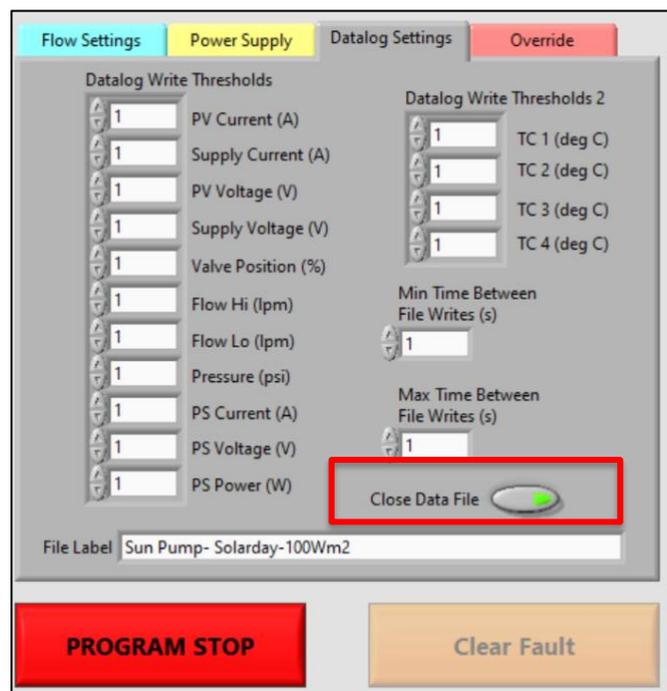
Figure 30. Open (click on) the data file button when ready to start recording test in LabView.

c. After inputting the file label name, click on the slider button next to "Close Data File" so that it turns green, which indicates that the file is being written.

d. As the file is being written for this irradiance step, watch the pressure (psi) measurement in LabView and try to maintain the target pressure. If the pressure is significantly oscillating, you'll need to continuously adjust the ball valve handle to maintain the target pressure as best as you can.

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e. After about two minutes have passed, you may click on the green slider in LabView to close the file, and the button will turn red.

40. You may then turn off the Chroma output in the Chroma software after the file has been written for that irradiance step/ head.

41. Open up the ball valve fully from the position it was in during testing.

42. In the Chroma, navigate to the next irradiance step that was previously saved in the software by clicking the IV file arrow up to the next step and reading in the IV curve for that step. Then, follow steps 39-41 for each step until reaching the 1000W/m2 step.

   a. Note that not all irradiance steps with a step size of 50 W/m2 must be tested. The minimum steps that must always be tested, if applicable are: the lowest irradiance step (flow >1 lpm), 700W/m2, 800W/m2, 850 W/m2, 900 W/m2, 950 W/m2, and 1000 W/m2. Other irradiance steps may also be tested, at the tester's discretion, but they must be in the interval of 50W/m2.

43. Copy or move all of the raw data files that were written during this test into the testing folder for the pump under test within the SolarDay subfolder made.

   a. The raw data should be saved directly from LabView onto the testing computer in a folder (this should be set up when the testing LabView file is initially saved on the testing computer).

   b. Note that the filename of the data file won't automatically match the name specified in LabView; the raw data files will, by default, be displayed in the following format: "pumptester-YYMMDD". It is best practice to update the filename before moving the raw data file into the testing folder. The files may be renamed to the following format: "pump name-test-irradiance step".

44. While testing, determine whether or not the SWP under test is compatible with the Chroma software.

   a. While testing, you can see the I-V curve in real time in the Chroma software along with the point along the curve where the SWP is operating from. Notice if the power point (of voltage and current) being drawn/ utilized by the pump is either close to or on the left-side on the curve of the "elbow" or maximum power point; this may indicate normal behavior and good interaction between a SWP's controller and the Chroma power output.

   b. There are several indicators that the interaction between the SWP and the Chroma is not compatible. See some following indicators that have been observed thus far:

      i. If the SWP is drawing power that is on the right-hand side of the maximum power point (elbow) of the I-V Curve, and/or

      ii. If the SWP power point is oscillating along the right-hand side of the I-V curve and very unstable, and/or

      iii. If the SWP power point is oscillating off of the curve.

   c. If any of the conditions in the steps above are observed, this may indicate that the SWP may need to be tested using the Alternative Test Method.

