United States Department of Agriculture

Natural Resources Conservation Service

July 2017

Technical Note No. 1

BISMARCK, NORTH DAKOTA

Solar-Powered Water Pump Systems for Stockwater Design

Issued July 2017

Cover photo courtesy of Scott Kelsch, Engineering Tech, ND NRCS.

ACKNOWLEDGEMENTS

This technical note was written by **Shane W. Ice**, North Dakota Assistant State Engineer, United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) – Bismarck, North Dakota

This technical note was formatted after the Oregon NRCS Technical Note No. 28 – Design of Small Photovoltaic (PV) Solar-Powered Water Pump System written by **Teresa D. Morales**, Oregon State Design Engineer, United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), Portland, Oregon, and **John Busch**, Oregon State Irrigation Engineer, USDA NRCS, Baker City, Oregon.

Drawings by **Shane W. Ice**, North Dakota Assistant State Engineer and are modeled after Oregon NRCS Standard Drawing Solar_Submersible_Pump_Well drawn by **Kristi Yasumiishi,** Civil Engineering Technician, USDA NRCS, Portland, Oregon.

PREFACE

The intent of this technical publication is to provide general guidance on the design of small solar-powered water pump systems for use with livestock operations or small, low flow irrigation systems. This document provides a review of the basic elements of electricity, a description of the different components of solar-powered water pump systems, important planning considerations, and general guidance on designing a solar-powered water pump system. This publication also provides design examples for typical design scenarios and detail drawings for use by the reader. However, this technical note is not intended to be used as a standalone document. Instead, users are encouraged to consult the NRCS National Engineering Manual (NEH 210) on hydraulics and irrigation engineering for additional assistance in the design of water delivery systems.

An Excel design tool, ND_Solar_Pump, has been developed for in state use and accompanies the technical information and design procedures presented in this technical note. A copy of the design tool and a supplemental user guide is available for download on the North Dakota NRCS Engineering website located at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/nd/technical/engineering/?cid=stelprdb1269590

All sources used in the development of this technical note are provided in the References section at the back of the document.

Contents

1. INTRODUCTION

A large number of grazing operations in North Dakota are located in remote areas. These areas tend to have electrical grid power that is non-existent or very limited. In most cases, it is nearly cost-prohibitive to run additional electrical line for the purpose of water production. Now, more than ever, solar power is a very viable and economical option over traditional grid power. Solar power tends to require less maintenance, have lower operation costs, and can increase water availability to these remote locations. When properly designed, solar powered watering systems can result in significant long-term cost savings and a smaller environmental footprint compared to systems that rely on conventional power.

A solar-powered system is made up of two basic components; the photovoltaic (PV) panel and the pump and controller. The first component is the energy collecting Photovoltaic (PV) panels. PV panels are often used for agricultural operations, especially in remote areas or where the use of an alternative energy source is desired. In particular, they have been demonstrated time and time again to reliably produce sufficient electricity directly from solar radiation (sunlight) to power livestock watering systems.

The other major component of these systems is the pump. Solar water pumps are specifically designed to use solar power efficiently. Conventional pumps require steady alternating current (AC) that utility lines or generators supply. Solar pumps are different in that they use direct current (DC) from batteries or PV panels. The use of DC power in solar applications is important due to its consistency over a wide variation in power supplied by the PV panels throughout the day. In other words, a DC motor runs at nearly constant speed for any given applied voltage even though the head the pump is working against may change. A controller is an important component in efficiently turning sunlight in to water. The main job of the controller is to monitor the solar panels performance and makes adjustments as needed to the voltage and current in order to maintain maximum performance of the pump.

The volume of water pumped by a solar powered system in a given interval depends on the total amount of solar energy available in that time period. Specifically, the flow rate of the water pumped is determined by both the intensity of the solar energy available and the size of the PV array used to convert that solar energy into direct current (DC) electricity. This provides for a unique benefit of using solar energy in livestock watering systems in that the increased water requirements for livestock tend to coincide with the seasonal availability of solar energy.

In summary, the principle components in a solar-powered water pump system (shown in **Figure 1.1**) include:

- The PV array and its support structure,
- An electrical controller, and
- An electric-powered pump.

It is important that the components be designed as part of an integrated system to ensure that all the equipment is compatible and that the system operates as intended. It is therefore recommended that all components be obtained from a single supplier to ensure their compatibility.

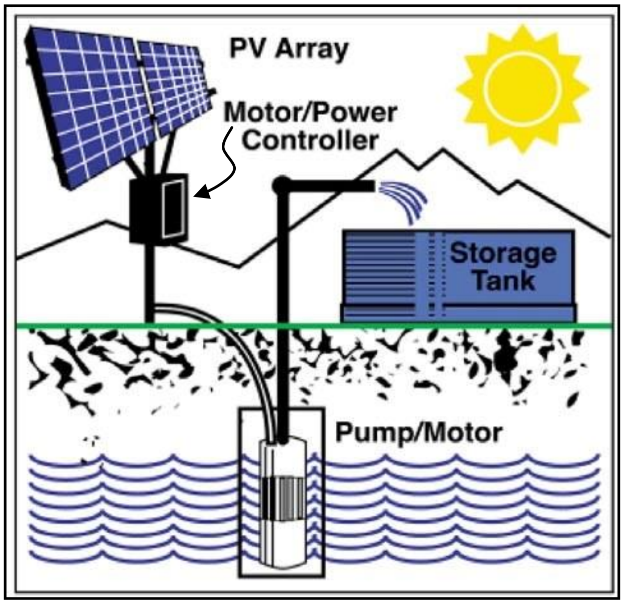


Figure 1.1 *– A typical solar-powered water pump system, which includes a solar array, controller, pump, and storage tank. (Source: "The Montana Agsolar Project – Expanding the Agricultural Uses of Solar Energy in Montana.")*

As with planning for any livestock watering system, the initial step is to do a thorough job of identifying needs and collecting information. It is good practice to determine the landowner's objectives and determine if those objectives are consistent with the purpose of the conservation practice. One of the key purposes associated with developing a livestock water system is to provide adequate water for the distribution of grazing. A complete inventory of existing resources and conditions gives the basic information necessary to provide the landowner/producer with a competent, functional, and cost effective design that meets the intended objectives. Asking the right questions and collecting pertinent information during the initial stages of a project will be extremely beneficial during the design process and ultimately save time during the installation phase. Information which must be obtained for a water system can vary considerably depending on the complexity of the water sources to be utilized, existing installations, and the physical size of the area being served.

For solar powered watering systems, the following information is critical in design of an effective system:

- The site-specific solar energy available ("solar insolation").
- The daily volume of water required by the livestock being grazed; including storage.
- The quantity and quality of available water.
- The total dynamic head (TDH) for the pump.
- The system's proposed layout.

The following sections will first provide an introduction to the basic concepts involved in solar-powered pump systems, then will provide descriptions of and design considerations for each individual system component. (See **Appendix J: Glossary of Solar-Powered Water Pump Terms** for definitions of the technical terms and abbreviations used.)

1.1 Electricity Basics

In the design of a solar-powered water pump system it is important to be familiar with fundamental electrical concepts, such as energy, voltage, amperage, and resistance. The topic of electricity is very complex. For simplicity and to provide just a basic understanding of the workings of electricity, only a general overview of these concepts are covered here.

Charge

The simplest component of electricity is the atom. ***Atoms*** are the basic units of matter and the defining structure of all elements. The basic atom consists of a central ***nucleus*** that is made up of positively charged protons and uncharged neutrons. Surrounding the nucleus are negatively charged particles called ***electrons***. These protons and electrons interact then interact with each other through their physical property known as ***electric charge***. A resulting ***electric field*** forms around the atom from this interaction between the two oppositely charged electrons and protons.

Think of an atom as a bee hive. Consider the center of the hive as the positively charged nucleus. Surrounding the hive is a swarm of negatively charged bees or electrons. While most of the electrons (bees) associated with an atom (hive) are tightly bound to the nucleus, there are some electrons that travel a good distance from the nuclei. These "free electrons" can have their attraction to any particular nucleus easily overcome. They are free to wander from one atom to another and this movement, when concentrated along a path, is what constitutes electric current. Materials, such as copper, have a large number of these "free electrons" and their ability to transfer current effectively is what makes them great conductors of electricity.

Current

As just discussed, ***current*** can best be described as the flow or movement of electrons along a path. This is very similar to how water travels through a pipeline; except that in electrical work this path is a wire. Current is measured by the amount of charge that passes a given spot in 1 second. This unit of measure is called an ***ampere*** or amp for short. When a charge flows at a steady rate in one direction only, the current is said to be ***direct current***, or DC. When charge flows back and forth sinusoidally, it is referred to as ***alternating current***, or AC. The type of current that is most associated with solar-powered systems is DC while AC is typically associated with grid power.

Voltage

Electrons cannot flow through a circuit unless they are given some kind of motivation to help send them along their way. That "push" is a term called ***voltage*** and is measured by the amount of energy given to a unit of charge. The voltage unit of measure is called a ***volt***. Relating this to the flow of water through a pipeline, voltage can be seen as the "pressure" that drives the system. As it is with pressure in a water pipeline system, voltage itself does not provide the driving force to push the current through the wire. Instead it is the change in voltage, or ***voltage drop***, across a wire that provides the driving force.

Power

Energy and power are two terms that are often confused or thought to be the same. ***Energy*** is defined as the ability to do work or total amount of work done and has units of joules or BTU. ***Power***, on the other hand, is the rate at which the work is being done or of which energy is being generated or used. This rate is what gives the units for power to be joules/second or BTU/Hour. For electricity, power is measured in ***watts***, which is in the rate of joules/second (1 J/s = 1 W). Electrical energy, therefore, is watts multiplied by time or watt-hours. Common units seen in most solar-powered water systems is ***kilowatt-hours (kWh)*** or 1,000 watt-hours. Calculation of electrical power, or watts, can be done by the multiplying the driving force of the system, voltage, by the rate at which the system flows, amperage. This is shown in **Equation 1.1**.

$$\boxed{\text{Watts} = \text{Volts} \times \text{Amps}}$$

Equation 1.1

Resistance

In an ideal situation, flow through any system would stay consistent and could continue forever without slowing down. Unfortunately, this is hardly ever the case. Whether it be because of friction caused by moving object across a surface or drag caused by flow over a surface, the system is affected by ***resistance*** and requires a larger "push" to get the same amount of production. In electricity, this resistance is measured in ***Ohms (Ω)*** and is the measure of a material's resistance to the flow of electrons across it. As with water flowing through a pipe, the resistance within electrical lines (or friction in the case of a pipeline) results in energy loss through the system. Resistance is influenced by the length, size, and type of wire conductor. Specifically, resistance is proportional to the length of the wire and inversely proportional to the cross-sectional area of the wire. In other words, the longer the wire, the greater the loss and the larger the wire diameter, the less the loss. Energy loss is also influenced by the wire material: a good conductor, such as copper, has a low resistance and will result in less energy loss when compared to a poor conductor such as rubber.

Another effective way to reduce electrical losses in a system is to decrease the current flow. Power losses in an electrical circuit are proportional to the square of the current, as shown in **Equation 1.2**:

$$\boxed{\text{Power Loss} = \text{Current}^2 \times \text{Resistance}}$$

Equation 1.2

Consequently, as indicated in **Equations 1.1 and 1.2**, increasing the voltage while reducing the current will result in the same power transmission, but with less power loss. Therefore, higher voltage pumps tend to be more efficient than lower voltage pumps, assuming all other properties are similar.

Load

The final term that needs to be discussed is ***load***. An electrical load is an electrical component or portion of a circuit that consumes electric power. It can also be referred to as the power consumed by a circuit. In watering systems, this would most typically be the pump.

As alluded to in the descriptions of the different electrical components, a good analogy to help describe the flow of electrons in a wire would be the flow of water through a pressurized pipeline. In order to help illustrate this analogy, **Table 1.1** compares the flow of electricity through a circuit with the flow of water through a pipeline.

***Table 1.1* – Electricity for Non-Electrical Engineers**

Electricity in a Wire	Water in a Pipe
Current (flow of electrons; Amps)	Q (flow rate of water; GPM)
Voltage (energy potential; Volts)	Pressure (energy potential; PSI, FT of H2O)
Power (Watts) = Amps x Volts	Power (HP) = (Q x Pressure Head) / 3960
Resistance (Ohms)	Friction Losses (FT)
High Voltage, Small Wire Results in: High Amps Resistive losses Heat and Fires	High Pressure, Small Pipe Results in: High Velocity High Friction Losses Ruptured Pipe

2. SOLAR RADIATION, SOLAR IRRADIANCE, AND SOLAR INSOLATION

To design and analyze a solar powered system, it is necessary to know how much sunlight is available within a particular area. Beyond sun availability, the intensity of the available sunlight is the key component in how much power can be produced. The source of this solar intensity is, of course, the sun. That giant ring of fire has a diameter of 1.4 million kilometers and produces 3.8×10^{20} megawatts of electromagnetic energy that radiates through space. As this solar wave, or ***solar radiation*** (kW/m^2), makes its way toward the earth's surface, some of it is absorbed. The area just outside the earth's atmosphere receives an amount of solar radiation that is nearly a constant 1.36 kW/m^2. By the time this energy reaches the earth's surface, however, the total amount of solar radiation is reduced to approximately 1 kW/m^2 or more commonly; ***1-Sun***. The actual amount of radiation received largely depends on the location, time of day, time of year, and the clarity of the atmosphere. For North Dakota, the maximum amount of radiation received at the surface is around 925 W/m^2.

The intensity of sun at any point on earth depends on how much atmosphere the radiation has to pass through. ***Solar intensity*** is greatest when the sun is straight overhead (also known as solar noon; see **Section 2.1 – Seasonal and Latitude Variation**) and light is passing through the least amount of atmosphere. Conversely, solar intensity is least during early morning and late afternoon hours when the sunlight passes through the greatest amount of atmosphere. In most areas, the most productive hours of sunlight (when solar radiation levels approach 1 kW/m^2) are from 9:00 a.m. to 3:00 p.m. Outside of this time range, solar power might still be produced, but at much lower levels.

Solar irradiance, on the other hand, is the amount of solar energy received by or projected onto a specific surface. Solar irradiance is also expressed in units of kW/m^2 and is measured at the surface of the material. In the case of a solar power system, this is the surface of the solar PV panel.

Finally, **solar insolation** is the amount of solar irradiance measured over a given period of time. It is typically quantified in ***peak sun hours*** or the equivalent number of hours per day when solar irradiance averages around the 1 kW/m^2. The solar insolation, therefore, is $kWh/m^2/day$ or hrs/day @ 1-Sun. It is important to note that while there may be over 14 hours of sunlight in a given day, it may only generate energy equivalent to 6 peak sun hours.

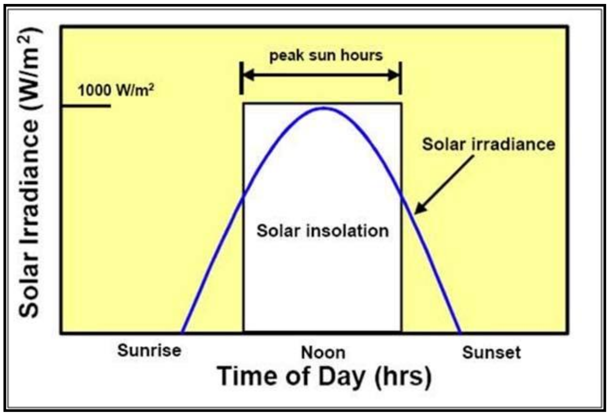


Figure 2.1 *– Solar irradiance and peak sun hours.*
(Source: "Renewable Energy Primer-Solar.")

Figure 2.1 shows how peak sun hours are defined for any particular day. The entire amount of solar irradiance (indicated by the blue arc) is divided by 1 kW/m^2, which equals the total number of peak sun hours for that day (indicated by the white rectangle). For example, an average daily insolation value of 5 kWh/m^2 is equivalent to a full 1-Sun ($1kW/m^2$) for 5 hours.

The average daily solar insolation or # of peak sun hours for North Dakota can vary widely depending on the time of year; see **Section 2.1 – Seasonal and Latitude Variation**. In July, the value is around 6.36 hrs/day while the value in December is around 1.21 hrs/day. Most manufactures base their daily water pumping volumes for solar pumps on the solar insolation available in July. Therefore, if the main water use period is for seasons other than mid-summer, adjustments would need to be made to the total daily production based on the reduced hours of insolation. When trying to size a system to provide adequate production throughout the period that it will be used, this method can become confusing and can lead to periods when sufficient water is not being provided. In North Dakota, the main grazing season typically ranges from March to October. A good rule of thumb, to help ensure that the daily water demand of the grazing herd is met throughout the entire grazing season, is to use the average solar insolation value for the month with the least solar intensity. In the typical scenario, this would be the state average value for October or 2.42 hrs/day.

When available, use of site specific data is best for design. The recommended method for determining solar insolation values for North Dakota is through the North Dakota Agricultural Weather Network (***NDAWN***). NDAWN is comprised of over 90 weather stations throughout the state and is managed by the North Dakota State University School of Natural Resource Sciences. Solar insolation is one of the parameters that is observed and recorded. A simple introduction to how to use NDAWN and the reported solar insolation values are provided in **APPENDIX E – NDAWN Approach to Determining Solar Insolation Values**.

A complete list of average insolation values collected at each NDAWN Station for each month of the year is included in **APPENDIX D – Average Monthly Solar Insolation Values for North Dakota by NDAWN Station**. It is recommended that a minimum of 5-years of data be available in order to have a reliable averaged value.

When determining solar insolation values it is also important to consider the latitude of the project site and the proposed tilt angle of the PV array. The importance of the project's latitude is discussed in **Section 2.1 – Seasonal and Latitude Variation**. The panel tilt angle is discussed in **Section 3.1 – PV Panel Orientation and Tracking** and is the angle of the panel relative to horizontal where 0° is horizontal and 90° is vertical.

2.1 Seasonal and Latitude Variation

Once earth shattering news, the earth revolves around the sun in an elliptical orbit, making one lap every 365.25 days. In addition to moving along this elliptical orbit, the earth rotates about its own axis at rate of 15° per hour, with a full rotation every 24-hours. Our spinning Earth is also set on a tilted angle as it laps around the sun. This tilt angle is currently 23.45° and is what causes our seasons. On March 21 and September 21, the line from the center of the sun to the center of the earth passes through the equator and everywhere on earth there is 12 hours of daylight and 12 hours of darkness and is referred to as the ***equinox***. On June 21 the sun reaches its highest point and makes an angle of 23.45° with the earth's equator and is known as the ***summer solstice*** in the Northern Hemisphere. On that day, the sun is directly over the latitude known as the ***Tropic of Cancer***. The opposite is true during the ***winter solstice***. On December 21 the sun is directly overhead 23.45° below the equator and defines the latitude known as the ***Tropic of Capricorn***. Because of this, those of us that live in the United States, with the exception of Hawaii, the sun will never be directly overhead. A depiction of this can be seen in **Figures 2.2 and 2.3**. The actual location of the sun in relation to the equator during anytime of the year is called the ***solar declination angle***, $\boldsymbol{\delta}$ and can be calculated using **Equation 1.1**.

$$\boldsymbol{\delta} = 23.45\, sin\left[\frac{360}{365}(n-81)\right] \quad \text{where n = Julian Day} \qquad \textbf{(1.1)}$$

Note: 80 is the Julian date for the spring equinox of March 21.

These changes in the earth's orbit affect the amount of sun's radiation striking the surface as well as the distribution of sunlight both geographically and seasonally.

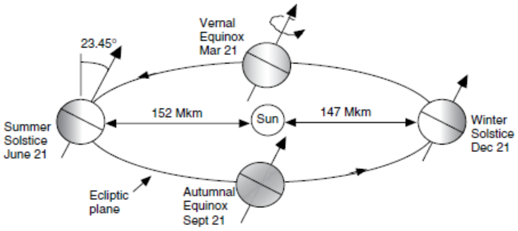


Figure 2.2 *– Tilt of the earth with respect to an elliptical orbit.*

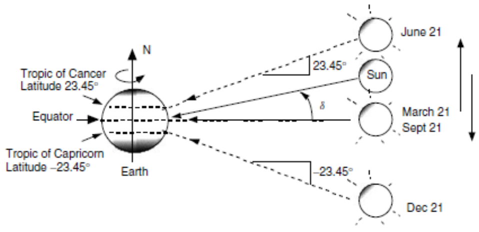


Figure 2.3 *– Location of the sun throughout the year. (Source: "Renewable and Efficient Electric Power Systems")*

As the sun makes it daily track across the sky, the moment at which the sun is directly over the line of longitude of a given location is called ***solar noon***. Respectively, it is also the moment when the sun reaches its highest elevation on a given day at a given location. Solar noon is an important reference point when determining locations for solar setups. Since all of the United States lays above the Tropic of Cancer, solar noon always occurs when the sun is due south of a referenced object. The rate at which the sun moves across the sky, either towards or away from solar noon, is the same as the Earth's rotation or 15°/hr.

The knowledge of solar position can be useful in setting the orientation and best tilt angle for solar panels to expose them to the greatest solar insolation. For the best annual performance, it can easily be seen that a south-facing solar panel set at a tilt angle equal to the local latitude would have the sun's rays strike the panel at the best possible angle; this is, perpendicular to the face of the panel. Panel orientation is discussed in more detail in **Section 3.3 – PV Panel Orientation and Tracking**.

The seasonal variation of the sun's intensity must also be considered when planning for a solar-powered system. In the northern hemisphere, the least amount of sunlight occurs in the winter because the days are shorter and the sun is lower in the sky, as shown in **Figure 2.4**. Therefore, sunlight intensity is least during early to mid-winter in the December – January period and greatest during mid-summer in the June – July period. Adjusting the tilt angle of the PV array to account for seasonal variations in the sun's elevation can result in increased electrical power output from the array.

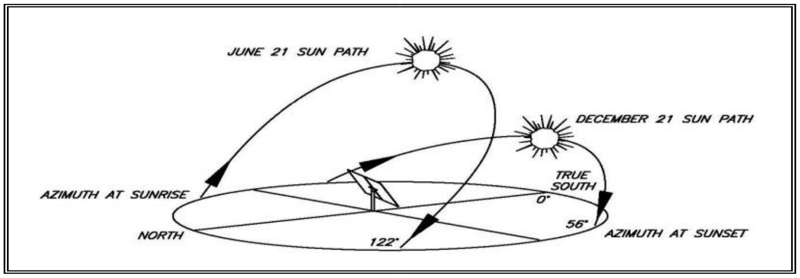


Figure 2.4 – *Example summer and winter sun elevation and angle. (Source: "Renewable Energy Primer-Solar.")*

2.2 Cloud Cover and Shading

Clouds, fog, and overcast skies are common weather events that occur throughout the year across North Dakota. The solar insolation values reported by the NDAWN Stations are observed values; therefore these common weather effects are already accounted for in the data. Reduction or adjustment of the solar insolation values (equivalent full sun hours) is therefore not needed. Another very important consideration in a design is shading. Solar systems are very shadow sensitive and sites located near or under heavy vegetation or in front of obstructions located along the southerly horizon can greatly affect the production of the system that would be otherwise correctly sized.

3. PHOTOVOLTAIC (PV) PANELS

PV panels are made up of a series of solar cells, as shown in **Figure 3.1**. Each solar cell has two or more specially prepared layers of semiconductor material that convert sunlight into electricity.

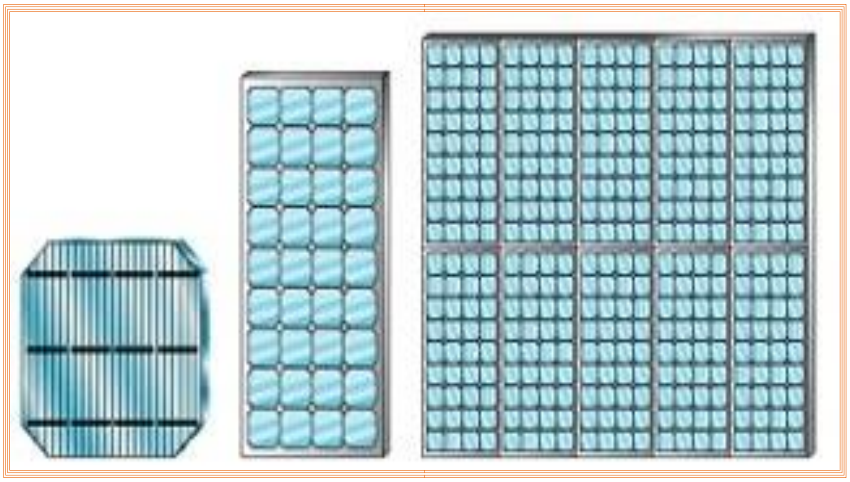


***Figure 3.1** – Solar cell, PV solar panel, and PV panel array.*
(Source: “Guide to Solar Powered Water Pumping Systems in New York State.”)

The semiconductor layers can be either crystalline or thin film. Crystalline solar cells are the most common type used in small scale PV applications and are constructed out of pure crystalline silicon. Silicon is quite abundant on earth and is estimated to be approximately 20% of the entire earth’s crust. The silicon used in PV applications usually comes from mined high quality silica or quartz. Other, less common, solar cells can be constructed out of thin films consisting of a variety of different metals that, when paired together, have similar characteristics as silicon.

3.1 The Photoelectric Effect

PV systems harness the sun’s energy by converting it into electricity via the ***photoelectric effect***. This occurs when incoming photons interact with a conductive surface, such as a silicon cell or metal film, and electrons in the material become excited and jump from one conductive layer to the other, as shown in **Figure 3.2**.

In this figure, the two semiconductor layers are shown as an n-type layer and a p-type layer. The ***n-type layer*** is a layer where the crystalline silicon is coated with an element such as phosphorus. This interaction causes an extra negative electron that is able to freely move around the layer and they are known as ***donor atoms***. The ***p-type layer***, on the other hand, uses a coating element such as boron, that when interacted with silicon creates a positively charge “hole”. These “holes” are perfect receptacles that an electron from a neighboring silicon atom can easily move into. These created impurities, therefore, are referred to as ***acceptors*** since they accept electrons. When these two layers are placed next to each other and they are exposed to sunlight, the solar photons are absorbed, electrons are excited, and the hole-electron pairs are formed. The p-side accumulates holes and the n-side accumulates electrons. This creates a voltage drop that can be used to deliver current to a load; i.e. the pump. When electrical contacts are attached to the top and bottom of the cell, electrons will flow out of the n-side into a connecting wire, through the load and back to the p-side. Since wire cannot conduct holes, it is only the electrons that actually move around the circuit. When they reach back to the p-side, they recombine with holes and complete the circuit.

In other words, the behavior of electrons in the solar cell creates a voltage that can be utilized to, for example, operate a water pump system.

