Irrigation Energy Audit Manual

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Irrigation Energy Audit Manual

Table of Contents

Chapter 1 - Energy Use in Irrigation

Total energy use in irrigated agriculture includes field operations and tillage, seed sources, chemicals, fertilizer, irrigation, and harvest/drying. Energy for pumping water accounts for a large portion of the energy used in an irrigated agriculture production system. Thus improvements in the performance of the irrigation system components can result in significant energy savings. An essential element to improving irrigation energy use efficiency is to conduct an energy audit to determine the current energy use of the irrigation system. The energy audit can then prioritize improvements for the irrigation system to save energy.

In Nebraska data from the 2008 USDA Farm and Ranch Irrigation Survey shows that the average energy use for irrigating crops would be equivalent to about 340 million gallons of diesel fuel annually if all pumps were powered with diesel engines. While use varies depending on annual precipitation, average yearly energy consumption is equivalent to about 40 gallons of diesel fuel per acre irrigated.

The 2008 Census of Agriculture lists 532,000 acres of irrigation in Michigan with about 94% sprinkler irrigated and 6% drip/trickle irrigated. On individual farms, irrigation accounts for a large portion of the farm energy use. The Census shows that the energy expenses for irrigation in Michigan exceed $17 million per year.

Most irrigation systems use energy to deliver water from the source and distribute it on the field. Table 1.1 lists the factors that affect irrigation energy use. Some of the factors cannot be modified, some can only be controlled in the design and installation stage, some can be changed by retrofits, and some are controllable throughout the life of the project.

The cost to irrigate a field is determined by the amount of water pumped and the cost to apply a unit (acre-inch) of water (Figure 1.1). Factors that determine pumping costs include those that are fixed for a given location (in the ovals in Figure 1.1) and those that producers can influence. The factors that producers can influence include: irrigation scheduling, application efficiency, efficiency of the pumping plant, and the pumping pressure required for the water distribution system. Pumping costs can be minimized by concentrating on these factors. Irrigators may also consider changing the type of energy used to power irrigation if they determine that one source provides a long-term advantage.

Irrigation scheduling can minimize the total volume of water applied to the field. Demonstration projects in central Nebraska have indicated that 1.5 to 2.0 inches of water can be saved by monitoring soil water, estimating crop water use, and scheduling irrigations using a water balance. The goal is to maximize use of stored soil water and precipitation to minimize pumping.

Improving the efficiency of water application is a second way to conserve energy. Water application efficiency is a comparison between the depth of water pumped and the depth stored in the soil that is available to the crop. Figure 1.2 is a simplified diagram of sprinkler irrigation application efficiency. Irrigation systems can lose water to evaporation in the air or from plant foliage and soil surfaces. Water can also be lost as runoff. Excess irrigation and/or rainfall may be lost through the crop root zone from deep percolation. For center pivots, water application efficiency is based largely on the sprinkler package and how the system is managed. High pressure sprinklers generally have higher evaporation losses while low pressure sprinklers can have greater runoff potential if application rates exceed soil intake rates. Good irrigation scheduling should minimize deep percolation.

Energy use can also be reduced by lowering the operating pressure of the irrigation system. However, reducing the pressure almost always results in an increased water application rate for a center pivot. The key is to make sure that the operating pressure is sufficient to eliminate the potential for surface runoff. Field soil characteristics, surface roughness, slope and tillage combine to control how fast water can be applied to the soil surface before surface runoff occurs. If water moves from the point of application, the savings in energy resulting from a reduction in operating pressure is counterbalanced by the need to pump more water to assure that all portions of the field receive at least the desired amount of water.

Finally, energy can be conserved by assuring that the pumping plant is operating as efficiently as possible. Efficient pumping plants require properly matched pumps and power units. An irrigation energy audit can be performed to evaluate the overall energy efficiency of the irrigation system and provide recommendations and guidance to improve some of the factors from the above table. The audit will also provide cost/return estimates for improvements to the irrigation system.

Table 1.1 - Factors affecting irrigation energy use.

Factors that cannot be controlled	Field topography and slope (may modify field slope with land leveling)
	Field size and location to water and energy sources
	Water source and aquifer characteristics if a well is used
	Weather including precipitation and crop water needs
	Price of energy
Factors that can be controlled during the design and installation stage	Well design and development
	Selection of pumping plant equipment
	Operating pressure of system
	Design of underground pipelines
	Design of distribution system
Factors that can be modified through retrofits	Replace irrigation system, i.e. change from flood irrigation to center pivot
	Replace pump or power unit
	Retrofit system to lower operating pressure or different sprinklers
Factors that can be controlled on an ongoing basis	Perform routine maintenance to achieve the highest possible fuel efficiency
	Operate the system to minimize overwatering to control runoff and deep percolation
	Monitor conditions in the field, i.e. soil water content, crop condition, and water losses
	Schedule irrigations using crop/soil/weather inputs
	Record pumping time and water/energy use

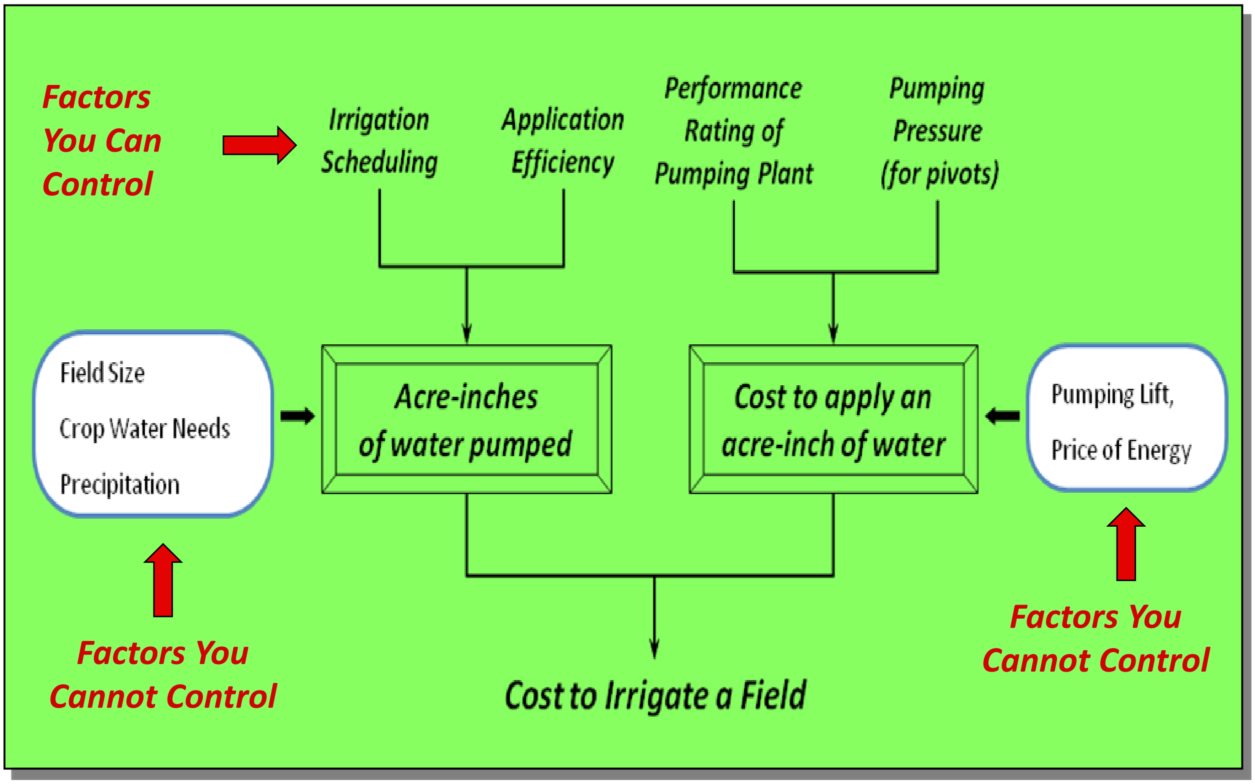


Figure 1.1 - Diagram of factors affecting irrigation pumping costs. (Center Pivot Management Handbook)

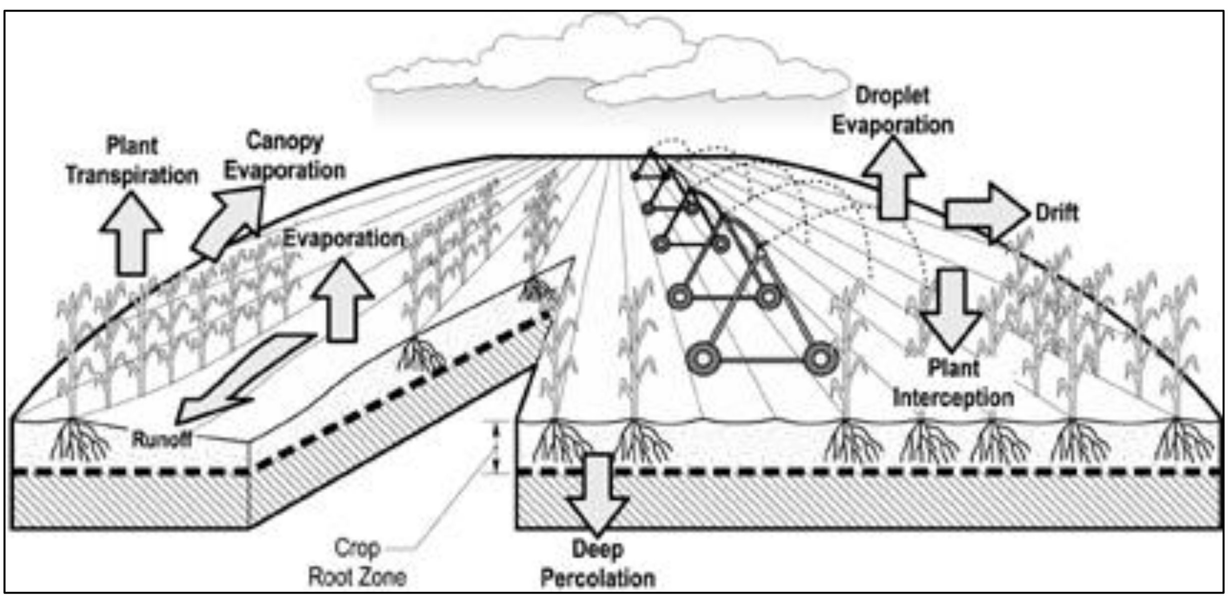


Figure 1.2 - Illustration of irrigation application efficiency. (Courtesy of MWPS 30)

Chapter 2 - Background Energy Principles

I. Energy principles

Energy is defined as the ability to do work and is governed by various physics principles. Energy can exist in several forms and a variety of energy transfer processes occur as water moves from the source through the delivery line and out of the distribution system. Any form of energy can be transformed into another form, but the total energy remains the same. This is known as the conservation of energy principle. Potential energy is the amount of energy an object has with respect to its form or position. Kinetic energy is the energy of an object with respect to its motion.

Efficiency is the term used to quantify how a system or component converts energy from one form to another. By definition it is the ratio of the usable energy output divided by the total energy input.

In the context of irrigation energy use efficiency, energy is delivered to the irrigation system as fuel, i.e. electricity or diesel fuel, with the expected outcome that water is delivered to the crop resulting in the greatest benefit for the fuel used. As an example, the thermal energy in diesel fuel (potential energy) is burned in an internal combustion engine to drive a pump that moves water (kinetic energy) to a higher elevation at a given pressure (potential energy). This potential energy as pressure is then converted to kinetic energy as the water is delivered to the crop by the irrigation distribution system, i.e. center pivot (Figure 2.1). Energy is transformed throughout this process where each step can have inefficiencies (Table 2.1). Many times these inefficiencies are referred to as “losses”, even though energy is not lost, only changed to a form that does not benefit the overall objective of irrigation. For example, the diesel engine or pump may not be at peak efficiency, the pipeline may have excessive friction, or the sprinkler system may not be applying water uniformly or suited to the crop water needs.

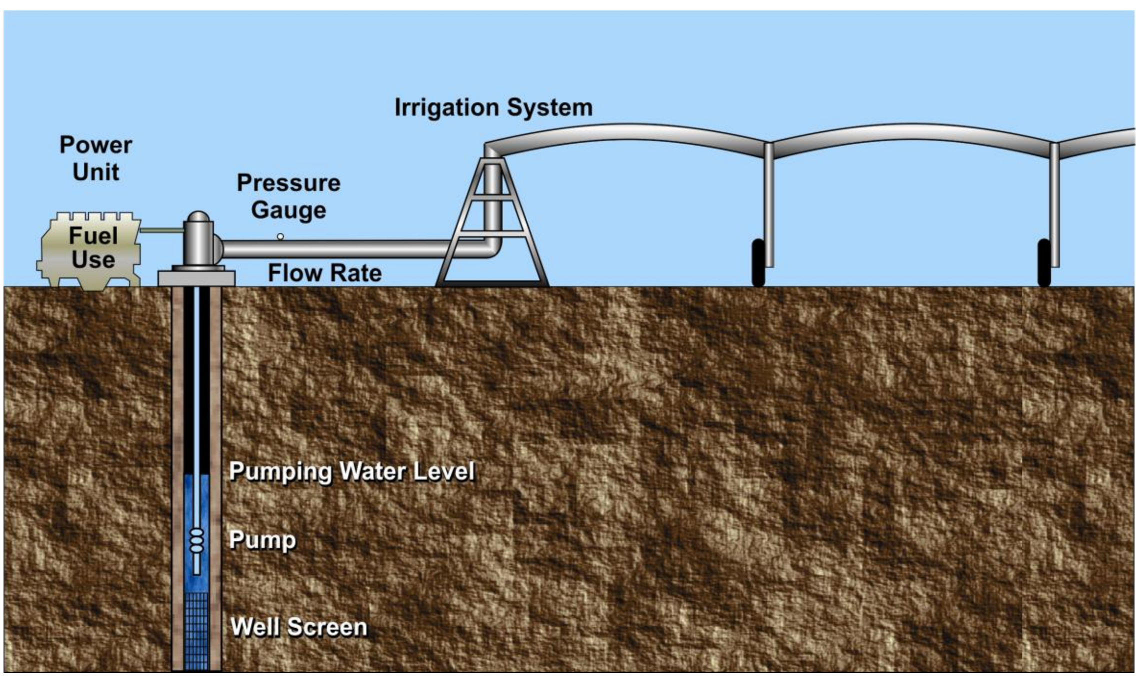


Figure 2.1 - Schematic of typical irrigation system cross-section showing items tested during energy audit.

Table 2.1 - Sources of inefficiencies in irrigation.

Water sources	Leakage of water from gravity fed ditches and canals
	Excessive well drawdown due to poor well design or lack of maintenance
Pumping plant	Improper pump intake
	Improper pump selection
	Inadequate pump maintenance
	Poorly sized power units
	Inadequate power unit maintenance
	Improper drive unit system (gear or belt drive)
Water conveyance	Improper valving and controls
	Undersized pipelines
	Water leaks
Water delivery	Mismatched components
	Non uniform water application
	Water losses to runoff, deep percolation and evaporation
	Overwatering

II. Power

Power is the rate of performing work, in other words, the rate that energy is converted from one form to another. Power for irrigation systems is generally provided by electricity or internal combustion engines. Other sources of power could be solar or wind, but these are not common for irrigation in Nebraska due to intermittent availability. Two measurement units are used to express power in irrigation -- kilowatts and horsepower. To compare the two, multiply horsepower by 0.746 to obtain kilowatts, or conversely, multiply kilowatts by 1.34 to obtain horsepower.

Electric power is expressed in kilowatts (KW). Electrical power usage is expressed as kilowatt-hours (KWH) which, as the name implies, is the kilowatts used for the number of hours of use. Kilowatt-hours are the units that appear on utility billing statements. Since electric motors convert electrical energy into mechanical energy, they often have nameplate ratings showing horsepower output. Most electric motors used in irrigation are approximately 88 to 92 percent efficient in converting electrical energy to mechanical energy. The 8 to 12 percent "loss" (difference between 100 percent and the 88 to 92 percent) is the amount of energy that the electric motor uses in converting electrical energy into mechanical energy (Figure 2.2). Most of the "loss" is in the form of heat. Figure 2.3 shows energy output and losses for a diesel engine.

Horsepower (HP) is the commonly used term to express power supplied by internal combustion engines. Internal combustion engines are not as efficient at converting fuel energy to mechanical energy as electric motors. Most engines are from 20 to 40 percent efficient, where most of the "lost" energy is released as heat. Diesel engines have the highest efficiency of the internal combustion engines used for irrigation.