      i. It is suggested to try observing what the behavior is at different irradiance

steps, because sometimes strange behavior is isolated to one specific power input.
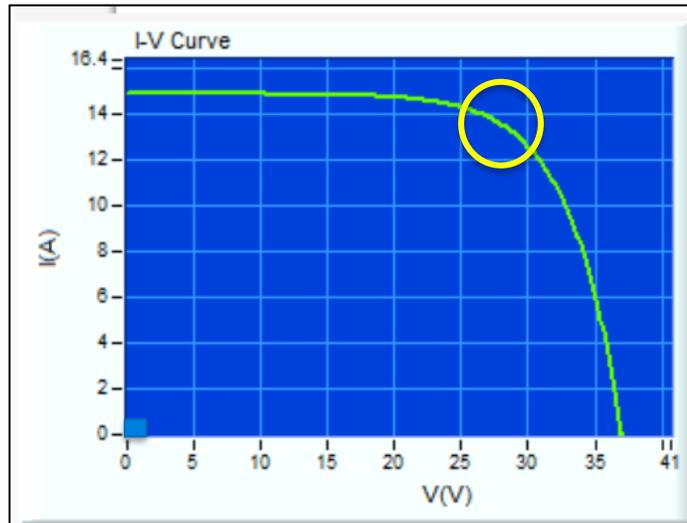
Figure 31. I-V Curve display in Chroma software (in real-time while testing). The "elbow" or maximum power point possible along the curve is within the yellow circle here.
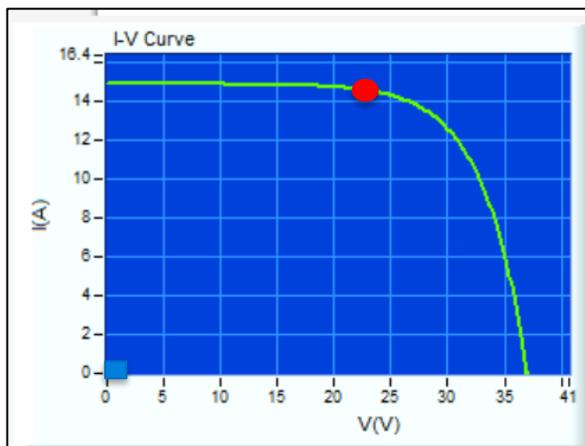
Figure 32. "Normal" behavior of a SWP being tested using the Chroma. The red dot is the power point at which the SWP is functioning at.
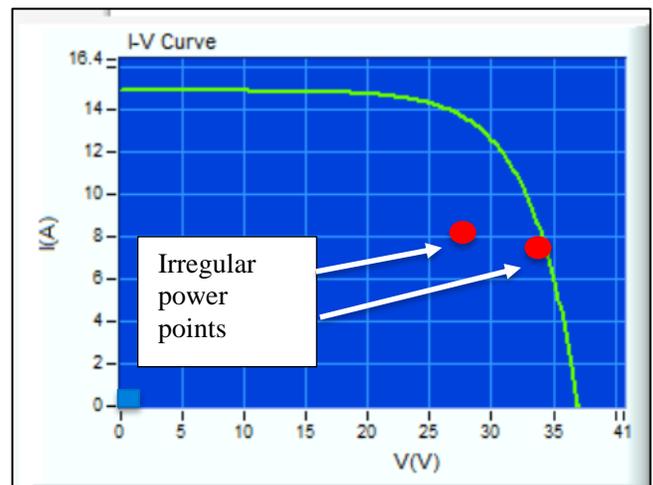
Figure 33. Not "normal" behavior of a SWP being tested using the Chroma- either the SWP power point is operating to the right of the "elbow" of the I-V curve OR it is operating somewhere off of the I-V curve, and may be unstable.

    d.   Sometimes, if there is incompatibility between a SWP and the Chroma, it is difficult to determine during the Cold Start Test and Inrush Current measurement, since less input power points are used for these preliminary tests, so the Solar Day Test should be looked at for determining this compatibility.

45. If there is incompatibility observed between the SWP or Chroma, notify the Lab Manager, and it may be determined that all testing should be conducted using the Alternative Test Method (refer to this SOP for instructions). Note that if this is the case, all tests that utilize the test bench that have already been done must be carried out again using the Alternative

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Test Method set up to ensure accurate results (See *11 SWP Alternative Test Method* SOP).

    a. Usually, incompatibility can be determined just observing the I-V curve in the Chroma software in real-time; however, any other "odd" behavior during testing could lead to the same conclusion. If there is anything "off" or unexpected that happens during testing in the way the SWP is performing, it is always best practice to discuss next steps with the Lab Manager to determine the best path forward.

Analyzing test results

After the test is done and all results are saved in the product testing folder, the data may be analyzed in the *IrradianceData* testing spreadsheet that was used in the beginning of this procedure. Note that in order to complete all of the analysis, the Head Range Test must have also already been performed as some of the Solar Day inputs are pulled from Head Range.

46. In the *IrradianceData* spreadsheet, there is a color-code. The yellow cells indicate places where user input is needed; the blue, white, or grey cells are formula cells; and the pink cells hold instructions for the user that provide guidance.
47. Before moving forward from Table 2 in the *Inputs* tab, the raw data must be entered into the spreadsheet.
48. Use the green *RawDataX* tabs to input the data saved in the raw data files from LabView.
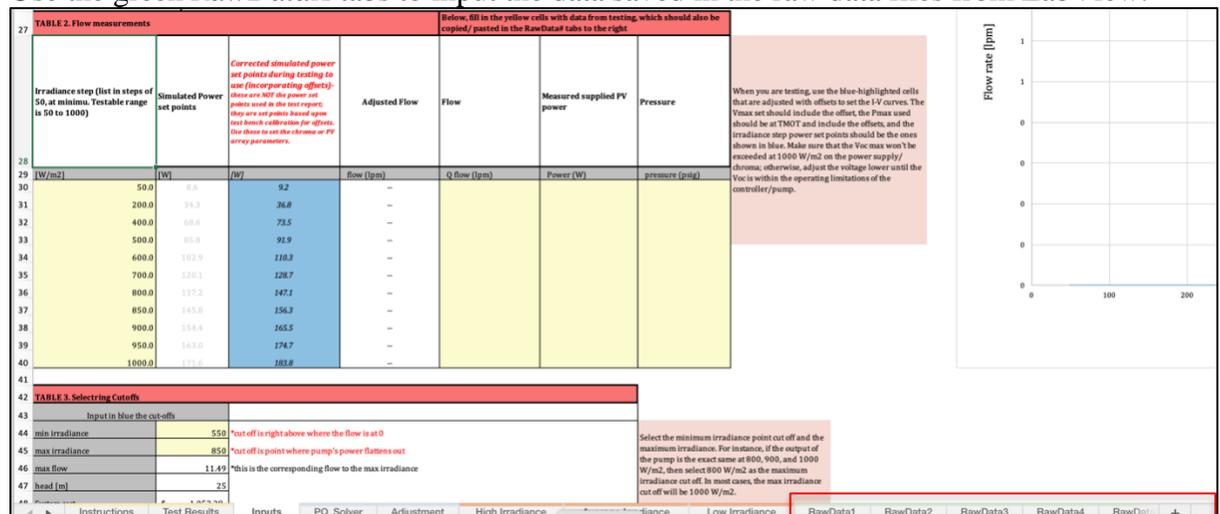
Figure 34. *IrradianceData* **spreadsheet.**

    a. Open the raw data file for the lowest irradiance from LabView, which should be saved in the Solar Day subfolder for the pump under test.

        i. Note that the raw data for each simulated irradiance will be copy/ pasted into the *IrradianceData* spreadsheet in increasing order.

    b. Select all of the content (shortcut: CTRL+A) and copy it (CTRL+C).

    c. Paste it (CTRL+V) into the RawData1 tab in the *IrradianceData* spreadsheet, and follow the instructions in that tab that tells you where to paste it.