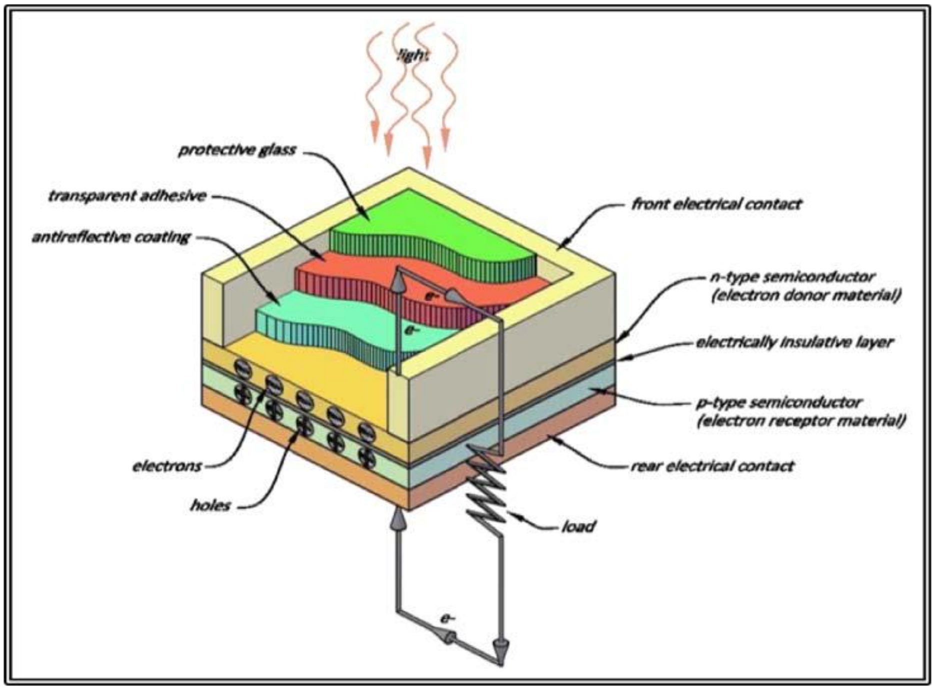


Figure 3.2 *– The photoelectric effect and subsequent electron motion.*

3.2 PV Panel Configuration and Electrical Characteristics

The smallest component of a PV panel is the ***solar cell***. An individual solar cell has the ability to produce about 3 watts of energy in full sunlight or around 0.5 volts of electricity. Because of this, there are rare applications where just a single cell is of any use. Instead, the basic building block for PV applications is a string of solar cells pre-wired in series called a ***module*** and encased in a ridged, weather resistant housing; see **Figure 3.1**. In solar powered watering systems a typical module will have 72 cells in series and be designated as a “24-Volt module”. This is an improvement over previous module generations that were 36-cell and designated as “12-Volt modules”. Even though these modules are termed 12- and 24-Volt, they are nominal values and are capable of producing much higher voltages than that. Larger 96- and 128-cell modules are becoming more common in larger scale PV systems. A major advantage of these larger celled modules is that they contain more cells per module; resulting in fewer modules and fewer interconnections between them.

As modules are wired together they can increase the amount of power they produce. Wiring of the modules can either be done in series or parallel. Modules wired in ***series*** will increase voltage by adding together the volts produced by each module while maintaining the same current. Modules in ***parallel***, on the other hand, will increase the supplied current by adding the amps of each module while maintaining the same voltage. One of the most important elements in the design of solar powered systems is determining how many modules should be connected in series and how many in parallel to deliver the power needed to supply the system. This combination of modules is referred to as an ***array***. Arrays are made up of some combination of series and parallel modules to increase power. Ideally, modules would first be wired in series to build up the required voltage and then strings would be paralleled to increase power. The total power output from a PV panel array is determined by multiplying the total output voltage by the total output current. It is important in wiring of the array that the resulting voltage and current are compatible with the controller and pump motor requirements. Basic PV panel wiring diagrams are shown in **APPENDIX I – Solar Panel Wiring**. The proper sizing of a PV array is discussed in **Section 7 – Design Process for Solar Powered Watering Systems**.

PV panels are rated according to their output, which is based on an incoming solar irradiance of 1-Sun (1 kW/m^2) at a specified temperature. Panel output data that is important in PV design includes ***rated power*** (P_{max} [Watts]), ***max power voltage*** (V_{mpp} [V]), and ***max power current*** (I_{mpp} [A]). An example of the electrical characteristics for a solar panel are shown in **Table 3.1**. These values can be found in the manufactures technical data sheet for the particular PV panel and are printed on a sticker located on the back of the panels themselves.

Table 3.1 **– Example PV Solar Panel Electrical Characteristics**

Characteristic	Value	Units
Rated Power (P_{max})	175	Watt [W]
Voltage @ P_{max} (V_{mpp})	35.8	Volts [V]
Current @ P_{max} (I_{mpp})	4.9	Amps [A]
De-Rated Power Value (DRV) @ 25-yrs = 85%		

The power output from a PV panel can vary slightly from the panel's rated power. Under conditions of reduced solar radiation, the current produced is decreased accordingly, but the voltage is only reduced slightly. Power output will also decline over time, typically at less than one percent per year, due to environmental wear on the system and is known as the ***de-rating value***. This is noted by the "De-Rated Power Value" in **Table 3.1** and is usually listed in the warranty section of the PV panel data sheet.

3.3 PV Panel Orientation and Tracking

Solar position and panel orientation are key in effectively siting a solar powered system. To be most effective, PV panels need to continuously and directly face incoming sunlight. Solar panel arrays can either be installed as a fixed-axis or with a tracking system.

A ***fixed-axis*** is when the solar array is set at a determined angle and stays at that angle until it is manually adjusted. As discussed in **Section 2.1 – Seasonal and Latitude Variation**, a south-facing solar panel set at a tilt angle equal to the local latitude would have the sun's rays strike the panel at the best possible angle for annual performance. Using the location of the sun and solar noon (the sun's highest elevation on any given day) a key solar angle called the ***altitude angle (*****β_N*****)*** can be determined for a given location during any day of the year. This is the angle between the sun and the local horizon directly beneath the sun during solar noon. This relationship can be calculated with **Equation 3.1**. Note that the subscript N defines this altitude angle is for the sun's position at solar noon.

$$\beta_N = 90° - L + \delta \qquad \textbf{(3.1)}$$

Where: L = Latitude of the Local Site
δ = Solar Declination (Equation 1.1)

Knowing this altitude angle, an ***optimal tilt angle*** of the PV panel can be determined as shown in **Equation 3.2**. When the altitude angle is calculated with the local latitude, this tilt angle will maximize annual energy production when the sun is at its highest.

$$Panel\ Tilt\ Angle, \sum = 90° - \beta_N \qquad \textbf{(3.2)}$$

Where: β_N = Altitude Angle of the Sun at Solar Noon

Analyzing each day of the year it can be seen that the max tilt angle for the year occurs on Dec 21 (Winter Solstice) and the minimum angle occurs on June 21 (Summer Solstice). Averaging the tilt angle for the entire year shows the tilt angle to be equal to the latitude of the local site and occurring on March 21 (Spring Equinox).

While setting a daily optimal tilt angle of the solar array would provide the best production for a fixed-axis installation, the time commitment to make this daily adjustment is not always reasonable. A seasonal tilt angle may prove to more effective. Most solar panels that are used to pump water are set to collect the maximum amount of energy in the summer, when water demands are greatest. However, to maximize energy for both summer and winter pumping, the tilt angle can be adjusted at the spring and autumn equinoxes (March 21st and September 21st). A tilt angle of +/- 15 degrees from latitude will increase energy production for the winter or summer months, respectively. In other words, the panel array tilt angle should be adjusted as follows:

- Summer tilt angle = latitude – 15° (when the sun is higher in the sky).
  Note: This is equivalent to around the first of May and middle of August
- Winter tilt angle = latitude + 15° (when the sun is lower in the sky).
  Note: This is equivalent to around the first of November and middle of February

Alternatively, an average tilt angle can be calculated for a range of any period. For instance, if grazing is only managed from March to October, then the tilt angle can be set as the average for just this period.

Example 3.1 *Find the various optimal tilt angles of a southern facing solar array for Bismarck, North Dakota.*

Solution Bismarck is located near the 47° N line of latitude.

Optimal Annual Average: The Spring Equinox (March 21) is typically the 80th day of the year so the solar declination (Equation 1.1) is

$$\delta = 23.45\, sin\left[\frac{360}{365}(n-81)\right] = 23.45\, sin\left[\frac{360}{365}(80-81)\right] = -0.40°$$

The altitude angle (Equation 3.1) of the sun is then equal to

$$\beta_N = 90° - L + \delta = 90° - 47° + (-0.40°) = 42.6°$$

The optimal annual tilt angle (Equation 3.2) for Bismarck would therefore be

$$Optimal\ Annual\ Tilt\ Angle, \sum = 90° - \beta_N = 90° - 42.6° = \mathbf{47.4}°$$

Note: During Leap Years the Spring Equinox falls on the 81st day and the resulting tilt angle would equal the exact latitude of the site location. For Bismarck, this would be **47°**.

Optimal Summer Tilt Angle: Adjusting for the most effective production in summer, the tilt angle would then be

$$Summer\ Tilt\ Angle, \sum = Latitude\ of\ Site\ Location - 15° = 47° - 15° = \mathbf{32}°$$

Optimal Winter Tilt Angle: Adjusting for the most effective production in winter, the tilt angle would then be

$$Winter\ Tilt\ Angle, \sum = Latitude\ of\ Site\ Location + 15° = 47° + 15° = \mathbf{62}°$$

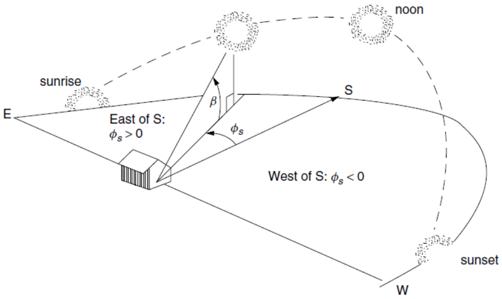
Optimal Tilt Angle for Custom Season: The grazing plan has determined that grazing is limited to March through October. Using a spreadsheet and averaging the solar array tilt angle of each day during this period, the tilt angle shows be

$$Grazing\ Period\ Tilt\ Angle, \sum = Average\ Daily\ Tilt\ Angle(March\ 1{:}\ October\ 31) = \mathbf{37.6}°$$

As shown in **Figure 3.3**, latitudes in North Dakota range from 46° N, along the South Dakota border, to 49° N, along the Canadian border. Summer tilt angles, therefore, are expected to range from 31° to 34° while winter tilt angles should range from 61° to 64°. The various tilt angles for each NDAWN station across North Dakota is calculated and shown in **APPENDIX F – Solar Array Tilt Angles**. It is also worth noting that if the array's tilt angle is adjusted seasonally, the site's solar insolation data that is used in the design of the solar-powered water pump system should reflect this.

***Figure 3.3** – Latitude and Longitude Map of North Dakota*
(Source: *www.mapsofworld.com*)

As discussed, fixed-axis setups are limited to the direction and angle they are set. The calculated angles for the fixed arrays are determined based on them being southern facing and the sun being located at solar noon. As the sun move either towards or away from its highest point in the day, the direct focus of the sun's radiation on the PV panel is reduced and therefore the potential available energy is too. This angle of the sun off of solar noon is shown in **Figure 3.4** and is referred to as the ***sun azimuth angle, ϕ_S***. There is another important angle to consider and it isn't related to the position of the sun. The ***collector azimuth angle, ϕ_C*** is the angle at which the PV panels are off of due south. This angle plays a critical role in how much direct sunlight is available to the array. A due south facing PV panel has an ϕ_C angle of 0° and, as described previously, is the best fixed orientation to maximize solar collection. Increasing this angle one way or another off of due south can greatly affect the amount of solar energy available to the panels. A 30° angle off of south at solar noon can cause a reduction of around 7-10% while this same angle when the sun azimuth angle is 30° off of solar noon in the opposite direction can have a reduction of nearly 50%. An example of this type of orientation is shown in **Figure 3.5**.



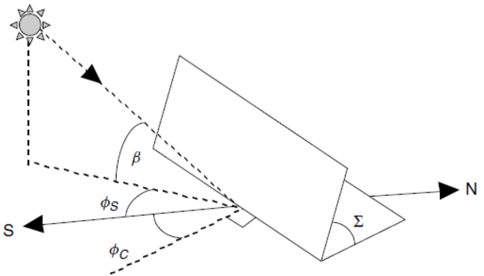


Figure 3.4 (Left) – *Position of the sun as described by its altitude angle, β and its azimuth angle, ϕ_S.*
Figure 3.5 (Right) – *Position of a collector as described by its azimuth angle, ϕ_C in relation to the sun's position.*
(Source: "Renewable and Efficient Electric Power Systems")

It can also be seen in **Figure 3.4** that as the sun's azimuth angle, ϕ_S increases away from solar noon, one direction or the other, its altitude angle, β decreases off the maximum altitude angle of noon, β_N.

One way to take advantage of this movement of the sun across the sky and harness the most solar energy as possible is by way of a tracking system.

Tracking systems require the use of either a single or double-axis tracking mechanism. A ***double-axis tracker*** tracks both the sun's azimuth and altitude angles so that the solar array is always pointed directly at the sun. A ***single-axis tracker***, on the other hand, only tracks one of these angles.

Single-axis tracking is most commonly set-up with a mount having a manually adjustable tilt angle along the north-south axis, and a tracking mechanism that rotates the solar array from east to west, as shown in **Figure 3.5**. As discussed previously for a fixed-axis, optimum annual collection can be obtained when the north-south axis is set at an angle of the local latitude (L) or L ± 15° when adjusting seasonally. The tracking mechanism of these mounts are generally always passive and therefore require no supplemental energy inputs. They use the warmth of the sun to heat Freon or other types of refrigerant and cause the fluid to move between cylinders in the tracker assembly. This causes the panels to rotate or "track" the sun, ideally at the same 15°/hr rate, so that the PV panels will directly face the sun throughout the day. Single-axis tracking can be very effective for increasing energy production throughout the year; generally by 20-30% or more over a fixed-axis mount during some months. Despite tracking both the sun's azimuth and altitude angles, double-axis trackers, however, tend to only harvest around 9% more solar energy over a single-axis tracker.

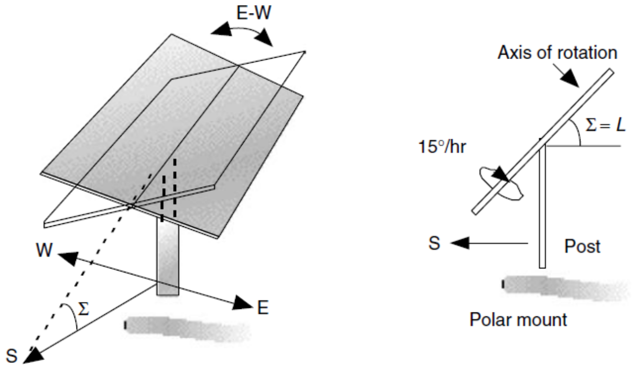


Figure 3.5 – *Movement of a Single-Axis Tracking Mount*
(Source: "Renewable and Efficient Electric Power Systems")

Tracking systems can be quite cost effective in that they are able to harvest more solar energy compared to the cost over a fixed system. However, they do tend to have complex tracking mechanisms and associated controls, leaving them susceptible to routine maintenance and repair. In addition, if the solar tracker system breaks down when the solar panels are at an extreme angle, the loss of production until the system is functional again can be substantial. Solar trackers are generally designed for climates with little to no snow making them a more viable solution in warmer climates. Fixed tracking accommodates harsher environmental conditions more easily than tracking systems. These are just a few of the reasons the preferred installation of solar powered watering systems are oriented due south and are fixed-axis and stationary; allowing them to take advantage of the maximum sunlight available in the middle of the day.

4. STRUCTURE AND FOUNDATION CONSIDERATIONS

4.1 Structural Supports for PV Panels

The structural supports used to attach the PV panels to their mounting posts are typically provided by the solar panel manufacturer. These supports are manufactured specifically for the type of panel and must be installed per the manufacturer's specifications to avoid any unintended stresses or eccentric loading to the panels, structural supports, and/or mounting posts. These unintended stresses and/or eccentricities can overstress the connection of the panel to the post, even under normal loading, and damage the system.

PV panels and all associated components (the mounting structure, power controller, and electrical connections) are subject to a host of environmental stresses, such as high temperatures; dust; significant wind, snow, ice, or hail loading; etc. To withstand such stresses, the panels should be shown to be tested and listed by Underwriters Laboratories (UL) to meet UL 1703; or tested and certified to withstand the impact of 25-mm (1-inch) diameter hail at a minimum velocity of 23-m/s (51-mph) without major visual defects by another nationally recognized testing lab in accordance with IEC 61215, or IEC 61646. It is also critical that the panels also be certified to withstand winds of 130-km/h (81-mph) or greater.

If a new commercially manufactured mounting structure is not available, a professional engineer shall design and certify a fabricated mounting structure that is capable of supporting the solar Panel array under loads caused by 130-km/h (81-mph) winds and ice loading of 25-mm (1-inch) thick minimum over all exposed surfaces.

4.2 Mounting Posts

A solar panel array mounted to a post that is driven into the ground behaves essentially in the same way as a sign or billboard and is therefore subject to the same types of ice and wind loading. A properly mounted solar panel array will result in a downward (axial) and lateral ***point load*** at the top of the mounting post while minimizing any ***eccentric loading***; i.e. bending of the post. Correctly analyzing these loads is essential for determining the correct foundation design and mounting post size.

An inadequate embedment depth for the mounting post can cause the panels to tilt or tip over during normal wind and/or ice loading and can lead to significant damage to the PV system. Tilting of the panels will also occur when loading on the panel results in localized failure of the soil column immediately around the post, which will then be able to move freely in the ground. Additional loading may lead to progressive failure of the foundation and/or reduced energy production as the panels will no longer be positioned to receive maximum solar insolation.

To reduce the potential for the panels to tip or tilt, the foundation must be designed to carry the expected wind and ice loads, as determined using the American Society of Civil Engineers (ASCE) 07-10 – Minimum Design Loads for Buildings and Other Structures. In North Dakota, it is common for the panel array to be only be installed seasonally during grazing (March – October) and then be stored for the winter. Design for ice loading is included to account for early and late season weather events that may occur after the panels have been placed into operation or before they are removed; respectively.

ND NRCS has developed a standard drawing for the installation of solar-powered water pump systems. A copy of the drawing is located in **APPENDIX G – ND NRCS Standard Drawing for Solar Installation**. The drawing provides a mounting post selection table that lists minimum pipe sizes, embedment depths, and concrete volumes based on the post height and panel array size for a proposed system. The values listed in the table are based on a wind speed of 95 mph, a 1-inch ice load, and a panel self-weight of 40lb per panel. Soil properties for the foundation design were presumed to have an allowable bearing pressure of 1,500psf and a lateral pressure per unit depth of 100psf/ft and is representative of all soil types except for organics. For a site whose conditions exceed these design parameters, the required mounting post size and embedment depth will need to be determined by a qualified engineer.

The standard drawing calls for all post holes to be backfilled with concrete. In order to ensure adequate foundation strength, the concrete should be properly batched above ground prior to placement in the post hole. Placement of dry ready mix concrete in the post hole and then filling the hole with water should be avoided. This method provides no way to ensure that the concrete has been adequately mixed and the required concrete strength achieved. Instead, the foundation is more likely to fail over time, resulting in a tilting panel and a potential reduction in power generation.

It is not recommended that a solar panel array be mounted to an existing structure, such as a barn or shed unless it is deemed acceptable by a qualified engineer. The self-weight of the panels can be significant, particularly with larger arrays. Furthermore, the addition of a solar panel array to a roof can change wind loading patterns on that roof. An older structure or a structure not designed to carry these larger loads could potentially be overwhelmed by the addition of a solar panel array and fail.

4.3 Corrosion Protection

Corrosion is a potentially serious issue with panel mounting structures that can be easily avoided by taking a few simple, protective steps.

For corrosion to occur, the following four elements need to be present:

1) **Anode** – a corroding metal surface
2) **Cathode** – a non-corroding metal surface
3) **Electrolyte** (solution) – a pathway for ionic energy transfer
4) **Conductor** – a pathway for energy transfer

When dissimilar metals (the anode and the cathode) come into contact under wet conditions (the electrolyte), a ***galvanic potential*** is created between the anode and the cathode, leading to the subsequent corrosion of the anode. For example, the use of plain carbon steel bolts, nuts, and washers to attach an aluminum mounting structure to the mounting post will begin to corrode the aluminum when the contact area between the bolts, nuts, and washers and the aluminum mounting structure is wet. The aluminum will act as the sacrificial material (anode) since it has a lower galvanic potential than the plain carbon steel.

However, if one of these issues is eliminated, the corrosion will cease. For example, the moisture may be removed or the contact between the mounting panel and bolts, nuts, and washers may be lost. The latter will most likely occur when the corrosion becomes severe enough to cause the bolted connection to fail. This can result in significant and costly damage to the panel array. In terms of the former solution, since PV-powered systems are continually exposed to the elements, the presence of moisture around the mounting structure connection is simply unavoidable. Selecting hardware that is made of a similar material is therefore the best and cheapest defense against corrosion. Overlooking this seemingly minor and inexpensive detail can result in costly damage to the array.

Any questions regarding the appropriate type of fasteners to use should be directed to the manufacturer, installer, and/or a qualified engineer.

5. SOLAR-POWERED PUMPS

Pumps that use PV systems are normally powered by DC motors. These motors use the DC output from the PV panels directly. DC motors are most commonly paired with solar-powered pumps because they do not require a power inverter like an AC motor would; thus DC motors resulting in more total energy availability.

The types of pump configuration and mounting can be either submersible, surface mount, or floating and are dependent on the application and water source. The large majority of solar powered pumping systems in North Dakota tend to be submersible pumps located within a drilled well.

Pumps, because of their mechanical nature, have certain well defined operating properties. These properties are flow and head and can widely vary between types of pumps, manufacturers, and pump models. Flow, or the ***system demand***, is the amount of water required of the system, in units of gallons per day, for the pump to produce. Head or more specifically, ***total dynamic head (TDH)***, is the amount of elevation and friction the pump has to overcome to produce that demand. Pump manufacturers publish information that describes how each pump will perform under these varying operating conditions. The choice of pump ultimately depends on the water volume needed, the efficiency at which the water is produced, and its reliability and price.

Solar-powered pumps are characterized as either positive displacement pumps or centrifugal pumps. ***Positive displacement pumps*** (e.g. helical rotor, piston, or diaphragm) are the most typical type for stockwater production and are used when the TDH is high and the flow rate (measured in gpm) required is low. They operate by drawing water into cavities inside the pump and force it upward. Their design enables them to maintain their lift capacity all through the solar day despite the slow and varying speeds caused by changing sunlight conditions. Conversely, ***centrifugal pumps*** are typically used for low TDH and high flow rates and are common in surface pump applications. These type of pumps operate by using a rotating impeller that propels water through the system. They start gradually and their flow output increases with the amount of current provided. However, because their output drops off at reduced speeds, a good match between a centrifugal pump and the solar array is necessary to achieve efficient production. The TDH and flow rate characteristics for any given pump can be found in the pump manufacturer's specifications and pump curves.

Pumps perform best with a compatible controller that serves as an interface between the solar energy gathered by the PV panels and the pump. The function of a controller is explained in greater detail in **Section 6.1 – Electronic Controllers**. Pumps can also be controlled with an electronic float switch or a standard pressure switch. ***Electronic float switches*** work by the direct wiring of a float switch to the pump. When water in a drinking facility or storage tank reaches "full", the switch will turn off the pump. The float will switch the pump back on when the water level drops below a set level. Another alternative is the use of a float valve and pressure switch. These setups are beneficial when the storage or drinking facilities are located remotely from the pump and they eliminate the need for a cable between them. A ***pressure switch*** is installed at the wellhead and is wired to the pump through the controller. When the tank fills, the float valve shuts, causing pressure to rise through the pipeline. The adjusted pressures of the switch then respond to the corresponding rise and fall of pressure within the system. With centrifugal pumps, it may be necessary to install a small pressure tank along with the pressure switch to limit the amount of start/stop cycling that may be caused by a slow acting or short set float valve.

Another important consideration when selecting the appropriate pump is the pump's operating voltage. Pump manufacturers may provide pumps with similar operating characteristics but different voltages. As noted in **Section 1.1 – Electricity Basics**, a higher operating voltage tends to be more efficient since there is less energy loss from the reduced current required to deliver the same power (wattage). This is important when considering the wire size and placement of the panels and controller relative to the location of the pump due to the voltage drop caused by resistance. Most solar pumps are designed to produce most efficiently at a given input voltage. The optimum operating voltage can range from as low as 12 volts for some brands all the way up to 300 volts for others. Pump efficiency and production can vary widely depending on the incoming power. As the supplied voltage to the pump decreases from the optimum operating voltage range the reduced efficiency can result in a production loss of 20% or more.

Maintenance of the pump is also important. Refer to the manufacturer product manual for the recommended operation and maintenance of the pump. In general, pumps should not be stored in water for a period longer than three months without being operated. Too long of a period of non-use may seize up the pump and they will have to be pulled to free them again.

5.1 Pump Selection

Factors affecting the selection of a solar powered pump include the following:

- The water source and pumping elevation (surface vs. well)
- The water requirement (flow rate and/or total volume in a given time period)
- Total Dynamic Head; TDH (in feet)
- The available electrical power (peak power) and energy (total energy, i.e. power x time) produced by the PV panel array

The water quality (including the amount of sediment, organic content, sand, and total dissolved solids [TDS]) may also be a required consideration for selecting a pump, as per the manufacturer's specifications.

Another factor to consider in solar-powered pumps is the ***hydraulic workload*** of the system. In pumping water, hydraulic workload is the amount of work required of a system to supply a flow against a given head (TDH) and is calculated as shown in **Equation 5.1**. Systems powered by solar are determined to be very effective when hydraulic workloads are less than 1,500 m^4. **Table 5.1** provides a range of hydraulic workload values and a corresponding applicability of use of solar power.

$$HW = TDH\ x\ 0.3048\ x\ \frac{WU\ x\ 3.7854}{1000} \tag{5.1}$$

where HW = Hydraulic Workload (m^4)
TDH = Total Dynamic Head (feet)
WU = Daily Water Use (Gallons per Day)

Hydraulic Workload	Solar Power Applicability
< 1,500 m^4	Power supplied by a properly sized solar-powered system is adequate.
1,500 – 2,000 m^4	Power required by the system may be limited by the use of solar-power.
> 2,000 m^4	More power is required than can be reasonably supplied by solar.

Table 5.1 – *Applicability of the use of solar power for a watering system*

5.2 Solar-Powered Pump Characteristics

A water pump can be selected using pump performance curves that show the operating characteristics for the solar-powered pump. The performance curves can have different parameters depending on the pump brand. For example, both Grundfos and Lorentz brand pumps include flow and input power axis parameters for varying TDH curves. The technical data for these pumps also give an optimal operating voltage that the pumps will perform at best efficiency. For Grundfos SQF model pumps this optimal voltage range is 120V-300V and for Lorentz it varies depending on the matched pump controller and can range from 17V for pumps paired with a PS2-150 controller to 238V for pumps paired with a PS2-4000 controller.