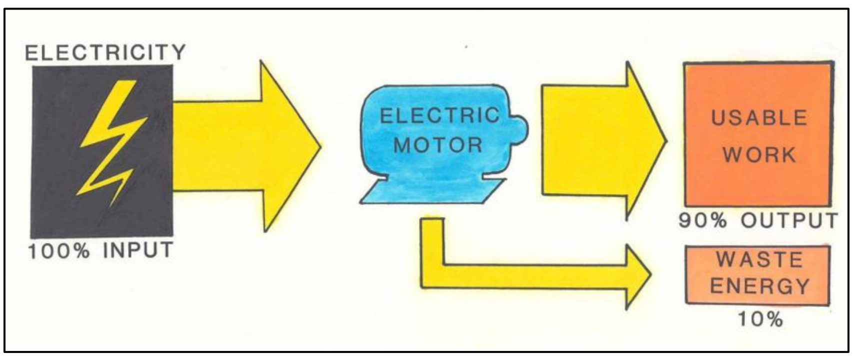


Figure 2.2 - Energy input and output for electric motors.

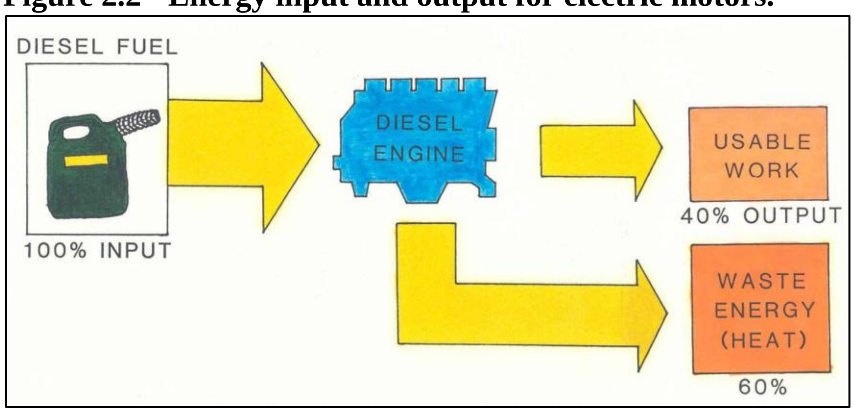


Figure 2.3 - Energy input and output for diesel engines.

III. Pressure versus head

Pressure and head are terms used to describe the amount of potential energy in the irrigation water. The units of pressure are often expressed as pounds per square inch (psi) and are quantified with a pressure gage attached to the pipeline. Head is expressed in “feet” and is the common unit used in calculations of horsepower. Multiply pressure in psi by 2.31 to convert it to feet of head.

Example 2.1: An irrigation pipeline with a pressure reading of 50 psi has 115.5 feet of head. Conversely multiply head in feet by 0.433 (which is the inverse of 2.31) to obtain pressure in psi.

A vertical column of water that is 70 feet tall will have a pressure of 30.3 psi at the bottom of the column (i.e. 70*0.433 or 30.3 psi).

Examples of how this applies to the energy audit are throughout this handbook.

Note: The equation notation used in this manual follows that used in computer spreadsheets, i.e. multiplication is indicated by “*” and division is indicated by “/”.

Note: All units and dimensions are given in English units which are common in the US irrigation industry.

IV. Water calculations

Water flow rate is a component of the irrigation energy audit analysis. Irrigation water flow rate is expressed in a variety of units. The most common flow rate term for enclosed pipelines is gallons per minute (gpm) while open channel flow is usually given as cubic feet per second (cfs). The distributed water over the field is presented as acre-inches per hour (ac-in/hr) or acre-feet per day (ac-ft/day). These flow rates are interchangeable if appropriate conversion factors are applied. Conversions are 1 cfs is equal to 449 gpm and 1 ac-in/hr is equal to 453 gpm. The gpm flow rate is used in horsepower calculations.

Flow rates are used to estimate the gross depth of water applied to a land area. First convert cfs or gpm to ac-in/hr. Then the acre-inch per hour flow rate is readily adapted to calculating an average depth of water applied to the land.

Example 2.2: Calculate the depth of water applied to 100 acres if 800 gpm is delivered for three days or 72 hours:

800 gpm/453 = 1.77 ac-in/hr

Multiply 1.77 ac-in/hr by the number of hours and divide by the acres to get the depth:

1.77*72/100 = 1.27 inches.

Chapter 3 – Components of an “Efficient” Irrigation System

I. Irrigation Water Supply

Water supplies for irrigation are either surface water sources or wells. Surface water sources include irrigation canals and ditches, streams and rivers, ponds and lakes, and other ditches or lagoons. Surface water does not contribute to increased energy use other than pump siting and pipeline length.

Wells provide the irrigation water for most irrigation systems in Nebraska and Michigan. Figure 3.1 shows a cross section of a well within an aquifer. It is critical that the well be constructed vertical and straight otherwise the pump cannot be installed properly. Wells must conform to codes for water well construction specified by state law. Only licensed well drillers are permitted to construct wells.

When water is pumped from the well, the water level inside the well will decline to a level called the pumping water level (Figure 3.2). The difference between the initial or static water level and the pumping water level is called drawdown. Drawdown is required to create the head (energy differential) needed to move water into the well from the surrounding aquifer. For a given well, less drawdown at the same pumping rate would mean that less energy is needed to pump water from the well. Thus higher well efficiency is achieved by having less drawdown. High well efficiency is achieved through the design and construction process. A detailed discussion of achieving high well efficiency is presented in Chapter 3 of MWPS 30 Sprinkler Irrigation Systems.

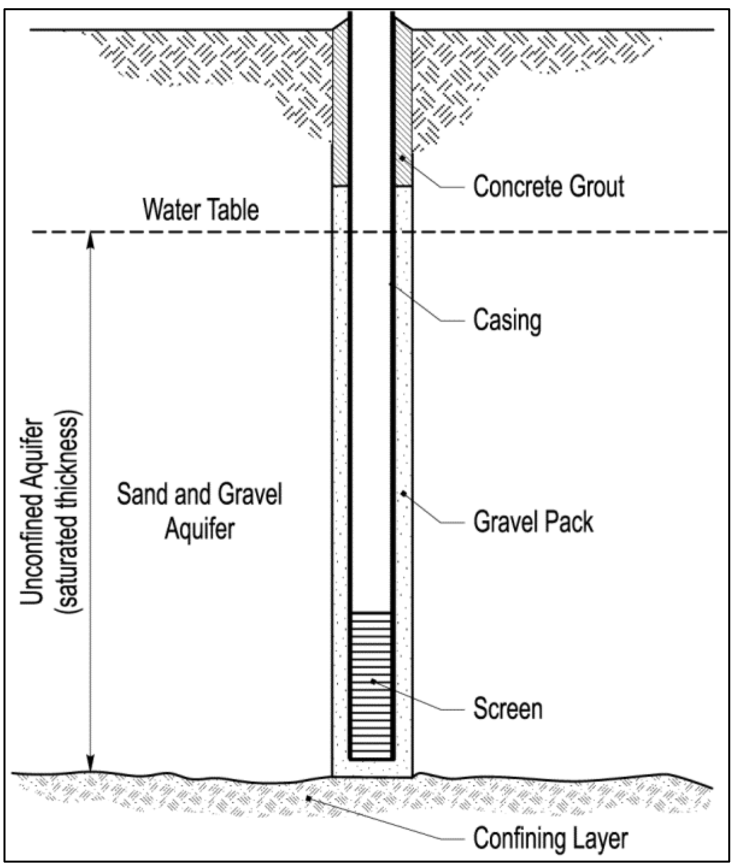


Figure 3.1 - Example well cross-section. (Courtesy of MWPS 30)

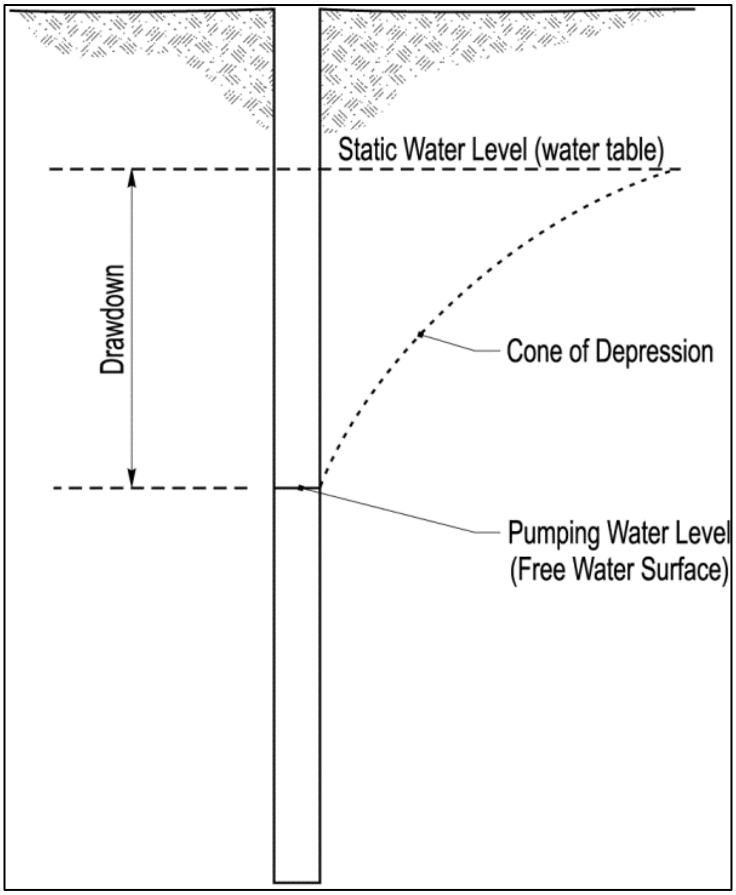


Figure 3.2 - Well hydraulics. (Courtesy of MWPS 30)

Determining well efficiency is beyond the scope of a typical irrigation energy audit. First, it is time-consuming and costly to determine well efficiency. Second, it is difficult to improve the well efficiency once the well has been put in service. It is important to note, however, that research has shown that well efficiency can be maximized by following recommended design and construction practices by the well driller.

It is important that each well be test pumped before designing the pumping equipment in order to match the well capacity to the system. Test pumping involves using the well driller's pump to determine the gpm output together with the drawdown to find the specific capacity of the well. Specific capacity is defined as the gpm per foot of drawdown.

Example 3.1: A well that delivers 600 gpm with a drawdown of 50 feet.
The specific capacity is:
SC = 600 gpm/50 ft = 12 gpm/ft

II. Pumping plant

Design of the pump system depends on the amount of water desired, the water source, and pressure required for the irrigation system. The pumping plant system includes the pump, power unit and drive component, if needed (Figure 3.3). All components have an energy efficiency associated with them. Correct design and maintenance of the pump and power unit is critical for low cost operation of the irrigation system. Several studies have shown that most irrigation pumping systems are below the target efficiencies. It is possible for a component to have a higher efficiency than those given in the table.

Figure 3.3 - Diesel powered turbine pump with right angle drive.

A. Irrigation pumps

Pumps commonly used for irrigation systems include horizontal or vertical centrifugal, deep-well line shaft turbine, and submersible. Line shaft turbine and submersible pumps are variations of a centrifugal pump that are designed to be used in wells or wet well installations. Chapter 7 of MWPS 30 Sprinkler Irrigation Systems and Chapter 5 of Center Pivot Irrigation Management Handbook provide complete discussion for selecting and designing irrigation pumps.

1. Centrifugal pumps

Centrifugal pumps are used to pump from reservoirs, lakes, streams, and shallow wells. Some models are used as pressure booster pumps within irrigation pipelines or to operate an end gun on center pivots. All centrifugal pumps must be completely filled with water or primed before they will operate. The intake (suction) line, as well as the pump, must be filled with water and free of air. Airtight joints and connections on the intake pipe are essential.

Figures 3.4 and 3.5 show horizontal centrifugal pump installations. The pump has a vertical impeller connected to a horizontal shaft. A vertical centrifugal has a horizontal impeller connected to a vertical shaft. The single impeller of both types is located inside a sealed housing called the volute case.

Figure 3.4 - Centrifugal pump with diesel power unit.

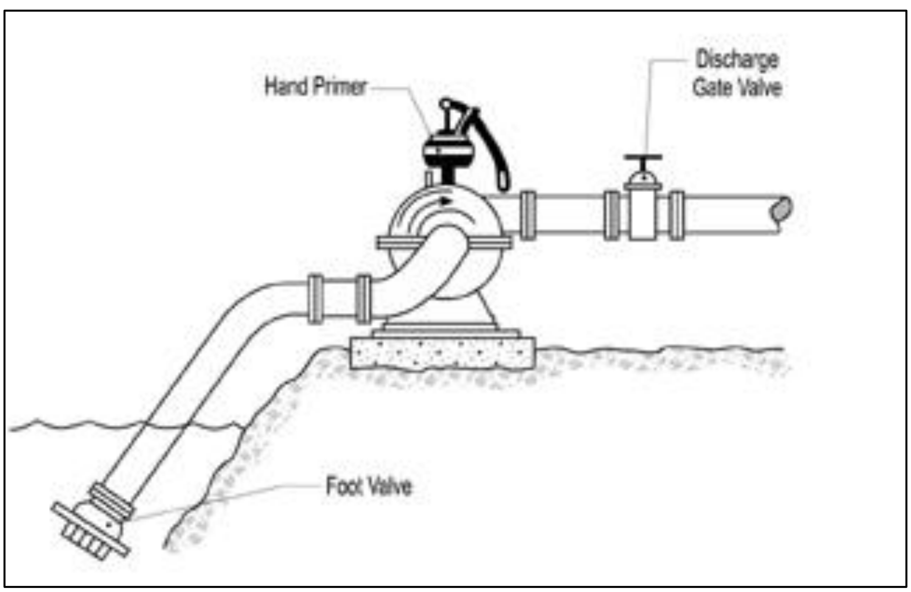


Figure 3.5 - Horizontal centrifugal pump installation.
(Courtesy of MWPS 30)

Horizontal centrifugal pumps are common for irrigation. They are generally less costly, require less maintenance, are easier to install, and are more accessible for inspection and maintenance than a vertical centrifugal. The horizontal pump's impeller shaft is typically powered by direct connection or v-belts to a horizontal electric motor or to a drive shaft of an engine. Vertical centrifugal pumps are powered typically by a vertical electric motor.

Centrifugal pumps are located above the water level. The pump does not suck water into the pump even though "suction" is commonly used to describe how the pump intake operates. Atmospheric pressure moves water into the intake line when the pump creates a negative gauge pressure, therefore, a centrifugal pump can only lift water vertically the equivalent of one atmosphere of pressure which is about 33 feet at sea level. Changes in elevation above sea level and in barometric pressure can reduce the maximum lift. Additionally, pump lift is reduced by friction losses in the intake line and fittings, vapor pressure reduction, and velocity head.

Centrifugal pumps draw water into the impellers after they have been primed. Impeller rotation throws water toward the outside of the impeller by centrifugal force and creates a lower pressure at the center of the impeller. This action develops a partial vacuum near the impeller inlet that causes the water to move into the impeller. Thus, they must not be set any higher than the manufacturer's recommended maximum practical suction lift (MPSL) above the water surface while pumping (also called the total dynamic suction lift, TDSL). MPSL values can vary from less than 10 to about 20 feet.

Operating a centrifugal pump at suction lifts greater than designed, or under conditions of high or fluctuating vacuum pressure, can result in pump damage by cavitation. Cavitation is caused by imploding air bubbles and water vapor that make a distinctive noise (like gravel flowing through the pump). Cavitation erodes the surface of the impeller and can eventually cause it to become deeply pitted.

The maximum suction lift can depend on the pump and the installation of the pump. Manufacturers determine and report the net positive suction head (NPSH) for pumps at sea level on each impeller performance curve. To find the maximum suction lift (head) at which a pump will operate, subtract the NPSH from 33 feet.

For a centrifugal pump to operate at its designed efficiency throughout its life, it should be correctly located, have a good foundation, and be properly aligned. Make sure the power unit drive shaft or belt drive rotates in the same direction as the arrows on the pump casing. Be sure the pump aligns with the power unit and piping.

Size suction pipes so that water velocity is less than 2 to 3 feet per second (fps). The intake pipe, especially with long intakes and high suction lifts, should have a uniform slope upward from the water source to the pump. Avoid high spots where air can collect and cause the pump to lose prime. Suspend the inlet end of the suction pipe above the bottom of a stream or pond, or lay it in a concrete or metal sump. On horizontal suction lines with a reducer, use the eccentric-type inlet with the straight section on the upper side of the line and the tapered section on the bottom side (Figure 3.6).

Air that enters the suction pipe may cause the pump to lose prime, or the air may become trapped in the impeller, which reduces the output of the pump. If the water level is too low or the suction pipe inlet is not sufficiently submerged in the water, air can enter the suction pipe through a vortex or whirlpool. In shallow water, a mat or float with vertical straightening vanes will reduce the potential for the problems a vortex causes.