Figure 35. *IrradianceData* **spreadsheet, where to paste raw data.**

   d. Organize the data by copying and pasting the values in columns for current, voltage, flow, and pressure into the yellow highlighted columns to the left (figure above). The yellow columns will be averaged in row 2, which is the row of values needed to be copy/ pasted back into the *Inputs* tab in the row corresponding to the irradiance step the raw data is related to (Figure below).

      i. NOTE: there are two columns for flow measurements: ensure you pull the correct column of data over to the yellow cells. For instance, if you only used the low flow valve, then ignore the high flow column of data and only copy/ paste over the low flow column of data into the yellow cells to average and use for the analysis.

     ii. Notice that there is a white-colored column that calculates and adjusted flowrate based upon the calibration of the test bench equipment. You do not need to overwrite this column.
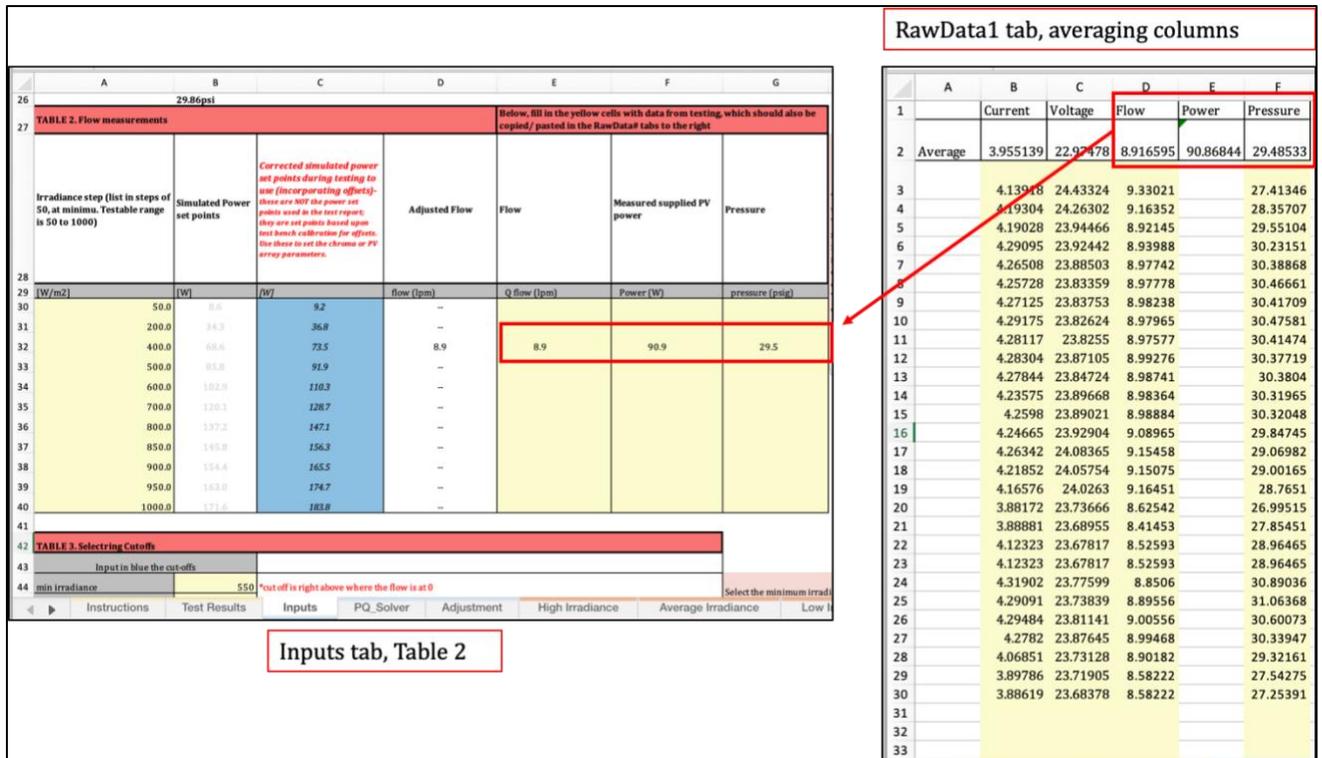
Figure 36. *IrradianceData* spreadsheet, where to move raw data averages.