SunPump brand pumps are unique in that their curves are set up to determine at which optimum voltage the pump requires for a given flow and TDH. An example of these are shown in **Figures 5.2, 5.3, and 5.4**. An explanation of how to use pump curves is provided in the design examples located in **APPENDIX C – Design Examples**.

Alternatively, some suppliers have computer programs and web-based utilities for selecting and sizing pumps for specified values of available solar radiation, pump flow rate, and pumping head. Two of these such utilities include the web-based Grundfos Product Center (formerly WebCAPs) and the Lorentz Compass software. It is important to note that the solar insolation values used by these utilities are default values for a given latitude and do not always reflect the actual conditions of the project site. See **Section 2 – Solar Radiation, Solar Irradiance, and Solar Insolation** for determining insolation values for a project site.

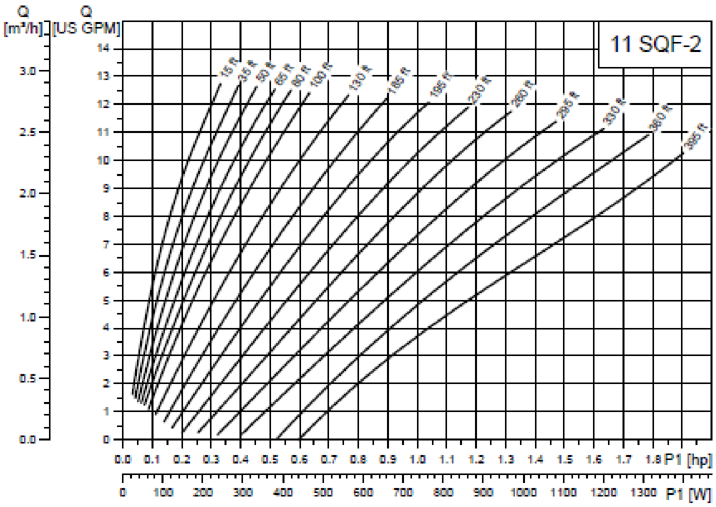


Figure 5.2 – *Example of a Grundfos SQF Model Pump*

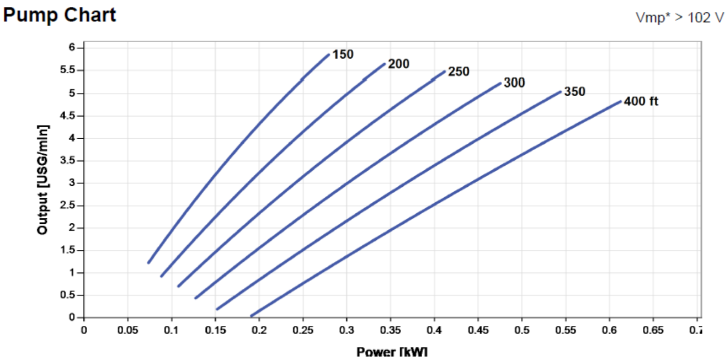


Figure 5.3 – *Example of a Lorentz Pump Paired with a PS2-1800 Controller*

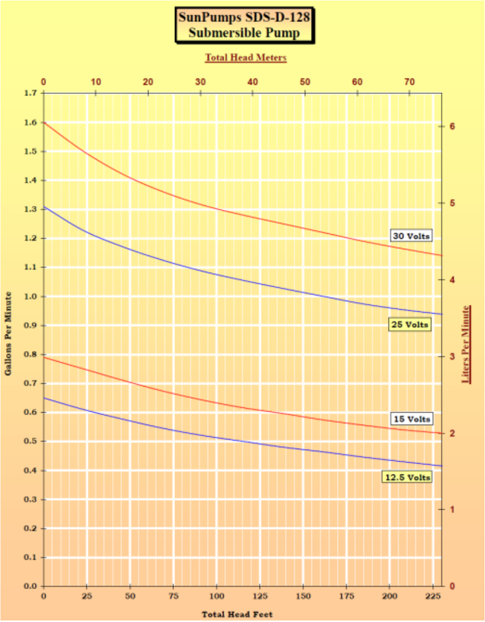


Figure 5.4 – *Example of a SunPump SDS Model Pump*

6. ELECTRICAL CONTROLLERS AND STORAGE

Up till now, the assumption has been that the solar panel array is wired directly into a load or, in the case of a watering system, a pumping plant. This assumption would be valid if the power supplied was constant but as explained in previous sections, solar energy is anything but constant. Directly wiring to a solar panel array can have substantial effects on the pump by either not having enough energy to run it or having too much supplied and burning out the motor. Electrical controllers have been developed to be installed as part of solar power systems to provide the control of the fluctuating energy received. In addition, solar power systems cannot provide power when there is no sunlight. Ideally, a system would be designed such that the desired demand can be met during the period which the energy source is available; i.e. daylight hours. There are times, however, where there are extended periods of abnormal cloud cover or additional demands on the system that will limit the incoming energy or require more production from the system. Added water storage or a properly sized battery backup system provides a way to store extra water or energy during times of plenty and be used during times of deficit.

6.1 Electrical Controllers

The main function of a ***controller*** is to act as the interface between the solar panels and the pump. First, it matches the output power that the pump receives with the input power available from the solar panels. Second, a controller usually provides voltage protection, whereby the system is switched off if the voltage is too low or too high for the operating voltage range of the pump. Once the energy from the solar panels is matched with the pumps, it is used to power the motor. PV panels produce a fairly constant voltage as the light intensity changes throughout the day; however, amperage changes dramatically with solar intensity. A pump controller trades voltage for current, which can allow the pump to start and run at reduced output in weak-sunlight periods. Additional safety devices are incorporated into controllers in order to provide necessary electrical protection and switching.

The controller normally includes a main switch to provide an electrical disconnect of the PV array from all other system components. Since the amount of power produced by the solar array depends on the intensity of incoming solar radiation, the controller can cause the pump to be switched off until sufficient power is available to meet the pump's specified minimum operating power input range. Likewise, when the PV panels produce too much power, the controller can limit the power output to the pump to prevent it from running faster than its maximum rated speed. The performance of the pump will vary depending on the type of controller selected. Matching pump motor performance to the available sunlight with a properly sized controller can increase the amount of water pumped in a day by 10 to 15 percent.

The pump's operation can also be controlled by the use of a float switch in the storage tank, which responds automatically when a preset water level is reached in the tank. Alternatively, the pump's operation can be controlled by a pressure switch, which responds when a designated water pressure is attained in the system. Another important safety device that should be included in most systems is a switch for low water dry run protection.

6.2 Water Storage

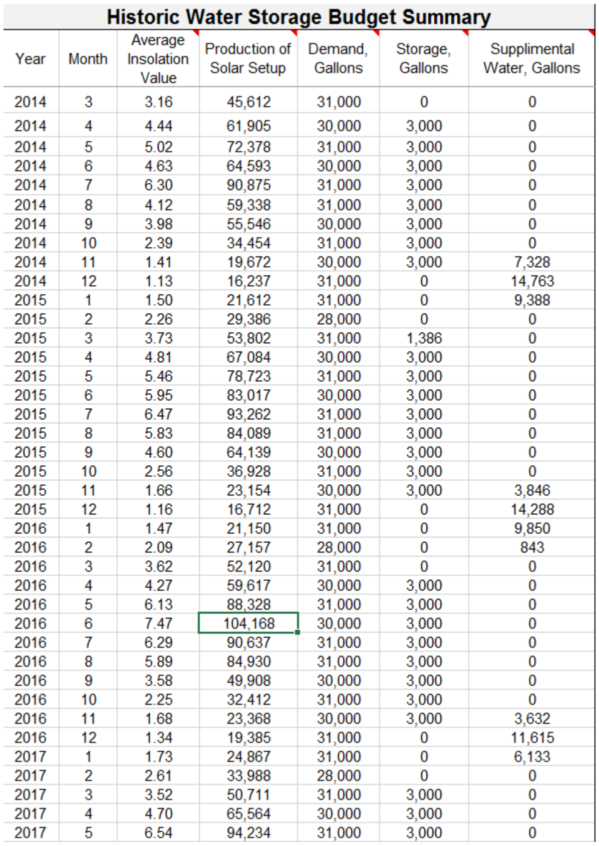
The most effective and typically least expensive means of utilizing excess incoming solar energy is to incorporate a water storage tank into the system. Once demand has been met for any given day, any extra water produced by the system can be stored for use in other periods where daily demand isn't being met. In North Dakota, NRCS requires 3 days of storage be supplied by a solar powered system. The storage can be a combination of drinking tanks and/or storage tanks. While calculating the required storage is straight forward (daily demand x 3 days), it can be quite confusing and difficult to determine the actual production of the system throughout the period of use. Assuming that the demand on a system stays constant throughout the year, the amount of production will depend on the amount of energy received. During design (see **Section 7 – Design Process for Solar Powered Watering Systems**), it may be determined that the actual daily production of the pump and solar array configuration will supply the 3 day storage volume. Other times, however, the daily production of the system may only meet the daily need and a more detailed analysis of the production vs demand would be needed; see Example 1 in **Appendix C – Design Examples**.

An effective way to determine if the storage provided is sufficient is through a water balance. A ***water balance*** will determine how much storage is still available during any period of time by keeping track of the daily production and demands into and out of the system. As noted in **Section 2 – Solar Radiation, Solar Irradiance, and Solar Insolation**, solar energy can vary throughout the day, day-to-day, and season-to-season. In June or July, when insolation values are between 6-7 hr/day, the production of a system designed to meet a daily demand for the month October will produce a great deal more than what is being used. During October, when the insolation values are 2-3 hr/day, the system will only produce around the daily demand for which it was designed.

Example 6.1 *Determine a Water Balance for a Solar Powered Watering System near Hazen, ND*

Given: *Daily Demand = 1,000 Gallons/Day Storage Tank = 3,000 Gallons Design Month = October*
System Layout = Grundfos pump w/ a 2 PV Panel Array Facing South and Tilted Up at 47°

Solution: *Using the last three years of record of recorded solar radiation data for the Hazen, ND NDAWN Station and the resulting production from the system, the following water balance starting in March of 2014 is as shown in the table below. This water balance assumes that the storage tank is initially empty.*



Historic Water Storage Budget Summary

Year	Month	Average Insolation Value	Production of Solar Setup	Demand, Gallons	Storage, Gallons	Supplimental Water, Gallons
2014	3	3.16	45,612	31,000	0	0
2014	4	4.44	61,905	30,000	3,000	0
2014	5	5.02	72,378	31,000	3,000	0
2014	6	4.63	64,593	30,000	3,000	0
2014	7	6.30	90,875	31,000	3,000	0
2014	8	4.12	59,338	31,000	3,000	0
2014	9	3.98	55,546	30,000	3,000	0
2014	10	2.39	34,454	31,000	3,000	0
2014	11	1.41	19,672	30,000	3,000	7,328
2014	12	1.13	16,237	31,000	0	14,763
2015	1	1.50	21,612	31,000	0	9,388
2015	2	2.26	29,386	28,000	0	0
2015	3	3.73	53,802	31,000	1,386	0
2015	4	4.81	67,084	30,000	3,000	0
2015	5	5.46	78,723	31,000	3,000	0
2015	6	5.95	83,017	30,000	3,000	0
2015	7	6.47	93,262	31,000	3,000	0
2015	8	5.83	84,089	31,000	3,000	0
2015	9	4.60	64,139	30,000	3,000	0
2015	10	2.56	36,928	31,000	3,000	0
2015	11	1.66	23,154	30,000	3,000	3,846
2015	12	1.16	16,712	31,000	0	14,288
2016	1	1.47	21,150	31,000	0	9,850
2016	2	2.09	27,157	28,000	0	843
2016	3	3.62	52,120	31,000	0	0
2016	4	4.27	59,617	30,000	3,000	0
2016	5	6.13	88,328	31,000	3,000	0
2016	6	7.47	104,168	30,000	3,000	0
2016	7	6.29	90,637	31,000	3,000	0
2016	8	5.89	84,930	31,000	3,000	0
2016	9	3.58	49,908	30,000	3,000	0
2016	10	2.25	32,412	31,000	3,000	0
2016	11	1.68	23,368	30,000	3,000	3,632
2016	12	1.34	19,385	31,000	0	11,615
2017	1	1.73	24,867	31,000	0	6,133
2017	2	2.61	33,988	28,000	0	0
2017	3	3.52	50,711	31,000	3,000	0
2017	4	4.70	65,564	30,000	3,000	0
2017	5	6.54	94,234	31,000	3,000	0

> *As the table shows, the only periods which the storage tank would not provide the required demand is November – January; with the exception of 2015 which is November – February. During the period of a typical grazing season, the provided storage is sufficient for the design. NOTE: This budget assumes that the system produces year round. In North Dakota, these systems would be shut down during the winter and the storage tank drained.*

The location of the water storage is important in the sizing of solar powered water systems. Ideally, a storage tank would be installed next to the well and solar array. When a tank is located remotely from the well and pump, in order to achieve necessary elevation for gravity flow to water tanks, additional head is added to the system. This additional head is the sum of any elevation change and friction loss through a pipeline from the well to the remote facility and needs to be included in the requirements for the pump and solar array. **Figure 5.1** shows a typical setup of a solar powered watering system with an installed storage tank near a well.

Figure 5.1 *– PV solar array with storage tank and stock.*
(Source: "Renewable Energy Primer-Solar.")

6.3 Batteries as Energy Storage for Solar Power Systems

A PV system may incorporate storage batteries that can be charged when incoming solar energy exceeds the pumping power requirement. The batteries can then be used to power the pump during periods where there is no sunlight available or is very limited. The use of batteries spreads the pumping over a longer period of time by providing a steady operating voltage to the DC motor of the pump. Thus, during the night or low light periods such as early morning/late evening or heavy overcast skies, the system can still deliver a constant source of water for livestock. ***<u>Both NRCS and the solar pump manufacturing industry strongly recommend water storage over energy storage as the most efficient means to provide backup power supply for low light conditions.</u>*** Installation of battery backup on solar systems is an alternative, however, and may be suited to some particular situations if the owner is willing to undertake the associated additional maintenance work and reoccurring replacement costs over the long-term.

The use of batteries does have its drawbacks. First, the use of a battery backup can reduce the overall efficiency of the system. This is due to the operating voltages being dictated by the batteries and not the PV panels. Depending on the temperature and their state of charge, the voltages supplied by batteries can be 1-4 volts lower than the voltage produced by PV panels during peak sun hours. This voltage drop, however, can be minimalized by a properly sized controller. Second, PV panels directly wired to the battery bank can produce voltages sufficient enough to overcharge the batteries causing severe damage. To prevent this overcharging, a

charge controller or charge regulator can be installed between the solar array and the battery bank. A charge controller is an essential part of nearly all power systems that charges batteries. They are so important that, when not present, it is common for batteries to fail after less than one quarter of their normal life, regardless of their quality or cost. These regulators work by allowing the full current produced by the PV panels to flow into the batteries until they are nearly fully charged. It then lowers the current causing the batteries to trickle charge until fully charged. Overload protection is also provided that protects the batteries from current surges or faults in the system (short circuits). A properly sized charge control regulator should be rated at the appropriate system voltage and the maximum number of amperes the solar panels can produce and be installed near the battery bank in accordance to manufacturer's instructions. Next, the battery bank can be severely damaged by deep-discharge during use. A ***low-voltage disconnect*** provides a low-voltage relay that acts as an automatic switch to disconnect the pump before the battery voltage gets too low. They work by way of a relay that, when the battery voltage drops to a "low-voltage" threshold, activates to receive incoming power from the PV panels. The relay then deactivates and switches back off when the battery voltage rises to a "reconnect" threshold. Most PV solar equipment suppliers can offer a charge controller or regulator that combines both overcharge protection and a low-voltage disconnect. Finally, due to the more complex control system the initial cost can be significant and require an increased cost in maintenance of the solar powered system.

6.4 Battery Basics

Among the various battery technologies available, it is the lowly and familiar lead-acid battery, most commonly deep-cycle types, that provides the best and cheapest energy storage available for solar applications. Lead acid batteries do not generate voltage on their own and can only store a charge from another source; hence the reason they are called storage batteries. Lithium-ion (Li-Ion) batteries can also be used quite effectively for storage but they do cost quite a bit more. Despite this, Li-Ions do typically have a longer life, perform better in harsh climates, and since they can be discharged nearly 100% without damage, they are far more forgiving when abused then their lead-acid counterparts. Li-Ions also pack a lot more energy within the same size package. The energy density for lead acid is around 40 Wh/kg while Li-Ions pack a whopping 150 Wh/kg.

Batteries store energy in units of ***amp-hours (Ah)*** at some nominal voltage and at some specified discharge rate. Lead-acid batteries typically have a nominal voltage of 2 Volts per cell; e.g. a 12-V battery would have 6 cells. Manufactures typically specify an amp-hour capacity at a discharge rate that would drain the battery down to 1.75 V per cell over a specified period of time. For example, a fully charged 12-V battery specified to have a 20-hr, 200-Ah capacity could deliver 20 Amps of current for 10-hours, at which point the battery would be drawn down to 10.5 V (6 cells x 1.75) and be considered fully discharged. It is also important to note that discharging a lead acid battery below 10.5 volts (for 12-V batteries) will severely damage it. Deep discharge lead-acid batteries can be routinely discharged by up to 80%, however, such long drawdowns will result in a lower lifetime number of cycles. Because of this and due to the extreme temperatures that North Dakota experiences the maximum drawdown allowed is 50%.

The amp-hour capacity of a battery is not only discharge rate dependent but also depends on temperature. The optimum operating condition of most batteries is around 25° C (77° F). For lead-acid batteries, capacity and voltage output can decrease dramatically the colder it gets. For example, at -30° C (-25° F) a battery can have only half its rated capacity. Li-Ion batteries, on the other hand, do not tend to suffer from these same cold weather effects. Heat is also not good for battery performance. A general rule of thumb estimate is that battery life is shortened by 50% for every 10° C (50° F) above the optimum 25° C operating temperature.

When batteries are wired to together, the resulting collection is referred to as a ***bank***. A bank of batteries wired together follow the same rules as when PV panels are wired together. For batteries wired in series, the voltages add and since the same current flows through each one, the amp-hour capacity of the string is the same as it is for each battery individually. Wired in parallel, the voltage across each battery is the same and the current produced by each one would add together. Batteries in series tend to have higher voltages and lower current causing the wired bank to have more manageable wire sizes and smaller fuses and switches. Wiring in series also means that to add more storage, a whole new string of batteries must be added. Banks wired in parallel, however, are easy to expand by just adding one battery at a time.

6.5 Sizing of a Battery Backup System

The size or power requirement of the battery backup is based on the amount of power required to run the system when there is very little or no solar power available. Instead of working with energy in kWh like with PV panels, it is the voltage of the battery bank and the amp-hour rating of each battery in the bank that matter. It is important to match the voltage of the battery bank to the input voltage requirements of the pump. Another guideline used when setting the voltage is to keep the maximum steady-steady state current drawn by the system to below 100-amps. With lower currents, smaller gauged wire and fuses can be used. **Table 6.1** can be used to determine the minimum system voltage needed by the batteries based on the power required by the pump to keep the system current below the 100-amp target.

Power Requirement of Pump	Minimum System Voltage Needed
< 1,200 W	12 V
1,200 – 2,400 W	24 V
2,400 – 4,800 W	48 V

Table 6.1 – *Minimum System Voltages for Limiting Current to 100-Amps*

The size of the battery bank can be determined by knowing the amount of power required by the pump to provide the flow rate that will produce the daily demand and necessary storage, and the operating voltage of the pump. The current required by the battery bank to provide the system in order to meet the demand and storage can be determined by **Equation 6.1**.

$$Required\ Current\ for\ System = \left(\frac{Pump\ Input\ Power}{Pump\ Operating\ Voltage}\right)/50\% \qquad \textbf{(6.1)}$$

where 50% is the maximum allowable battery discharge

The voltage required by the battery bank is simply the operating voltage of the pump. The number of batteries required to be wired in series to supply the operating voltage and produce the daily demand can be determined by **Equation 6.2**.

$$Batteries\ in\ Series = \frac{Pump\ Operating\ Voltage}{Battery\ Rated\ Voltage} \qquad \textbf{(6.2)}$$

As noted in **Section 6.2 – Water Storage**, North Dakota NRCS requires a minimum of 3 days storage for solar powered watering systems. North Dakota Practice Standard 614 – Watering Facility allows for battery power to supply 2 of those 3 days.

Example 6.2 *Determine the size of the battery bank to provide 2 out of the 3 day storage for a system that has a daily demand of 1,000 gallons/day.*

Given: Grundfos 3 SQF-2 Pump Total Dynamic Head = 100-ft

Battery Used → 12V Deep Cycle Lead Acid 20 Hour Rate: 200 Ah

Solution: *System Flow Rate = 2,000 GPD / (24 x 60) = 1.4 GPM*

From the Grundfos 3 SQF-2 pump curve → 1.4 GPM @ 100ft TDH = 110W

The optimum operating voltage of Grundfos SQF pumps is 120V but can operate at voltages as low as 30V.

*Required Current using (**6.1**) → (110W/120V) / 50% = 1.83 Amps*

for 30V → (110W/30V) / 50% = 7.33 Amps

*# of Batteries Wired in Series (**6.2**) → 120V / 12V = 10 Batteries*

for 30V → 30V / 12V = 2.5 or 3 Batteries

A battery with a 20 Hour Rate of 200Ah will provide 20 Amps for 10 hours. The selected battery will easily be able to supply the calculated current over a full day for both the minimum and optimal operating voltages and the battery bank will only require a single parallel string.

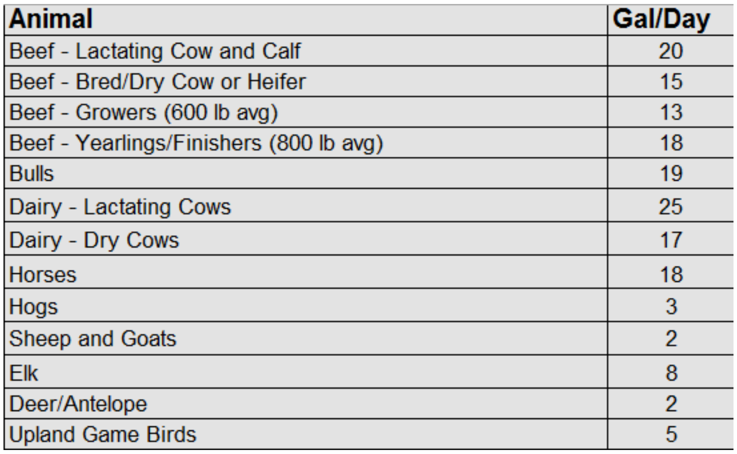
Minimum Size of Battery Bank – A single string of three 12V Deep Cycle Lead Acid batteries with a 20 Hour 200 Ah rating and wired in series will provide the system with enough power to supply the demand for the two out of three days.

7. DESIGN PROCESS FOR SOLAR POWERED WATERING SYSTEMS

The following twelve steps can be used in the design process for a PV-powered water pump system. These steps are a guide that can assist in the design, layout, and proper function of the system.

7.1 Step 1 – Water Requirement

The first step in any watering system is to determine the overall water requirement for the operation. The daily summer drinking demands for primary users of a typical watering system are shown in **Table 7.1**. There is limited published data on water requirements for bison; however, it is generally assumed that the daily requirements are similar if not slightly less for bison cows, calves, and bulls as it is for beef cattle.



Animal	Gal/Day
Beef - Lactating Cow and Calf	20
Beef - Bred/Dry Cow or Heifer	15
Beef - Growers (600 lb avg)	13
Beef - Yearlings/Finishers (800 lb avg)	18
Bulls	19
Dairy - Lactating Cows	25
Dairy - Dry Cows	17
Horses	18
Hogs	3
Sheep and Goats	2
Elk	8
Deer/Antelope	2
Upland Game Birds	5

Table 7.1 – *Daily Animal Water Requirements*

If the watering system will supply water to different species other than shown, ensure that sufficient water is provided to meet the sum of the seasonal high daily water requirements of all the animals. Local conditions should also be taken into consideration. Design documentation is required for water requirement values not included in the table. It is also worth noting that the system's water requirement may vary throughout the year depending on the period of use. The **North Dakota ENG-39 Watering System Resource Inventory Datasheet** can be used to determine and document the required daily animal demand.

7.2 Step 2 – Water Source

The configuration of the water system will be defined primarily by the type of water source used, the local topography, and the location(s) of the delivery point(s). The water source may be either subsurface (a well) or surface (a pond, stream, or spring). In North Dakota, solar powered watering system will mostly be supplied by either a new or existing drilled well.

If the water source is a well, the following items will need to be determined:

- The static water level (water elevation in the well when not pumping)
- The dynamic water level (drawdown of the water in the well at the designed pumping rate)
- Any seasonal variation of the water level in the well
- The water quality

Information on water levels and well production can be obtained from the well log. (A sample well log is provided in **APPENDIX H – Sample Well Log**)

The dynamic water level obtained from the well log should be used to determine the production potential of the well to ensure that the well will be able to supply the system's estimated water needs. If the well log indicates an excessive drawdown during the given testing time, the well may not have the capacity to meet the water demands of the project. If the capacity of the well is in question, a complete well test should be performed and the drawdown levels measured for different flow rates. The dynamic water level should be used when determining the pumping lift and Total Dynamic Head (TDH) during pumping.

If a new well is to be drilled for the project, information from well logs of existing, nearby wells can provide valuable information about the subsurface hydrology in the area and the potential yield of the proposed well. Records of well logs are available online from the North Dakota State Water Commission MapService: http://mapservice.swc.nd.gov/index.phtml?active=Drillers

For surface water sources, such as a stream, pond, or spring, the following need to be determined, taking seasonal variations into account:

- Water availability
- Pumping levels
- Water quality, including the presence of silt and organic debris.

With surface water, availability and water level can vary seasonally. In particular, the amount and quality of the water may be low during the summer, when it is needed most. Additionally, when a surface water source is used, proper screening of the pump intake is necessary to ensure that debris and sediment from the surface water body are not pumped into the system.

7.3 Step 3 – System Layout

The third step in the system development process is to determine the layout of the entire system, including the locations and elevations of the following components:

- Water source
- Pump
- PV panel array
- Storage tanks
- Delivery points (i.e. water troughs)
- Pipeline routes

An example of a proposed system layout is provided in **Figures 7.1 and 7.2**.

It is also important to consider potential vandalism and theft when locating PV panels and pump systems. Unfortunately, since most solar panel systems are located in remote areas on open landscapes, there can be a risk of vandalism and/or theft. If possible, panels, tanks, and controllers should be located away from roads and public access to limit these concerns. Care should be taken to situate the PV array far enough away and to the south of tall bushes and trees and other types of vegetation to reduce the potential for their obstruction by shadows during peak solar insolation hours.