Make any bend in the suction line a long sweep or long radius elbow and place it as far away from the pump as practical. A short elbow at the pump inlet disturbs the water flow and may cause noisy operation, efficiency loss, and heavy end thrusts, particularly with high suction lift.

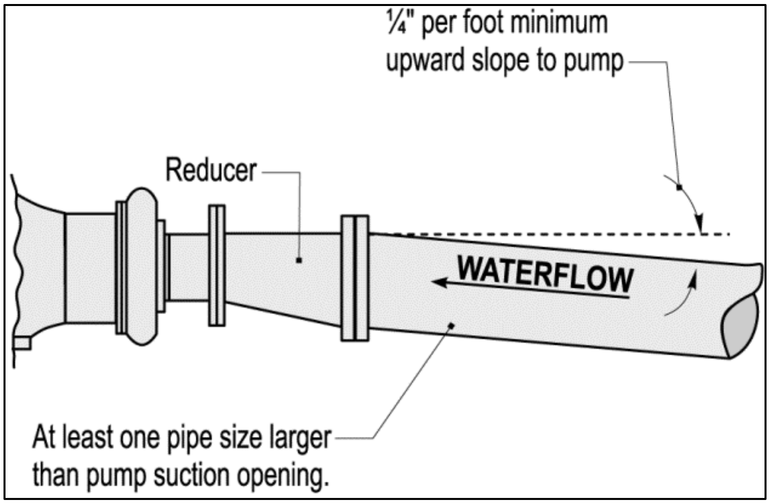


Figure 3.6 – Illustration of centrifugal pump inlet pipe. (Courtesy of MWPS 30)

Example 3.2: A pump has a NPSH determined from the pump curve of 20 feet at a given temperature, speed, capacity, and discharge head. It is 1000 ft above sea level and friction loss on suction side of the pump is estimated at 3 ft. **(See pipe friction section for calculating friction.)** Estimate the maximum practical suction lift (MPSL) with the following equation:

Equation 3.1 - Maximum Practical Suction Lift (MPSL).

$$MPSL = H_{atm} - (NPSH + H_f + e_s + f_s + ELT)$$

Where:

MPSL = Maximum practical suction lift, feet
H_{atm} = Atmospheric pressure (H_{atm} = 33 feet of head at sea level)
NPSH = Net positive suction head required by the pump at the capacity the pump will operate, feet (from pump curve)
H_f = Friction losses on suction side of pump, feet
e_s = Vapor pressure of water (about 0.5 feet at 50 $^{\circ}$F water temperature)
f_s = Safety factor, feet (about 2.0 feet)
ELT = 0.0012 times the site elevation above sea level

$$MPSL = 33 - (20 + 3 + 0.5 + 2 + 0.0012*1000)$$
$$= 6.3 \text{ ft}$$

Thus, 6.3 feet is the maximum vertical distance the pump can be set above the pumping water level.

2. Turbine pumps

Deep-well turbine pumps are used in cased wells or where the water surface is below the practical limits of a centrifugal pump (Figure 3.3). Turbine pumps also are used with some surface water supplies where the pumps are set in wet wells or sumps. Priming is not a concern because the intake for the turbine pump is continuously under water. Turbine pump efficiencies are comparable to or greater than those of most centrifugal pumps. Turbine pumps give long and dependable service if properly installed and maintained.

A turbine pump includes the bowl assembly, line shaft and pump column assembly, and the discharge head assembly (Figure 3.7). The bowl assembly contains an inlet and one or more bowl assemblies or stages with impellers located below the pumping water level in the well. The shaft and column assembly connects the head and bowl assemblies and is positioned inside the well casing. The line shaft carries the power, and the pump column carries the water upward. The line shaft on a turbine may be lubricated by oil or water.

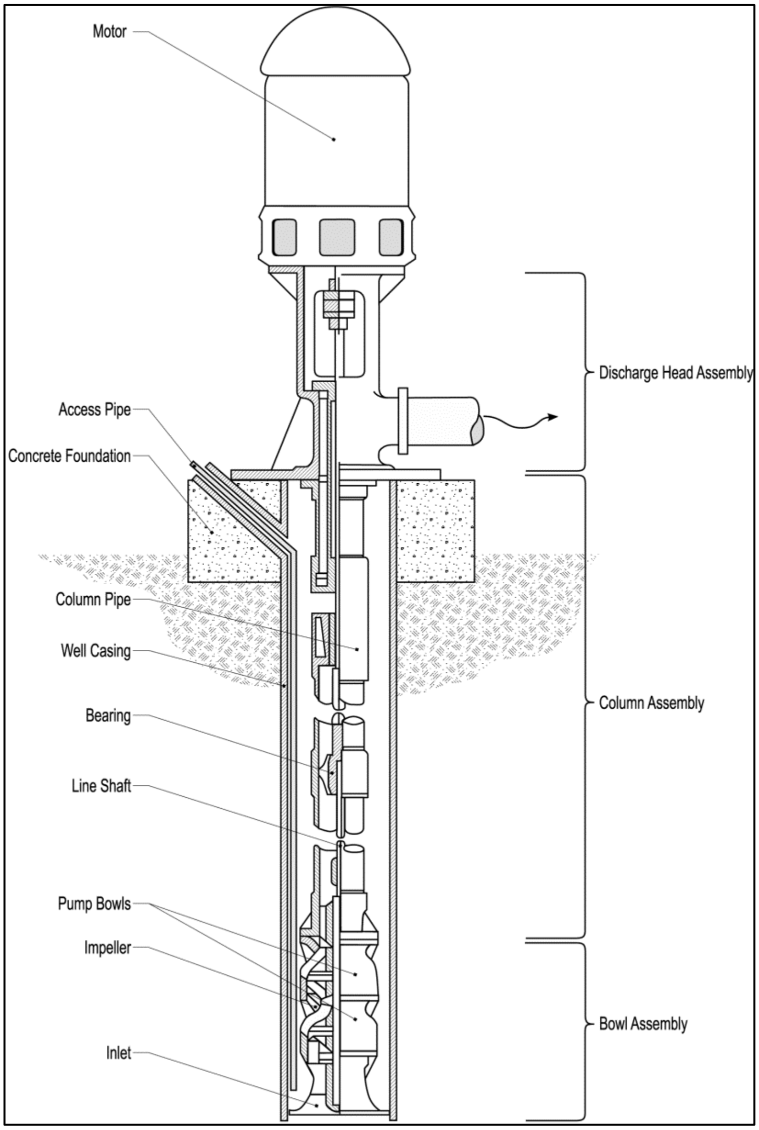


Figure 3.7 - Turbine pump cross-section. (Courtesy of MWPS 30)

An oil-lubricated pump has an enclosed shaft into which oil drips, lubricating the bearings; it keeps sand carried in the water out of the bearings. A water-lubricated pump has an open shaft where the bearings are lubricated by the pumped water. A water-lubricated pump is free of oil and is preferred for a domestic or municipal water supply.

The discharge head assembly supports the column and shaft assembly and the bowl assembly in the well. The discharge head includes a port for the water discharge and a mounting platform for an electric motor or a right angle drive to connect a horizontal power shaft from an engine.

Deep-well turbine pumps must have correct alignment of the well casing, column, pump head, and the power unit. Alignment of the pump in the well casing is most important so that no part of the pump assembly touches the well casing; otherwise vibration will wear holes in the well casing where the two touch. A permanent foundation is required for the discharge head to maintain alignment between the pump, drive, and well casing.

The impeller in a turbine pump operates similarly to an impeller in a centrifugal pump, but because the bowl and impeller diameter is limited in size, each impeller develops less pressure head. To achieve the desired pressure head several impellers are installed in series, one impeller above the other, with each impeller having its own bowl assembly. Each rotating impeller unit raises the operating head for a turbine pump a set amount at a given flow rate. With this stacking or staging of impellers, a three-stage bowl assembly has three impellers attached to a common shaft and develops three times the pressure head of a single-stage pump at that flow rate.

The operating characteristics of a turbine pump, like a centrifugal pump, depend mainly on bowl design, impeller diameter, and speed of rotation. Total head capacity, efficiency, horsepower, and speed are similar to those for centrifugal pumps producing a similar flow rate and head.

Impellers in turbine pumps are either semi-open or enclosed. A semi-open impeller has only the top side of the impeller vanes closed (Figure 3.8). The bottom side runs with a close clearance to the pump bowl assembly, or it may have a special seal. For non-sealed impellers, this clearance is critical and must be adjusted when the pump is installed. Adjustments to the impellers are made by tightening or loosening the adjustment nut at the top of the head assembly. A maladjusted impeller clearance causes inefficient operation if the impellers are set too high. Mechanical damage results from impellers set so low that they touch the bowl assemblies. Adjustment tolerances are not as critical for enclosed impellers.

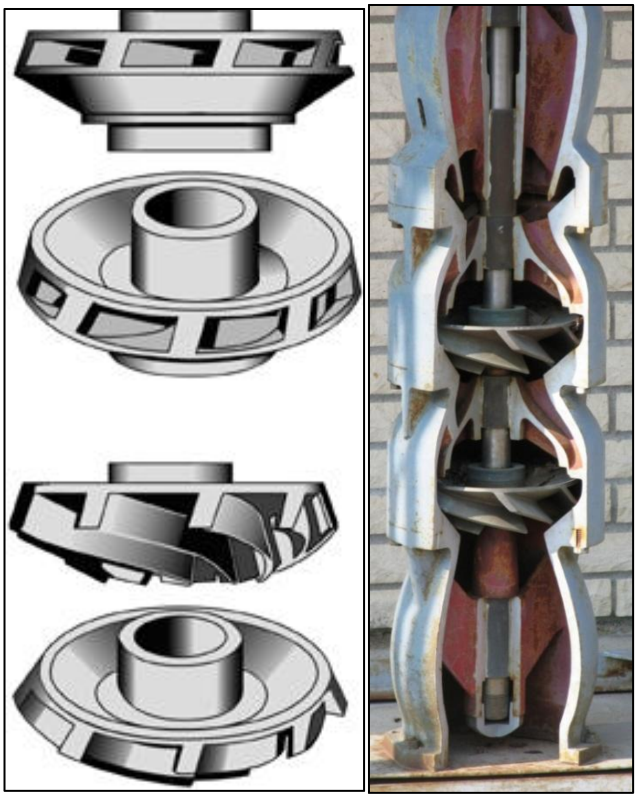


Figure 3.8 - Turbine pump impellers and two-stage bowl assembly cross-section. (Courtesy of MWPS 30)

3. Submersible pumps

A submersible pump is a turbine pump with a submersible electric motor attached to the bottom of the bowl inlet (Figure 3.9). Both the pump and motor are suspended in water, which eliminates long line shaft and bearings of deep-well turbines. Operating characteristics are similar to those of deep well turbine pumps.

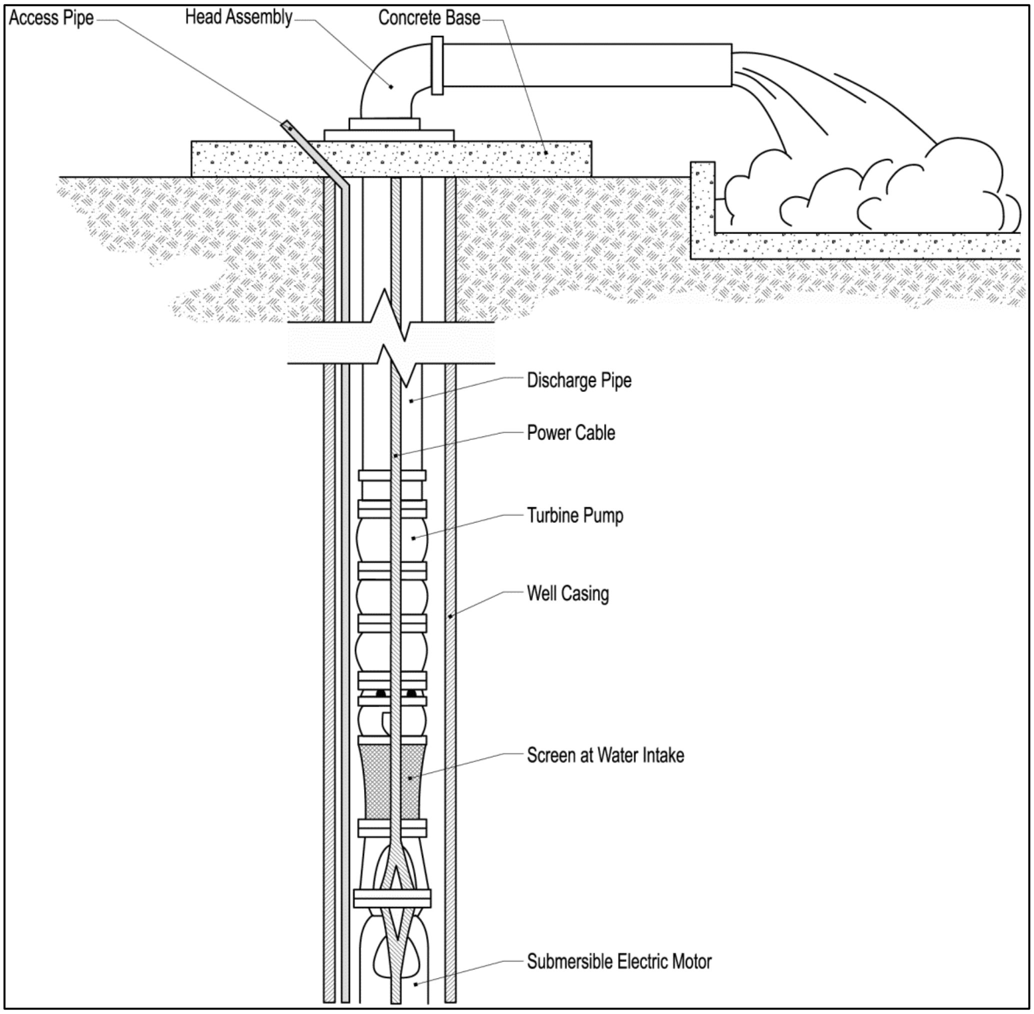


Figure 3.9 - Submersible pump installation. (Courtesy of MWPS 30)

The submersible pump has enclosed impellers. A screened water inlet is between the motor and pump. Water must flow past the motor for cooling purposes, and some assemblies contain a shroud to direct intake water past the motor housing.

Submersible motors are small in diameter and are much longer than ordinary motors. Submersible pumps come in a range of capacities for 4-inch wells or larger. Electric wiring for the motors should be sized based on the electrical code.

4. Pump affinity laws

Pump affinity laws describe the relationship of changes in pump speed and impeller diameter to expected pump output. Varying the pump speed and impeller diameter results in changes in water discharge flow rate, total head (TH), and brake horsepower (BHP) according to the following formulas:

Flow rate affinity law

$GPM_{final} = GPM_{initial} * (SPEED_{final}/SPEED_{initial})$
$GPM_{final} = GPM_{initial} * (DIAM_{final}/DIAM_{initial})$

Total head affinity law

$TH_{final} = TH_{initial} * (SPEED_{final}/SPEED_{initial})^2$
$TH_{final} = TH_{initial} * (DIAM_{final}/DIAM_{initial})^2$

Brake horsepower affinity law

$BHP_{final} = BHP_{initial} * (SPEED_{final}/SPEED_{initial})^3$
$BHP_{final} = BHP_{initial} * (DIAM_{final}/DIAM_{initial})^3$

The flow rate (gpm) is proportional to changes in speed and impeller diameter. However, the ratio is squared to determine the impact on total head and cubed to determine the impact on brake horsepower. Thus, small changes in speed or impeller diameter can have much larger changes in brake horsepower. To determine specific changes in performance of a pump due to speed and diameter changes, use the pump curve (discussed in the next section).

Example 3.3: For a pump operating at 1800 rpm, calculate the change in head and horsepower for the pump if the speed is increased 10% to 1980 rpm.

$TH_{final} = (SPEED_{final}/SPEED_{initial})^2 *100\% = 1.21 * 100\% = 121\%$

$BHP_{final} = (SPEED_{final}/SPEED_{initial})^3 * 100\% = 1.33 * 100\% = 133\%$

5. Pump curves

Pump curves are graphical charts that show flow rate versus head along with pump efficiency, brake horsepower, and other elements used in the design of the pumping plant. Pump curves are also called pump performance curves or pump characteristic curves. Manufacturers run tests to determine the operating characteristics of their pumps and publish the results in pump curves. To select the best pump for the design, examine pump curves from several pumps to identify a pump that will operate near maximum efficiency under the desired irrigation system discharge capacity and total dynamic head.

All pump curves are plotted with the flow rate in gpm on the horizontal axis and the head in feet for a single impeller on the vertical axis. A pump operates over a wide range of conditions, but optimum operating conditions are specific and depend on the design criteria for a given system and site.