e. Notice in the figure above that the averaged raw data was copy and pasted into the 400W/m2 row in the Inputs tab. This was because this raw data was taken while simulating the 400W/m2 irradiance step, indicated in its filename. Since 400W/m2 was the lowest irradiance for this example for this test, then you will want to move it up in Table 2 so that it is in the top row, as shown below. The only empty cells in this table should be below all data (not in between or above measurements).
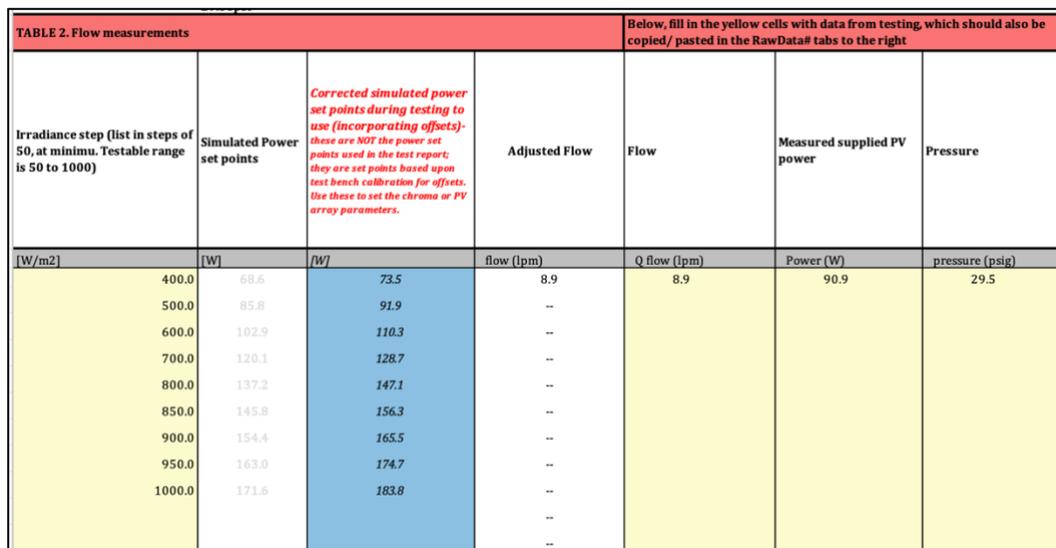
Figure 37. *IrradianceData* spreadsheet, Table 2 being filled in.

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49. Repeat steps 2-3, using a *RawDataX* tab for each simulated irradiance, working your way up to 1000 W/m2.

50. After Table 2 in the *IrradianceData* spreadsheet is filled in with all of the raw data from testing, you may move forward and fill out Table 3, below.

TABLE 3. Selectring Cutoffs			
Input in blue the cut-offs			
min irradiance		400	*cut off is right above where the flow is at 0
max irradiance		850	*cut off is point where pump's power flattens out
max flow		11.93	*this is the corresponding flow to the max irradiance
head [m]		25	
System cost	$	1,052.28	

Select the minimum irradiance point cut off and the maximum irradiance. For instance, if the output of the pump is the exact same at 800, 900, and 1000 W/m2, then select 800 W/m2 as the maximum irradiance cut off. In most cases, the max irradiance cut off will be 1000 W/m2.

| ▶ | Instructions | Test Results | Inputs | PQ_Solver | Adjustment | High Irradiance | Average Irradiance | Low Irradiance | RawD |

Figure 38. IrradianceData spreadsheet- filling in Table 3 with min/max irradiances.

51. In Table 3, you'll notice there are two inputs needed, a min irradiance and max irradiance. The minimum irradiance is the lowest irradiance that you have data and measurements for in Table 2. The max irradiance requires one additional check.

f. Most of the time, the max irradiance will be 1000; however, sometimes, like in this example case (figure above), the flow rate might not increase as the power input increases with higher irradiance steps; this may indicate that the pump has reached its maximum power input, or simulated irradiance step, in which its performance flattens out. This should be indicated in this table if it's the case.

g. In this example, see the figure below to see what Table 2 might look like in a case where 1000 W/m2 is not the max irradiance.

Figure 39. *IrradianceData* **spreadsheet- determining the max irradiance using Table 2 results.**

52. After Table 3 is fully filled out, navigate to the next tab in the spreadsheet, *PQ_Solver*.

Figure 40. *PQ_Solver* **tab; remove unused data in Table 4.**

53. In the *PQ_Solver* tab, you'll notice two tables and a plot. In Table 4, the yellow cells should contain data obtained directly from Table 2 in the Inputs tab for all of the *included* irradiance steps (enter this in manually). For instance, if we use the same example from the previous few steps, you would not include steps 900, 950, or 1000 W/m2 since we determined the max irradiance was 850 in Table 3 in the Inputs tab.

54. Make sure the grey columns in Table 4 are populated only in each row that lists an included irradiance step. The grey columns calculate *MPPT efficiency* (column D), calculated flow rate including test bench offsets (column F), and the square of residuals (column G).

55. Then, ensure the formulas in row 15 of Table 4 reference all of the calculations from each included irradiance step.

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Figure 41. Table 4- checking formulas.

56. Follow the instructions in light red in this tab, they are helpful especially for the next steps outlined below.

57. Use the Excel's Solver tool to determine the polynomial that can be best fit to the raw data in the plot on the right.

    a. Click on the "Data" ribbon on the top of the window.
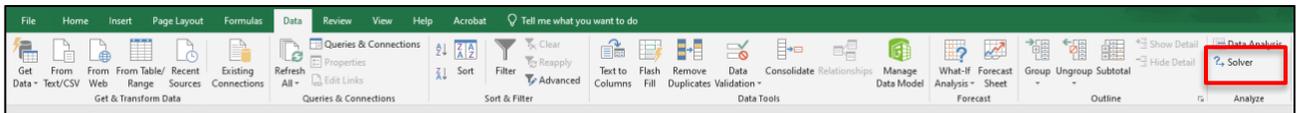
Figure 42. Solver button in the "Data" tab.

    b. Click on "Solver" (red rectangle in image above).

        i. Note if you do not see a Solver option, it will need to be installed.

        ii. Click on the "File" tab in the Excel window and navigate to "Options".

        iii. A pop-up window will appear. Click on "Add-ins", and select "Solver Add-in".