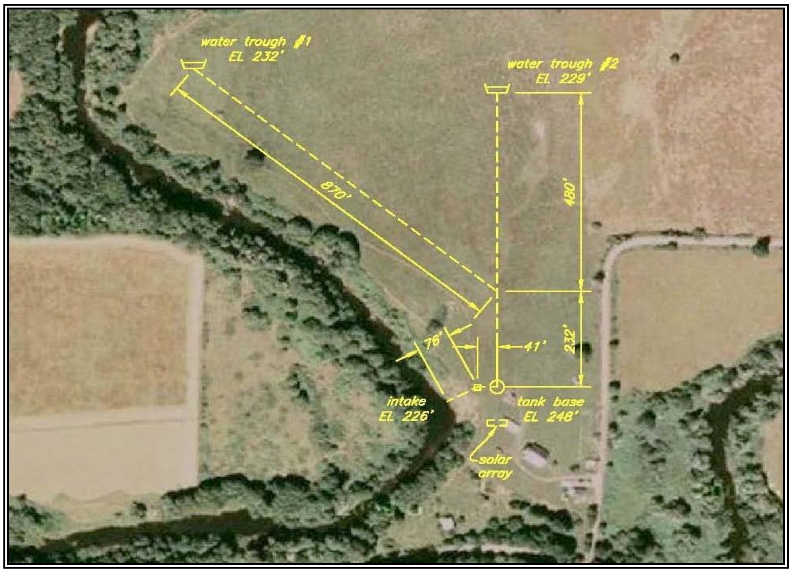


Figure 7.1 – *Example layout of a solar powered watering system*

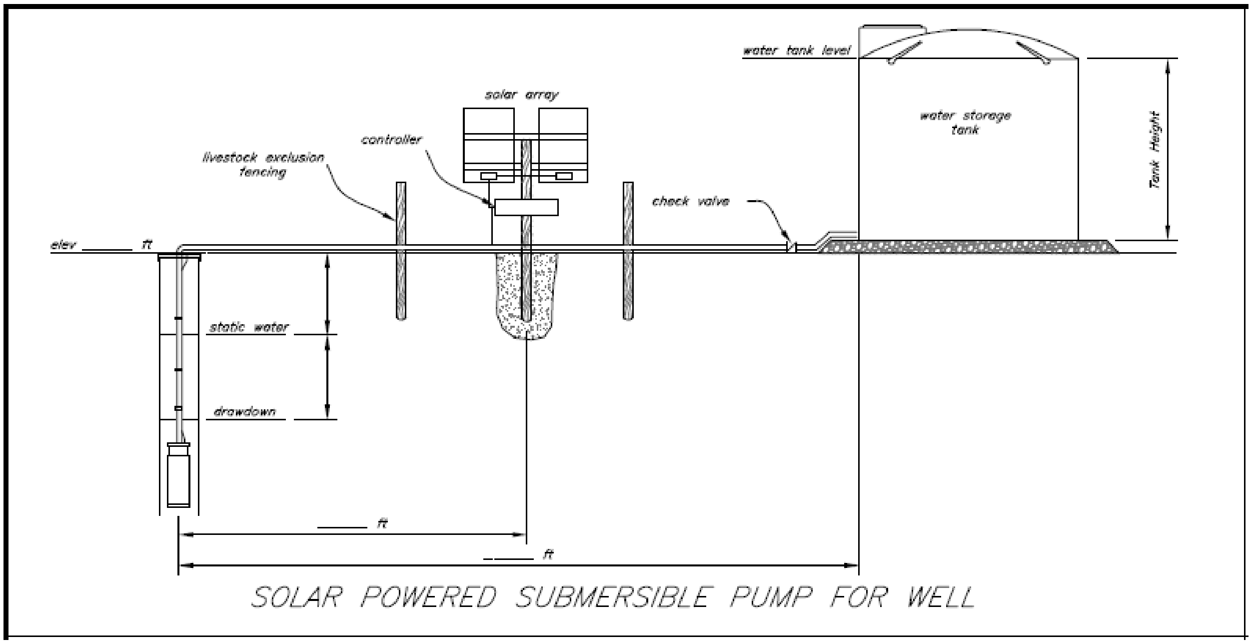


Figure 7.2 – *Elements of a typical installation supplied by a well.*

In addition, secure fencing is essential to protect the PV-powered system. Secure fencing provides added protection against vandalism and theft, as well as against inadvertent damage from wandering wildlife or livestock.

Finally, selecting the correct size and type of wire when connecting the pump to the solar array or a battery backup bank increases the performance and reliability of the system. If possible, it is recommended that the solar array and pump set within 100 feet of each other. At this distance, a #12 gauge wire is sufficient to keep the voltage loss in most 24-volt systems to roughly 3%. For longer distances, resistance increases accordingly. Larger diameter wire, therefore, would be required to keep the voltage loss in the system at a minimum. A voltage drop of only 5% can translate to a 7-8% power loss at the pump.

7.4 Step 4 – Solar Insolation and Solar Array Layout

The key in properly sizing a solar powered watering system is determining what value to use for the system's input power and the location and layout of all the system components. **Section 2 – Solar Radiation, Solar Irradiance, and Solar Insolation** provides a good introduction to solar energy and how to determine solar insolation values for North Dakota. For design, the nearest NDAWN weather station to the project site is to be used to determine the insolation value. A list of insolation values are included the tables in **Appendix D** and an introduction of how to use the NDAWN website is provided in **Appendix E**.

Despite the large network of NDAWN stations across the state, an on-site investigation could be needed for sites where solar insolation data is lacking or questionable. The investigation should be conducted by a qualified specialist and include data verifying the actual solar insolation at the site.

In order to maximize the solar-powered system's energy production, the panels should be south facing with no significant shading in their vicinity in order to achieve full sun exposure. However, partial shading (e.g., shadows from tall trees) in the distance during the early morning or late afternoon may be unavoidable. The effects of any shading present should be considered when determining the amount of available solar energy. Also consider the potential effects that the slope and aspect of future shading due to continued tree growth may have.

As discussed in **Section 3.3 – PV Panel Orientation and Tracking**, the orientation of the solar array is critical in the overall performance of the system. The ideal tilt angle to harvest the greatest amount of solar energy is equal to the local latitude of the project site. **Example 3.1** works through the method of determining the optimal tilt angle for a fixed-axis solar array. A project site located near Bismarck, ND will have a year round optimal tilt angle equal to its latitude of 47° or an optimal summer tilt angle of 32° and winter tilt angle of 62°. An optimal tilt angle can also be calculated for a custom period such as a grazing season. A grazing season of March – October for the Bismarck site will result in a custom optimal tilt angle of 37.6°. A complete list of optimal tilt angles for each NDAWN station is provided in **Appendix F**.

7.5 Step 5 – Design System Flow Rate for Pump

To help ensure that the daily water demand of the grazing herd is met throughout the entire grazing season, the average solar insolation value for the month with the least solar intensity should be used. The design system flow rate to be delivered by the pump is calculated using **Equation 7.1** and is the daily water needs of the operation divided by the solar insolation value determined in **Step 4**.

$$Design\ Flow\ Rate = \frac{Daily\ Demand}{Solar\ Insolation\ x\ 60} \qquad \textbf{(7.1)}$$

For example, for a daily water requirement of 1,000 gallons/day and a solar insolation value of 2.52 kWh/m^2/day, or 2.52 hr/day:

$$Design\ Flow\ Rate = \frac{1{,}000}{2.52\ x\ 60} = 6.6\ gpm$$

7.6 Step 6 – Total Dynamic Head (TDH) Requirement of the Pump

As described in **Section 5 – Solar Powered Pumps** and shown in **Equation 7.2**, the TDH for a pump is the sum of the vertical lift, pressure or elevation head, and friction loss. Friction losses apply only to the piping and appurtenances between the point of intake (i.e. the well) and the point of discharge (i.e. the storage tank or stock tank). While a majority of systems are laid out with a storage tank or watering facility located near the well and pump, there can be applications where the storage would be located remotely. For these applications, the friction loss of the connecting pipeline and the elevation difference between the well and the storage will need to be included in the TDH calculation.

$$Total\ Dynamic\ Head\ (TDH) = Vertical\ Lift + Elevation\ Head + Friction\ Loss \qquad \textbf{(7.2)}$$

First, the vertical lift of a typical water well application is measured from the pumping or dynamic water level within the well to the outlet of the well. The vertical lift for surface water systems is measured from the ground elevation of the surface pump to the elevation of the intake. It is recommended that the intake be located a minimum of 5ft below the average water level in the pond/stream in order to account for evaporation and seasonal fluctuations. For systems with storage next to the water source, water will outlet directly into the watering facility and would include the height above the ground surface to the inlet of the tank. The vertical lift for systems with remote storage would be measured to the inlet elevation of the connecting pipeline from the water source.

Next, the elevation head is the difference in elevation between the water source and the outlet. System layouts with storage located next to the water source generally do not have any elevation difference between itself and the source. Systems with remote storage can have a measurable elevation difference between the water source and the outlet. This elevation difference must be accounted for to ensure that the pump is able to deliver the demand.

Finally, the friction loss includes the losses through both the pump column pipe, along its associated fittings, and the pipeline between the water source and the storage or watering facility.

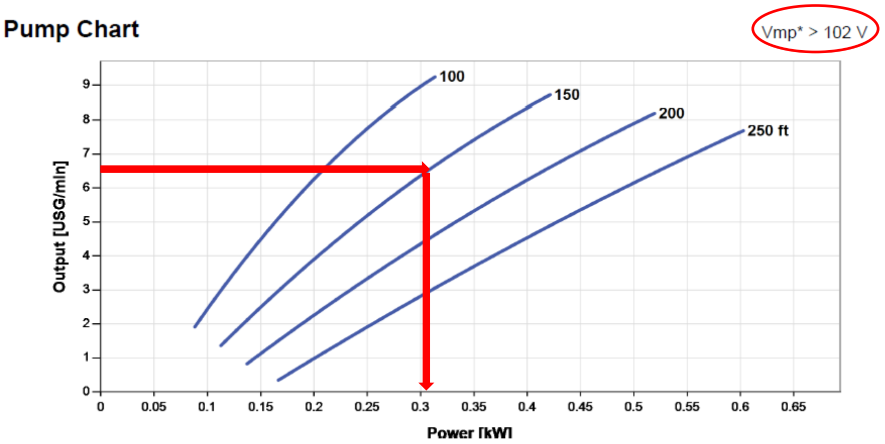
Flow from a storage tank to the point of use (i.e. the trough) is typically gravity fed. Therefore, friction losses between the storage tank and the point of use are independent from the pump and do not need to be accounted for when sizing the pump.

Note: **Steps 7 – 10** are typically completed by an equipment supplier hired by the agricultural producer, on the basis of the daily demand, TDH, and solar insolation value specified by NRCS in the design. NRCS employees, however, are expected to verify that the selected equipment was correctly designed.

7.7 Step 7 – Pump Selection and Associated Voltage and Power Requirement

The pump should be selected using the appropriate pump performance curve from the manufacturer. Examples of performance curves for brands common in North Dakota are shown in **Figures 5.2, 5.3, and 5.4** (page 19). The curves are essential in ensuring that the pump can deliver the required flow (**Step 5**) against the known TDH (**Step 6**). The peak power requirement for the pump can be determined from these curves for a given flow rate and TDH to help make the appropriate pump selection, as well as the appropriate PV panel selection (**Step 8**). As discussed in **Section 5 – Solar-Powered Pumps**, pumps produce most efficiently at an optimum voltage range. The manufacturer technical data sheet for model of pump will give the full operating voltage range for the pump as well as an optimum operating range.

For example, the power requirement for a pump installed in a well that is designed to produce the 6.6-gpm from **Step 5** and against a determined TDH of 150-ft from **Step 6** is 0.31kW or 310W and the optimum operating voltage is 102V:



Pump efficiency can also be determined from these characteristics as well. Some pump curves can contain an extra set of curves for efficiency but this can be calculated by **Equation 7.3** as well.

$$Pump\ Efficiency\ (P_{eff}) = \frac{0.1885\ x\ TDH\ x\ Q_{Inso}}{P_{in}}\ x\ 100 \tag{7.3}$$

where TDH = *Total Dynamic Head*
Q_{Inso} = *Flow Rate required by pump from the Solar Insolation value to meet the daily demand*
P_{in} = *Required Pump Input Power*

Continuing the pump example, the pump efficiency would be:

$$Pump\ Efficiency\ (P_{eff}) = \frac{0.1885\ x\ 150ft\ x\ 6.6gpm}{310W}\ x\ 100 = 60\%$$

7.8 Step 8 – PV Panel Selection and Wiring of Solar Array

Once the voltage and peak power requirement (**Step 7**) for the selected pump is known, this value can be used to select the solar panel or array of panels required to supply that power.

Just as with pumps, different brands and models of solar panels have unique performance characteristics. A table with the panel's electrical characteristics can be found in the technical data sheet from the manufacturer and is also typically located on a sticker located on the back of the panels themselves; as shown in **Figure 7.3**.

HELIOS SOLAR WORKS LLC
www.heliossolar.us

Model No	HSE250-60P
Rated Maximum Power (Pmp)	250W
Tolerance	± 3%
Voltage at Pmp(Vmp)	30.6V
Current at Pmp(Imp)	8.17A
Open-circuit Voltage (Voc)	36.3V
Short-circuit Current (Isc)	8.71A
Maximum Series Fuse Rating	15A
Maximum System Voltage	600V(UL)

All technical data at standard test condition
AM=1.5 E=1000W/m² Tc=25 ℃
Application Class A
Design load : 2400Pa Size:1640mm*990mm*35mm
Fire rating: Class C Weight:19KG
System Fire Class Rating: See Installation Instructions for Installation Requirements to Achieve a Specified System Fire Class Rating with this Product
Add: 1207 West Canal street ,Milwaukee Wisconsin

Figure 7.3 – *Example of Solar Panel Electrical Characteristics*

As discussed in **Section 3 – Photovoltaic (PV) Panels**, solar arrays are a set of PV panels wired in some combination of series and parallel strings. It is critical to ensure that the wiring of the array is within both the voltage and amperage limits of the controller and pump. **Equations 7.4 and 7.5** can be used to determine the number of panels to be wired in series and parallel; respectively.

$$Wired\ in\ Series\ (SP_{Series}) = \frac{P_{volts}}{V_{mpp}} \tag{7.4}$$

where P_{volts} = *Optimum Operating Voltage of Pump*
V_{mpp} = *Voltage of PV Panel @ Rated Power*

$$Wired\ in\ Parallel\ (SP_{II}) = \frac{P_{in}}{SP_{Series}\ x\ V_{mpp}\ x\ I_{mpp}\ x\ DRV} \quad \textbf{(7.5)}$$

where P_{in} *= Required Pump Input Power*
I_{mpp} *= Current of PV Panel @ Rated Power*
DRV = De-Rating Value of the Panel (Typically 85%)

The total voltage and current produced by the solar array is then the combination of the wired panels. The power output of the individual panels can be added together to determine the total power they produce.

Continuing with the pump example from **Step 7** and the PV panel characteristics of **Figure 7.3**, the size of the solar array would be as followed:

$$Wired\ in\ Series = \frac{102V}{30.6V} = 3.33\ or\ 4\ Panels\ in\ a\ String$$

$$Wired\ in\ Parallel = \frac{310W}{4\ x\ 30.6V\ x\ 8.17A\ x\ 0.85} = 0.37\ or\ 1\ String$$

The solar array would then be composed of 1 String of 4 panels wired in series. Given that the PV Panel is rated at 250W, the 4 panels will easily meet the 310W power requirement of the pump. It is important, however, to make sure that the total power supplied by the solar array does not exceed the maximum rated limit of the pump and controller.

See **APPENDIX I – Solar Panel Wiring** for examples of wiring panels in series, parallel, and a combination of series and parallel.

7.9 Step 9 – PV Array Mounting and Foundation Requirements

Hardware for mounting panels to a post is normally provided by the supplier. If no supplier mount is provided, contact a qualified engineer for design details. **Section 4.1 – Structural Supports for PV Panels** gives the minimum criteria required for the mounts.

A ND NRCS Standard Drawing for a PV panel embedded post mount that meets the design criteria listed in **Section 4.2 – Mounting Posts** is provided in **APPENDIX G**. Designs that exceed the criteria listed in the drawing must be constructed by a qualified engineer. Panel mount posts other than the standard posts and associated embedment shown in **APPENDIX G** require a documented engineering design.

If a panel or array of panels is to be mounted on an existing structure, that structure must first be analyzed by a qualified engineer to ensure that it has the structural integrity necessary to withstand all local wind, snow, and ice conditions once the panel(s) are mounted.

Solar water pumping systems attract lighting because of the excellent grounding they provide. If possible, do not locate the system in the highest points of the surrounding area. For the safety of the equipment and everyone who may come into contact with the pump system, it is important to properly ground all electrical components and solar panel structures to reduce the possibility of damage from lightning strikes. It would be beneficial to install lightning rods on higher terrain around the system if lightning is a known problem.

7.10 Step 10 – System Production and Flow Rate

The entire system, including the PV panels, pump, pipe, and any storage tanks, must be analyzed to ensure that the design demand and corresponding flow rate can be delivered to the delivery point at an acceptable velocity and required pressure in order to properly operate any valves (e.g., a float valve).

The total output production and corresponding flow rate of the pump and solar array configuration can then be determined by **Equations 7.6 and 7.7**; respectively.

$$System\ Production\ (Q_{System}) = \frac{V_{mpp}\ x\ I_{mpp}\ x\ SP_{Total}\ x\ Solar\ Insolation\ x\ 60\ x\ DRV\ x\ P_{Eff}}{0.1885\ x\ TDH} \quad \textbf{(7.6)}$$

where V_{mpp} = *Voltage of PV Panel @ Rated Power*
I_{mpp} = *Current of PV Panel @ Rated Power*
SP_{Total} = *Total # of Panels in Array*
DRV = De-Rating Value of the Panel (Typically 85%)
P_{Eff} = *Pump Efficiency*
TDH = Total Dynamic Head

$$Actual\ Flow\ Rate\ of\ System = \frac{Q_{System}}{Solar\ Insolation\ x\ 60} \quad \textbf{(7.7)}$$

Continuing with the pump example from **Steps 5, 7, and 8** the system production and corresponding flow rate would be:

$$System\ Production\ \left(Q_{System}\right) = \frac{30.6V\ x\ 8.17A\ x\ 4\ x\ 2.52hr/day\ x\ 60min/hr\ x\ 0.85\ x\ 60\%}{0.1885\ x\ 150ft} = \ 2{,}750\ GPD$$

$$Actual\ Flow\ Rate\ of\ System = \frac{2{,}750\ GPD}{2.52hr/day\ x\ 60} = 18\ GPM$$

The resulting production of the system verifies that the required daily water use of 1,000 GPD of **Step 5** is indeed met. The system's pipeline and associated appurtenances would then need to be verified that the corresponding flow rate will not cause issues; i.e. velocities exceeding 5 ft/sec.

7.11 Step 11 – Water Storage

As described in **Section 6.2 – Water Storage**, a water storage tank is an essential element in an economically viable solar powered water pump system. A storage tank can be used to store enough water during peak energy production to meet water needs in the event of abnormally cloudy weather or maintenance issues with the power system. In North Dakota, it is required that storage be sized to store at least a three-day water supply. This can be done with a single storage tank or multiple tanks, which can including drinking tanks, if a very large volume of water needed.

7.12 Step 12 – Summary Description of the System

The designer should provide a descriptive summary of the completed system to the landowner/contractor that includes the following information:

- All system components and their specifications.
- System operating characteristics, such as required water use demand, TDH, voltages, amperages, wattages, etc.
- Special considerations required in the system design, including any environmental factors.

8. ADDITIONAL CONSIDERATIONS

This technical note has reviewed the many different elements that should be considered in the design of a solar-powered water pump system. However, since each system will have its own unique set of design constraints, this technical note is not intended as a standalone document. Rather, its intent is to provide a starting point for the design process.

In addition to using this technical note, the designer is encouraged to perform research using the recommended references located in **Appendix B – Additional Resources** to collect further information on solar-powered water pump systems.

APPENDIX A: References

Gilbert M. Masters. "Renewable and Efficient Electric Power Systems". 2004 (1st Ed) and 2013 (2nd Ed). John Wiley & Sons, Inc. Hoboken, New Jersey.

"South Dakota Livestock Systems Guide". Design Technical Note No. SD2009-1. 2009. USDA NRCS – Huron, South Dakota. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_036102.pdf

"Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems". Technical Note No. 28. 2010. USDA NRCS – Portland, Oregon. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_040138.pdf

Lance Brown. "B.C. Livestock Watering Handbook". 2006. British Columbia Ministry of Agriculture and Lands. Abbotsford, B.C.

Christopher W. Sinton, Roy Butler, and Richard Winnett. "Guide to Solar Powered Water Pumping Systems in New York State". New York State Energy Research and Development Authority. Albany, NY.

Michael J. Buschermohle and Robert T. Burns. "Solar-Powered Livestock Watering Systems". PB 1640. Agricultural Extension Service, University of Tennessee. *http://utextension.tennessee.edu/publications/Documents/pb1640/pdf*

"Renewable Energy Primer-Solar". 2003. USDA NRCS West National Technical Center. Portland, Oregon.

Notes from Corrosion Control Seminar. 2005. U.S.Army Corps of Engineer Professional Development Support Center. Huntsville, AL.

APPENDIX B: Additional Resources

Additional information on solar-powered water pump systems can be found by doing an internet search for the following:

- National Renewable Energy Laboratory
- US Department of Energy, Energy Efficiency & Renewable Energy
- USDA NRCS Energy Self-Assessment
- National Sustainable Agriculture Information Service
- Database of State Incentives for Renewables and Efficiency
- Renewable Energy Site for Do-It-Yourselfers
- American Solar Energy Society – Directory/Tools/Costs
- Homepower Magazine – Dealers/Installers
- Real Good Solar Products
- Solar System Rating and Certification

APPENDIX C: Design Examples

This appendix contains two examples that demonstrate how to design a solar-powered water pump system. The first scenario utilizes a subsurface water source (a well) while the second utilizes a surface water source (a pond).

The intent of these two typical design scenarios is to walk you through the basic design process. These examples are not meant to address all the elements needed for the design and implementation of all solar-powered water pump system but merely to demonstrate the basic concepts. Each system will have its own unique set of design considerations and constraints, which will need to be addressed accordingly.

EXAMPLE 1: Solar-Powered Water Pump System Using a Well as a Water Source

Determine:

Design a solar-powered water pump system that consists of a midsize cow/calf operation near Hazen, North Dakota. It is necessary to determine the size of the system needed, including the pump, piping, PV panels, appropriate mounting structure and tilt angle, tank size, etc.

Given:

- The landowner runs 50 cow/calf pairs on 85 acres of pasture land.
- The landowner intends to use an existing well in the pasture for the water supply.
- The grazing season is planned from March through October.
- The landowner lives nearby and is on site daily for routine maintenance but would like a storage tank sized for a minimum of three days of water storage in the event of extended cloudy weather or maintenance issues that prevent the pump from operating.
- The storage tank is located near the well and the inlet into the tank is 7' above the ground.
- The landowner intends to gravity feed two watering troughs located 1,000ft and 1,150ft from the proposed storage tank.
- Two 500-gallon troughs are to be used. Each trough will be equipped with a float valve that requires 2 psi to operate properly.

Analysis:

Step 1. Water Requirement

To determine the operation's water needs, use **Table 7.1** (page 26) to calculate the total water requirement for the cattle, as shown below:

50 Cow/Calf Pairs x 20 gallons/day/animal
= 1,000 gallons/day

Step 2. Water Source

A search of the ND State Water Commission MapService found the well log for the existing well; see **Appendix H**.

The well log contains the following pertinent information with respect to a ground elevation of 1,000ft:

- Depth of Well Below Surface – 285ft
- Static Water Level Below Surface – 190ft
- Dynamic Water Level Below Surface – 70ft of drawdown after 2hrs @ 10gmp (260ft)
- Depth of Pump Below Surface – 275ft

Step 3. System Layout

The next step is to determine the layout of the proposed system. The identified distances and elevations for the well, pump, PV panels, storage tank, and water troughs are shown in **Figure C1**. For this example, based on the site-specific data provided in the aerial view, the site has good south-facing exposure and appears well suited for solar power. Flow from the storage tank to the water troughs will be gravity fed. Based on the given elevations, the natural layout of the site appears to provide an adequate elevation difference between the storage tank and the water troughs to operate the tank float valves in the water troughs. In addition, the storage, pump, and PV panels can all be located in close proximity to one other in order to minimize electric power and pipeline friction losses.

Figure C2 depicts the profile of the proposed layout of the pump and PV panels.