Figure 3.10 illustrates a typical centrifugal pump performance curve and Figure 3.11 illustrates a typical deep well turbine pump curve. Some charts show various pump speeds (rpm) while others show various impeller diameters. Note that pump speed and impeller diameter result in similarly shaped curves as would be expected from the affinity laws. Select pump curves that show rpm when using an engine and curves that show impeller diameter when using an electric motor.

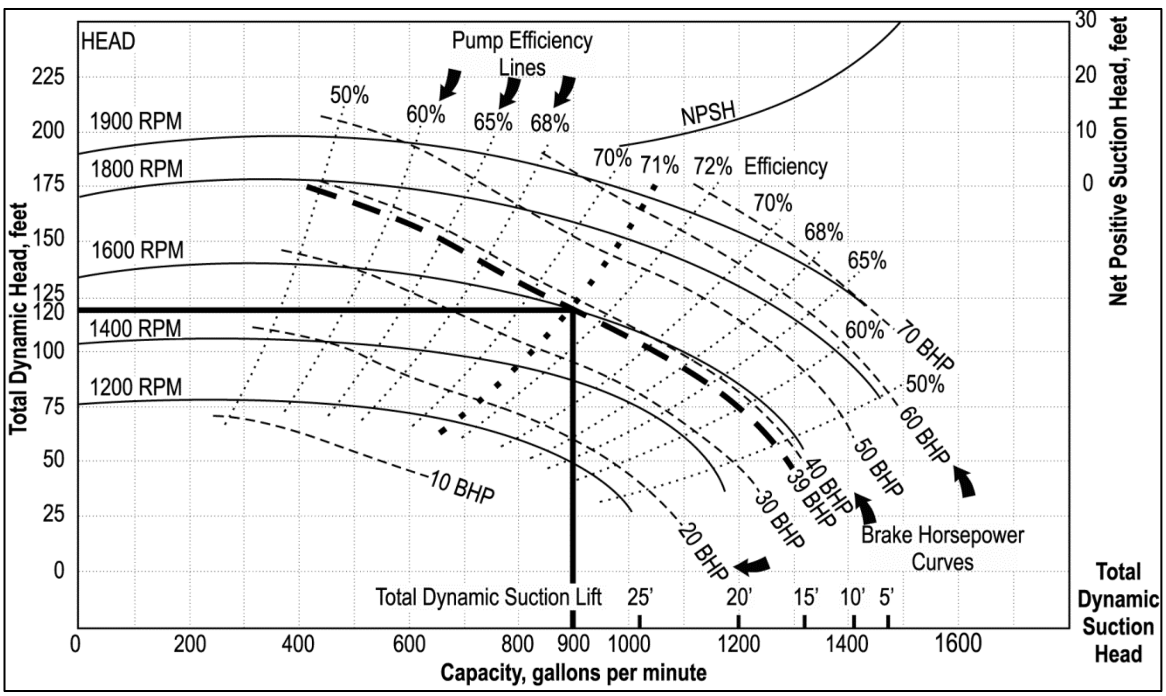


Figure 3.10 - Typical pump curve for a horizontal centrifugal pump. (Courtesy of MWPS 30)

The curve is used by selecting the desired flow rate (gpm) along the horizontal axis and creating a vertical line above the gpm. Then create a horizontal line at the total head (total dynamic head) that is needed for the system. Where the horizontal line intercepts the vertical line is the match point at which the pump will perform. Find the pump efficiency that matches the intersecting point and also read the brake horsepower at the same point. It may be necessary to interpolate between adjacent lines. Always read the pump curves horizontally and vertically. For example, the pump curve in Figure 3.10 at 1600 rpm could produce 120 feet of head at 900 gpm.

If pump speed lines are shown on the chart, select the pump speed for the system that most closely matches the intersecting point. The engine needs to be selected to match the brake horsepower at that speed. If an electric motor is used to drive the pump, find pump curves that show impeller diameter rather than rpm. Likewise, choose an impeller diameter that best matches the intersecting point. Size the electric motor to the required brake horsepower. If using an electric motor using a variable frequency drive (VFD), pump speed curves can be used similar to engines. The net positive suction head (NPSH) is also read from the chart and is used to calculate the maximum practical suction lift (MPSL) in Equation 3.1.

Turbine pump curves, such as those in Figure 3.11, are similar but only show the performance for a single impeller. A similar process is used where a vertical line is constructed above the gpm. Creating the horizontal total head line is more iterative since most turbine pumps have multiple stages. On the vertical line select a pump diameter (or speed) at the highest efficiency for the flow rate. Read horizontally from the gpm intersection to find the head for one stage at that diameter (or speed). Divide that value into the total head required for the system. Select the next larger whole number which is the number of pump stages. If the match point does not coincide with one of the chart lines, interpolate to obtain the best diameter (or speed). In some cases, more than one impeller diameter may be used to best match the system. Multiple impeller speeds are not possible because the line shaft turns at only one speed. Also, read the brake horsepower from the chart and multiply by the number of stages to get the total BHP. Look at the pump specification sheet for adjustments to the overall pump efficiency if too few or too many stages are used.

Note that pump suppliers have specifications and curves for their pumps (many are online) and will often assist with pump selection for a given set of conditions such as gpm and TH. Appendix E has examples of various pump curves. The NRCS also has a large number of pump curves available on the following website:

http://www.wcc.nrcs.usda.gov/ftpref/wntsc/Pump%20Curves/

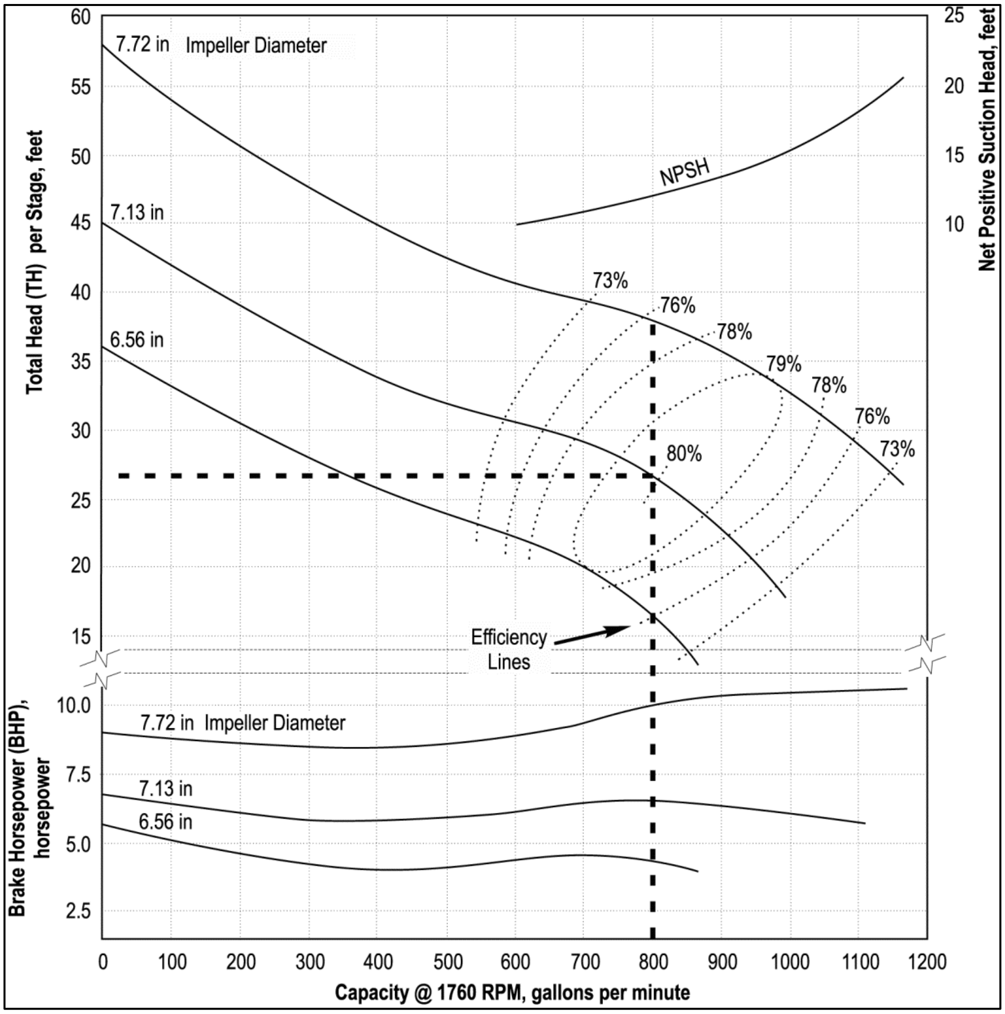


Figure 3.11 - Pump curve for a deep well turbine pump.
(Courtesy of MWPS 30)

B. Power units

The power unit on an irrigation system must supply power to lift water and deliver pressure at the desired flow rate to the irrigation delivery system. Common irrigation power units include electric motors and stationary internal combustion engines. The power unit must be matched to the irrigation pump requirements to achieve an efficient operation. An engine or motor that is too small cannot deliver the water at the rate and/or pressure required by the irrigation system. An engine or motor that is too large may be inefficient and have excessive initial and operating costs because of the unused capacity. An irrigation load is relatively constant, so the power unit must be suitable for continuous duty at the design load. Electric motors are designed and rated for continuous loads, while internal combustion engines must either be rated for continuous duty at the design load or be derated from some other horsepower rating to a continuous horsepower rating.

1. Internal combustion engines

In Nebraska internal combustion engines are used on about 48% of the irrigated land with diesel and natural gas engines most common. In Michigan diesel engines are used on about 35% if irrigated land. See Figure 3.3 for a photo of a diesel engine.

It is important that engine horsepower be matched to the requirements of the pump plus any other accessories, such as a generator for electric center pivot tower motors or a hydraulic oil pump. An electrically driven center pivot may require 15 to 20 additional BHP to run a three-phase generator to provide power to the tower motors and end gun booster pump motor.

Manufacturer's performance curves show horsepower ratings at various speeds for each engine along with other information such as torque and fuel consumption. At laboratory conditions of 60 °F air temperature and sea level elevation, the curves are developed with a bare engine resulting in the maximum horsepower per unit of engine weight. Curves should be corrected for power loss from accessories, elevation differences, and air temperature. Reductions of bare engine horsepower are summarized in Table 3.1.

Table 3.1 – Reductions to bare engine horsepower.

Condition	Correction
Deduct for each 1000 ft of sea level	3%
Deduct for each 10°F above 60°F	1%
Deduct for accessories (generator, etc.)	5%
Deduct for radiator and fan	5%
Deduct for continuous operation	20%

Some manufacturers publish intermittent, maximum, and continuous brake horsepower curves (Figure 3.12). When only one power curve is shown, it is usually the intermittent horsepower and must be reduced for continuous horsepower. If only intermittent curves are provided, engine ratings must be corrected to compensate for continuous loading of irrigation pumping. Appendix E shows additional examples of power unit performance curves.

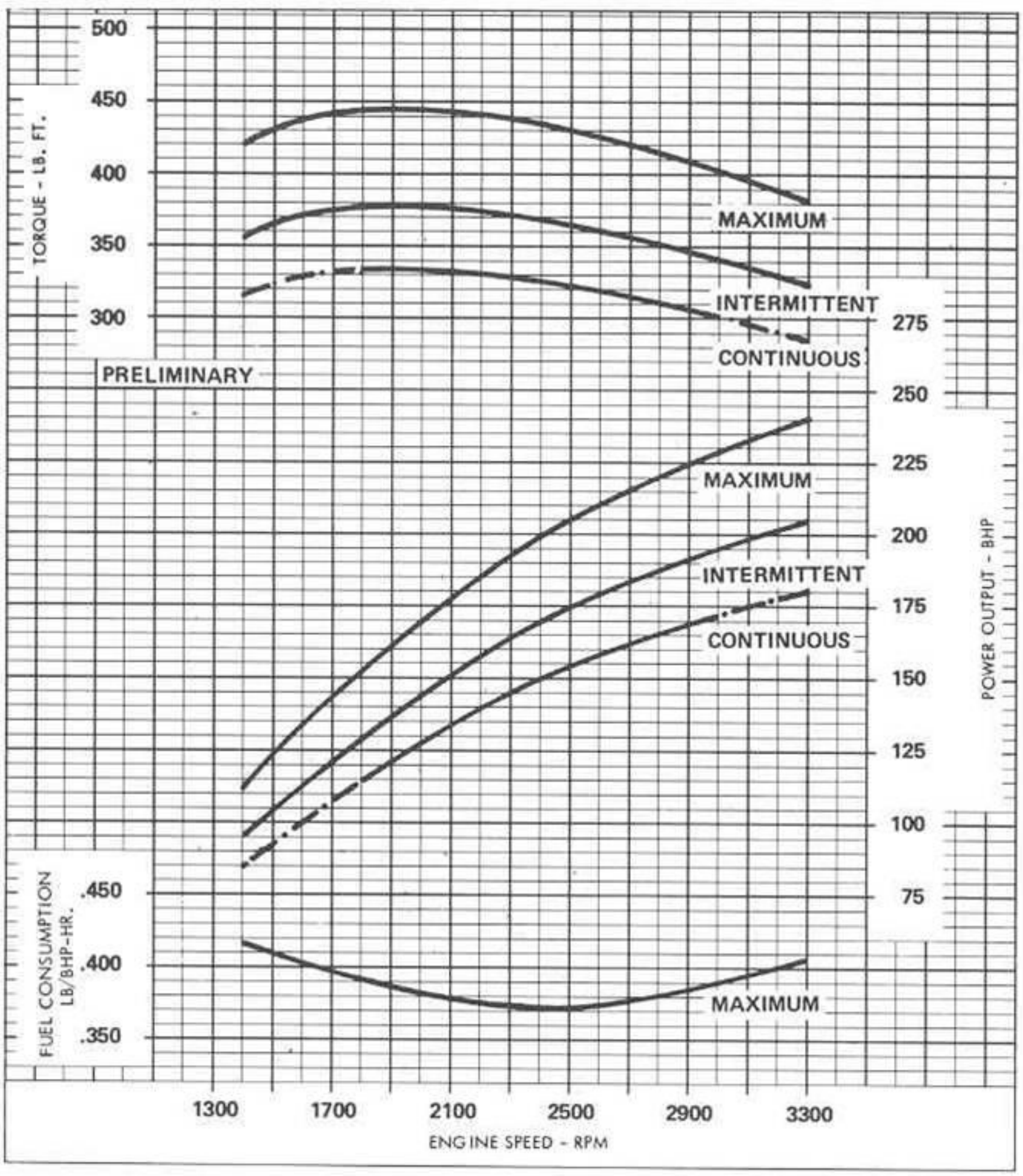


Figure 3.12 - Example engine curve showing continuous BHP output versus to other ratings. Courtesy of MWPS 30.

The most efficient operating load for an internal combustion engine is at or slightly under the continuous brake horsepower curve. Running an engine under much lighter loads (50% or less) usually results in poor fuel economy because too much horsepower is need to overcome the engine friction and throttling losses. However, the engine life expectancy may be longer. Running over the engine's maximum horsepower shortens the life and invites engine trouble and excess fuel consumption.

Engines often are connected to horizontal centrifugal pumps by a shaft, but also may be connected by flat or v-belts. On deep-well turbines, a right-angle gear head is common for transferring horizontal power to the vertical shaft. Table 3.2 gives some commonly used drive efficiencies for typical pump drive units.

Table 3.2 - Efficiencies of pump drive components.

Drive component	Efficiency
Direct	100%
V-belt	95%
Right angle gear	95%

2. Electric motors

Electric motors are used to deliver irrigation water to more than 52% of the irrigated land in Nebraska and 63% in Michigan. Most electric motors use three-phase electric power and operate at a single rated speed. The nameplate on the electric motor specifies the maximum power output for the motor. Even though an electric motor can output more power than the nameplate, never overload the electric motor since that will cause overheating and reduce the life of the motor.

The best and most commonly used connection is a direct coupling of the motor to the pump. Electric motors used with horizontal centrifugal pumps generally use a direct connection between the pump and the motor. On deep-well turbine pumps, a vertical hollow shaft electric motor connects directly on top of the pump shaft (Figure 3.13). The hollow-shaft unit is necessary so the pump impellers can be adjusted.

Alternatives with electric motors may be required where three-phase power is not available. Three-phase electric motors sometimes can be served from single-phase power using a phase converter. Phase converters change single-phase electric power to three-phase power and are either static or rotary. Static phase converters are applicable to single motor loads where the load on the pump is nearly constant such as the water pump. Rotary-phase converters serve either single or multiple motor loads. They are desirable when motor loads vary, such as where the tower drive motors on an electric drive center pivot system are constantly starting and stopping or an end gun cycles on and off. A separate static converter for the pump motor and a small rotary converter for the center pivot towers is a workable arrangement.

Other newer circuitry technologies such as frequency modulation (VFD) or Written-Pole enables the starting current to be much lower than for standard motors. One arrangement has a device that allows full control of the operating speed of the motor from start up to full load. Another can operate a three-phase motor with single phase power by using a control box containing starting and running capacitors.