        iv. Click "OK" to add the solver package to Excel. You normally only need to do this once for a computer.
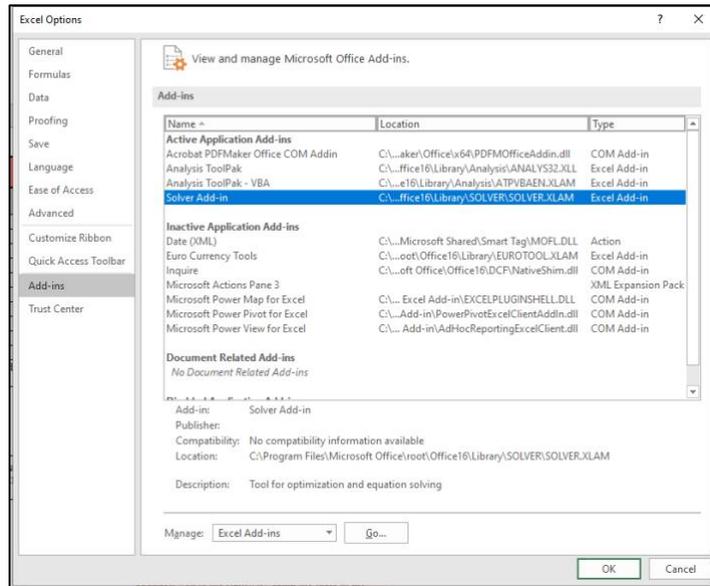
Figure 43. Adding the Solver package to Excel.

c. Once you click on Solver, a pop-up window will appear named "Solver Parameters".
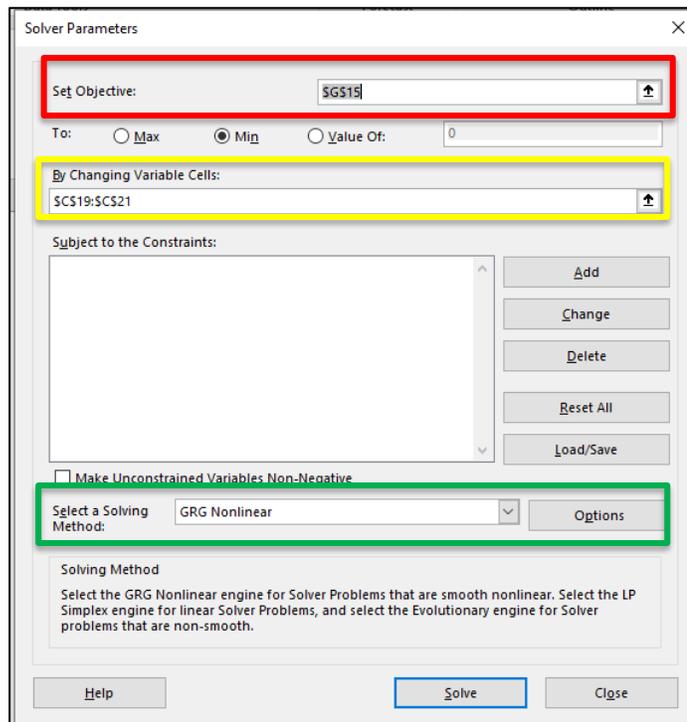
Figure 44. Solver pop-up window.

d. You will want to ensure the following are true:
  i. The objective cell selected is the sum of squared residuals in Table 4, cell G15.
  ii. The variable cells selected are the starting coefficients entered into the grey

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table below Table 4 and labeled as the changed variables (cells C19:C21).

Figure 45. Checking objective cell and variable cells referenced in Solver iterative calculations.

       iii.   The solving method is GRG Nonlinear (the calculation type used for this set of calculations).

   e.   Click "Solve". Excel might take a few seconds (or longer) to calculate multiple iterations attempting to reduce the objective cell so that it is as close to zero as possible. When solver is done, click "OK" in the pop-up window that appears and then look at cell G15 at the objective cell to see how close it is to zero. Also, take a look at the Irradiance/ Flow Curve plot to the right to see how close the orange line (fitted polynomial) is to the blue line (raw data).

Figure 46. Checking that the objective cell is close to zero and that the calculated line of best fit is close to the raw data plot after solving.

   f.   Always run another Solver calculation to make sure the objective cell doesn't change after the second round of iterations that could bring the number closer to zero.

   g.   If the objective cell is less than 10^1 and the calculated polynomial looks fairly fitted

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to the raw data line, it is OK to move forward to the next steps. If the objective cell is greater than 10^1, and the two plotted lines do not look close, then it's possible that a different polynomial or type of equation might need to be used for this specific pump. Notify the Lab Manager if this is the case for input.

  i. If a new equation is needed for the fitted line, ensure the following is updated to accommodate this change:

    1. Variable cells are changed and reformatted in the tab AND in the solver reference upon performing additional calculations with this tool.

    2. The calculated flow in column F in Table 4 has its formula adjusted so it is written as the new line formula and that it references the new variable cells (for instance, if the formula was written -ax2 + bx -c for a second-degree polynomial, update this to whatever equation is used for future iterations).

58. After Solver has been successfully used, and there is an acceptable fitted line to the raw data, move to the *Adjustment* tab in the spreadsheet.

Figure 47. *Adjustment* tab in *IrradianceData* spreadsheet.

59. In this tab, there is a lot of content; however, there is only one table that requires regular user input for each pump tested, which is highlighted in the yellow rectangle in the photo above.

  a. Open the *HeadRange* spreadsheet already filled in for the pump under test.

  b. Navigate to the "Calculations" tab and find the right-most variables table under the Flow Curve data. This table should say "for pasting into the Irradiance Curves Template for this pump" above it.