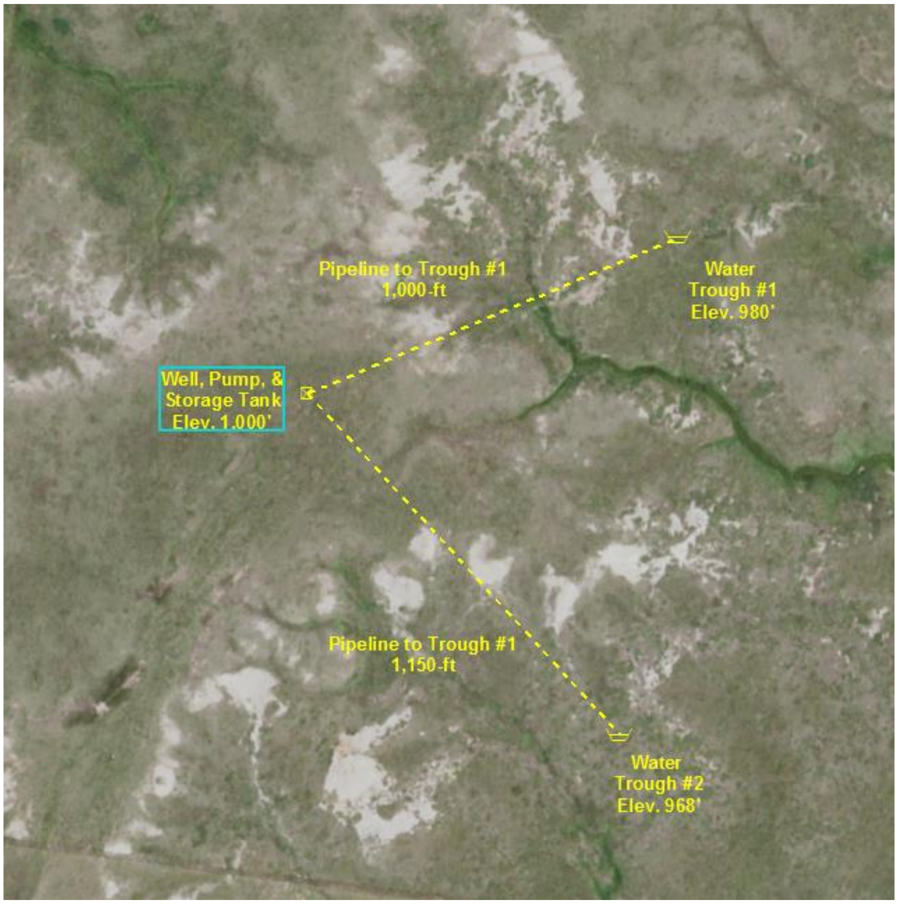


***Figure C1** – System Layout for Design Example 1.*

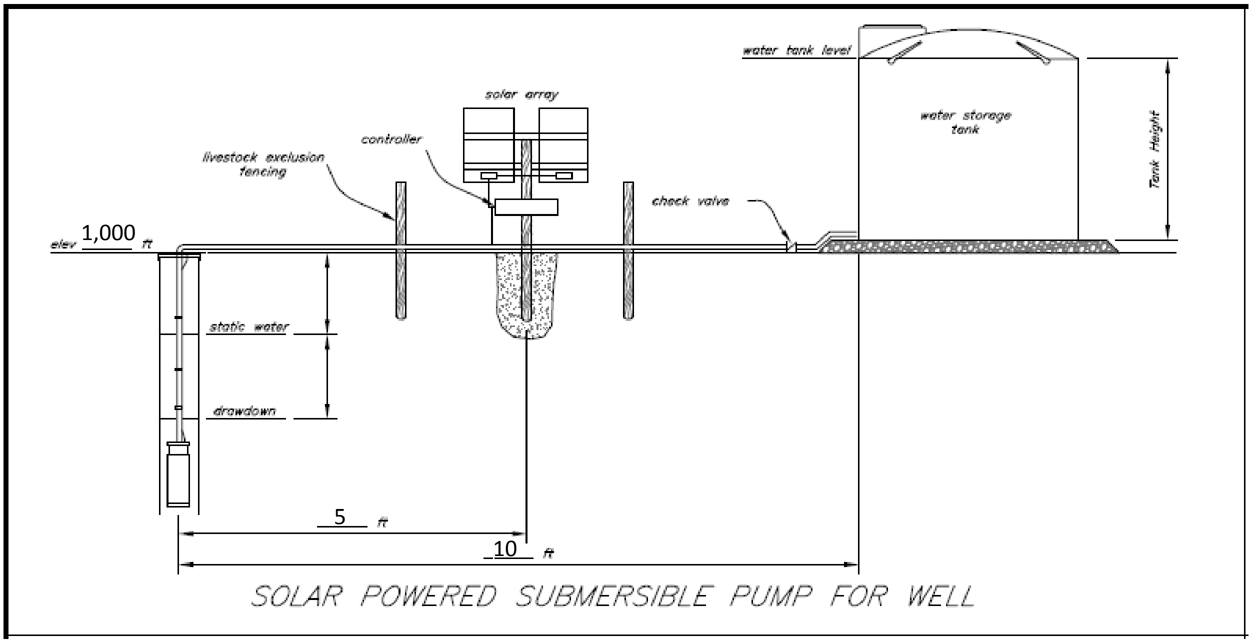


Figure C2 *– System Layout Profile for Design Example 1.*

Step 4. Solar Insolation and Solar Array Layout

The closest observed solar insolation values for the project site is from the NDAWN station near Hazen, ND and can be found in **Appendix D** and are shown in the table below. Given that grazing is planned March – October, the month with the lowest average value, October, will be the target insolation value used for the design; 2.52 hrs/day.

Station Name	March	April	May	June	July	August	September	October
Hazen	3.75	4.88	5.59	6.21	6.58	5.52	4.09	2.52

The average solar insolation values given in **Appendix D** assume that the solar array is facing south with an optimal fixed tilt angle. These tilt angles are listed in **Appendix F** and are shown in the table below.

Station Name	Latitude	Optimal Average Annual Tilt Angle	Optimal Summer Tilt Angle	Optimal Grazing Season Tilt Angle (March – October)
Hazen	47.5°	47.5°	32.5°	38°

To minimize the labor needed in adjusting the tilt angle throughout the grazing season, the optimal tilt angle calculated for March – October will be used; 38°.

Step 5. Design Flow Rate for Pump

The pump's design flow rate is based on the operation's estimated daily water needs of **Step 1** divided by the number of peak sun hours per day of **Step 4**, as shown in **Equation 7.1** (page 29).

$$\frac{1{,}000\ \text{gallons}}{(2.52\ \text{hours/day} \times 60\ \text{minutes/hour})} = 6.6\ \text{gpm}$$

Insolation values for other months may be considered if supported by the grazing plan through either adjusted livestock numbers or grazing period or some combination of the two. The decision of which values to use is up to the discretion of the designer and should be based on good engineering judgment and supporting documentation.

Step 6. Total Dynamic Head (TDH) for the Pump

The pump's TDH is determined from **Equation 7.2** (page 29):

TDH = Vertical Lift + Elevation Head. +
Friction Losses

The **Vertical Lift**, for this example, is the vertical distance between the ground surface and the dynamic or pumping water level in the well + the height from the ground surface to the "full" water level of the storage tank.

Vertical Lift = 1000' – (1000' - 260') + 7 ft
= 267 ft

The **Elevation Head**, for this example, is the elevation difference from the ground elevation at the well and the bottom of the storage tank. For this example, there is no elevation difference between the well and storage tank, so:

Elevation Head = 0 ft

Friction loss is the loss of pressure due to the friction of the water as it flows through the pipe. Friction loss is determined by four factors: the pipe size (inside diameter), the flow rate, the length of the pipe, and the pipe's roughness as shown in the following equation:

$$h_f = 10.4057\ x\ \frac{Q}{C}^{1.85185}\ x\ \frac{L}{d^{4.87037}}$$

Where hf = friction loss (ft)
Q = flow rate (GPM)
C = 150 (for plastic pipe)
D = inside pipe diameter (in)
L = pipe length (ft)

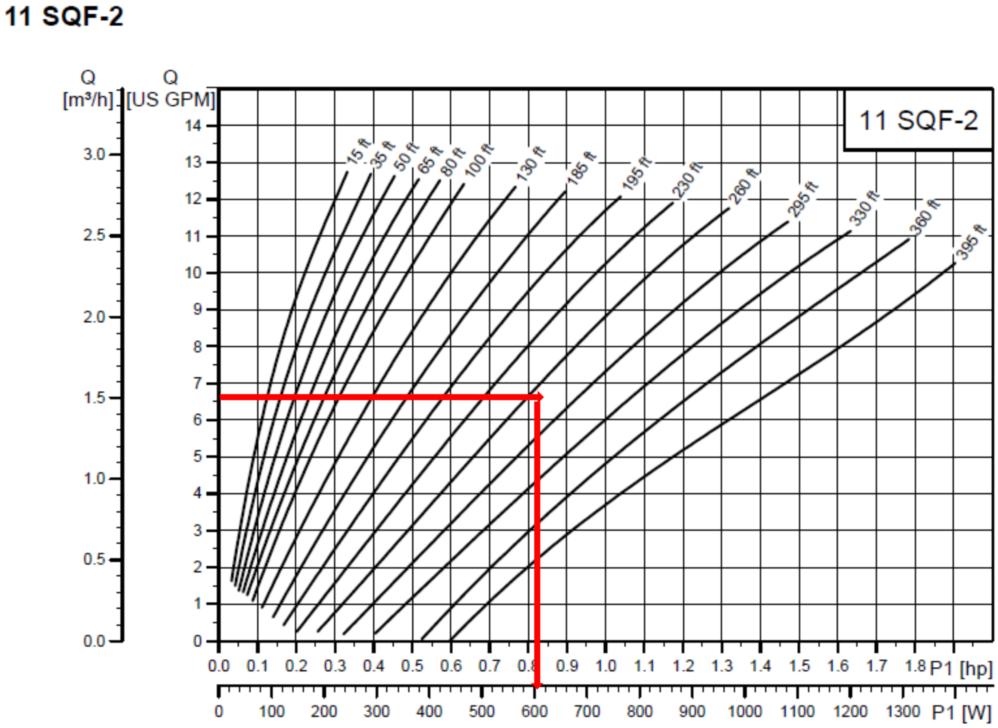
The friction loss needs to be calculated for both the column pipe in the well and the pipeline from the pump to the inlet of the storage tank. From the well information in **Step 2**, the length of column pipe is the distance from the lowered pumped water elevation in the well up to the ground surface; a length of 260ft. The pipeline from the well to the storage has a length of 10ft. The column pipe is 1 ¼" PVC Schedule 40 with an inside diameter of 1.38" and the pipe to the storage is 1 ½" PE 4710 SR11 with an inside diameter of 1.53". Using the calculated flow rate from **Step 5** of 6.6 GPM, the combined friction loss for both the column pipe and the pipeline to the storage tank calculates out to be 2.33ft.

Therefore, the TDH for the proposed system is calculated as shown below.

TDH = 267ft + 0ft + 2.33ft
= 269.3ft → use 270ft

Step 7. Pump Selection and Associated Voltage and Power Requirement

The pump can be selected by comparing the design flow rate and TDH calculated in **Steps 5 and 6** with the information from the manufacturer's pump curves. A Grundfos 11 SQF-2 pump and CU-200 controller combination has been selected for use and the associated pump curve is shown below.



The first step for this example is to locate the design flow rate of 6.6 gpm on the y-axis of the pump curve diagram and draw a horizontal line across the chart, as shown. Next, locate where this line intersects the curve representing a TDH of 270ft (use a point to the right of the 260ft curve). From this point of intersection, draw a vertical line to the bottom of the graph. The point where the vertical line crosses the x-axis shows the peak power requirement for the pump. As shown, based on a calculated flow rate of 6.6 gpm and a TDH of 270ft, a minimum input of 610 Watts of peak power is required. The pump literature states that the optimal operating voltage for the pump is specified as a 120 volts.

The efficiency of the pump can be computed for these operating conditions with **Equation 7.3** (page 31).

$$Pump\ Efficiency\ (P_{eff}) = \frac{0.1885\ x\ 270ft\ x\ 6.6gpm}{610W}x\ 100 = \ 55\%$$

Step 8. PV Panel Selection and Wiring of Solar Array

The PV panels selected for this system must be able to provide the minimum energy requirement to run the pump. As determined in **Step 7**, the minimum power needed is 610 Watts and the voltage requirement is 120 Volts.

A PV panel is selected that has the electrical characteristics shown in **Figure 7.3** (page 31): a peak power output of 250 W at a V_{mpp} of 30.6 V and an I_{mpp} of 8.17 A. Using **Equations 7.4 and 7.5** (page 31 and 32; respectively), the number of panels required to be wired in series or parallel can be determined.

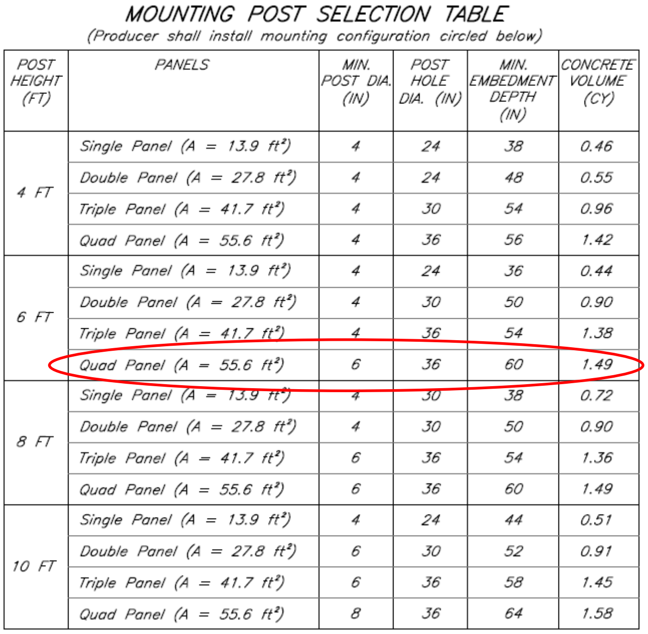
$$Wired\ in\ Series = \frac{120\ V}{30.6\ V} = 3.92\ or\ 4\ Panels\ in\ a\ String$$

$$Wired\ in\ Parallel = \frac{610\ W}{4\ x\ 30.6\ V\ x\ 8.17\ A\ x\ 0.85} = 0.72\ or\ 1\ String$$

The solar array then calculates to be composed of 1 string of 4 panels wired in series. (See **Appendix I** for panel wiring information.) Given that a single PV panel is rated at 250W, the 4 panel (4 x 250W = 1,000W) will easily meet the 610W requirement of the pump. It is important, however, to make sure that the total power supplied by the solar array does not exceed the maximum rated limit of the pump and controller.

Step 9. PV Array Mounting and Foundation Requirements

Since site conditions permit (i.e. the depth of embedment is not limited by shallow bedrock) the details for mounting structure embedded posts listed in the ND NRCS Standard Drawing (**Appendix G)** may be used. A post height above ground of 6ft has been determined for this site. For a quad mounted solar array and from the Mounting Post Selection Table of the ND NRCS Standard Drawing, a minimum post diameter of 6” will be needed. The posthole will need to be a minimum diameter of 36” with the post being embedded a minimum of 60” and encased with a minimum of 1.49CY of concrete.



MOUNTING POST SELECTION TABLE

(Producer shall install mounting configuration circled below)

POST HEIGHT (FT)	PANELS	MIN. POST DIA. (IN)	POST HOLE DIA. (IN)	MIN. EMBEDMENT DEPTH (IN)	CONCRETE VOLUME (CY)
4 FT	Single Panel ($A = 13.9\ ft^2$)	4	24	38	0.46
	Double Panel ($A = 27.8\ ft^2$)	4	24	48	0.55
	Triple Panel ($A = 41.7\ ft^2$)	4	30	54	0.96
	Quad Panel ($A = 55.6\ ft^2$)	4	36	56	1.42
6 FT	Single Panel ($A = 13.9\ ft^2$)	4	24	36	0.44
	Double Panel ($A = 27.8\ ft^2$)	4	30	50	0.90
	Triple Panel ($A = 41.7\ ft^2$)	4	36	54	1.38
	Quad Panel ($A = 55.6\ ft^2$)	6	36	60	1.49
8 FT	Single Panel ($A = 13.9\ ft^2$)	4	30	38	0.72
	Double Panel ($A = 27.8\ ft^2$)	4	30	50	0.90
	Triple Panel ($A = 41.7\ ft^2$)	6	36	54	1.36
	Quad Panel ($A = 55.6\ ft^2$)	6	36	60	1.49
10 FT	Single Panel ($A = 13.9\ ft^2$)	4	24	44	0.51
	Double Panel ($A = 27.8\ ft^2$)	6	30	52	0.91
	Triple Panel ($A = 41.7\ ft^2$)	6	36	58	1.45
	Quad Panel ($A = 55.6\ ft^2$)	8	36	64	1.58

Step 10. System Production and Flow Rate

Now that the pump requirements and size of the solar array has been determined (**Steps 7 and 8**; respectively), the actual production and flow rate of the system can be calculated using **Equations 7.6 and 7.7** (page 33).

$$System\ Production\ (Q_{System}) = \frac{30.6V\ x\ 8.17A\ x\ 4\ x\ 2.52hr/day\ x\ 60min/hr\ x\ 0.85\ x\ 55\%}{0.1885\ x\ 270ft} = 1{,}386\ GPD$$

$$Actual\ Flow\ Rate\ of\ System = \frac{1{,}386\ GPD}{2.52hr/day\ x\ 60} = 9.2\ GPM$$

Note: It is important to check that the actual produced flow rate of the system does not cause velocities within the connecting pipeline to exceed 5ft/sec.

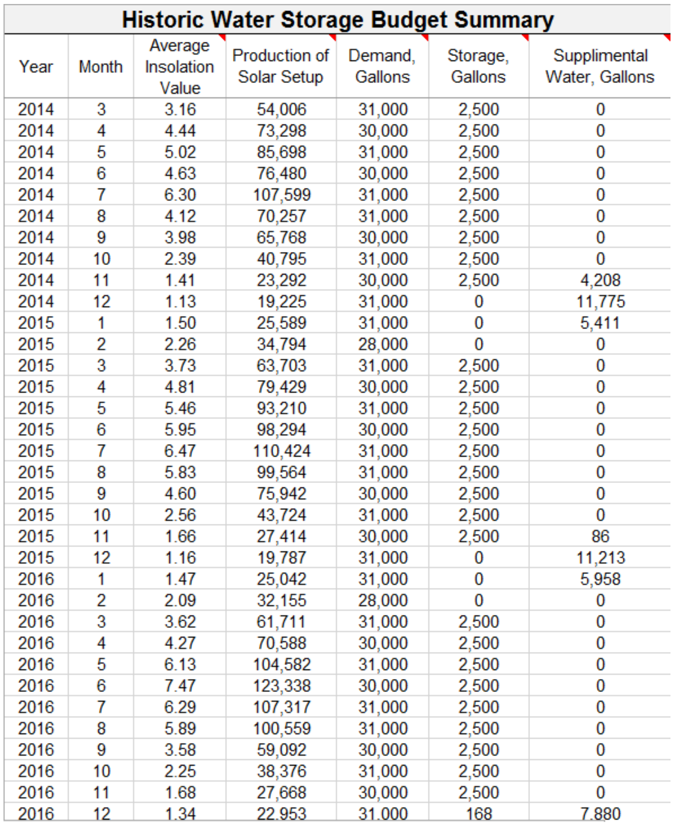
Step 11. Water Storage

The system's total water storage capacity should be sufficient for a minimum of three days water use. This minimum storage capacity is calculated below using the water requirement derived in **Step 1**.

1,000 gallons/day x 3 days
= 3,000 gallons

Two 500-gallon water troughs are included in the system, providing a total storage capacity of 1,000 gallons (2 x 500 = 1,000). Therefore, the storage tank must be sized to hold a minimum of 2,000 gallons (3,000 – 1,000 = 2,000). Based on information from different distributors, a 2,500-gallon water tank is a readily available size. A common tank of this size is 95 inches in diameter and 91 inches tall. The actual system production only shows to produce 1,386 GPD of the 3,000 gallons required for storage. A more detailed analysis needs to be done to determine if the provided storage volume is adequate.

From the system production calculated in **Step 10**, a water balance for the past several years can be done to check if the provided storage is sufficient.



Historic Water Storage Budget Summary

Year	Month	Average Insolation Value	Production of Solar Setup	Demand, Gallons	Storage, Gallons	Supplimental Water, Gallons
2014	3	3.16	54,006	31,000	2,500	0
2014	4	4.44	73,298	30,000	2,500	0
2014	5	5.02	85,698	31,000	2,500	0
2014	6	4.63	76,480	30,000	2,500	0
2014	7	6.30	107,599	31,000	2,500	0
2014	8	4.12	70,257	31,000	2,500	0
2014	9	3.98	65,768	30,000	2,500	0
2014	10	2.39	40,795	31,000	2,500	0
2014	11	1.41	23,292	30,000	2,500	4,208
2014	12	1.13	19,225	31,000	0	11,775
2015	1	1.50	25,589	31,000	0	5,411
2015	2	2.26	34,794	28,000	0	0
2015	3	3.73	63,703	31,000	2,500	0
2015	4	4.81	79,429	30,000	2,500	0
2015	5	5.46	93,210	31,000	2,500	0
2015	6	5.95	98,294	30,000	2,500	0
2015	7	6.47	110,424	31,000	2,500	0
2015	8	5.83	99,564	31,000	2,500	0
2015	9	4.60	75,942	30,000	2,500	0
2015	10	2.56	43,724	31,000	2,500	0
2015	11	1.66	27,414	30,000	2,500	86
2015	12	1.16	19,787	31,000	0	11,213
2016	1	1.47	25,042	31,000	0	5,958
2016	2	2.09	32,155	28,000	0	0
2016	3	3.62	61,711	31,000	2,500	0
2016	4	4.27	70,588	30,000	2,500	0
2016	5	6.13	104,582	31,000	2,500	0
2016	6	7.47	123,338	30,000	2,500	0
2016	7	6.29	107,317	31,000	2,500	0
2016	8	5.89	100,559	31,000	2,500	0
2016	9	3.58	59,092	30,000	2,500	0
2016	10	2.25	38,376	31,000	2,500	0
2016	11	1.68	27,668	30,000	2,500	0
2016	12	1.34	22,953	31,000	168	7,880

The shown water balance compares the actual monthly production of the system against the monthly demand of the livestock and determines if the provided storage is adequate in meeting the demand. The water balance assumes that the storage tank is initially empty. As the table shows, the only periods which the storage tank would not provide the required demand is November – January. During the period of the noted grazing season, March – October, the provided storage is sufficient for the design.

Installation requirements of the storage tank is provided in the **ND Construction Specification 614 – Watering Facility** and **ND Standard Drawing ND-100 – Above Ground Storage Tank**.

Step 12. Summary Description of the System

The system information can be summarized as followed:

Storage Tank: 2,500 Gallon 95” x 91” Poly Tank

Pump Requirements:
- Flow Rate 6.6 GPM
- TDH 270ft

From Performance Curve (Grundfos 11 SQF-2):
- Power Required 610 Watts
- Voltage Required 120 Volts

Solar Panel Rating (Helios Solar Works HSE250-60P):
- 250 Watts
- 30.6 Volts
- 8.17 Amps

Layout of Solar Array:

4 panels wired in series and mounted to a quad solar rack attached to a post with a minimum diameter of 6” and extending 6ft above ground. The post is to set in a hole with a minimum diameter of 36” and embedded a minimum of 60” and encased with a minimum of 1.49CY of concrete.

System Production: 1,387 GPD
- 9.2 GPM

This information can be summarized on a copy of the ND NRCS Standard Drawing located in **Appendix G**, which is provided as part of the design package.

EXAMPLE 2: Solar-Powered Water Pump System Using Surface Water (a Pond) as a Water Source

Determine:

Design a solar-powered water pump system that consists of a midsize cow/calf operation near Hazen, North Dakota. It is necessary to determine the size of the system needed, including the pump, PV panels, appropriate mounting structure, pipes, tank size, etc.

Given:

- The landowner runs 50 cow/calf pairs on 85 acres of pasture land.
- The landowner intends to draw water from a dugout pond in the neighboring pasture from March through October, when the animals are let out to pasture.
- The intake of the suction line is located 10ft below the base of the surface mounted centrifugal pump and 5ft below average water level in the pond to account for evaporation in the summer months. (Note that when lifting water higher than 25ft, the use of a submersible pump instead of a surface-mount pump is required to avoid suction lift problems and cavitation.)
- The landowner lives nearby and is on site daily for routine maintenance but would like a storage tank sized for a minimum of three days of water storage in the event of extended cloudy weather or maintenance issues that prevent the pump from operating.
- The storage tank is to be located 100ft from the pump and the inlet into the tank is 7' above the ground.
- The landowner intends to gravity feed two watering troughs located 1,550ft and 1,000ft from the proposed storage tank.
- Two 500-gallon troughs are to be used. Each trough will be equipped with a float valve that requires 2 psi to operate properly.

Analysis:

Step 1. Water Requirement

To determine the operation's water needs, use **Table 7.1** (page 26) to calculate the total water requirement for the cattle, as shown below:

50 Cow/Calf Pairs x 20 gallons/day/animal
= 1,000 gallons/day

Step 2. Water Source

The water source for the planned system is a dugout pit pond located in a neighboring pasture. The 1-2 year runoff for the pond's watershed is found to be sufficient to keep the pond filled, and the water quality is suitable for livestock.

Step 3. System Layout

The next step is to determine the layout of the proposed system. The identified distances and elevations for the intake point, pump, PV panels, storage tank, and water troughs are shown in **Figure C3**. For this example, based on the site-specific data provided in the aerial view, the site has good south-facing exposure and appears well suited for solar power. Flow from the storage tank to the water troughs will be gravity fed. Based on the given elevations, the natural layout of the site appears to provide an adequate elevation difference between the storage and the water troughs to operate the tank float valves in the water troughs. In addition, the storage tank, pump, and PV panels can all be located in close proximity to one other in order to minimize electric power and pipeline friction losses.

Figure C4 depicts the profile of the proposed layout of the pump and PV panels.