All installations should comply with the *National Electric Code* and meet local electrical codes and regulations. Motors, electrical enclosures, and other electrical equipment must be effectively grounded by a separate grounding conductor suitably connected to the power supply grounding system.

Figure 3.13 - Vertical hollow shaft electric motor driving a vertical turbine pump.

C. Pipelines and fittings

For most sprinkler irrigation applications, water is transported from the source to the irrigation system through pressurized pipelines. Pipelines are either laid on the surface for portability, or they are permanently buried with risers (outlets) installed as needed. Buried pipelines reduce labor and are out of the way, but they involve greater initial costs and have little salvage value except in association with the land.

Pipe selection and sizing depends on portability needs, field topography, flow rate, water velocity, operating pressure along the pipeline, and the cost of energy and piping materials. The best pipe size or fitting is not always the lowest cost unit. An assessment of the fixed cost of the pipe and fittings as well as the operating cost should be done to determine the most economical pipeline arrangement.

Irrigation pipes are most commonly made from aluminum, steel, polyethylene (PE) or polyvinyl chloride (PVC) material. Refer to Table 7-4 in MWPS 30 Sprinkler Irrigation Systems for the available sizes and pressure ratings of each of the materials and their respective wall thickness and dimensions. For the specifics of a given pipe product and size options, consult the respective manufacturer's technical specifications.

Pipelines are the major component of a water delivery system, but the pipeline itself must have appropriate fittings, connections, and associated devices to deliver and control the water as intended. Several pipeline accessories such as control valves and water flow meters, are available to help an operator better manage the irrigation system.

1. Pipe sizing

To avoid excessive friction losses, extreme surge problems, and possible pipeline failure, the velocity of water in the mainline pipe should not exceed 5 feet per second (fps). Piping systems with greater velocities require pressure relief devices to help control surge and water hammer pressures. For example, the pipeline of a center pivot and linear-move lateral will most often have its water velocity exceed this value, but the sprinkler nozzles serve as relief valves to reduce water hammer potential. However, if water hammer pressures are too great, some sprinkler heads with pressure regulators can be damaged.

Table 3.3 shows the flow rate for several pipe sizes when water velocity is held at 5 feet per second. Comparing sizes of pipe made of the same material shows larger sizes cost more initially, but the water velocity will be less, resulting in lower friction losses and decreased overall operating costs. Consider the cost of piping materials as well as energy costs for the desired flow rate.

Table 3.3 – Pipeline flow rate to maintain water velocity below 5 fps.

Nominal size (in)	4	6	8	10	12	16
Flow rate (gpm)	200	440	780	1225	1760	3140

Pressure loss from friction is the pressure drop in a length of pipe caused by friction between the pipe walls and the water. Excessive friction loss raises the pump pressure requirements and increases horsepower needs, thus raising overall pumping costs. The pressure loss within mainline pipes should be less than 1 foot of head per 100 feet of pipe.

Total friction pressure loss in a pipeline depends on several factors:

- Flow rate.
- Length of pipe.
- Pipe inside diameter.
- Pipe material and inside roughness.
- Number and types of fittings and bends in the pipeline.
- Number of discharging outlets along submains or laterals.

Information from the manufacturer is the best source to determine friction loss in a specific pipeline. If manufacturer's data are not available, Table 7-3 in MWPS 30 Sprinkler Irrigation Systems and Equation 3.2 can be used to estimate friction losses in pipelines. Friction can also be obtained from tables such as those found on the Irrigation Association web site from the link below. Pipe suppliers also have charts and sliderules to estimate friction loss.

http://www.irrigation.org/Resources/Tools___Calculators.aspx

Table 3.4 – Values of C for Hazen-Williams friction formula.

Pipe Material	C value
Plastic: PVC, PE	150
Epoxy-coated steel	145 – 150
Polyethylene lined steel	135 – 145
Cement asbestos	140
Galvanized steel	135 – 145
Aluminum	130
Steel (new)	130
Steel (old) or concrete	100

Equation 3.2 - Pipe friction loss:

$$H_f = 10.44 * L * (Q/C)^{1.85} / D^{4.87}$$

Where:

H_f = Friction loss, feet of head
L = Length of pipe in feet
Q = Flow rate, gpm
C = Friction coefficient for type of pipe
D = Inside diameter of the pipe, inches

Fittings and accessories produce friction losses like pipelines, but sometimes at a greater rate because of the additional water turbulence their design creates. For a pipeline system, include pressure losses from accessory valves and fittings when calculating Total Head (TH) for the system. Friction loss data for a given accessory or fitting are best obtained from the respective manufacturer's literature.

Example 3.4: Mainline pipe friction loss

Given: Pipeline is:

1500 ft long

8 in nominal diameter, Class 125 PVC

Includes 4 – 8 in 90° elbows and 1 – 8 in gate valve

Flow rate is 850 gpm

Find friction loss in pipeline:

Equivalent pipe length for fittings

L_{eq} = 4 * 14 ft + 5 ft =61 ft (Table 7-8 MWPS 30)

Pipe length including fittings = 1561 ft

Pipe inside diameter (ID) = 7.66 in (Table 7-4 MWPS 30)

C value of PVC pipe = 150 (Figure 7-12 MWPS 30)

$$H_f = 10.44 * 1561 * (850/150)^{1.85} / 7.66^{4.87}$$

$$H_f = 10.44 * 1561 * 24.75 / 20239 = 19.9 \text{ ft}$$

$$P = 8.6 \text{ psi}$$

The pressure loss along a multi-outlet submain pipeline or a solid-set lateral with evenly spaced outlets is equal to a fractional percentage of the total pressure loss that would have occurred in a pipe of the same length, diameter, and total flow but with only an end outlet. Table 3.5 shows the fractional values for pipelines of different outlet numbers. Multi-outlet pipelines should be sized so the total pressure drop is less than ±10% of the sprinkler operating pressure.

Table 3.5 – Fractional values for friction loss in multiple outlet laterals.

Number of Outlets	Fractional percentage
1	1.00
2	0.64
3	0.53
4	0.49
5	0.46
6	0.44
7	0.43
8	0.42
9	0.41
10 to 11	0.40
12 to 14	0.39
15 to 20	0.38
21 to 35	0.37
> 35	0.36

Center pivots have a similar pressure loss relationship, but it is much more complex to calculate because most of the water in a center pivot is discharged at the outer sections where most of the land area is covered. Hence, friction loss for a center pivot lateral can be reasonably estimated by taking 54% of an equivalent length of pipeline with all discharge at the end for the given flow (Example 3.5).

Example 3.5: Compare friction loss in a center pivot lateral with galvanized steel pipeline for 6 in OD versus 6 5/8 in OD.

Given: A 1300 ft long center pivot without an end gun and 900 gpm delivered.

Pipe inside diameters (ID)

6 in OD = 5.79 ID (Table 7-4 MWPS 30)

6 5/8 in OD = 6.42 in ID

C value of new galvanized steel pipe = 140

Friction loss coefficient for center pivot = 0.54

6 in: $H_f = 10.44 * 1300 * (900/140)^{1.85} / 5.79^{4.87} * 0.54 = 44.2$ ft

$P = 19.1$ psi

6 5/8 in: $H_f = 10.44 * 1300 * (900/140)^{1.85} / 6.42^{4.87} * 0.54 = 26.8$ ft

$P = 11.6$ psi

Where an end gun is used on a center pivot, the effective hydraulic length should be used to account for the extra water that is delivered to the end gun. Example 3.6 illustrates the effective length calculation.

Example 3.6: Find the effective length of a center pivot that is 1320 feet long with a total flow rate of 850 gpm and end gun flow rate of 70 gpm.

$$L_{eff} = L * (Q_{tot} / (Q_{tot} – Q_{gun}))^{0.5}$$

$$L_{eff} = 1320 * (850/ (850 – 70))^{0.5} = 1320 * 1.044 = 1378 \text{ feet}$$

D. Irrigation distribution system

A wide variety of irrigation distribution systems exists including center pivots, flood irrigation, traveling guns, side roll, solid set, hand move and drip irrigation. In Nebraska, most of the irrigated land is sprinkler irrigated (85%). Virtually all of the sprinkler irrigated land is irrigated by center pivots. Thus this manual will only discuss conducting energy audits on center pivots and gravity (flood) systems. Appendix C and Chapter 4 of MWPS 30 Sprinkler Irrigation Systems have detailed descriptions of irrigation distribution systems. Chapter 2 of Center Pivot Irrigation Management Handbook has specific discussion of center pivot design and selection.

1. Center pivot system

The center pivot is a self-propelled moving system that rotates around a central or pivot point with a lateral pipeline that is supported by one or more towers. The towers have two wheels that propel the system around the circle and are typically 90 to 200 feet apart. Center pivots vary in size from less than 10 acres to over 500 acres. Most center pivots have seven to ten towers on a quarter-section size unit. Modern systems are propelled using electricity or oil hydraulics. The lateral pipeline carries the water, is part of the support structure, and delivers water to the sprinklers. The lateral pipelines can be a variety of sizes and materials with 6- or 6 5/8-inch galvanized steel pipe most common.

The most common center pivot systems operate on quarter-section sized fields irrigating 125 to 130 acres. Figure 3.14 presents the area irrigated by a typical system on a quarter-section field. Since the spans at the end of the system travel much farther per revolution of the pivot, the outer spans irrigate more area than spans of the same length that are located at the center of the field. Because of this, sprinkler discharges increase with distance from the central point to the outer end of the lateral pipeline to accommodate the increasingly larger areas covered by the pivot lateral.

A wide variety of sprinklers are available for center pivots. Sprinkler choices impact energy use because sprinkler options are available with a range of operating pressures. End guns are often used at the end of the lateral to cover extra area in corners and odd shaped fields. Appendix D has a discussion of selecting center pivot sprinkler packages and matching them to the field.

Sprinkler packages offer opportunities to significantly lower energy use with center pivot irrigation. Many older center pivots were high pressure to operate the sprinklers and drive of the system. Today most center pivots operate at lower pressures resulting in significant energy savings. Note, however that changing the sprinkler pressure requires that the pumping plant be modified to match the lower pressure sprinkler package. Failure to do this could negate much of the energy savings.

Even though some center pivots operate in part-circle mode, the majority make a full circle of a field. Many center pivots can cover one rotation of the field in less than 24 hours when equipped with high speed motors. Varying the rotational speed determines the depth of water applied to the field. Movement of the machine for virtually all center pivots is governed by the outside tower drive unit. All intermediate towers stay in line using alignment devices at each tower to control their speed and movement.

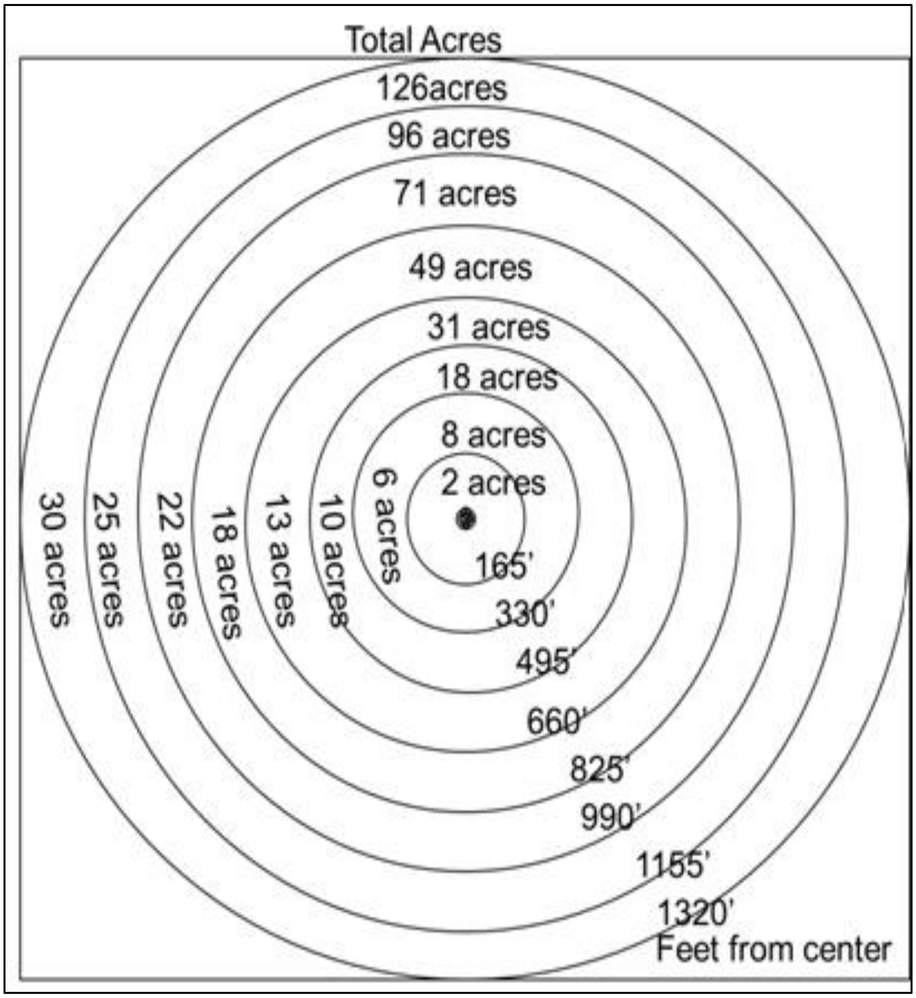


Figure 3.14 – Typical center pivot layout.

Example 3.7: Find the potential energy savings by changing a center pivot from a high pressure to a low pressure sprinkler package. Existing pivot pressure is 60 psi – new pivot pressure will be 30 psi. Flow rate is 800 gpm.

Pressure change = 30 psi = 69.3 ft head
Water horsepower change
WHP = Head * gpm / 3960 = 69.3 * 800 /3960 = 14 WHP

For an electric pump, 15.8 KWh could be saved per hour.
For a diesel pump, 1.1 gallons of fuel could be saved per hour.

Some center pivots include a swing-arm systems called corner units used to irrigate added area in field corners or non-circular fields. The corner unit is attached to the outer end of the main system lateral. The arm swings out and the sprinklers on it turn on and off as the system moves around the field. Flow rate needs to change for the system since more acres are covered as the arm extends.

Several factors govern the energy use and efficiency of center pivot systems. These factors include:

- Length of the center pivot
- Type of drive system
- Elevation differences and topography
- Flow rate (gpm)
- Pipeline material and diameter
- Sprinkler package
- Operating pressure
- End gun use and booster pump.

The standard energy audit will evaluate energy use by the center pivot system. To evaluate the efficiency and uniformity of the water application, a can test is needed. Discussion of uniformity testing of center pivot systems is covered in Chapter 4-V.

Application efficiency is the fraction of water that is stored in the soil and available for use by the crop (net irrigation) versus the total water pumped (gross irrigation). Application efficiency results from a combination of the system characteristics, the operating conditions such as weather, and how the system is managed. Losses subtract water that is pumped from the total water that the plant could use. High efficiency application strives to minimize all the losses.

2. Surface flood (gravity) irrigation system

Surface irrigation distributes water to the field by using gravity to convey water over the soil surface. It is the oldest method of irrigation. Because the water is not distributed across the field via pipelines, no pressure nor energy is used other than the potential energy of elevation to move the water across the field.

When water is delivered to the field by canals and ditches, no energy is used by the system. When water is pumped from a well or surface water source and delivered by pipelines or ditches to the field, pumping energy is used. Even though the discharge pressure may be low with these systems, application efficiency and uniformity can also be quite low. Thus, total water pumped may be high compared to sprinkler and drip irrigation systems.

For pumped surface irrigation systems, an energy audit should evaluate the following:

- Pumping efficiency by performing a pump test
- Water management evaluation
- Application uniformity evaluation including in-field uniformity, field leveling, tail water discharges, and water depths applied.

Chapter IX of <u>Farm Irrigation System Evaluation: A Guide for Management</u> is a resource for evaluating surface (furrow) irrigation systems.

3. Drip/trickle irrigation system

Drip (trickle) irrigation involves placing small diameter tubes along and near plant rows. Small emitters along the tube deliver water to the plants. Drip irrigation is, by design, low flow and low pressure. The laterals are tubes or tapes that are attached to a manifold. The manifold, in turn, is fed by a mainline that receives water from the pumping station. The pumping station includes pumps, power units, filters, and the necessary piping and fittings to plumb the system.

Emitter flow rate is generally between 0.4 to 2 gallons per hour (gph). Emitters can be spaced closely to provide a wetted band for row crops or they can be spaced various distances apart along the lateral to accommodate specific plant spacing.

Water used in drip and microspray irrigation must be clean, without debris that could clog the emitters. Filters are used to prevent clogging, and chemigation is used to prevent bacterial growth from plugging emitters as well.