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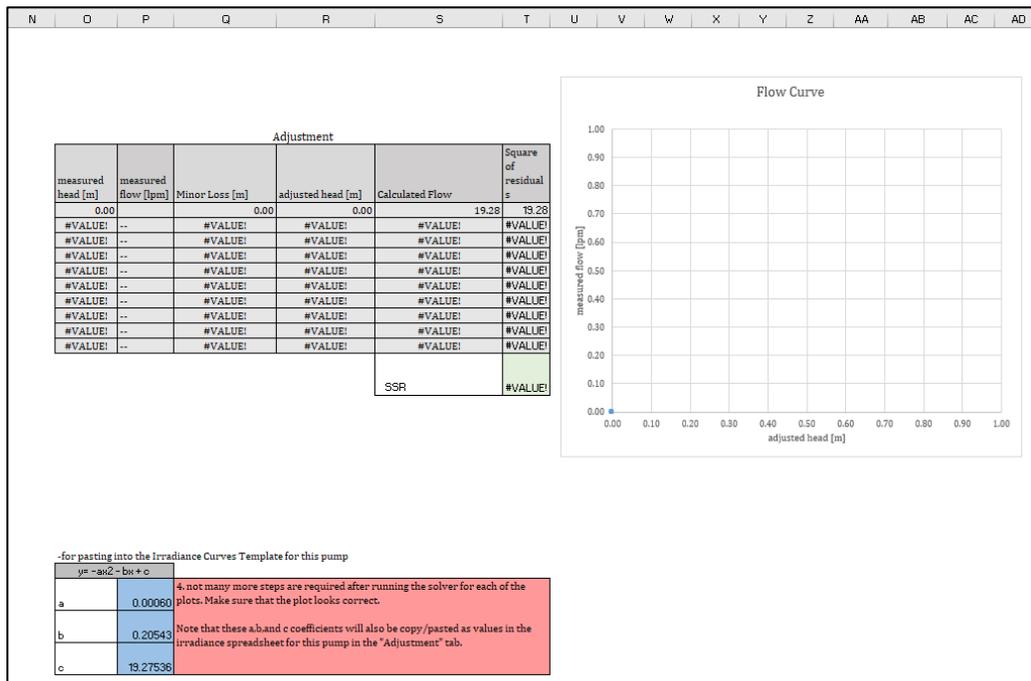
Figure 48. *Calculations* **tab in the** *HeadRange* **spreadsheet; this is where to find the variable cells for the flow curve to copy and paste into the** *Adjustment* **tab in the** *IrradianceData* **spreadsheet.**

    c. Copy the coefficients in cells Q26:Q29 for a,b, and c of the polynomial for the Flow curve and pate them into the yellow cells in the *IrradianceData* spreadsheet.
        i. These coefficients are incorporated into the offsets incorporating minor losses for flow rate.
    d. Note: these variables should only be copied and pasted from the *HeadRange* spreadsheet *after* the data from the Head Range test has been collected and fully analyzed.

60. Next, navigate to the orange tabs in the *IrradianceData* spreadsheet, named *High Irradiance*, *Average Irradiance*, and *Low Irradiance*. These tabs contain the calculations and solar day plots for the three defined solar days. The only action needed in these tabs is adjusting the y-axis so that the flow curve (green) sits below the irradiance curve (blue) in each plot.
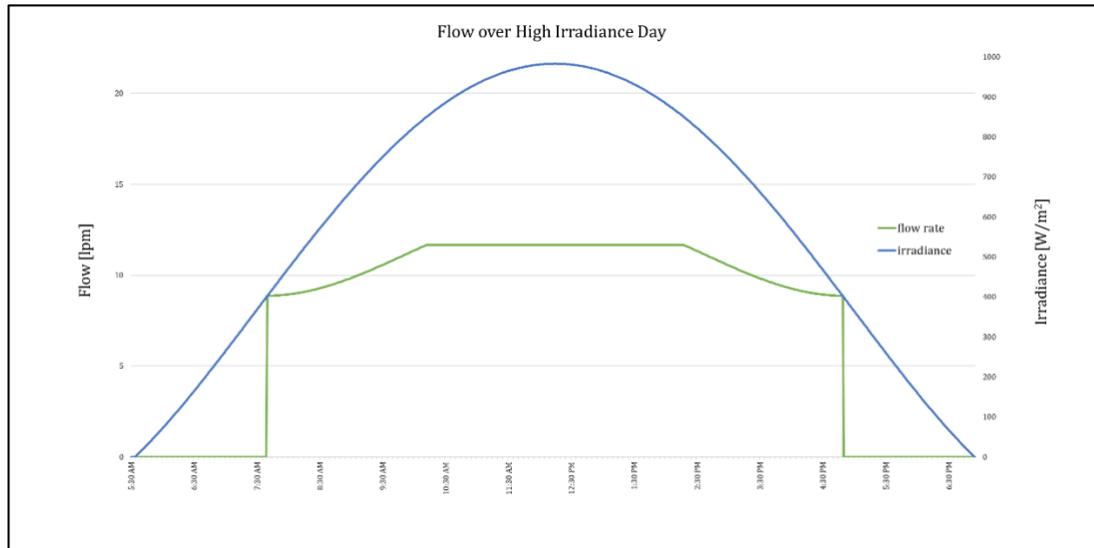
Figure 49. *High Irradiance* **tab in the** *IrradianceData* **spreadsheet; adjust the y-axis for Flow to ensure green line is under blue line.**

Reporting

61. After all the data analysis has been done and checked to ensure everything looks as expected, you may copy and paste the test results from this test into the test report template for this product.
    a. Note that a test report template should have been saved in the product testing folder prior to the Intake and Visual Screening procedure.
62. Open the test report spreadsheet for this product and navigate to the "Test Results" tab.
63. Scroll down to the "Simulated irradiance curve" section.

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75	Simulated irradiance curve				
76					
77	Sample	Simulated irradiance step [W/m2]	Simulated head step [m]	Simulated PV power [W]	Measured flow [lpm]
78					
79					
80					
81					
82					
83					
84					
85					
86					
87					
88	Simulated P-Q curve				
89					
90					
91					
92					
93					
94					

Figure 50. Test report template for product under test; where to paste in data in the "Simulated irradiance curve" section.