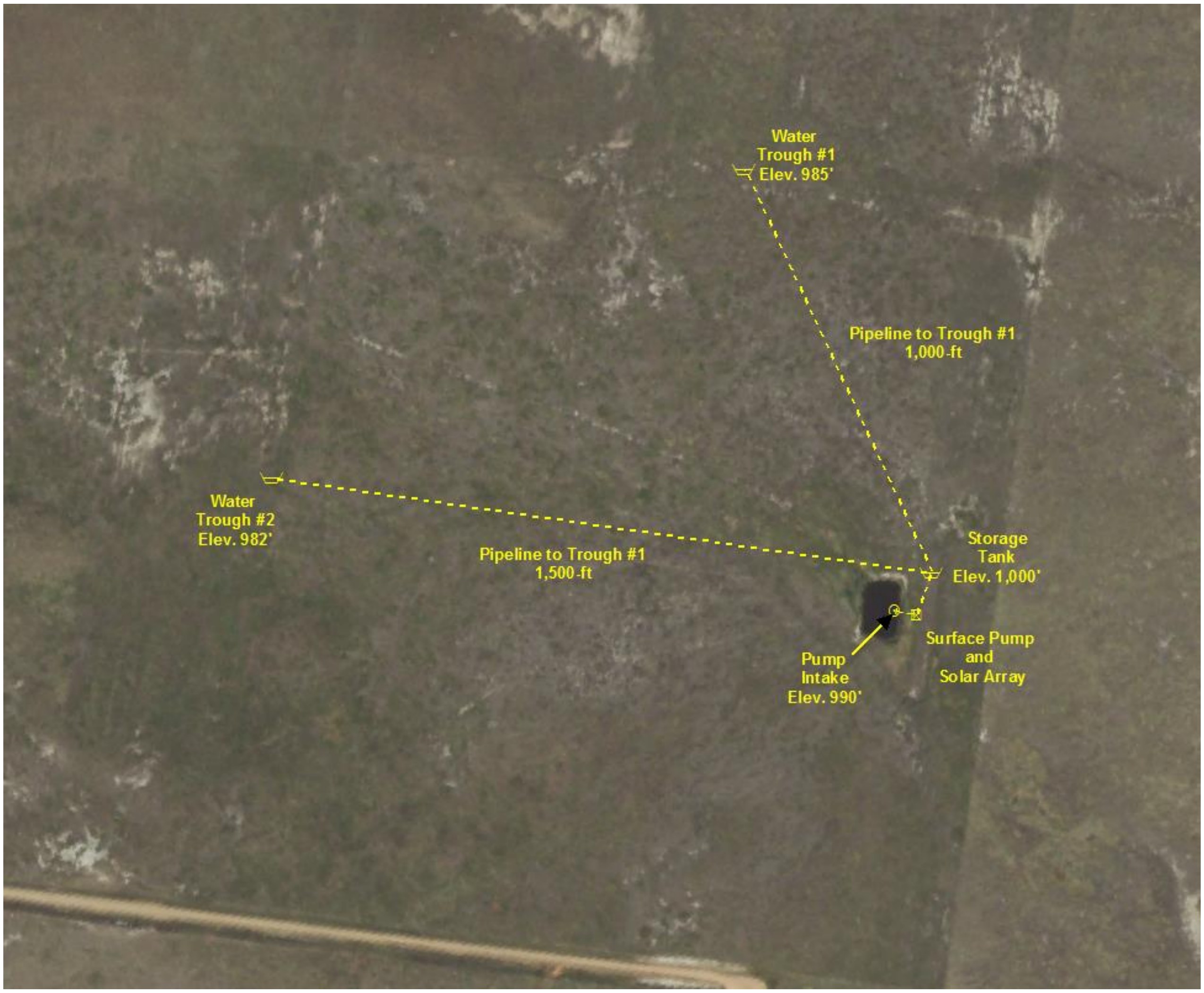


***Figure C3** – System Layout for Design Example 2.*

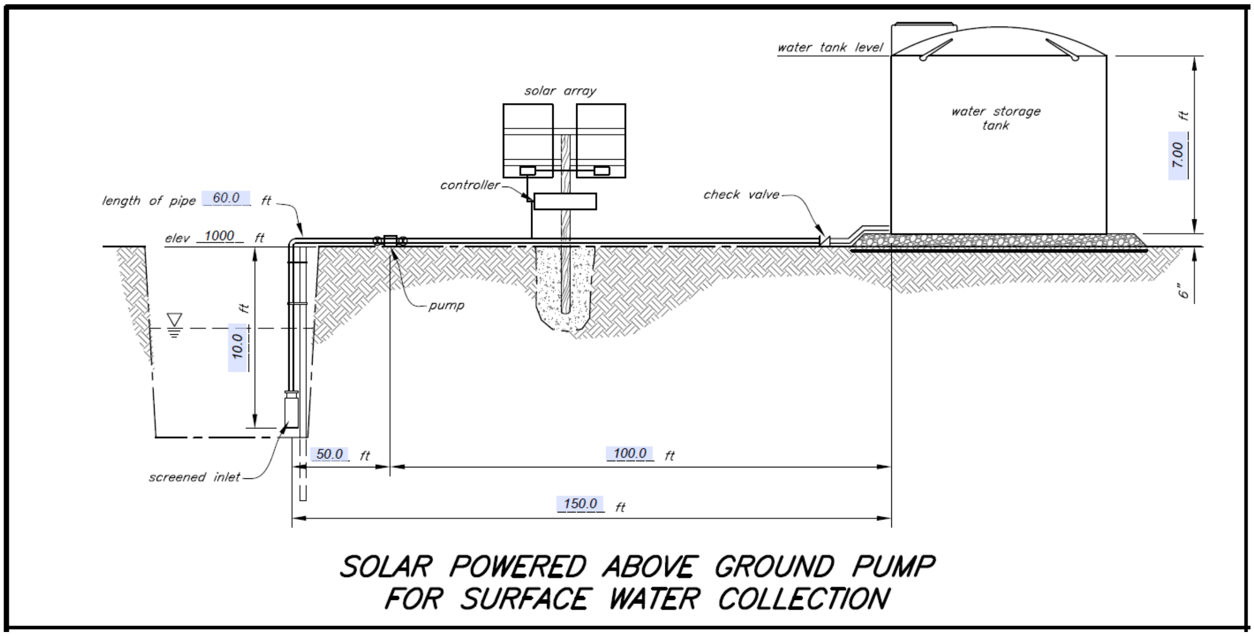


***Figure C4** – System Layout Profile for Design Example 2.*

Step 4. Solar Insolation and Solar Array Layout

The closest observed solar insolation values for the project site is from the NDAWN Station near Hazen, ND and can be found in **Appendix D** and are shown in the table below. Given that grazing is planned March – October, the month with the lowest average value, October, will be the target insolation value used for the design; 2.52 hrs/day.

Station Name	March	April	May	June	July	August	September	October
Hazen	3.75	4.88	5.59	6.21	6.58	5.52	4.09	2.52

The average solar insolation values given in **Appendix D** assume that the solar array is facing south with an optimal fixed tilt angle. These tilt angles are listed in **Appendix F** and are shown in the table below.

Station Name	Latitude	Optimal Average Annual Tilt Angle	Optimal Summer Tilt Angle	Optimal Grazing Season Tilt Angle (March – October)
Hazen	47.5°	47.5°	32.5°	38°

To minimize the labor needed in adjusting the tilt angle throughout the grazing season, the optimal tilt angle calculated for March – October will be used; 38°.

Step 5. Design Flow Rate for Pump

The pump's design flow rate is based on the operation's estimated daily water needs of **Step 1** divided by the number of peak sun hours per day of **Step 4**, as shown in **Equation 7.1** (page 29).

$$\frac{1{,}000\ \text{gallons}}{(2.52\ \text{hours/day} \times 60\ \text{minutes/hour})} = 6.6\ \text{gpm}$$

Insolation values for other months may be considered if supported by the grazing plan through either adjusted livestock numbers or grazing period or some combination of the two. The decision of which values to use is up to the discretion of the designer and should be based on good engineering judgment and supporting documentation.

Step 6. Total Dynamic Head (TDH) for the Pump

The pump's TDH is determined from **Equation 7.2** (page 29):

TDH = Vertical Lift + Elevation Head. + Friction Losses

The **Vertical Lift**, for this example, is the vertical distance between the water surface at the intake point (the pond's water surface) and the water surface at the delivery point (the bottom elevation of the storage tank + the height to the "full" water level of the tank).

Vertical Lift = 1000' – (1000' - 5') + 7 ft
= 12 ft

The **Elevation Head**, for this example, is the elevation difference from the surface pump and the bottom of the storage tank. For this example, there is no elevation difference between the pump and storage tank, so:

Elevation Head = 0 ft

Friction loss is the loss of pressure due to the friction of the water as it flows through the pipe. Friction loss is determined by four factors: the pipe size (inside diameter), the flow rate, the length of the pipe, and the pipe's roughness as shown in the following equation:

$$h_f = 10.4057\, x\, \frac{Q}{C}^{1.85185}\; x\, \frac{L}{d^{4.87037}}$$

Where hf = friction loss (ft)
Q = flow rate (GPM)
C = 150 (for plastic pipe)
D = inside pipe diameter (in)
L = pipe length (ft)

The friction loss needs to be calculated for both the suction line between the pump and the intake within the pond and the pipeline from the pump to the inlet of the storage tank. From the layout in **Step 3**, the suction line has a length of 60ft and the pipeline to the storage has a length of 100ft. Both are PE 4710 SR11 1 ½" pipe and have an inside diameter of 1.53". Using the calculated flow rate from **Step 5** of 6.6 GPM, the combined friction loss for both the suction hose and the pipeline to the storage tank calculates out to be 1.06ft.

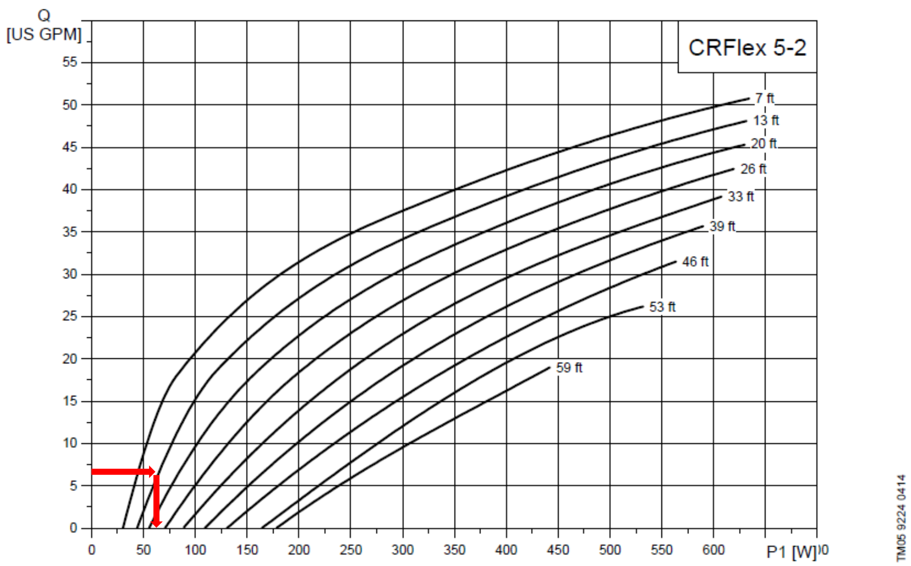
Therefore, the TDH for the proposed system is calculated as shown below.

TDH = 12ft + 0ft + 1.06ft
= 13.06ft → use 14ft

Step 7. Pump Selection and Associated Voltage and Power Requirement

The pump can be selected by comparing the design flow rate and TDH calculated in **Steps 5 and 6** with the information from the manufacturer's pump curves. A Grundfos CRFlex 5-2 centrifugal pump and IO-101 controller combination has been selected for use and the associated pump curve is shown below.

CRFlex 5-2



The first step for this example is to locate the design flow rate of 6.6 gpm on the y-axis of the pump curve diagram and draw a horizontal line across the chart, as shown. Next, locate where this line intersects the curve representing a TDH of 14ft (use the 13ft curve as it is the closest curve). From this point of intersection, draw a vertical line to the bottom of the graph. The point where the vertical line crosses the x-axis shows the peak power requirement for the pump. As shown, based on a calculated flow rate of 6.6 gpm and a TDH of 14ft (rounded to 13ft), a minimum input of 70 Watts of peak power is required. The pump literature states that the operating voltage for the pump is specified as a minimum of 30 volts.

The efficiency of the pump can be computed for these operating conditions with **Equation 7.3** (page 31).

$$Pump\ Efficiency\ (P_{eff}) = \frac{0.1885\ x\ 14ft\ x\ 6.6gpm}{70W} x\ 100 = \ 25\%$$

Step 8. PV Panel Selection and Wiring of Solar Array

The PV panels selected for this system must be able to provide the minimum energy requirement to run the pump. As determined in **Step 7**, the minimum power needed is 70 Watts and the voltage requirement is 30 volts.

A PV panel is selected that has the electrical characteristics shown in **Figure 7.3** (page 31): a peak power output of 250 W at a V_{mpp} of 30.6 V and an I_{mpp} of 8.17 A. Using **Equations 7.4 and 7.5** (page 31 and 32; respectively), the number of panels required to be wired in series or parallel can be determined.

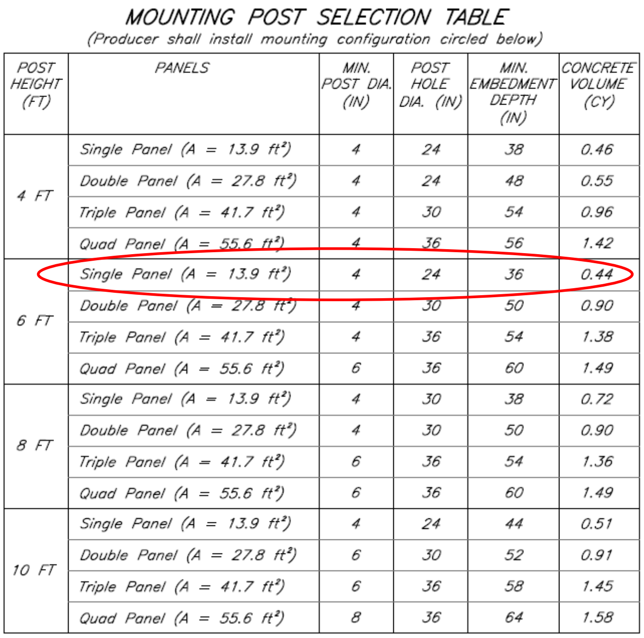
$$Wired\ in\ Series = \frac{30\ V}{30.6\ V} = 0.98\ or\ 1\ Panels\ in\ a\ String$$

$$Wired\ in\ Parallel = \frac{70\ W}{1\ x\ 30.6\ V\ x\ 8.17\ A\ x\ 0.85} = 0.33\ or\ 1\ String$$

The solar array then calculates to be composed of 1 string of a single panel. (See **Appendix I** for panel wiring information.) Given that a single PV panel is rated at 250W, a single panel will easily meet the 70W requirement of the pump. It is important, however, to make sure that the total power supplied by the solar array does not exceed the maximum rated limit of the pump and controller.

Step 9. PV Array Mounting and Foundation Requirements

Since site conditions permit (i.e. the depth of embedment is not limited by shallow bedrock) the details for mounting structure embedded posts listed in **Appendix G** may be used. A post height above ground of 6ft has been determined for this site. For a quad mounted solar array and from the Mounting Post Selection Table of the ND NRCS Standard drawing, a minimum post diameter of 4” will be needed. The posthole will need to be a minimum diameter of 24” with the post being embedded a minimum of 36” and encased with a minimum of 0.44CY of concrete.



MOUNTING POST SELECTION TABLE

(Producer shall install mounting configuration circled below)

POST HEIGHT (FT)	PANELS	MIN. POST DIA. (IN)	POST HOLE DIA. (IN)	MIN. EMBEDMENT DEPTH (IN)	CONCRETE VOLUME (CY)
4 FT	Single Panel ($A = 13.9\ ft^2$)	4	24	38	0.46
	Double Panel ($A = 27.8\ ft^2$)	4	24	48	0.55
	Triple Panel ($A = 41.7\ ft^2$)	4	30	54	0.96
	Quad Panel ($A = 55.6\ ft^2$)	4	36	56	1.42
6 FT	Single Panel ($A = 13.9\ ft^2$)	4	24	36	0.44
	Double Panel ($A = 27.8\ ft^2$)	4	30	50	0.90
	Triple Panel ($A = 41.7\ ft^2$)	4	36	54	1.38
	Quad Panel ($A = 55.6\ ft^2$)	6	36	60	1.49
8 FT	Single Panel ($A = 13.9\ ft^2$)	4	30	38	0.72
	Double Panel ($A = 27.8\ ft^2$)	4	30	50	0.90
	Triple Panel ($A = 41.7\ ft^2$)	6	36	54	1.36
	Quad Panel ($A = 55.6\ ft^2$)	6	36	60	1.49
10 FT	Single Panel ($A = 13.9\ ft^2$)	4	24	44	0.51
	Double Panel ($A = 27.8\ ft^2$)	6	30	52	0.91
	Triple Panel ($A = 41.7\ ft^2$)	6	36	58	1.45
	Quad Panel ($A = 55.6\ ft^2$)	8	36	64	1.58

Step 10. System Production and Flow Rate

Now that the pump requirements and size of the solar array has been determined (**Steps 7 and 8**; respectively), the actual production and flow rate of the system can be calculated using **Equations 7.6 and 7.7** (page 33).

$$System\ Production\ (Q_{System}) = \frac{30.6V\ x\ 8.17A\ x\ 1\ x\ 2.52hr/day\ x\ 60min/hr\ x\ 0.85\ x\ 25\%}{0.1885\ x\ 14ft} = 3{,}028\ GPD$$

$$Actual\ Flow\ Rate\ of\ System = \frac{3{,}028\ GPD}{2.52hr/day\ x\ 60} = 20\ GPM$$

Note: It is important to check that the actual produced flow rate of the system does not cause velocities within the connecting pipeline to exceed 5ft/sec.

Step 11. Water Storage

The system's total water storage capacity should be sufficient for a minimum of three days water use. This minimum storage capacity is calculated below using the water requirement derived in **Step 1**.

1,000 gallons/day x 3 days
= 3,000 gallons

Two 500-gallon water troughs are included in the system, providing a total storage capacity of 1,000 gallons (2 x 500 = 1,000). Therefore, the storage tank must be sized to hold a minimum of 2,000 gallons (3,000 – 1,000 = 2,000). Based on information from different distributors, a 2,500-gallon water tank is a readily available size. A common tank of this size is 95 inches in diameter and 91 inches tall.

The actual system production calculated in **Step 10** show to be sufficient in providing this required storage.

Installation requirements of the storage tank is provided in the **ND Construction Specification 614 – Watering Facility** and **ND Standard Drawing ND-100 – Above Ground Storage Tank**.

Step 12. Summary Description of the System

The system information can be summarized as followed:

Pump Requirements:		From Performance Curve (Grundfos CRFlex 5-2):	
Flow Rate	6.6 GPM	Power Required	70 Watts
TDH	14ft		

Solar Panel Rating (Helios Solar Works HSE250-60P):
250 Watts
30.6 Volts
8.17 Amps

Layout of Solar Array:

1 panels mounted to a solar rack attached to a post with a minimum diameter of 4". The post is to set in a hole with a minimum diameter of 24" and embedded a minimum of 36" and encased with a minimum of 0.44CY of concrete.

System Production:	3,028 GPD 20 GPM

This information can be summarized on a copy of the ND NRCS Standard Drawing located in **Appendix G**, which is provided as part of the design package.

APPENDIX D: Average Monthly Solar Insolation Values for North Dakota by NDAWN Station

Note: The values in the table were tabulated from a download of all NDAWN stations in June, 2017 and are representative of observed values up to that date.

Station Name	Years of Data	January	February	March	April	May	June	July	August	September	October	November	December
Ada	10	1.65	2.67	3.68	4.66	5.26	5.79	6.21	5.24	3.93	2.30	1.46	1.24
Baker	24	1.50	2.56	3.84	4.96	5.54	5.98	6.36	5.49	3.98	2.41	1.51	1.14
Beach	24	1.72	2.63	3.91	5.04	5.83	6.57	6.96	5.83	4.38	2.78	1.81	1.38
Berthold	16	1.51	2.50	3.73	4.89	5.44	6.05	6.48	5.35	3.96	2.43	1.58	1.16
Bismarck	5	1.62	2.44	3.84	4.90	5.54	6.19	6.57	5.59	4.22	2.52	1.60	1.28
Bottineau	25	1.52	2.61	3.84	4.96	5.62	6.07	6.48	5.42	3.95	2.41	1.49	1.14
Bowbells	16	1.47	2.49	3.70	4.91	5.56	6.18	6.60	5.40	3.99	2.40	1.51	1.13
Bowman	25	1.73	2.66	3.91	5.00	5.77	6.53	6.80	5.73	4.33	2.75	1.81	1.39
Brampton	3	1.61	2.45	3.64	4.78	5.36	6.56	6.51	5.67	4.02	2.56	1.81	1.22
Britton	16	1.67	2.68	3.71	4.74	5.25	5.83	6.32	5.38	4.13	2.51	1.71	1.35
Brorson	23	1.57	2.49	3.81	4.94	5.85	6.52	6.94	5.74	4.25	2.64	1.67	1.24
Campbell	2	1.53	2.27	3.31	4.04	5.79	6.01	6.05	5.49	3.91	2.50	1.70	1.20
Cando	23	1.57	2.65	3.90	4.97	5.51	5.99	6.39	5.42	3.92	2.38	1.54	1.19
Carrington	27	1.55	2.51	3.67	4.74	5.46	5.90	6.21	5.32	3.92	2.44	1.54	1.20
Carson	1	1.84	2.55	3.55	4.73	6.35	6.58	6.83	5.75	4.41	2.78	1.88	1.57
Cavalier	24	1.45	2.50	3.71	4.93	5.46	5.95	6.29	5.28	3.81	2.26	1.38	1.08
Columbus	9	1.46	2.44	3.78	4.83	5.73	5.93	6.35	5.58	4.03	2.48	1.42	1.11
Cooperstown	3	1.57	2.50	3.70	4.71	5.59	6.53	6.19	5.66	3.92	2.41	1.62	1.24
Crary	18	1.51	2.57	3.69	4.79	5.38	5.92	6.32	5.31	3.85	2.36	1.50	1.14
Crosby	15	1.44	2.45	3.64	4.83	5.40	6.04	6.46	5.25	3.95	2.32	1.48	1.06
Dazey	25	1.59	2.63	3.80	4.87	5.46	6.07	6.33	5.46	4.04	2.44	1.56	1.24
Dickinson	27	1.61	2.51	3.74	4.88	5.67	6.30	6.64	5.65	4.24	2.66	1.67	1.27

Dunn	8	1.70	2.62	3.79	4.86	5.66	6.58	6.70	5.51	4.30	2.49	1.74	1.28
Edgeley	24	1.71	2.69	3.81	4.82	5.42	6.08	6.34	5.42	4.08	2.57	1.71	1.36
Egeland	1	1.61	2.91	4.13	5.54	6.26	5.95	6.37	5.40	4.13	2.68	1.32	1.08
Ekre	11	1.68	2.73	3.73	4.83	5.41	6.07	6.49	5.37	4.06	2.45	1.61	1.29
Eldred	22	1.51	2.49	3.59	4.61	5.09	5.70	6.05	5.16	3.77	2.18	1.39	1.13
Fargo	27	1.53	2.46	3.52	4.58	5.32	5.83	6.06	5.26	3.90	2.35	1.46	1.17
Fingal	15	1.57	2.60	3.62	4.71	5.14	5.84	6.27	5.23	3.94	2.41	1.54	1.21
Finley	2	1.51	2.42	3.58	4.54	5.31	6.30	6.04	5.55	3.82	2.34	1.55	1.18
Forest River	26	1.51	2.52	3.65	4.77	5.36	5.79	6.03	5.20	3.75	2.30	1.42	1.13
Fort Yates	2	1.68	2.48	3.69	4.64	6.27	7.41	6.33	5.76	4.14	2.72	1.81	1.38
Fox	1	1.44	2.53	3.61	4.71	5.47	5.89	6.02	5.49	3.34	1.99	1.35	1.05
Froid	2	1.67	2.35	3.50	4.75	6.21	7.54	6.73	6.07	3.63	2.37	1.63	1.26
Galesburg	22	1.51	2.49	3.67	4.66	5.07	5.73	6.11	5.25	3.86	2.31	1.46	1.16
Garrison	4	1.67	2.61	3.74	4.70	5.90	6.47	6.64	5.52	4.13	2.38	1.63	1.26
Grafton	11	1.51	2.57	3.56	4.69	5.26	5.85	6.33	5.17	3.79	2.21	1.31	1.10
Grand Forks	27	1.50	2.46	3.54	4.58	5.32	5.83	6.10	5.22	3.75	2.28	1.39	1.12
Greenbush	14	1.45	2.54	3.63	4.73	5.15	5.68	6.12	5.05	3.65	2.17	1.30	1.05
Harvey	23	1.57	2.56	3.80	4.90	5.51	6.11	6.54	5.51	4.05	2.45	1.61	1.23
Hazen	24	1.60	2.52	3.75	4.88	5.59	6.21	6.58	5.52	4.09	2.52	1.62	1.24
Hettinger	27	1.78	2.68	3.94	4.98	5.83	6.57	6.78	5.84	4.46	2.88	1.85	1.45
Hillsboro	24	1.56	2.55	3.68	4.68	5.28	5.92	6.28	5.34	3.89	2.31	1.47	1.18
Hofflund	18	1.55	2.56	3.77	4.87	5.63	6.24	6.63	5.46	3.99	2.49	1.60	1.18
Horace	7	1.71	2.65	3.96	4.78	5.66	6.27	6.40	5.66	4.17	2.48	1.63	1.38
Humboldt	22	1.44	2.49	3.69	4.86	5.26	5.74	6.23	5.21	3.76	2.17	1.34	1.06
Inkster	8	1.45	2.50	3.55	4.55	4.97	5.57	6.05	5.10	3.78	2.28	1.42	1.11
Jamestown	27	1.61	2.57	3.72	4.80	5.58	6.11	6.35	5.48	4.08	2.55	1.62	1.27
Karlsruhe	16	1.55	2.58	3.76	4.89	5.45	6.08	6.48	5.32	3.93	2.41	1.58	1.18

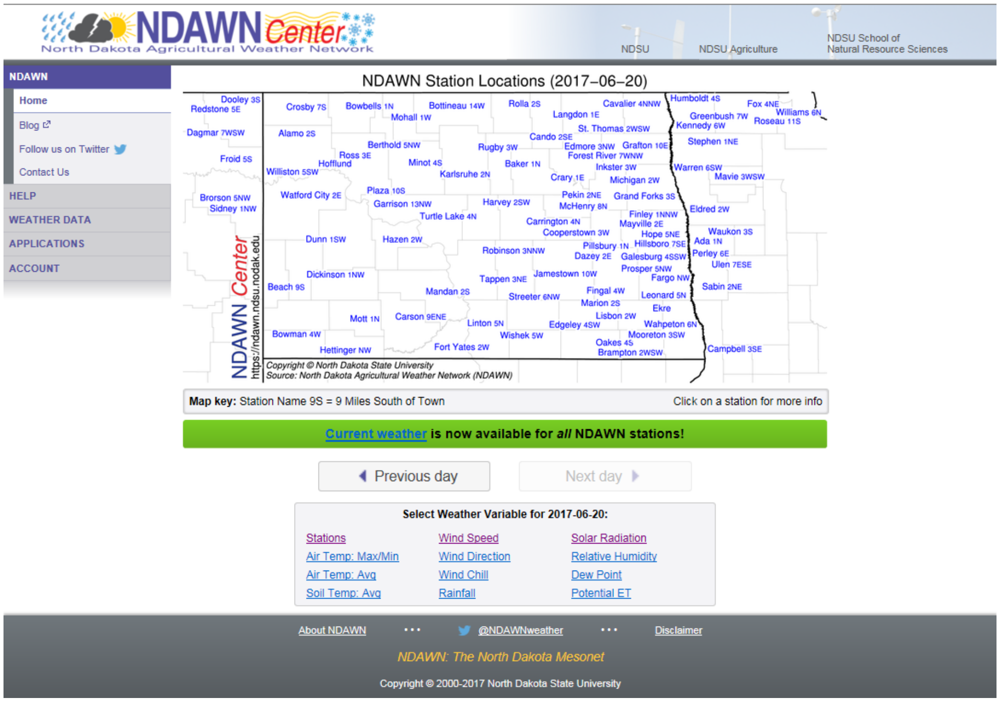
Kennedy	4	1.47	2.50	3.47	4.37	4.72	5.62	6.00	5.12	3.61	2.12	1.31	1.08
Langdon	27	1.46	2.53	3.79	4.89	5.46	5.89	6.24	5.31	3.82	2.32	1.41	1.1
Leonard	15	1.69	2.75	3.75	4.82	5.25	6.00	6.52	5.50	4.02	2.45	1.56	1.28
Linton	25	1.74	2.78	4.02	5.15	5.90	6.53	6.79	5.83	4.41	2.77	1.83	1.40
Lisbon	11	1.66	2.65	3.68	4.74	5.35	6.03	6.53	5.40	4.09	2.47	1.63	1.28
Mandan	18	1.63	2.61	3.81	4.94	5.57	6.25	6.53	5.52	4.17	2.61	1.72	1.29
Marion	10	1.71	2.69	3.75	4.69	5.22	5.89	6.32	5.34	4.12	2.48	1.64	1.33
Mavie	15	1.50	2.61	3.67	4.81	5.19	5.75	6.22	5.22	3.73	2.26	1.39	1.10
Mayville	22	1.57	2.57	3.75	4.78	5.38	5.99	6.33	5.41	3.93	2.35	1.48	1.18
McHenry	22	1.62	2.68	3.96	5.06	5.66	6.20	6.52	5.59	4.11	2.51	1.61	1.23
McLeod	8	1.65	2.61	3.86	4.66	5.56	6.17	6.16	5.61	4.19	2.51	1.61	1.35
Michigan	14	1.55	2.61	3.70	4.82	5.27	5.81	6.19	5.20	3.82	2.35	1.47	1.15
Minot	27	1.52	2.45	3.73	4.84	5.57	6.09	6.52	5.57	4.03	2.50	1.55	1.17
Mohall	24	1.51	2.53	3.75	4.89	5.54	6.06	6.52	5.43	3.95	2.42	1.52	1.15
Mooreton	27	1.60	2.57	3.63	4.63	5.26	5.87	6.21	5.37	3.99	2.41	1.56	1.25
Mott	15	1.76	2.69	3.92	5.10	5.77	6.62	6.88	5.71	4.41	2.78	1.86	1.39
Northwood	10	1.41	2.32	3.62	4.50	5.11	5.69	5.68	5.05	3.64	2.17	1.36	1.04
Oakes	27	1.63	2.60	3.71	4.74	5.44	6.08	6.39	5.51	4.17	2.57	1.64	1.30
Pekin	2	1.65	2.45	3.73	4.43	5.70	6.34	6.01	5.65	3.85	2.41	1.60	1.32
Perley	22	1.56	2.53	3.60	4.61	5.13	5.76	6.08	5.19	3.82	2.23	1.43	1.17
Pillsbury	16	1.58	2.65	3.72	4.83	5.29	5.88	6.31	5.32	3.93	2.38	1.55	1.22
Plaza	15	1.57	2.54	3.72	4.79	5.37	6.12	6.53	5.34	4.00	2.43	1.60	1.17
Prosper	27	1.60	2.59	3.71	4.68	5.30	5.73	6	5.32	3.95	2.40	1.51	1.25
Robinson	24	1.70	2.74	3.96	5.05	5.73	6.27	6.58	5.57	4.20	2.58	1.69	1.33
Rolla	21	1.48	2.54	3.78	4.90	5.38	5.84	6.27	5.30	3.79	2.34	1.48	1.11
Roseau	16	1.40	2.48	3.63	4.70	5.15	5.70	6.06	4.95	3.63	2.13	1.31	1.02
Ross	15	1.50	2.46	3.60	4.68	5.28	6.01	6.43	5.16	3.90	2.35	1.54	1.12