Drip irrigation is very efficient since evaporation is low and uncropped areas do not receive water. Drip irrigation is usually used in specialty crops like potatoes, broccoli, lettuce, peppers, melons and cotton or in tree and vine crops. Drip lines can either be used for a single season or installed for multiseason use.

See Appendix C for more details on Drip irrigation.

E. Irrigation water management

Irrigation water management is the process of applying water to the field to meet the water needs of the crop. The irrigator needs to understand soil water relationships together with the water use of the crop to schedule irrigations in order to achieve production goals while applying water efficiently. Under application of water can have negative impact on the crop yield while over application is costly by wasting water and energy. Improved irrigation management has been shown to save one or more inches of water without impacting crop production.

> **Example 3.8:** Find the estimated energy savings from applying two fewer inches of irrigation water with good water management.
>
> Given: 130 acre center pivot, 850 gpm, 140 ft total head, and diesel powered pump
>
> Water savings = 2 in * 130 acres = 260 acre-inches

Four items are critical to irrigation water management. First, rainfall must be measured in the field (Figure 3.15), and irrigation depth must be measured or estimated. Use multiple rain gages to measure irrigation depth to arrive at an average depth applied.

Figure 3.15 - Measuring rainfall at the field is essential management tool.

Second, soil water content must be monitored to determine the amount of water in the soil throughout the irrigation season. Several methods are available for soil water measurement including probe and feel method, tensiometers, resistance blocks, TDR, and other electronic tools. More discussion of soil water monitoring is included in Appendix D. Figure 3.16 illustrates soil water readings during the growing season.

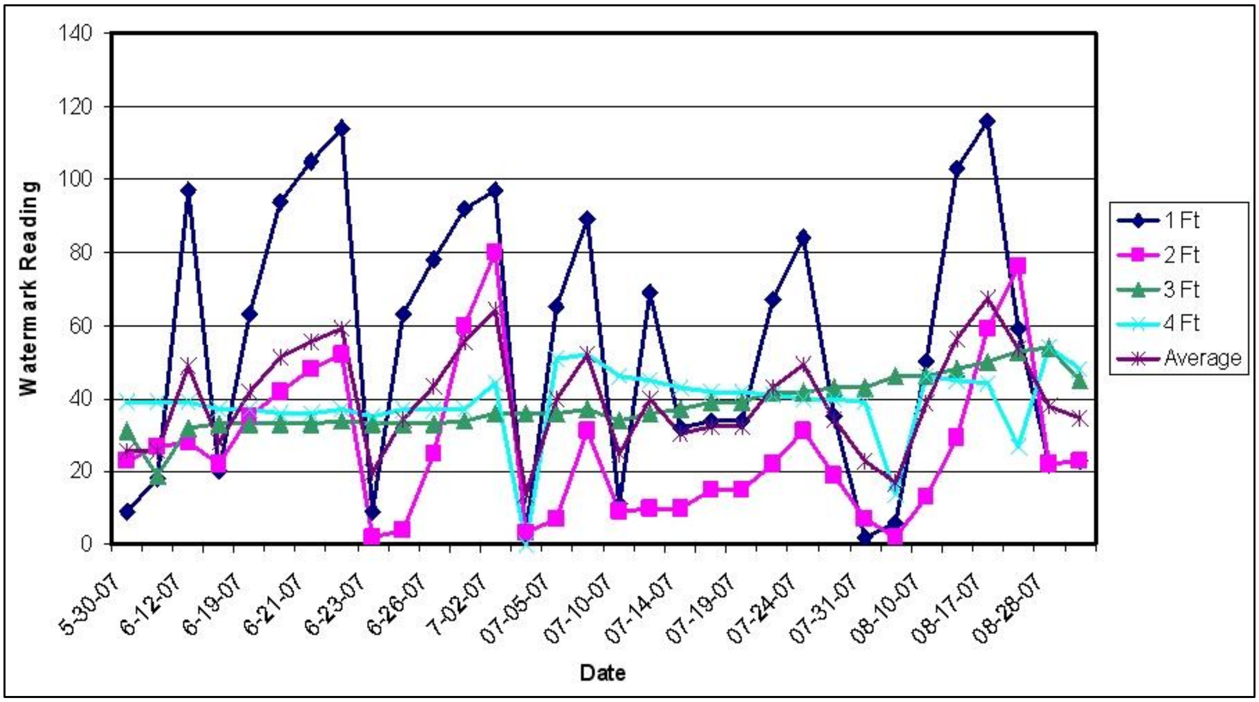


Figure 3.16 - Plot of soil water readings during the irrigation season for various soil depths.

Third, crop water use or evapotranspiration (ET) estimates are needed. ET estimates can be obtained using crop water use charts (Figure 3.17), computer models, an ET gage (Figure 3.18), or values obtained from nearby weather stations.

Maximum Temperature °F	Week After Emergence																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
50-59	.02	.02	.03	.04	.05	.07	.08	.09	.10	.10	.10	.10	.10	.09	.07	.06	.05	.04
60-69	.03	.03	.04	.05	.07	.09	.11	.12	.14	.14	.14	.14	.13	.12	.10	.09	.10	.08
70-79	.04	.06	.05	.07	.10	.13	.16	.18	.19	.20	.21	.20	.19	.17	.15	.12	.10	.08
80-89	.06	.06	.07	.10	.13	.18	.21	.24	.26	.28	.28	.27	.26	.23	.20	.17	.14	.11
90-99	.07	.08	.09	.13	.17	.23	.27	.31	.34	.36	.36	.35	.33	.30	.28	.22	.18	.14
>100	.09	.10	.12	.16	.22	.29	.34	.39	.43	.45	.45	.44	.42	.38	.32	.27	.22	.18
			↑ 3 Leaf			↑ 8 Leaf		↑ 1st Tassel	↑ Silk		↑ Blister Kernel			↑ Early Dent			↑ Black Layer	

Figure 3.17 – Example corn water use chart.

For information on soil types, water holding capacities, slopes, and other data, access the USDA Web Soil Survey at:

http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

Figure 3.18 - ET gage.

Finally, irrigation water management requires calculating and recording a soil water balance for the field. The soil water balance includes water inputs from rainfall and irrigation, water use by the crop, and losses from evaporation, runoff or deep percolation (Figure 3.19). The soil water balance is calculated daily and used to plan or schedule the irrigation applications so that no part of the field will experience water stress. Keeping a log of the inputs and soil water balance is essential to good water management. This can be done using a simple checkbook approach, computer spreadsheet or commercial software, or by contracting with a management service.

Week After Emergence	Date	Soil Water Reading		Maximum Temperature	Add	Subtract		Total	
					Crop Water Use	Rainfall	Net Irrigation	Soil Water Deficit	
		A	B					A	B

Figure 3.19 - Soil water balance worksheet.

Chapter 4 - Conducting the Irrigation Energy Audit

<u>Note:</u> Follow safety practices and procedures when conducting field audits or operating equipment. Multiple hazards exist around irrigation systems. See section Chapter 4-VI for safety discussion.

On irrigated farms, irrigation energy use is one of the highest energy inputs to the operation. Chapter 1 discussed various factors that influence energy use and resultant inefficiencies. Energy use is dependent on how much water is delivered to the field and what the pumping requirements are to deliver that water including pumping lift and operating pressure. This chapter covers how to evaluate the energy efficiency of various irrigation system components.

The irrigation energy audit is a four step process. The first step in the energy audit is to inventory and record all components of the irrigation system. This is outlined in Sections I and II of this chapter. Much of the information obtained will be used to determine the energy use and serve as background to developing recommendations for energy use improvements.

Second is to conduct an assessment of the irrigation water management practices. As previously discussed, good irrigation water management can reduce irrigation water applications, or at the very least, improve crop production using the same amount of water. An **Irrigation Water Management Assessment** should evaluate the following items (Chapter 3 Section E).

- ✓ Record rainfall using rain gauges installed near or in the field. Rainfall should be measured and recorded daily. It is best to have more than one rain gauge to evaluate variability in rainfall.
- ✓ Measure and record irrigation applications. With sprinkler irrigation, rain gauges can be used to collect water application depths at several locations and then averaged. Often, the irrigation depth can be estimated using the water delivery rate (gpm) which is converted to irrigation depth and an estimate of water application efficiency. This procedure is used with drip irrigation.
- ✓ Monitor soil water levels in the field. Several proven methods of measuring soil water content are available including feel method, water blocks, tensiometers and others. See Appendix D.
- ✓ Estimate daily crop water use (evapotranspiration). Several methods can be used to estimate crop water use including computer software, water use tables, values from local weather stations, or an ET gauge.
- ✓ Maintain a soil water balance using a worksheet, computer spreadsheet or other method.
- ✓ Plan irrigation applications based on data for each field and crop.

The third step in the energy audit is to conduct an **Irrigation System Assessment**. The Irrigation System Assessment is used to evaluate the general condition of the system and note deficiencies that could impact energy use. Items that should be evaluated in the assessment include:

- ✓ Pump and power unit: listen for unusual sounds like grinding or clunking, note if the unit vibrates, verify that all safety shields are in place and functional, and inspect fuel storage for leaks if engine driven. For electric systems, check that the electric panels are in good condition, required grounding is installed, and wiring/cables are in good condition. Ask the operator they have noticed any problems with the pumping system.

- ✓ Operating pressure: noting whether the pump discharge pressure is the same as when the system was new is an indicator of system condition. If the pressure has changed, it may indicate that there are problems with the system, pumping water level has changed, or the system operating conditions have been modified. The system energy efficiency may have room for improvement even if the pressure is the same because it may not have been designed and installed properly.
- ✓ Pipeline: note operating pressure and condition of pressure gauge check all exposed pipelines for leaks, determine whether relief and check valves are operating correctly, and check condition of flow meter. Note whether the gate valve is fully open when the system is running.
- ✓ Center pivot: look for structural problems with the towers and trusses, check for leaks at the pivot point and each tower boot, look for sprinklers that have leaks or are broken, inspect sprinklers for blockage, verify that the end gun is operating and part-circle angle adjusted correctly, note whether the end gun shuts off at field edges to not water errantly, check tires for inflation, check for excessive wheel tracking, and note the quantity of sand in the end sand trap. Listen for air from sprinklers indicating that the pump is pumping air. From the sprinkler chart verify that the sprinklers are installed correctly.
- ✓ Other sprinkler systems: look for pipeline and gasket leaks, insure the sprinklers are operating in an upright position, record the sprinkler spacing between lateral lines and between sprinklers along the line, determine the sprinkler nozzle size, and note the condition of the crop from non-uniform distribution. Check sprinkler nozzle pressure at both ends of the sprinkler line.
- ✓ Drip/trickle: record pressure gauge and flow meter readings, determine manifold and drip lateral sizes, record lateral lengths and expected flows, look for leaks and areas of excess water, and note how many laterals are operating for each set.
- ✓ Chemigation: if used, evaluate the condition of the injection equipment; verify suitable check/backflow valves, and proper chemical storage and containment.
- ✓ Management: look for areas that may be over or under watered, note if rills have formed in the soil surface due to runoff, ponding, or erosion, visually evaluate condition of crop for non-uniformity and stress conditions, and evaluate the general condition of the pump and irrigation site for trash, weeds, safety hazards, etc.

The fourth step in an energy audit is to conduct the pumping system field test (Section III of this chapter). An online assessment tool can be used to evaluate system performance prior to conducting the field test to estimate the general energy use of the system. The assessment tool link is:

http://ruralenergy.wisc.edu/conservation/irrigation/default_irrigation.aspx

Use the information collected from the system inventory as input into the online assessment.

I. Inspection and Inventory of Equipment Components

Information on a number of components should be collected either by inspection at the irrigation site or obtained from the owner/operator. Some information is needed to help determine if field testing is justified and before the field energy testing can be performed. Additional information will be used in analyzing the data collected during the field testing. Items that should be recorded for the audit are included in the sample input form below.

- Water source
  - Well
    - Location relative to irrigation system
    - Casing diameter
    - Access to inside of casing for water level measurement
  - Surface water
    - Location relative to irrigation system
    - Type of water (pond, ditch, stream, reuse pit)
- Pump
  - Centrifugal pump
    - Make and model
    - Serial number
    - Impeller diameter
    - Suction pipeline size, length, and fittings
    - Gear or belt drive specifications
  - Turbine pump
    - Make and model
    - Serial number and number of stages
    - Size and length of column
    - Length of tail pipe
  - Submersible pump
    - Make and model
    - Serial number and number of stages
    - Horsepower
    - Size and length of discharge pipe
- Power unit
  - Electric
    - Make and model
    - Three phase or single phase and voltage
    - Horsepower rating
    - Nominal speed
    - Other including VFD or Written Pole
  - Internal combustion
    - Fuel type
    - Make and model number
    - Clutch used?
    - Drive type and specifications
      - Right angle gear drive ratio
    - Normal operating speed

- Auxiliary generator
- Safety shielding

Delivery pipeline
- Size or sizes
- Lengths
- Fittings and valves
- Pipeline material and pressure rating
- Functional flow meter
- Access to pressure outlets

Distribution system
- Center pivot
    - Brand and model (and age)
    - Type of tower drive
    - Length of spans
    - Number of towers
    - Operation parameters and layout
        - Corner system
        - Full or part circle
        - Speed settings
    - Pivot pipeline size(s)
    - Sprinkler type and pressure
        - Drops used?
        - Spacing
    - Control panel type
    - End gun
        - Size and pressure rating
        - Booster pump size
- Other sprinkler systems
    - Type (traveler, wheel move, towline, solid set, etc.)
    - Make and model
    - Flow rate
    - Area covered per set and total
    - Operating pressure
    - Pipeline diameter and material
- Surface irrigation
    - Size and layout
        - Length of run(s)
        - Number of rows per set
        - Stream size
    - Area covered
    - Pipeline size(s)
    - Discharge pressure
    - Land leveled
    - Field average down-row grade
    - Reuse system
    - Surge valve

- Drip/microirrigation
  - Layout
    - Subsurface or surface
  - Area covered
    - Zone sizes
  - Pipeline and manifold sizes
    - Discharge pressure
  - Dripline size(s)
    - Emitter flow and spacing
  - Length(s) of run
  - Filter type
  - System controller
- Field information
  - Location and map
  - Crop type(s) grown and area
  - Stage of growth
  - Water management used
    - Soil water content monitoring method
    - Irrigation scheduling method
    - Copy of calculation sheets

II. Collecting Off-Site Information

Information on the irrigation system and site should be collected. Some data will be used for analysis of the audit data, for example, projected well pumping water level. Contact the state agency responsible for regulating irrigation well installations to obtain information on a specific location.

Well data

- Use the Nebraska online well data retrieval system to obtain information on the well.
  - http://dnrdata.dnr.ne.gov/wellscs/Menu.aspx
- For Michigan, use the following web site for well data.
  - http://gwmap.rsgis.msu.edu/viewer.htm

Information that should be collected includes:

- Well location
- Well depth
- Static water level
- Pumping water level and flow rate (gpm)

Pump data

- The online well retrieval system may have information on the pump that was installed in the well. Record pump information if available.
  - Make and model
  - Column length (drop pipe)
  - Flow rate and pumping level if different from above
- Obtain additional pump information from the pump installer including
  - The number of stages (bowls) and impeller diameter(s) (trim)
  - Column size and type
  - Tailpipe length
  - Pump characteristic curve

Power unit

- Obtain complete information on the power unit in addition to the onsite data. These data should be available from the pump or irrigation installer.
  - Electric
    - Motor manufacturer
    - Horsepower rating
    - Three phase or single phase
    - Voltage and amperage
    - Power factor
    - Other motor characteristics, i.e. VFD, phase converter, soft start
  - Internal combustion engine
    - Make and model
    - Engine operating curves
    - Speed
    - Design fuel performance, BHP-hr/gal

System information

- Obtain sprinkler charts for center pivot from owner or irrigation dealer.
- Obtain drip irrigation design information from the owner or irrigation dealer.

Field and site information

Topographic data

Obtain topographic data using topographic maps, online maps, or GPS system to determine field elevation data including:

- Elevation of the well
- Highest and lowest elevations in the field
- Elevation of the pivot point for center pivot
- Field slopes

Soil Mapping Units

Online Soil Surveys are available at:

http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

Record number of acres, slopes, soil textures, and water holding capacities

III. Field Testing Energy Efficiency

Field testing may involve one or more of the following components of the irrigation system. Combining all components of the testing would provide an estimate of the overall irrigation system energy efficiency.

Well efficiency test
Pumping plant performance test
Irrigation system uniformity and efficiency test
Irrigation management evaluation

A. Well efficiency test

The well efficiency test is a procedure where observation wells are used to determine the aquifer characteristics. The well is pumped at a known flow rate for a prescribed time period while measuring the drawdown in the pumped well and the observation wells. The test measurements are used to determine the drawdown for a 100% efficient well and compared to the actual well drawdown to determine the efficiency. Well efficiency can never exceed 100% and seldom approaches 100%. Testing well efficiency is an elaborate process that involves considerable time and expense, thus it is not commonly performed. Additionally, improving poor well efficiency is an expensive process that may involve drilling and developing a new well.