64. Now go back to the *IrradianceData* spreadsheet and open the *Test Results* tab in this spreadsheet.

65. Copy and paste the first table from the *IrradianceData* into the blank table (in the red rectangle in the photo above) in the test report spreadsheet. Make sure to paste as a value so that the formula is not pasted, too.

Irradiance Step [W/m2]	Simulated Head Step [m]	Measured PV power [W]	Measured flow [lpm]
400	25	91	8.9
600	25	93	9.0
700	25	116	10.5
800	25	119	11.2
850	25	124	11.5
900	25	119	11.2
950	25	118	11.1
1000	25	117	11.1
--	--	--	--
--	--	--	--

Figure 51. IrradianceData spreadsheet Test Results tab.

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66. Then, navigate to the "Inputs" tab in the *IrradianceData* spreadsheet. Copy and paste the P-Q curve into the test report (in the space in the green rectangle in the figure from step 63).
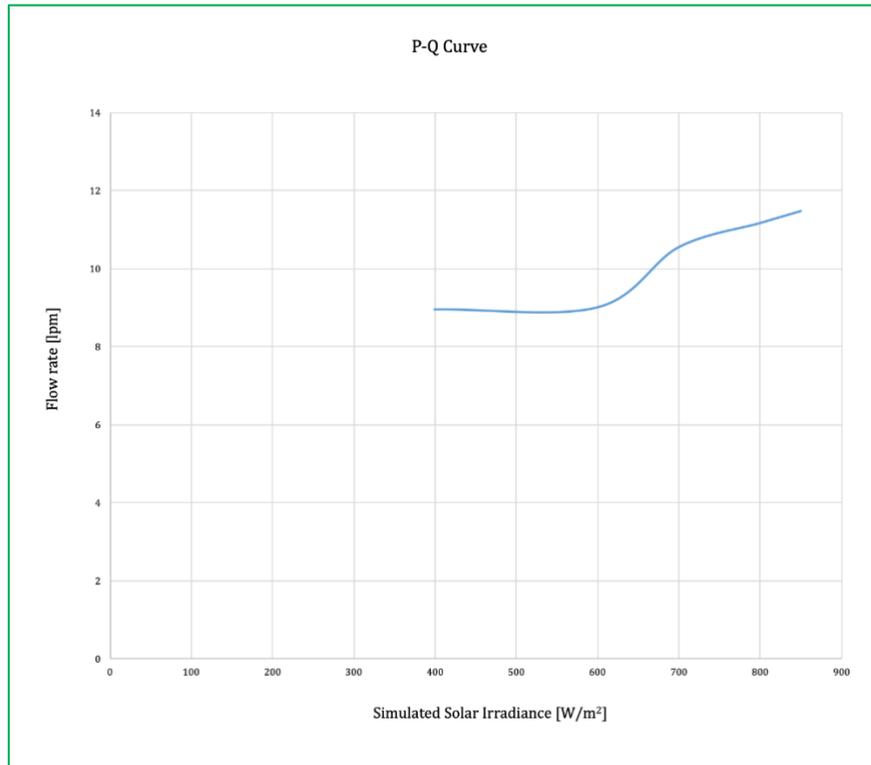
Figure 52. P-Q Curve from *IrradianceData* spreadsheet, Inputs tab to be copied/ pasted into test results template for product under test.

67. Scroll down in the test report spreadsheet to the next section, "Total volume moved during each solar day".
    a. Enter the FOB (freight on board) price of the SWP (not including PV module(s)) in the yellow cell in the first table of the section. The FOB should have been provided by the manufacturer and should have been already input into the *IrradianceData* spreadsheet as well.
        i. Note: sometimes, the submitting entity provides the retail price instead of the FOB. If this is the case, you may overwrite the "Retail" row in the test report in this table (figure shown below) with the actual retail cost values and remove the asterisk notes.

–	Pump aggregate retail price (without PV module price)	**Estimated PV module price based on standard assumption	Balance of system price	Total price
FOB		--	--	$ -
assumed multiplier	1.80	0.81	--	--
*Retail	$ -	$ -	--	$ -
*the retail price is assumed to be 1.8 times the reported FOB price				
**the PV module price is estimated using the assumption: $0.81/Watt				

Figure 53. FOB entry in the test report template for product under test.

    b. In the *IrradianceData* spreadsheet, open the *Test Results* tab again and copy and

paste the second table's data (in the red rectangle in the figure below) into the second table in this test report section (in the blue rectangle in the second figure below). Again, make sure to paste as values so the formulas aren't included.

Solar Day	Total volume of water moved per solar day [m3/day]	Maximum flow [lpm]	Hours of operation [h]	Hydraulic energy per day [Wh]	Hydraulic energy per day provided per dollar [Wh/$]	Average wire to water efficiency
High Irradiance Day	5.89	11.7	9.17	401	0.38	37%
Average Irradiance Day	3.83	10.1	6.72	261	0.25	42%
Low Irradiance Day	1.78	9.0	3.33	121	0.12	51%

Figure 54. *Test Results* **tab in the** *IrradianceData* **spreadsheet; copy data from this table.**

Simulated head [m]						
***Irradiance day	Total volume of water moved per solar day [m3/day]	Maximum flow [lpm]	Hours of operation [h]	Hydraulic energy per day [Wh/day]	Hydraulic energy provided per dollar [Wh/$]	Average wire to water efficiency
high						
average						
low						
***Note that the values found in the table above are calculated based upon testing data being fitted to three standard testing curves.						
Comments:						

Figure 55. Test report template for the product under test; the green rectangle is the input for simulated head, and the blue rectangle is showing where to paste as value in the data in the red rectangle in the figure above from the *IrradianceData* **spreadsheet.**

    c.   Also, input the simulated head in this table in the test report, which is highlighted in the green rectangle in the figure above.
        i.   The simulated head is found in the *Inputs* tab of the *IrradianceData* spreadsheet in Table 1.
68. Scroll down to the next section in the test report spreadsheet, where you will need to insert the three solar day plots (high irradiance, average irradiance, low irradiance) from the orange tabs in the *IrradianceData* spreadsheet.