Rugby	14	1.53	2.60	3.73	4.89	5.41	5.99	6.4	5.29	3.91	2.32	1.56	1.15
Sabin	16	1.58	2.60	3.57	4.67	5.11	5.75	6.19	5.20	3.89	2.33	1.49	1.21
Sidney	23	1.48	2.37	3.66	4.78	5.69	6.43	6.75	5.70	4.20	2.57	1.60	1.19
St. Thomas	23	1.5	2.53	3.66	4.82	5.30	5.85	6.27	5.30	3.81	2.26	1.40	1.11
Stephen	23	1.46	2.51	3.68	4.8	5.47	5.91	6.28	5.29	3.78	2.22	1.38	1.10
Streeter	27	1.66	2.63	3.82	4.83	5.56	6.09	6.33	5.50	4.12	2.57	1.66	1.29
Tappen	15	1.62	2.63	3.72	4.88	5.52	6.17	6.51	5.37	4.10	2.47	1.64	1.24
Towner	11	1.52	2.53	3.88	4.92	5.74	5.96	6.26	5.52	3.91	2.45	1.48	1.17
Turtle Lake	24	1.61	2.64	3.88	4.94	5.64	6.14	6.48	5.55	4.11	2.55	1.61	1.23
Ulen	2	1.6	2.37	3.49	4.43	5.85	6.40	6.14	5.66	3.81	2.23	1.55	1.20
Wahpeton	16	1.6	2.61	3.58	4.7	5.09	5.76	6.21	5.26	3.95	2.36	1.56	1.25
Walhalla	11	1.45	2.47	3.85	4.99	5.44	5.73	6.1	5.25	3.71	2.24	1.43	1.07
Warren	22	1.5	2.53	3.71	4.71	5.29	5.79	6.17	5.22	3.77	2.22	1.39	1.12
Watford City	25	1.57	2.52	3.75	4.83	5.68	6.30	6.74	5.65	4.18	2.55	1.62	1.21
Waukon	2	1.54	2.41	3.39	4.17	5.68	6.15	5.91	5.40	3.66	2.03	1.51	1.13
Williams	1	1.35	2.52	3.79	4.52	5.54	5.80	6.04	5.25	3.32	2.11	1.40	1.00
Williston	27	1.52	2.45	3.72	4.80	5.73	6.22	6.70	5.63	4.17	2.54	1.56	1.17
Wishek	16	1.66	2.69	3.78	4.89	5.46	6.21	6.48	5.49	4.17	2.55	1.71	1.27
All Stations	1,537												
Average		1.57	2.56	3.72	4.78	5.49	6.08	6.36	5.43	3.97	2.42	1.55	1.21
Max		1.84	2.91	4.13	5.54	6.35	7.54	6.96	6.07	4.46	2.88	1.88	1.57
Min		1.35	2.27	3.31	4.04	4.72	5.57	5.68	4.95	3.32	1.99	1.30	1.00

APPENDIX E: NDAWN Approach to Determining Solar Insolation Values

Step 1 – Navigate to the NDAWN Website

The NDAWN website is located at https://ndawn.ndsu.nodak.edu/



Map key: Station Name 9S = 9 Miles South of Town

Click on a station for more info

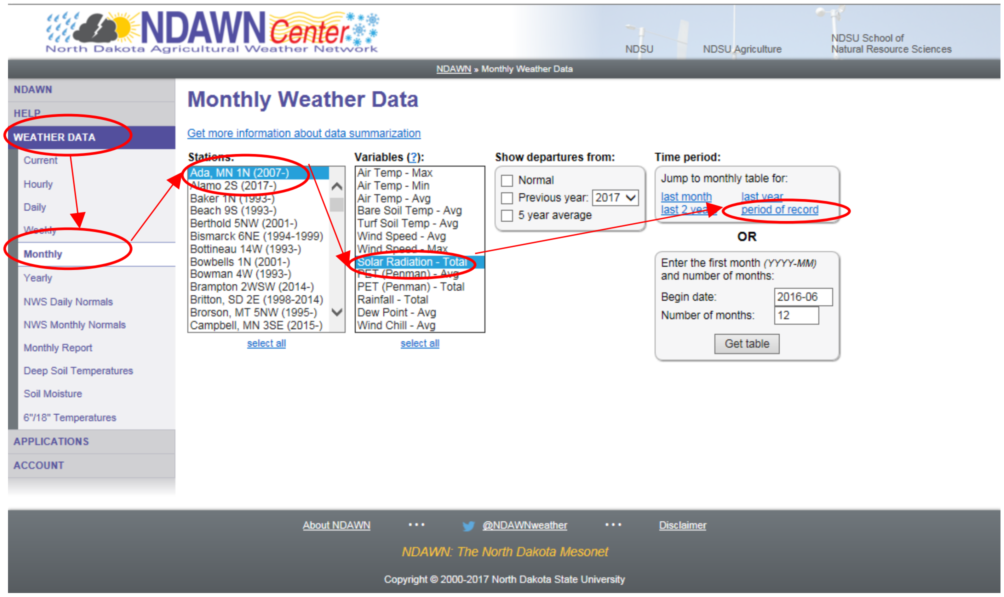
Current weather is now available for *all* NDAWN stations!

Select Weather Variable for 2017-06-20:

NDAWN: The North Dakota Mesonet

Copyright © 2000-2017 North Dakota State University

Step 2 – Download Weather Data Table



Monthly Weather Data

Enter the first month (*YYYY-MM*) and number of months:

Begin date: 2016-06

Number of months: 12

NDAWN: The North Dakota Mesonet

Copyright © 2000-2017 North Dakota State University

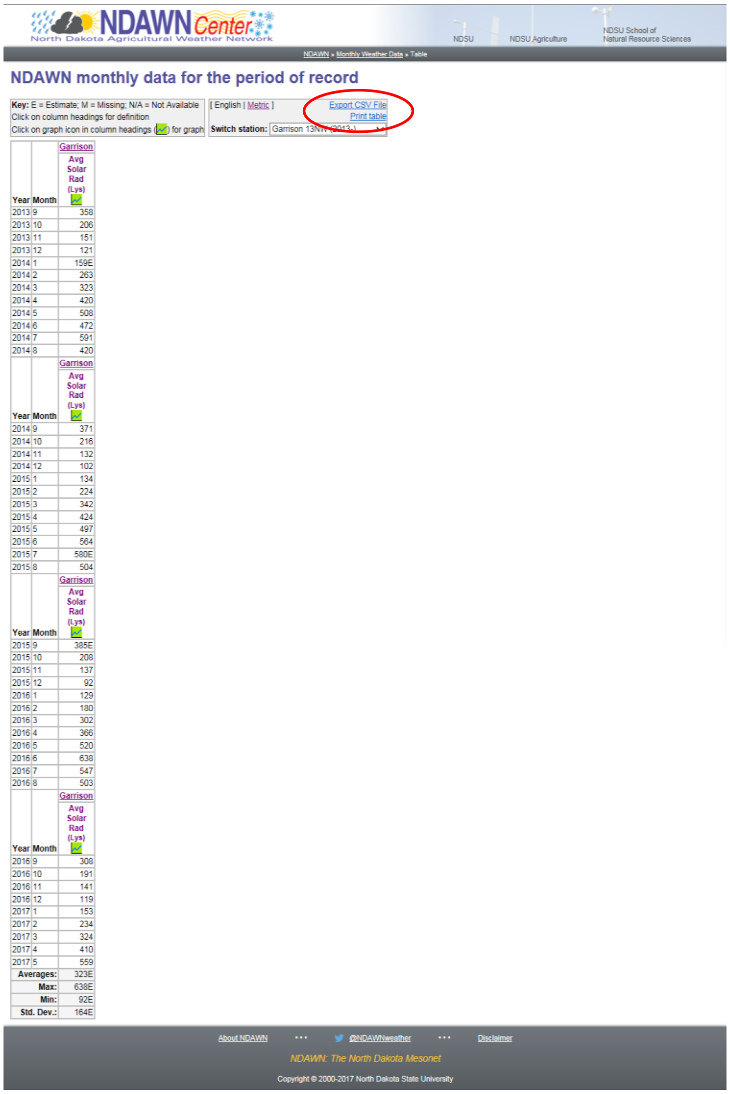
a) Select "WEATHER DATA"
b) Select "Monthly"
c) Select the NDAWN Station closest to project site
d) Select "Solar Radiation – Total"
e) Click "period of record"

Step 3 – Review and Export Table

Solar radiation values for the entire period of record are shown in a table for the selected NDAWN Station. Solar radiation flux density is measured every 60 seconds in units of Watts per meter^2. The measured values are reported in units of Langleys (Lys) per day. These values are averaged for each hour and converted to the total solar energy received during the hour. The hourly values from midnight to midnight of a given day are then added together for a total daily value. The monthly radiation values are the average of all daily totals for the month.

The bottom of the table shows the Average, Max, Min, and Standard Deviation for all months during the Period of Record. To obtain a value for a given month then the desired month for each year will need to be added together and averaged.

The displayed table can be directly printed or a CSV file with more detailed data can be downloaded. A table of this same data can be directly printed also.



NDAWN monthly data for the period of record

Key: E = Estimate; M = Missing; N/A = Not Available
Click on column headings for definition
Click on graph icon in column headings (📈) for graph

Switch station: Garrison 13NW (2013-)

Year	Month	Garrison Avg Solar Rad (Lys)
2013	9	358
2013	10	206
2013	11	151
2013	12	121
2014	1	159E
2014	2	263
2014	3	323
2014	4	420
2014	5	508
2014	6	472
2014	7	591
2014	8	420
Year	Month	Garrison Avg Solar Rad (Lys)
2014	9	371
2014	10	216
2014	11	132
2014	12	102
2015	1	134
2015	2	224
2015	3	342
2015	4	424
2015	5	497
2015	6	564
2015	7	580E
2015	8	504
Year	Month	Garrison Avg Solar Rad (Lys)
2015	9	385E
2015	10	208
2015	11	137
2015	12	92
2016	1	129
2016	2	180
2016	3	302
2016	4	366
2016	5	520
2016	6	638
2016	7	547
2016	8	503
Year	Month	Garrison Avg Solar Rad (Lys)
2016	9	308
2016	10	191
2016	11	141
2016	12	119
2017	1	153
2017	2	234
2017	3	324
2017	4	410
2017	5	559
Averages:		323E
Max:		638E
Min:		92E
Std. Dev.:		164E

Step 4 – Convert Units

The statistical values listed at the bottom of the displayed table are in units of Langleys per Day and needs to be converted to kW/m^2/day. The printed or downloaded CSV file we need to be averaged manually or with the aid of a spreadsheet. The Total Solar Radiation values will need to be converted as well. This conversion is done with the following equation:

$$1\ Langley = 11.6\ \frac{Watts}{m^2}$$

Example: *323 Langley/Day x 11.6 = 3,747 Watts/m^2/day / 1000 =* ***<u>3.7 kW/m^2/day</u>***

APPENDIX F: Solar Array Tilt Angles

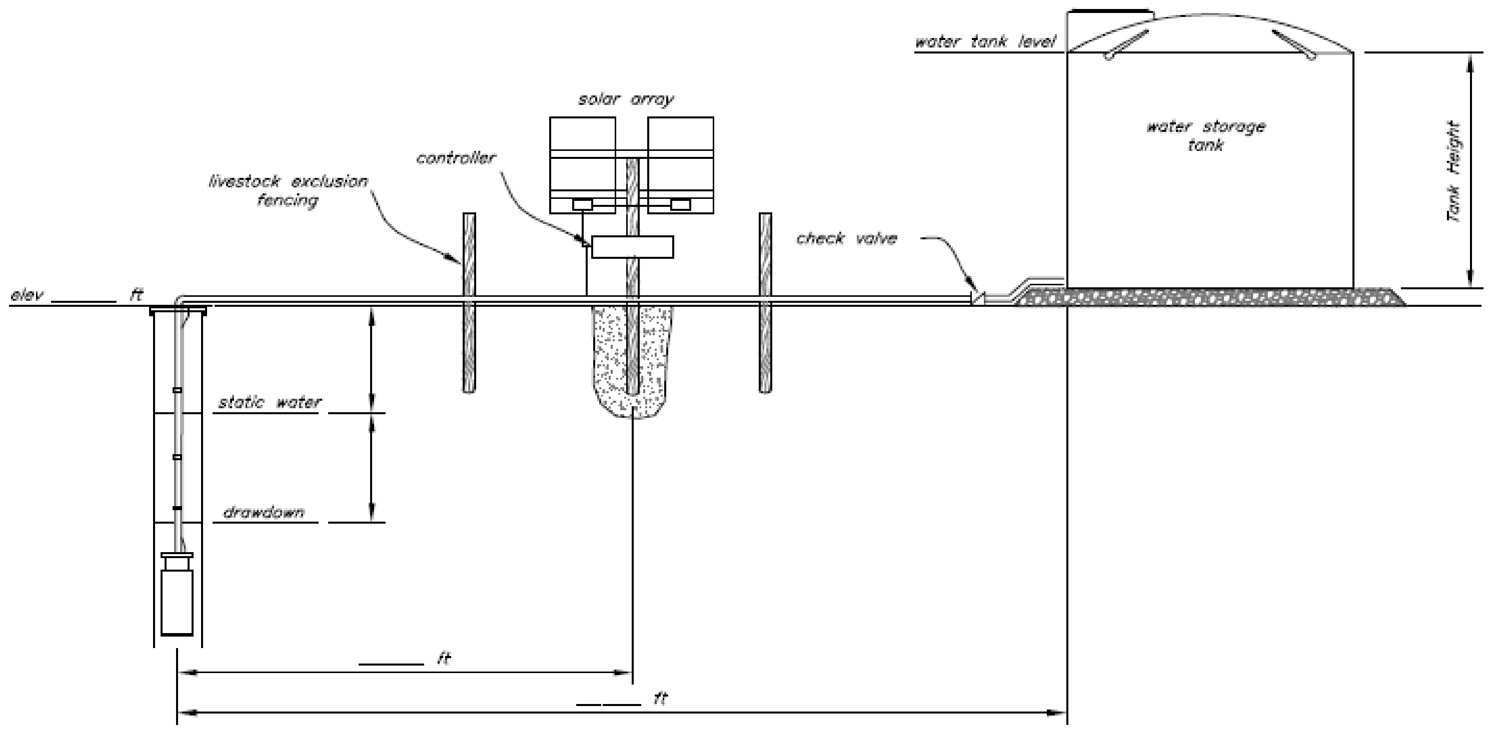
The below table gives the various optimal tilt angles for a fixed-axis PV panel mount. The angles are calculated from the local latitude of the corresponding NDAWN station and the equations from **Section 3.3 – PV Panel Orientation and Tracking**. The latitudes and corresponding tilt angles listed in the table are rounded to the nearest 0.5°.

Station Name	Latitude	Optimal Average Annual Tilt Angle	Optimal Summer Tilt Angle	Optimal Grazing Season Tilt Angle (March – October)
Ada	47.5°	47.5°	32.5°	38°
Baker	48°	48°	33°	38.5°
Beach	47°	47°	32°	37.5°
Berthold	48.5°	48.5°	33.5°	39°
Bismarck	47°	47°	32°	37.5°
Bottineau	49°	49°	34°	39.5°
Bowbells	49°	49°	34°	39.5°
Bowman	46°	46°	31°	36.5°
Brampton	46°	46°	31°	36.5°
Britton	46°	46°	31°	36.5°
Brorson	48°	48°	33°	38.5°
Campbell	46°	46°	31°	36.5°
Cando	48.5°	48.5°	33.5°	39°
Carrington	47.5°	47.5°	32.5°	38°
Carson	46.5°	46.5°	31.5°	37°
Cavalier	49°	49°	34°	39.5°
Columbus	48.5°	48.5°	33.5°	39°
Cooperstown	47.5°	47.5°	32.5°	38°
Crary	48°	48°	33°	38.5°
Crosby	49°	49°	34°	39.5°
Dazey	46.5°	46.5°	31.5°	37°
Dickinson	47°	47°	32°	37.5°
Dunn	47.5°	47.5°	32.5°	38°
Edgeley	46.5°	46.5°	31.5°	37°
Egeland	48.5°	48.5°	33.5°	39°
Ekre	46.5°	46.5°	31.5°	37°
Eldred	47.5°	47.5°	32.5°	38°
Fargo	47°	47°	32°	37.5°
Fingal	47°	47°	32°	37.5°

Finley	47.5°	47.5°	32.5°	38°
Forest River	48.5°	48.5°	33.5°	39°
Fort Yates	46°	46°	31°	36.5°
Fox	49°	49°	34°	39.5°
Froid	48.5°	48.5°	33.5°	39°
Galesburg	47°	47°	32°	37.5°
Garrison	47.5°	47.5°	32.5°	38°
Grafton	48.5°	48.5°	33.5°	39°
Grand Forks	48°	48°	33°	38.5°
Greenbush	48.5°	48.5°	33.5°	39°
Harvey	47.5°	47.5°	32.5°	38°
Hazen	47.5°	47.5°	32.5°	38°
Hettinger	46°	46°	31°	36.5°
Hillsboro	47.5°	47.5°	32.5°	38°
Hofflund	48°	48°	33°	38.5°
Horace	47°	47°	32°	37.5°
Humboldt	49°	49°	34°	39.5°
Inkster	48°	48°	33°	38.5°
Jamestown	47°	47°	32°	37.5°
Karlsruhe	48°	48°	33°	38.5°
Kennedy	48.5°	48.5°	33.5°	39°
Langdon	49°	49°	34°	39.5°
Leonard	47°	47°	32°	37.5°
Linton	46.5°	46.5°	31.5°	37°
Lisbon	46.5°	46.5°	31.5°	37°
Mandan	47°	47°	32°	37.5°
Marion	46.5°	46.5°	31.5°	37°
Mavie	48°	48°	33°	38.5°
Mayville	47.5°	47.5°	32.5°	38°
McHenry	47.5°	47.5°	32.5°	38°
McLeod	46.5°	46.5°	31.5°	37°
Michigan	48°	48°	33°	38.5°
Minot	48°	48°	33°	38.5°
Mohall	49°	49°	34°	39.5°
Mooreton	46°	46°	31°	36.5°
Mott	46.5°	46.5°	31.5°	37°
Northwood	47.5°	47.5°	32.5°	38°

Oakes	46°	46°	31°	36.5°
Pekin	48°	48°	33°	38.5°
Perley	47°	47°	32°	37.5°
Pillsbury	47°	47°	32°	37.5°
Plaza	48°	48°	33°	38.5°
Prosper	47°	47°	32°	37.5°
Robinson	47°	47°	32°	37.5°
Rolla	49°	49°	34°	39.5°
Roseau	48.5°	48.5°	33.5°	39°
Ross	48.5°	48.5°	33.5°	39°
Rugby	48.5°	48.5°	33.5°	39°
Sabin	47°	47°	32°	37.5°
Sidney	47.5°	47.5°	32.5°	38°
St. Thomas	48.5°	48.5°	33.5°	39°
Stephen	48.5°	48.5°	33.5°	39°
Streeter	47°	47°	32°	37.5°
Tappen	47°	47°	32°	37.5°
Towner	48.5°	48.5°	33.5°	39°
Turtle Lake	47.5°	47.5°	32.5°	38°
Ulen	47°	47°	32°	37.5°
Wahpeton	46.5°	46.5°	31.5°	37°
Walhalla	49°	49°	34°	39.5°
Warren	48°	48°	33°	38.5°
Watford City	48°	48°	33°	38.5°
Waukon	47.5°	47.5°	32.5°	38°
Williams	49°	49°	34°	39.5°
Williston	48°	48°	33°	38.5°
Wishek	46.5°	46.5°	31.5°	37°

APPENDIX G: ND NRCS Standard Drawing for Solar Installation



SOLAR POWERED SUBMERSIBLE PUMP FOR WELL

PUMP[1]
____ design TDH ____ design gpm
____ Input Power ____ Operating Voltage
____ manufacturer
____ model
____ controller
____ ____ description of switch box or shut-off valves

PV PANELS ____ Rated Maximum Power, Watts
____ Vmpp Tracker ____ YES ____ NO
____ Impp ____ Fixed Tilt Angle

PANEL CONFIGURATION[2] ____ series ____ parallel

[1] Pump controller, valves, switch box to be specified by manufacturer's recommendation.

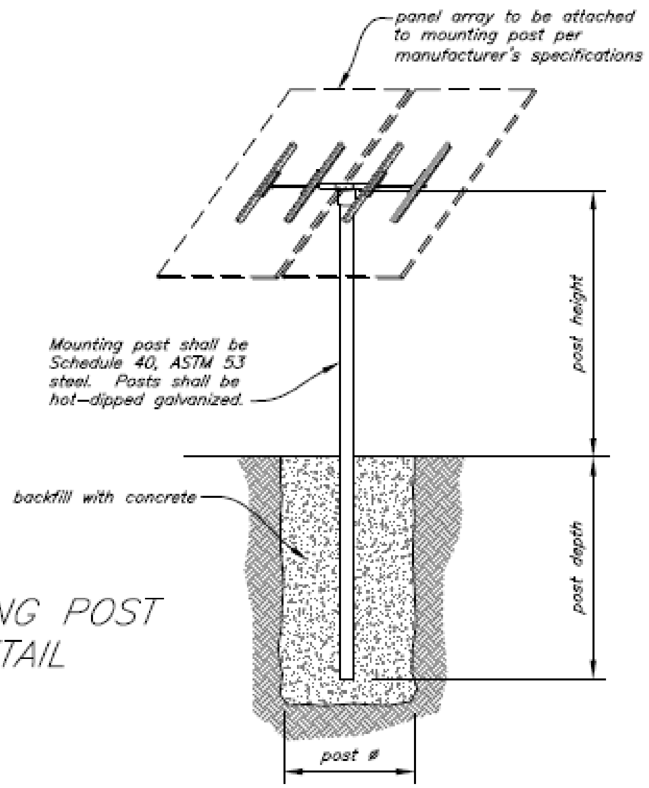
[2] Contractor to provide landowner/NRCS a diagram of the panel array wiring configuration.

PV SYSTEM AS-BUILT

MOUNTING POST SELECTION TABLE

(Producer shall install mounting configuration circled below)

POST HEIGHT (FT)	PANELS	MIN. POST DIA. (IN)	POST HOLE DIA. (IN)	MIN. EMBEDMENT DEPTH (IN)	CONCRETE VOLUME (CY)
4 FT	Single Panel (A = 13.9 ft^2)	4	24	38	0.46
	Double Panel (A = 27.8 ft^2)	4	24	48	0.55
	Triple Panel (A = 41.7 ft^2)	4	30	54	0.96
	Quad Panel (A = 55.6 ft^2)	4	36	56	1.42
6 FT	Single Panel (A = 13.9 ft^2)	4	24	36	0.44
	Double Panel (A = 27.8 ft^2)	4	30	50	0.90
	Triple Panel (A = 41.7 ft^2)	4	36	54	1.38
	Quad Panel (A = 55.6 ft^2)	6	36	60	1.49
8 FT	Single Panel (A = 13.9 ft^2)	4	30	38	0.72
	Double Panel (A = 27.8 ft^2)	4	30	50	0.90
	Triple Panel (A = 41.7 ft^2)	6	36	54	1.36
	Quad Panel (A = 55.6 ft^2)	6	36	60	1.49
10 FT	Single Panel (A = 13.9 ft^2)	4	24	44	0.51
	Double Panel (A = 27.8 ft^2)	6	30	52	0.91
	Triple Panel (A = 41.7 ft^2)	6	36	58	1.45
	Quad Panel (A = 55.6 ft^2)	8	36	64	1.58



MOUNTING POST DETAIL

NOTES:

1. PV panels are to shown to be tested and listed by Underwriters Laboratories (UL) to meet UL 1703 or tested and certified to withstand the impast of a 25-mm (1-inch) diameter hail at a minimum velocity of 23-m/s (51-mph) without major visual defects by another nationally recognized testing lab in accordance with IEC 61215 or IEC 61646. The panels are to also be certified to withstand winds of 130-km/hr (81-mph) or greater and an ice loading of 25-mm (1-inch) thick minimum over all exposed surfaces.
2. Installation of the storage tank shall meet North Dakota NRCS Specification 614 – Watering Facility.
3. Minimum post diameter, post hole diameter and post depth values in the Mounting Post Section Table have been designed for a wind speed of 95 mph and a 1 inch thick ice load. Soil properties for the foundation design were presumed to have an allowable bearing pressure of 1,500psf and a lateral pressure per unit depth of 100psf/ft and is representative of all soil types except for organics. For a site whose conditions do exceed these design parameters, the required mounting post size and embedment depth will need to be determined by a qualified engineer.
4. The concrete backfill is to be properly batched above ground prior to placement in the post hole. It is not acceptable to place dry ready mix concrete in the post hole and then fill the hole with water.
5. Care should be taken that all connections associated with the solar power system are made of similar materials to avoid the potential for corrosion.
6. The PV panel mount and all electrical components shall be properly grounded to provide lightning protection. Lightning rods are recommended for systems installed on high terrain if lightning is a known problem.