B. Pumping plant performance test

The procedure for conducting the pumping efficiency portion of the test determines four important items which determine the performance of a pumping plant, namely:

- Pumping lift (ft)
- Discharge pressure (psi)
- Water flow rate (gpm)
- Fuel use rate (units/hour)
- Pump speed (rpm)

Figure 4.1 illustrates the lift and pressure measurements required for a pumping efficiency test. The fuel use rate for the power unit recorded as kilowatts (KW) for electric motors, gallons per hour (gph) for liquid fuel engines, and 1000 cubic feet per hour (mcf/h) for natural gas engines.

1. Pumping lift

a. Wells

Before conducting a pumping plant evaluation, consult with the well driller or regulatory agency to determine what the probable static and pumping water levels and also the total pump column length.

Figure 4.2 illustrates some methods for measuring water levels in wells. An access hole is needed to lower the measuring cable or tape into the well (Figure 4.3). The access hole must be outside of the column pipe, but inside of the well casing. For deep well turbine pumps, the discharge head on many units has an access hole that is covered by a plate or plug. Where no hole is located, a hole can be drilled through the pump base. The hole needs to be large enough to allow easy access with the measuring cable or tape and should be tapped to plug the hole after use. Care must be taken not to drill into the water carrying section of the pump base. A similar procedure can be followed with a submersible pump.

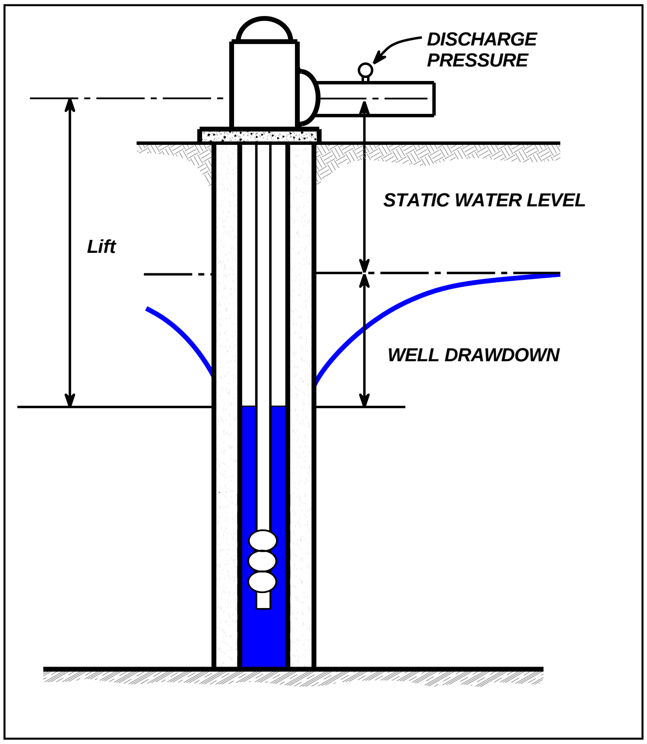


Figure 4.1 - Pumping test measurements for irrigation wells.

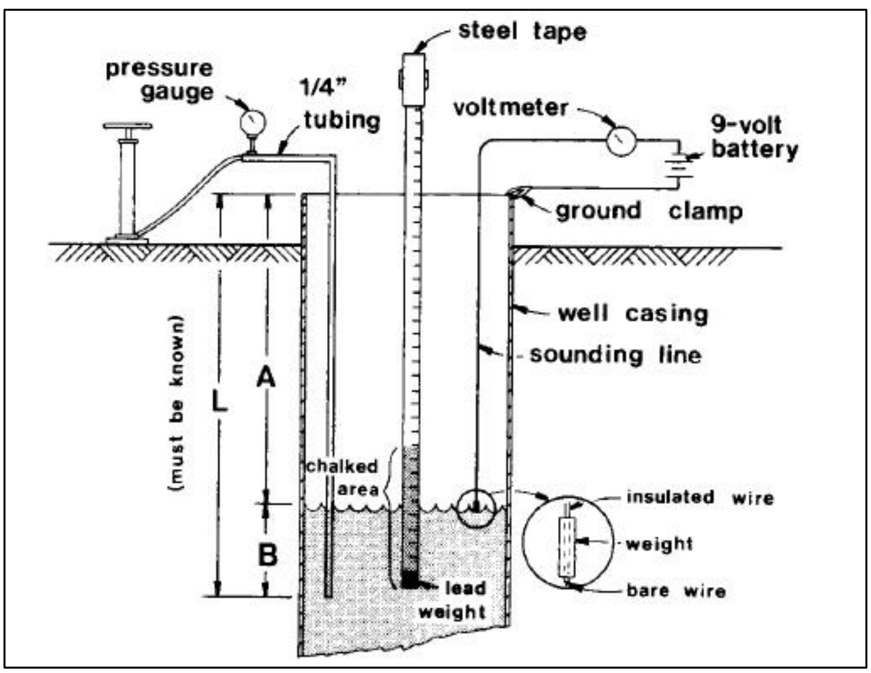


Figure 4.2 - Illustration of methods of measuring well water levels.


Figure 4.3 - Well access hole for measuring water levels.

1) **Electric water level indicator**

WARNING: Never let out more cable than the pump setting depth (column length). If more cable is reeled out than the depth of the pump setting, the cable and/or electrode could be drawn into the pump. If this occurs the cable will become stuck and the pump will usually stop pumping water. The pump assembly would have to be pulled to remove the cable and expensive repairs may be needed.

Figures 4.3 and 4.4 illustrate using an electric water level indicator to measure both static (non-pumping) and pumping water level in the well. The weighted electrode cable is lowered into the well through the access hole. Insure that the probe continues into the well by pulling up on the cable periodically to test the weight. Continue lowering until the meter indicates a completed circuit. Once the needle movement has stabilized, raise the cable until the meter begins moving towards zero. This point is the water level in the well. Note the depth reading on the cable at the center of the outlet pipe. It may be necessary to interpolate between markings on the cable.

In wells with oil lubricated pumps, a layer of oil may be floating on top of the water. When the electrode passes through the oil, the sounder may not respond since the electrode becomes covered with oil. If the sounder responds sufficiently to get a reading, consider that the "water level" has been located, even though water may not be present. The oil may also coat the electrode requiring a special electrode tip.

Read the amount of cable in the well. Most cables have a marker attached at 5 or 10 ft intervals. Interpolate between the markers to get the depth reading. Other sensors have markings on the cable every 0.1 foot and are easy to read. Make sure that the indicators on the cable indicate the actual length of cable to the sensor.

Figure 4.4 - Electric water level indicator.

Reel the cable up before shutting down the pumping plant at least to the static water level after recording the pumping water level. If this is not done, the cable could wrap around the pump column as the water level rises in the well when pumping stops.

Some wells have water from the aquifer cascading down into the well casing to the pumping water level. The meter needle movement will be erratic if the electrode contacts the falling water. Continue lowering the cable until the meter needle stabilizes. Severe cascading may prevent an accurate reading. Special electrode tips are available for cascading water.

2) Tape measure

A steel tape with a weighted end may also be used to measure the water levels in the well. The tape should have legible markings along the length. To take a measurement, use chalk to coat the tape for a distance from the end. The tape is lowered into the well casing to a depth that will reach the water level. Read the tape length in the well. When withdrawing the tape, note the reading of the water level on the tape shown by the wet chalk. Subtract this reading from the total length of tape that was lowered into the well to obtain the water level.

The tape method may not work well with cascading water, but is effective where an oil layer is on top of the water. It should be possible to distinguish the difference between the oil and water on the tape.

3) Pressure transducer

An electronic pressure transducer can be used to measure water levels in the well. The transducer is lowered into the well with a sensor cable to a depth below the anticipated pumping water level but above the pump intake. The transducer is connected to a data logger via the cable. The transducer should not be affected by cascading water or oil in the well. This method has the advantage that water levels can be measured continuously throughout the test which provides real-time water levels for system analysis.

4) Airline method

The airline method uses a tube placed in the well to measure water levels. This method is discussed in the Appendix G.

b. Surface water with centrifugal pump

For centrifugal pumps, suction lift or head is the vertical distance from the water surface to the pump intake (Figure 4.5). Two methods can be used to estimate the suction head on a centrifugal pump operating above a water surface such as a lake, stream, or canal. The first involves installing a vacuum gauge on the suction line near the pump intake. The second involves measuring the vertical lift from the pumping water level to the eye of the pump impeller and adding the various suction losses.

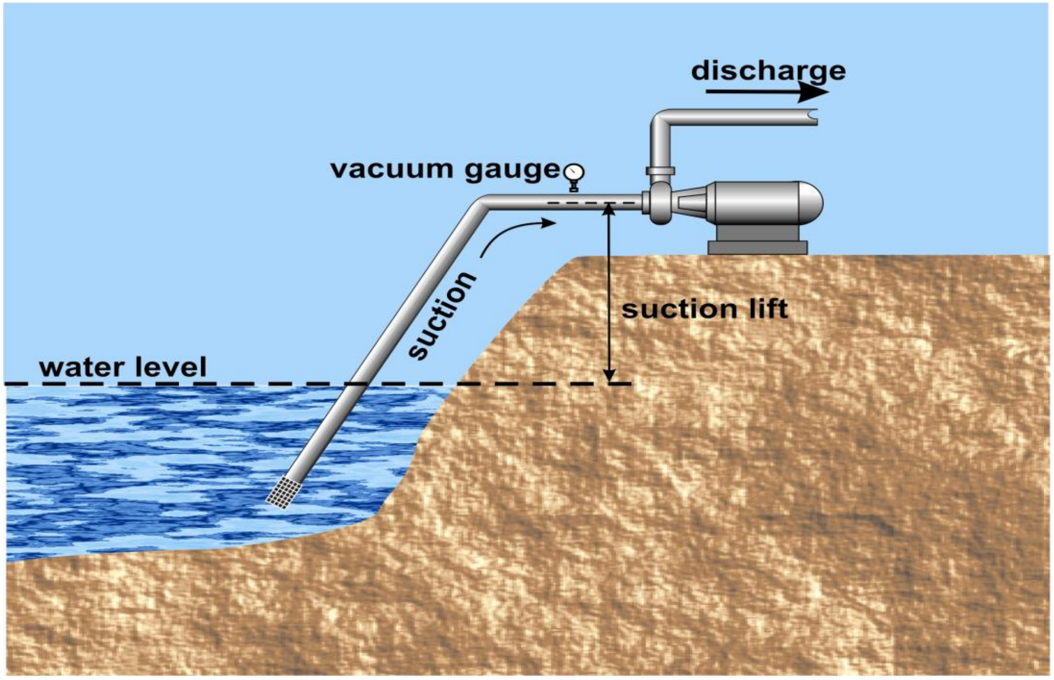


Figure 4.5 - Illustration of suction lift for centrifugal pump.

1) Vacuum gauge method

The vacuum gauge can be used to determine the suction head or pumping lift of centrifugal pumps. This method accounts for the elevation of the pump from the water surface (lift) and also the friction, suction and velocity losses due to the suction pipe. Read the vacuum gauge after the pumping and irrigation system is at its normal operating condition. In addition to providing the operating suction lift, the resulting suction reading can indicate whether the suction conditions are exceeding the required NPSH of the pump.

Note that the pump will lose prime when installing and removing the vacuum gauge requiring refilling and repriming of the pump. This method should only be used if a port and air tight connection is available near the pump intake. Insure that an air tight plug is installed when finishing the test.

The vacuum gauge, installed at the suction entrance of the pump, is usually graduated in inches of mercury. One inch of mercury is equivalent to 1.13 feet of water head.

Example 4.1: Reading of vacuum gauge on intake of centrifugal pump is 8 inches of mercury. Find the suction head.

H_s = 8 in Hg * 1.13 = 9.04 ft head

Example 4.2: Reading of vacuum gauge on intake of centrifugal pump is 3 psi. Find the suction head.

H_s = 3 psi * 2.31 = 6.93 ft head

2) Suction head calculation method

The suction head can be estimated by the following procedure:

1) Measure the vertical lift from the pumping water level to the eye of the impeller (center) of pump intake.
2) Determine the elevation correction by multiplying the site elevation in feet above sea level by 0.0012 to obtain elevation head.
3) Calculate the friction loss in the suction line including fitting, intake screen, and foot valve. See pipelines and fittings section.
4) Use 0.5 feet of head for vapor pressure reduction.
5) Calculate velocity head.
6) Total components 1 through 5 to obtain suction head in feet.

Example 4.3: Suction head calculation

1) Vertical lift is measured at 6 ft
   $H_l = 6$ ft
2) Elevation of site is 1800 ft.
   $H_e = 1800 * 0.0012 = 2.16$ ft
3) 6 inch aluminum suction pipe is 40 ft long, flow rate is 600 gpm, fitting are long sweep elbow, foot valve and intake screen.
   Fittings equivalent pipe (Table 7-8, MWPS 30) = 14 + 14 +76 = 104 ft
   Effective pipe length = 40 + 104 = 144 ft
   6 in aluminum pipe ID = 5.88 in
   $H_f = 10.44 * 144 * (600/140)^{1.85} / 5.88^{4.87} = 2.87$ ft
4) Vapor pressure reduction (H_{vp}) = 0.5 ft
5) Velocity head
   Calculate flow rate in cfs:
   cfs = 600 gpm / 449 = 1.34 cfs
   Calculate inside cross-sectional pipe area (A_{ID}) in square feet:
   $A_{ID} = \pi * ((ID/2)/12)^2) = \pi * ((5.88/2)/12)^2) = 0.189$ sq ft
   Calculate pipeline water velocity (V) in feet per second (fps):
   $V = cfs/ A_{ID} = 1.34 / 0.189 = 7.09$ fps
   Calculate velocity head (H_V) in feet:
   $H_V = V^2 / 64.4 = 7.09^2 / 64.4 = 0.78$ ft
6) Total components 1 through 5 to obtain H_s
   $H_s = 6 + 2.16 + 2.87 + 0.5 + 0.78 = 12.31$ ft

2. Discharge pressure

a. Pressure gauge

Select a pressure gauge which has a range which exceeds the anticipated system pressure, yet is matched closely. Digital pressure gauges or a liquid-filled dial gauge is recommended for this use. It should be calibrated to verify accuracy and corrected to adjust for discrepancies. Pressure range guidelines are:

Gated pipe: 0-15 psi
Center pivot: 0-60 psi (low pressure) or 0-100 psi (standard pressure)
Other sprinkler systems: 0-100 psi
Big guns: 0-200 psi
Drip or microirrigation: 0-30 psi or 0-50 psi

b. Pressure gauge installation:

The pressure gauge must be installed near the pump discharge before (upstream of) any valve or other obstruction. The pressure at the gauge will then indicate the true pressure head at that point regardless of elevation changes or friction head loss downstream of the gauge (Figure 4.6).

Figure 4.6 - Pressure gauge installation on well discharge pipe.

Often an existing port on the system can be used. Most pressure gauges will have ¼ inch tapered pipe thread. If the port on the system to be used is larger, a reducing bushing will be required. If a suitable port is not available, a 7/16 inch hole can be drilled at the desired location and tapped for ¼ inch pipe thread. The pipe section to be drilled must have adequate wall thickness (>1/16") to be tapped. A pipe sealing compound or Teflon tape is recommended to eliminate leakage and provide lubrication for the gauge threads. Use a wrench, not your hand, to tighten the gauge. Be careful not to over tighten the gauge, as damage may result to the threads.

If possible, install a pipe tee to allow use of the existing system pressure gauge to verify its accuracy. Installation of a ¼ inch cock valve before the pressure gauges will protect the gauges if a water hammer condition occurs in the system. Open the valve when the system is up to operating pressure. The valve can be left when the test is complete for subsequent reading by the operator and will prolong the life of the gauge. The valve also makes it easy to change gauges, if necessary while the system is operating.

c. Pressure measurement

Record the pressure reading after the pumping plant and irrigation system has stabilized (Figure 4.7). Take the pressure reading at the same time interval that the pumping water level is measured. If the gauge was installed above the discharge pipe, the vertical distance between the gauge and the center line of the discharge pipe must be added to the discharge head. If the gauge is below the pipe, subtract the distance from the pressure gauge to center line of the discharge pipe.

Figure 4.7 - Example pressure gauge reading.

3. Water flow measurement

An accurate flow rate measurement is required to determine the pumping plant efficiency. Do not use an existing flow meter (propeller) for the flow rate determination since the unit may not be accurate due to installation or proper servicing. A transit-time ultrasonic flow meter is recommended. Older methods using probes or pitot tube devices are discussed in the appendix.