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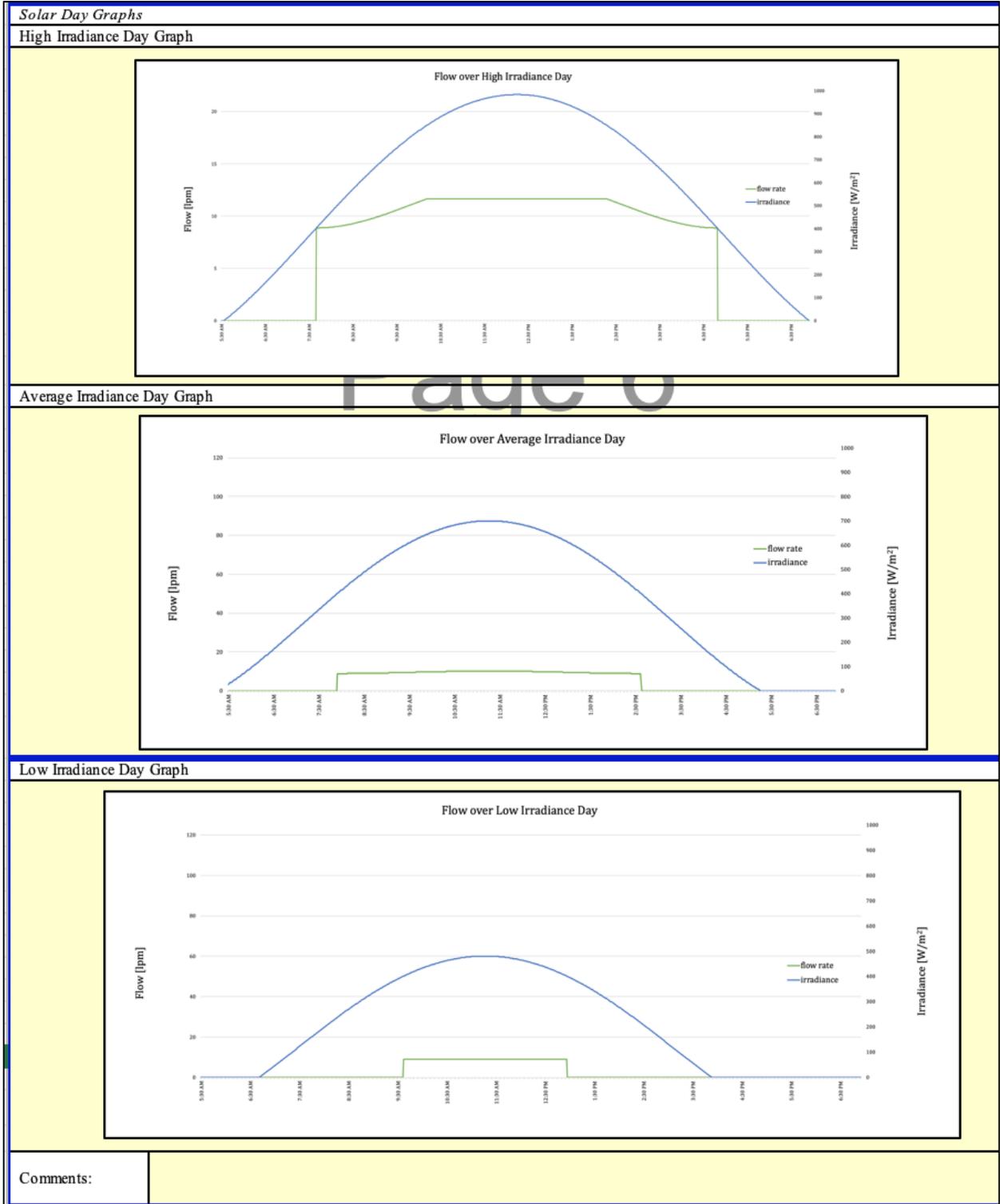
Figure 56. Test report template for product under test in the "Solar day graphs" section with included plots from the orange tabs in the *IrradianceData* spreadsheet.

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69. Include any comments in this section of the test report, including a statement if there is no flow rate data included in any of the plots, which happens more commonly in the low irradiance day plot. If there is no flow data plotted, this could indicate that there wasn't enough power input throughout the day that allowed the tested pump to operate at the simulated vertical head.

Troubleshooting

If the SWP will not turn on

There are several quick checks if the SWP will not turn on in the beginning of the test:

1. Check the 16A fuse, if applicable, to ensure it is connected (showing red above the switch). If it is green above the switch, it means the fuse is disconnected, opening the circuit.
2. Check that the SWP leads are not in reverse order. If there aren't clear instructions, it can make sense to try different connection combinations to see what works. Beware of the pump functioning but in reverse, which means the pump's leads are connected in the wrong configuration that may result in lower flow and inaccurate test results.
3. Check the external controller, if applicable, to ensure that the controller or pump power switch is ON, if there is one. Also, check the external controller, if applicable, for any error messages that could be interpreted by either the user manual if this is available, or by the company (the Lab Manager could contact a company representative).
4. Check to make sure that all electrical connections are secure.
5. Ask another tester or Lab Manager to check the testing set up to ensure everything is fully connected correctly.

Reference Procedures

This procedure references *IEC 62253: P-Q characterization (5.3.2).*