	Date
Designed ...	...
Drawn ...	...
Checked ...	...
Approved ...	...

Installation of a PV Watering System
... Project
... County, North Dakota

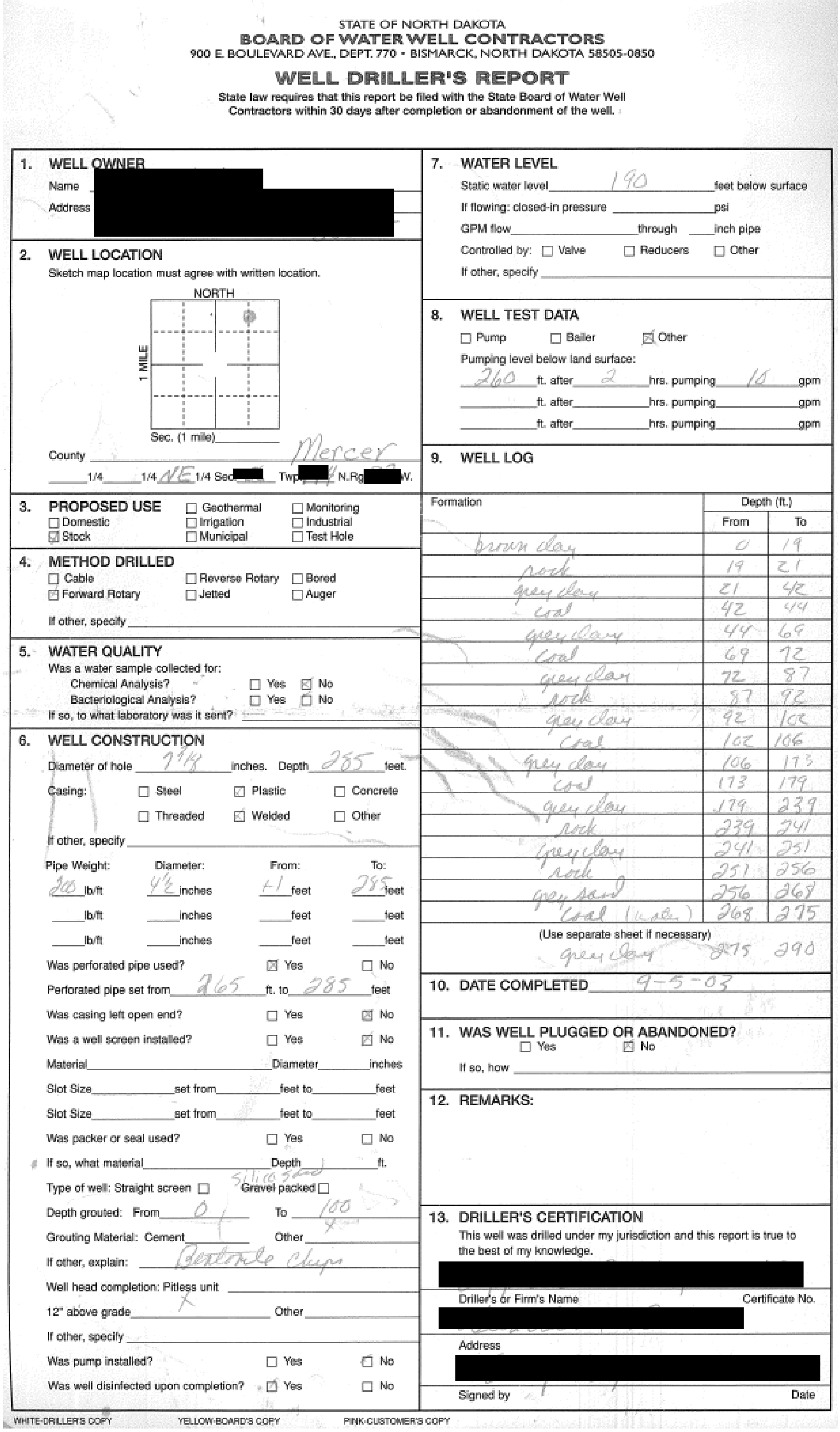
United States Department of Agriculture
Natural Resources Conservation Service

File Name
ND_Solar_Installation.dwg

DWG Number
ND-134

6/29/2017
Sheet _ of ...

APPENDIX H: Sample Well Log



STATE OF NORTH DAKOTA
BOARD OF WATER WELL CONTRACTORS
900 E. BOULEVARD AVE., DEPT. 770 • BISMARCK, NORTH DAKOTA 58505-0850

WELL DRILLER'S REPORT

State law requires that this report be filed with the State Board of Water Well Contractors within 30 days after completion or abandonment of the well.

1. WELL OWNER

Name [redacted]
Address

2. WELL LOCATION

Sketch map location must agree with written location.

Sec. (1 mile)______
County Mercer
____1/4____1/4 NE 1/4 Sec [redacted] Twp [redacted] N.Rg [redacted] W.

3. PROPOSED USE

☐ Domestic
☑ Stock
☐ Geothermal
☐ Irrigation
☐ Municipal
☐ Monitoring
☐ Industrial
☐ Test Hole

4. METHOD DRILLED

☐ Cable
☑ Forward Rotary
☐ Reverse Rotary
☐ Jetted
☐ Bored
☐ Auger

If other, specify ______

5. WATER QUALITY

Was a water sample collected for:
Chemical Analysis? ☐ Yes ☒ No
Bacteriological Analysis? ☐ Yes ☐ No
If so, to what laboratory was it sent? ______

6. WELL CONSTRUCTION

Diameter of hole 7 7/8 inches. Depth 285 feet.

Casing: ☐ Steel ☑ Plastic ☐ Concrete
☐ Threaded ☒ Welded ☐ Other

If other, specify ______

Pipe Weight:	Diameter:	From:	To:
200 lb/ft	4 1/2 inches	+1 feet	285 feet
___ lb/ft	___ inches	___ feet	___ feet
___ lb/ft	___ inches	___ feet	___ feet

Was perforated pipe used? ☒ Yes ☐ No
Perforated pipe set from 265 ft. to 285 feet
Was casing left open end? ☐ Yes ☒ No
Was a well screen installed? ☐ Yes ☒ No
Material______ Diameter______ inches
Slot Size______ set from______ feet to______ feet
Slot Size______ set from______ feet to______ feet
Was packer or seal used? ☐ Yes ☐ No
If so, what material______ Depth______ ft.
Type of well: Straight screen ☐ Silica sand Gravel packed ☐
Depth grouted: From 0 To 100
Grouting Material: Cement______ Other______
If other, explain: Bentonite Chips
Well head completion: Pitless unit X
12" above grade______ Other______
If other, specify ______
Was pump installed? ☐ Yes ☑ No
Was well disinfected upon completion? ☑ Yes ☐ No

7. WATER LEVEL

Static water level 190 feet below surface
If flowing: closed-in pressure ______ psi
GPM flow______ through ____ inch pipe
Controlled by: ☐ Valve ☐ Reducers ☐ Other
If other, specify ______

8. WELL TEST DATA

☐ Pump ☐ Bailer ☒ Other
Pumping level below land surface:
260 ft. after 2 hrs. pumping 10 gpm
______ ft. after______ hrs. pumping______ gpm
______ ft. after______ hrs. pumping______ gpm

9. WELL LOG

Formation	Depth (ft.)	
	From	To
brown clay	0	19
rock	19	21
grey clay	21	42
coal	42	44
grey clay	44	69
coal	69	72
grey clay	72	87
rock	87	92
grey clay	92	102
coal	102	106
grey clay	106	173
coal	173	179
grey clay	179	239
rock	239	241
grey clay	241	251
rock	251	256
grey sand	256	268
coal (water)	268	275

(Use separate sheet if necessary)
grey clay 275 290

10. DATE COMPLETED 9-5-03

11. WAS WELL PLUGGED OR ABANDONED? ☐ Yes ☒ No
If so, how ______

12. REMARKS:

13. DRILLER'S CERTIFICATION

This well was drilled under my jurisdiction and this report is true to the best of my knowledge.

[redacted]
Driller's or Firm's Name Certificate No.
[redacted]
Address
[redacted]
Signed by Date

WHITE-DRILLER'S COPY YELLOW-BOARD'S COPY PINK-CUSTOMER'S COPY

APPENDIX I: Solar Panel Wiring

PV solar panels can be wired together in series, in parallel or in a combination of series and parallel to obtain the needed output voltage and current. Solar panels have a negative (-) and a positive terminal (+) similar to the terminals on a battery.

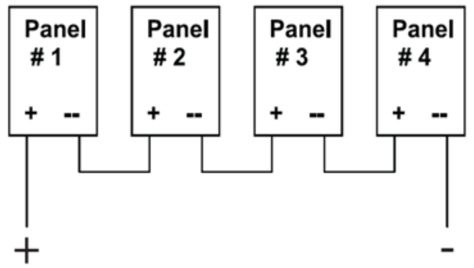


Figure I1 *- Solar panel wired in series.*

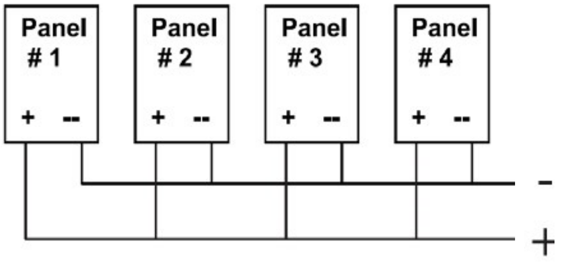


Figure I2 *- Solar panel wiring in parallel.*

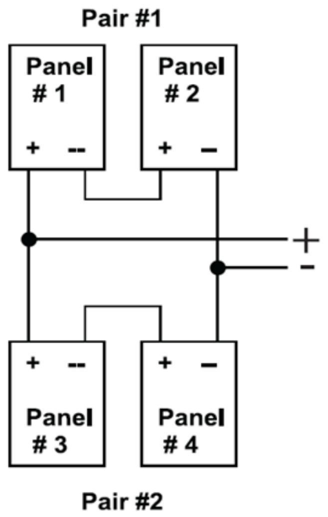


Figure I3 *- Solar panel wiring in combination of series and parallel.*

PV panels are wired in series by connecting the negative terminal of one panel to the positive terminal of the next panel as shown in **Figure I1**. When panels are wired in series, the panel voltages are added.

If the panel has the characteristics shown in **Figure 7.3**, the resultant voltage output for panels shown in **Figure I1** is

30.6 + 30.6 + 30.6 + 30.6 = 122.4V

The current output would be the same as for an individual panel or 8.17A.

Panels are wired in parallel by connecting positive terminals and negative terminals as shown in **Figure I2**. In this case, the output voltage is the same as the individual panel voltage, and the currents of individual panels are added.

For the panel characteristics shown in **Figure 7.3**, the output for panels in parallel is:

8.17 + 8.17 + 8.17 + 8.17 = 32.68A

The output voltage is 30.6V

A series/parallel circuit as shown in **Figure I3** is considered to be two or more series circuits that are wired together in parallel. In the example, two panels are wired in series, and two of these groups are wired in parallel.

The voltage output for two panels in series (using the information from **Figure 7.3**) is:

30.6 + 30.6 = 61.2V

The current produced is the sum of the current produced by each group of two panels wired in series:

8.17 + 8.17 = 16.34A

The solar panel data in **Figure 7.3** shows that the rated maximum power of each panel is 250W. For 4 panels the total rated power should be 1000W. Calculating the total power produced by all three configurations proves that this is indeed true:

(122.4V x 8.17A) = (30.6V x 32.68A) = (*61.2V X 16.34A) = 1000W*

It is important to ensure that the values for voltage and current meet the requirements of the motor supplied.

APPENDIX J: Glossary of Electrical, Solar-Power, and Water System Terms

1-Sun	The total amount of solar radiation reaching the earth's surface. Equivalent to approximately 1kW/m^2. (See Solar Radiation and Solar Insolation)
Acceptors	The atoms that are formed from the interaction in a p-Type semiconductor. This interaction leaves an abundant number of positively charged "holes" and an electron deficiency. (See p-Type Layer)
Alternating Current (AC)	An electric current that reverses its direction at regularly recurring intervals.
Altitude Angle (β_N)	The angle between the sun and the local horizon directly beneath the sun during solar noon. (See Solar Noon).
Amperes (Amps or A)	A measure of electric current in a conductor. The voltage drop in a conductor is directly related to the current (A). (See Voltage Drop.)
Amp-Hours (Ah)	The unit of storage for batteries.
Anode	A positively charged electrode that attracts electrons and thus is susceptible to corrosion.
Array	The combination of solar modules wired in some configuration of series and parallel. (See Series and Parallel).
Atom	The basic unit of matter and the defining structure of all elements
Bank	A collection of batteries that are wired together to power a system.
Casing	A plastic or steel tube that is permanently inserted into a well after it is drilled. Its size is specified according to its inside diameter.
Cathode	A negatively charged electrode that attracts positive charge and is the source of electrons. Cathodes are said to generate charge and thus are not susceptible to corrosion.
Centrifugal Pump	A pumping mechanism that spins water by means of an impeller. Water is forced out of the impeller by centrifugal force, thus giving energy (head) to the water. (Also see Multi-Stage Centrifugal Pump.)
Charge Controller/Regulator	A component of a charging system that allows for current to flow into a bank of batteries until they are fully charged.
Check Valve	A valve that allows water to flow one way but not the other.
Collector Azimuth Angle (ϕ_C)	The angle at which the PV panels are off of due south.
Column Pipe	The pipe that carries water from a pump in a well up to the surface. Also referred to as Drop Pipe.
Conductor	A type of material that allows the flow of electrical current in one or more directions. (See Current).

Corrosion	The gradual destruction of materials by chemical reaction with their environment.
Current	The flow or movement of electrons along a path. (See Electrons) Common units are in Amperes. (See Amperes).
DC Motor, Brush-Type	A traditional DC motor in which small, conductive carbon blocks, called "brushes", conduct current into the spinning portion of the motor. They are used in DC surface pumps and also in some DC submersible pumps. Brushes naturally wear with time and must be replaced. (See Direct Current (DC).)
DC Motor, Permanent Magnet	A DC motor that solar pumps use in some form. Being a variable speed motor by nature, reduced input power (in low sun) produces proportionally reduced speed and causes no harm to the motor. (See Direct Current (DC).
De-Rating Value	The loss of power output and efficiency of a PV panel due to all the factors that interfere with the system. Factors include the age and service life of the panel and environmental wear and tear.
Direct Current (DC)	An electric current flowing in one direction only and substantially constant in value.
Donor Atoms	The atoms that are formed from the interaction in an n-Type semiconductor. This interaction leaves an abundant number of negatively charged electrons that are free to interact with neighboring atoms. (See n-Type Layer)
Double Axis Tracker	A solar panel mount that tracks both the sun's azimuth and altitude angles so that the solar array is always pointed directly at the sun. (See Sun Azimuth Angle and Altitude Angle).
Drawdown	The lowering of the level of water in a well due to pumping.
Eccentric Loading	A load or force upon a portion of a column or post causing it not to be symmetric with its central axis; i.e. bending of the column or post.
Efficiency	The percentage of power that gets converted to useful work.
Electric Charge	The physical property of all matter that creates a force that is the basics of all electricity.
Electric Field	The force that fills the space around every electric charge or group of charges.
Electrolyte	A substance that produces an electrically conducting solution when dissolved in water.
Electronic Float Switch	A switch in form of a float that is connected to a pump that will shut power off to the pump when the float is in the "full" position.
Electrons	Subatomic particles with a negative charge and are the primary carriers of electricity in solids.
Energy	The ability of a system to do work or the total amount of work done. Common units are Joules or BTU. In electricity, energy is measured in Watt-Hours. (See Power or Watts)

Equinox	The time or date at which the sun crosses the earth's equator and when day and night are of equal length. Two equinoxes occur each year; March 21st and September 21st.
Fixed-Axis Mount	A mounted PV panel that is set at a determined angle and stays at that angle until it is manually adjusted.
Flow Rate	The amount of fluid that flows in a given time, normally expressed in units of gallons per minute (gpm) in solar-powered systems.
Friction Loss	The loss of pressure due to the friction caused by the flow of water in a pipe. Friction loss is determined by four factors: the pipe size (inside diameter), the flow rate, the length of the pipe, and the pipe's roughness. Friction loss is normally expressed in psi or ft per length of pipe. (See Flow Rate.)
Gravity Flow	The use of gravity to produce pressure and water flow (2.31 vertical feet = 1 psi). A storage tank will be elevated above the point of use so that water will flow with no further pumping required. A booster pump may be used to increase pressure. (See Pressure.)
Head	The amount of energy per unit weight of water. The three principle components of head are the elevation (lift), pressure, and velocity of flowing water. (See Vertical Lift and Total Dynamic Head.)
Hydraulic Workload	The amount of work required of a system to supply a flow against a given head (TDH)
Inverter	An electronic control device that produces AC output from DC input. (See Alternating Current (AC) and Direct Current (DC).)
Kilowatt (kW)	A unit of power equal to 1,000 Watts. (See Watts)
Kilowatt-Hour (kWh)	A unit of energy that is the multiplication of power in kilowatts (kW) and time in hours. (See Kilowatt (kW).)
Load	An electrical component or portion of a circuit that consumes electric power. In watering systems the load is typically the pump.
Low-Voltage Disconnect	A component of a charging system that acts as an automatic switch that will disconnect the pump before the battery voltage gets too low.
Maximum Power Current (I_{mpp})	The maximum current produced by a PV panel at the rated power of the panel. (See Rated Panel Power).
Maximum Power Voltage (V_{mpp})	The maximum voltage produced by a PV panel at the rated power of the panel. (See Rated Panel Power).
Module	A string of solar cells pre-wired in series and encased in a ridged, weather resistant housing. (See Solar Cell and Series)
NDAWN	The North Dakota Agricultural Weather Network, NDAWN, is a network of weather stations operated by North Dakota State University.

n-Type Layer	A layer of a semiconductor material coated with an element such as phosphorus that causes an interaction that produces extra negative electrons. (See Donor Atom)
National Electrical Code (NEC)	A United States standard for the safe installation of electrical wiring and equipment published by the National Fire Protection Association.
Ohms (Ω)	The measure of a material's resistance to the flow of electrons across it. Ohms are the unit for electrical resistance. (See Resistance)
Open Discharge	The filling of a water vessel that is not sealed to hold pressure (e.g., a water tank, storage (holding) tank, or pond). (Contrast with Pressure Tank.)
Optimal Tilt Angle	The seasonal best tilt angle for a fixed-axis mount to provide the best production for a system. (See Fixed-Axis)
p-Type Layer	A layer of a semiconductor material coated with an element such as boron that causes an interaction that produces positively charged "holes". (See Acceptors)
Parallel	A method of wiring together a set of strings wired in series to increase the output of a system component. Strings of solar modules wired in parallel will cause the current of each module to add.
Peak Sun Hours	The equivalent number of hours per day when solar irradiance averages 1-Sun. (See Solar Irradiance and 1-Sun).
Perforations	Slits cut into the well casing to allow groundwater to enter. They may be located at more than one level to coincide with water-bearing strata in the earth. (See Casing.)
Photoelectric Effect	The effect of metals emitting electrons when exposed to sunlight.
Photovoltaic (PV) Panel	An array of photovoltaic cells encapsulated in a protective frame and transparent cover and manufactured to meet specific standards. PV panels are normally rated based on their power output, including voltage and amperage. (See Amperes and Volts.)
Pitless Adapter	A below-ground pipe fitting for a well casing that allows the pump discharge pipe to pass horizontally through the casing so that no pipe is exposed above ground, where it could freeze. The adapter contains a seal so the pump can be installed and removed without further need to dig around the casing. (See Casing.)
Point Load	A force applied to a single, specific point on a structural member. Point loads can either be axial or lateral.
Positive Displacement Pump	Any mechanism that seals water in a chamber, then forces it out by reducing the volume of the chamber (e.g., a piston (including a jack), diaphragm, or rotary vane). It is used for low volume and high lift. (Contrast with Centrifugal Pump.)
Power	The rate at which work is done or the rate at which energy is generated or used. Common units are Joules/Second or BTU/Hour. In electricity, power is measured in Watts; 1 Watt = 1 Joule/Second.

Power Loss	The amount of power lost in a system and is the ratio of the power absorbed by a circuit to the power delivered to the load. The loss is proportional to the square of the current multiplied by the resistance.
Pressure	The amount of force produced by water over a given area, normally measured in pounds per square inch (psi). One psi will sustain a vertical column of water 2.31 ft tall (psi X 2.31 = ft of head).
Pressure Switch	An electrical switch actuated by the pressure in a pressure tank. When the pressure drops to a low set point (cut-in), the pressure switch turns the pump on. When the pressure reaches a high point (cut-out), the pressure switch turns the pump off. (See Pressure Tank.)
Pressure Tank	A fully enclosed tank that contains air space. As water is forced in, the air compresses. The stored water may be released after the pump has stopped. Most pressure tanks use a rubber bladder to contain the air and are referred to as “captive air” or “bladder tanks”.
Pressure Tank – Pre-Charging	The pressure of compressed air stored in a pressure tank. A reading should be taken with an air pressure gauge (tire gauge) when the water pressure is at zero. The air pressure should then be adjusted to about 3 psi lower than the cut-in pressure. If the pre-charge is not set properly, the tank will not work at full capacity and the pump will cycle on and off more frequently. (See Pressure Switch and Pressure Tank.)
Priming	The process of hand filling the suction and intake pipes of a surface pump with water. Priming is generally necessary when a pump is located above the water source such as a suction pump.
Pump Controller	An electronic device that controls or processes power between the solar array and the pump. It may perform any of the following functions: stopping and starting the pump, protecting the pump from overload, and converting or matching power. It also allows the pump to start and run under low sun conditions without stalling.
Rated Panel Power (P_{max})	The rated power output of a PV panel.
Recovery or Recharge Rate	The rate at which groundwater refills a well casing after the water level is drawn down. This term is used to define the production rate of the well. (See Casing and Drawdown.)
Resistance	The measure of the difficulty of passing an electric current through a conductive material. The more resistance in a circuit, the less electricity will flow through the circuit. Resistance is measured in units of Ohms (Ω). (See Ohms)
Self-Priming Pump	A pump that is able to draw some air suction in order to prime itself. (See Priming.)
Series	A method of wiring or stringing together, in a line, components of a system to increase the output of that component. Solar modules wired in series will cause the voltage of each module to add.
Single Axis Tracker	A solar panel mount that tracks either the sun’s azimuth angle or the altitude angle. (See Sun Azimuth Angle and Altitude Angle).

Solar Azimuth Angle (ϕ_S)	The azimuth angle of the sun relative to due south and solar noon. (See Solar Noon).
Solar Cell	The smallest component of a PV panel.
Solar Declination Angle (δ)	The angle corresponding to the actual location of the sun in relation to the equator during anytime of the year.
Solar Elevation Angle	The elevation angle of the sun, which is related to latitude and time of year. The greater the latitude, the lower the solar elevation angle. The elevation angle is greatest at summer solstice and least at winter solstice.
Solar Insolation	The amount of solar irradiance measured over a given period of time. (See Solar Irradiance). Expressed in units of KW/m^2/day or hrs/day @ 1-Sun. (See 1-Sun). Solar insolation values are dependent on latitude, time of year, and local conditions, such as cloud cover. (See Kilowatts (kW), Kilowatt-Hours (kWh), and Watts (W).)
Solar Intensity	The intensity of solar radiation is the amount of solar power per unit area and describes how much energy the sun deposits in an area within a specified amount of time.
Solar Irradiance	The amount of solar energy received by or projected onto a specific surface. Expressed in units of kW/m^2 and is measured at the surface of the object.
Solar Noon	The moment at which the sun is directly over the line of longitude of a given location.
Solar Radiation	The radiant energy emitted by the sun. Expressed in units of kW/m^2.
Static Water Level	The depth to the water surface in a well under static conditions (when it is not being pumped). It may be subject to seasonal changes or change after extended pumping.
Submergence	As applied to submersible pumps, the distance beneath the static water level at which a pump is set. Synonym: immersion level.
Submersible Cable	An electrical cable designed for in-well submersion. The conductor (wire) sizing is specified in millimeters or (in the U.S.) by American Wire Gauge (AWG). (See Wire Gage.)
Submersible Pump	A motor/pump combination designed to be placed entirely below the water surface.
Suction Lift	As applied to surface pumps, the vertical distance from the surface of the water supply to the pump. This distance should be no more than 25 feet at sea level (subtract 1 ft per 1,000 ft altitude) and should be minimized for best results.
Summer Solstice	The time and date when the sun reaches its highest point and makes an angle of 23.45° above the earth's equator. In the Northern Hemisphere, the Summer Solstice is on June 21st.
System Demand	The amount or water required of the system, in units of gallons per day, for the pump to produce.

Total Dynamic Head	Vertical lift + pressure head (psi/2.31) + friction loss in piping. It is sometimes referred to as “Pumping Head.” (See Vertical Lift, Pressure, and Friction Loss.)
Surface Pump	A pump that is not submersible. It must be placed no more than 25 ft above the surface of the water in the well. (See Priming and Submersible Pump.)
Tropic of Cancer	The name of latitude 23.45° N when the sun reaches its highest point in the Norther Hemisphere and is directly overhead at noon on June 21st. (See Summer Solstice)
Tropic of Capricorn	The name of latitude 23.45° S when the sun reaches its highest point in the Southern Hemisphere and is directly overhead at noon on December 21st. (See Winter Solstice)
Vertical Lift	The vertical distance that water is pumped.
Voltage	The amount of energy given to a unit of charge. Voltage is measured as the difference in electric potential energy between two points of charge and has the units of Volts. (See Volts)
Volts (V)	A measure of electric potential.
Voltage Drop	The drop in voltage within an electrical system due to electrical resistance and losses in the system, including in the wires and controls. The voltage drop in a conductor (wire) is directly related to the current (A), the size of the conductor, and the type of conductor material. An allowable voltage drop may be specified by the manufacturer and/or the National Electrical Code. (See Amperes (A) and National Electric Code (NEC).)
Water Balance or Budget	A method of record keeping that keeps track of the inputs and outputs of a system. An input for a solar powered watering system is the daily, monthly, or yearly production of the pump and solar array. The output would be the demand requirement of the system for the same time period.
Watts (W)	A measure of electric power. Watts = Volts x Amps. 1 W = 1 Joule / Second 1 W = 1 V X 1 A 1,000 W = 1 kW 1 kW = 1.34 horsepower 1 horsepower = 746 W = 0.746 kW
Well Seal	The top plate of a well casing that provides a sanitary seal and support for the drop pipe and pump. (Alternative: See Pitless Adapter).
Winter Solstice	The time and date when the sun reaches its highest point and makes an angle of 23.45° below the earth’s equator. In the Northern Hemisphere, the Winter Solstice is on December 21st.
Wire Gage	The diameter of wire, including electrical wire. In the American Wire Gage (AWG) system, the wire size decreases with an increasing AWG number. In the metric wire gage scale, the wire size increases with an increasing metric wire gage.