The test flow meter must be attached at the proper location on a straight section of the discharge pipeline to assure accurate reading. The flow meter should be placed at least 10 pipe diameters downstream from any valve, fitting, or obstruction. Additionally, the flow meter should be at least 5 pipe diameters upstream from any valve, fitting, or obstruction (Figure 4.8). Full pipe flow is required in the pipeline, and most ultrasonic flow meters work only on single wall pipe. Pipe inside diameter (ID) is needed. Figure 4.9 illustrates a portable ultrasonic flow meter installation. Do not install on telescoping pipes or where an engine heat exchanger is used.

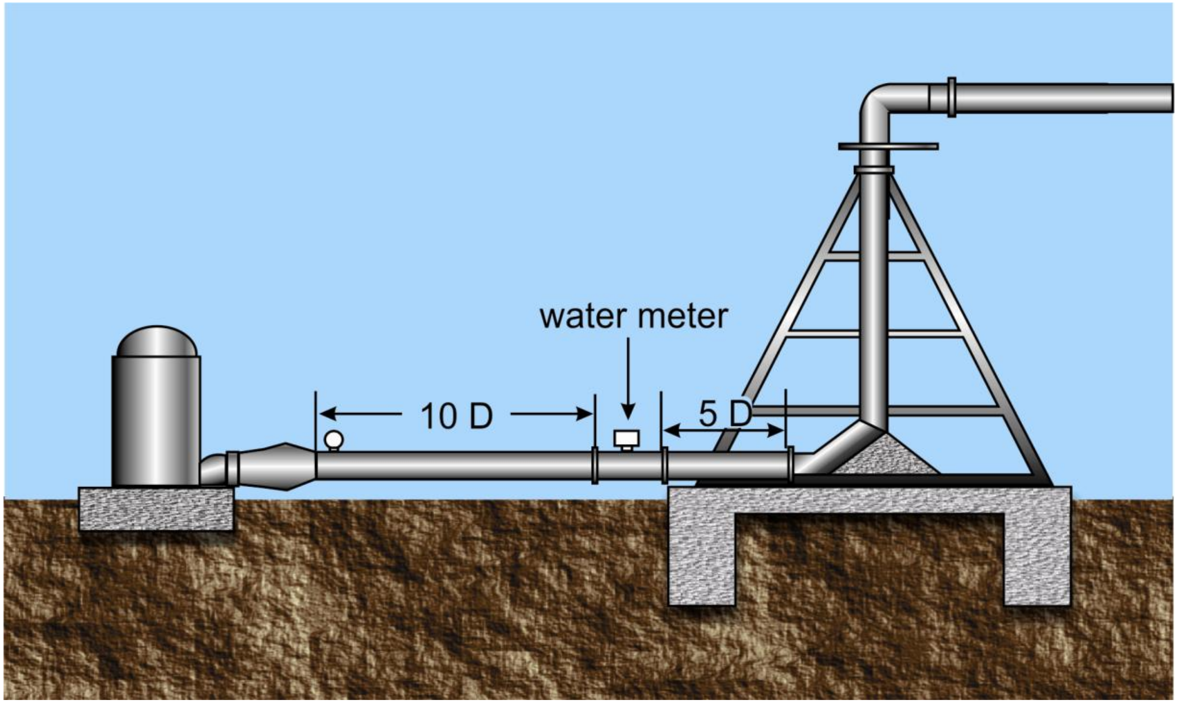


Figure 4.8 - Cross-section showing correct installation of flow meter.

Figure 4.9 - Portable ultrasonic flow meter.

4. Energy use

a. Electric energy use

The electric energy use rate in kilowatts (KW) can be determined by using the electric meter serving the installation (Figure 4.10). Most meters utilize digital technology to measure KW, KWh, power factor, and other variables. Various meter configurations may exist depending on the electric supplier. Consult with the local electric supplier for procedure to read the meter and also obtain the correct multiplier for the installation.

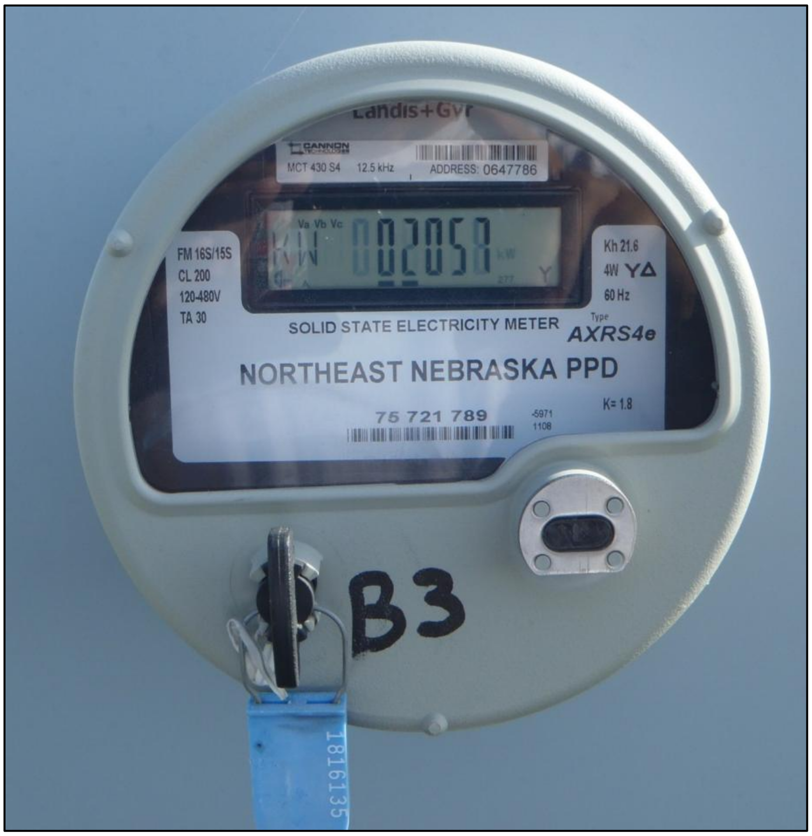


Figure 4.10 - Kilowatt hours are measured using electronic meter.

b. Internal combustion energy use

1) Torque meter

A torque meter measures the output of an internal combustion engine including the torque, speed, and horsepower of the engine. It is used to measure the power output of the engine. Once the system is at the normal operating condition, readings of the torque meter along with the fuel consumption are used to determine the operating efficiency of the engine.

The torque meter is attached to the output shaft of the engine (Figure 4.11). Some units clamp on to the drive shaft while others are integral to a shaft that replaces the drive shaft for the test duration. The meter must be securely attached to the shaft and the engine frame for the test. It is critical that the drive shaft connections be properly aligned to prevent damage to components and personnel conducting the test. Insure that all guards are installed and functional to prevent entanglement in the unit.

Figure 4.11 - Torque meter attached to engine drive shaft.

2) Engine fuel use

Measurement of the fuel use rate provides the value for energy input into the engine. When combined with the output power measured by the torque meter, actual engine efficiency can be calculated. Some modern engines can provide fuel use values using an appropriate electronic readout device.

a) Liquid fuel – diesel, propane, and gasoline

For liquid fuel engines, three methods can be used to measure the fuel use rate of the engine: Coriolis meters, positive displacement meters, and weighing method. Coriolis meters measure mass flow rate and are very accurate if installed correctly and calibrated (Figure 4.12). Positive displacement meters are also accurate when installed correctly.

Fuel flow meters must be plumbed into the fuel supply lines for the engines. Insure that all hoses and fittings maintain sealed connections. Flow meters used with diesel engines need to plumb the fuel return line into the flow meter to account for return flows. When installing and removing meters and plumbing on diesel units, air can get into the fuel lines. Care must be taken to bleed any air from the system. A priming pump should be incorporated into the fuel measuring system to purge the air.

The weighing method of measuring fuel flow is less accurate than flow meters. A discussion of this method is included in the Appendix H.

Figure 4.12 – Coriolis flow meter used for pumping plant test.

b) Natural gas fuel use

Natural gas fuel use can be measured by disconnecting the natural gas lines from the supply lines from the gas meter and replacing them with a test meter. All hoses and connections must be secure. Some models of coriolis meters can also be used for natural gas. If the existing gas meter is used for the test, appropriate calibration and correction factors must be obtained from the supplier. Insure that the meter reading is only for the engine being tested, as some meters may serve multiple units.

5. Pump speed

Although the pump and power unit speed is not necessary for calculation of the pumping plant performance, it is an invaluable aid for analysis of the pump and power unit. Knowing the pump and power unit speeds allow identifying the operating points on the pump and power unit curves.

Two types of tachometers are commonly used. One requires physical contact with the rotating part. The other, known as a photo tachometer (Figure 4.13), uses reflected light and need not touch the rotating part. Both count the number of revolutions over a small time interval and read in revolutions per minute (rpm). Digital tachometer types are the most accurate (± 1 rpm) and are recommended for use.

Figure 4.13 – Photo reflective tachometer.

Caution: Extreme care must be taken when using tachometers due to rotating parts. Loose clothing such as shirt tails, cuffs, and ties can easily be entangled with drastic, even fatal, results. Fingers, arms, and hair must be kept as far away as possible.

Points to remember:

- For vertical electric motor installations, the pump rpm is the same as the power unit rpm.
- For belt-driven or right angle gearbox installations, both pump and power unit rpm should be measured.
- Power unit rpm should be measured synchronous with the pump rpm.
- To measure pump speed of vertical pumps, the cover on the top of the vertical electric motor or right angle drive must be removed.
- Knowing the gearhead or pulley ratios and one of the speeds would allow calculation of the other speed. However, there have been cases where the gears were changed in the right angle gearhead to a different ratio and the name plate reflected only the original ratio. On belt driven equipment, there is some slippage and the pulley ratio will not always reflect the true rpm.
- The pump rpm can be taken from the head shaft on vertical pumps or from the input shaft of a centrifugal pump.
- Engine rpm can be taken from the driveshaft, flywheel, or crankshaft pulley.

IV. Pumping Plant Testing Procedure

Conducting the pumping system test requires that the pumping and irrigation system be operated at the normal pressure. However, before starting the system, insure that all existing equipment is installed properly. Many irrigation systems have been in operation for several years and may not have been maintained as prescribed. **Insure that all safety precautions are taken. See the Section VI on safety procedures.** Below is a prescribed sequence for the test procedure.

Procedure for pumping plant test:

- Perform a walkthrough of the entire system to inspect components. Note any problems and remedy any safety issues before starting. Remember that the equipment may not conform to the standards of proper installation and maintenance.
- For center pivots and other delivery systems that may use power to drive the system, i.e. drive motors or end gun booster pumps, set the travel speed to zero and turn off end guns.
- Measure and record the static water level in the well, if a well is used.
- Start the pumping plant and bring the system to normal operating pressure following the normal procedure. It is recommended that the owner/operator perform the starting sequence.
- Check and note the pumping water level.
- Check to see if the pressure and/or water flow rate is set at their normal operating point. Make changes if necessary.
- Check and note pumping water level.
- Repeat these steps until the pumping water level has stabilized.
- Make sure the power unit is operating properly.
- If an electric motor is used, record the nominal operating speed (rpm).
- Begin test by recording power unit and pump rpm. If a right angle drive or belt drive is used, measure both the power unit speed and the pump speed.
- Measure and record KW use for electric or engine fuel flow rate.
- Measure and record torque meter readings.
- Measure and record water flow rate.
- Measure and record pumping water level.

- *Test is valid if pump rpm did not change + 1/2% rpm during the test (i.e. 10 rpm at 1760 rpm) and if pumping water level did not change ± 1% during the test (i.e. 1 foot at 100 ft; 2 feet at 200 ft.)*

- If the test readings are not valid, repeat test.

Proper test procedures are very important to obtain accurate measurements. Errors in the test measurements can be equipment related or the result of operator error. Also errors can result from inability to obtain readings, i.e. no well access. The most accurate equipment can be used, but if operator error occurs, the errors in the test can far exceed the inaccuracy caused by the testing equipment.

The accuracy of each variable of the test, namely pressure, lift, water flow rate, and fuel consumption is dependent on both equipment accuracy and the procedure used. The overall accuracy of the test is dependent on the cumulative accuracy of each variable. Each variable inaccuracy will either add or subtract to the overall accuracy. Consider an example of a diesel pumping plant test.

Variable	Actual	Observed	Error
Pressure	78.4 psi	80 psi	2% high
Lift	147.0 ft	150 ft	2% high
Flow rate	980 gpm	1000 gpm	2% high
Fuel consumption	6.83 gph	6.7 gph	2% low

The observed performance rating would indicate the pumping plant is 101% of the standard. The actual performance rating is 95%.

The pumping plant test must be performed in the same time frame with all conditions constant throughout the test. The test should not begin until the pumping water level in the well and operating pressure are stabilized. Stabilized can be considered as less than one foot change in pumping water level over the time of the test. To minimize the effect of a change of pumping water level during a test, the discharge pressure should be taken at the same time the pumping water level measurement is made. On closed systems such as a center pivot irrigation system, a drop in pumping water level will also show a change of discharge pressure head.

For internal combustion engines, the engine rpm (throttle setting) should not be changed during the test. A change in engine speed will affect the operating characteristics of the engine which would change the fuel consumption of the engine over the period of the test. More importantly, the gpm, psi, and lift would change and the horsepower required would change, which in turn changes fuel consumption.

The pumping plant must also be operated long enough to allow proper warm-up of mechanical parts. Engines and gearheads should be at their normal operating temperature before the test begins. Generally the warm up period will coincide with the time required to reach a stable pumping water level, however, the warm up period should be no less than 30 minutes,

Care must also be taken to account for loads drawn from an engine or power line which are not applied to the pump. This situation occurs when a center pivot tower drives are powered from an engine driven alternator or hydraulic pump, or from electricity drawn through the watt-hour meter common to the electric motor for the pumping plant. Ideally, the pivot should not be moved during the test. Make sure that the end gun booster pump is either on or off for the entire test.

Finally, overall accuracy of the test can be enhanced if certain measurements are taken during a specific time interval. For example, water flow rate and fuel measurement should be taken during the same time interval. A small change in water output during the test would reflect a corresponding change in fuel consumption. If the measurements are taken during the same time interval, the average flow rate and the average fuel consumption during the test time interval would correspond. This same idea applies to the discharge pressure and lift measurement. They should be taken at the same time as indicated previously.

In order to get a good average value for each of the pump test variables, the test period should continue for at least 30 minutes with data being recorded every 5 minutes. This procedure addresses small changes in the readings without having to conduct a second test.

V. Sprinkler System Performance Testing

The center pivot sprinkler system distributes water across the field. Properly designed, the sprinkler package will deliver water efficiently and uniformly across the field. Properly managed and maintained, the sprinkler package should continue to perform as designed. As a general rule, if the crop is to be sufficiently watered, good distribution uniformity is a prerequisite for good irrigation efficiency.

Irrigation systems can be evaluated for application efficiency and uniformity. Uniform water application may not mean the irrigation system is highly efficient because water can be uniformly over applied. Under irrigation could result in high application efficiency. High irrigation efficiency, however, requires uniform water application over the entire application area. Nonuniformity that contributes to over-irrigation of all or parts of the field is undesirable.

A. System uniformity evaluation

Water application uniformity is a measure of the evenness of water distribution over the entire irrigated area. Irrigation systems should apply the water uniformly in sufficient quantities to meet the crop water needs without over watering or generating runoff. In a practical sense, achieving perfect uniformity is not possible. However, the goal of a well-designed and operated irrigation system is to apply the water at over 90% uniformity.

Uniformity in irrigation is an important factor when it comes to conserving and using water efficiently. Uneven application of water will result in under watering and/or over watering of parts of the field. Over-irrigation can result in waterlogging or runoff. Thus, plant growth is curtailed, nutrients are leached out of the rooting zone, and both water and energy are wasted. Whereas, under irrigation could result in plant stress and reduced yields.

Catch can tests can be used to find the uniformity of an irrigation system (Figure 4.14). Measuring the amount of water caught in the cans during an irrigation event allows estimates of efficiency and uniformity to be made. It is important that enough catch cans are used to provide reasonable estimates of the actual net irrigation. Measured irrigation application with catch cans is compared to the average catch to arrive at a value for uniformity.

The two most common methods of expressing uniformity are the CU (coefficient of uniformity) and DU (distribution uniformity). CU calculates the average deviation of the catch compared to the average depth of the catch. DU is calculated by dividing the average catch of the low one-quarter of the catch by the average catch. Refer to Farm Irrigation System Evaluation: A Guide for Management to evaluate uniformity of solid set or set-move irrigation systems.

For center-pivot evaluations, the CU accounts for the increased area covered by each sprinkler as you move further from the pivot center. Sprinklers near the end cover greater area than those close to the center pivot. The deviations and averages are weighted for the relative area represented by each catch can. The CU is calculated using the Heermann and Hein Modified method. Refer to ASABE S436.1, Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray or Sprinkler Nozzles, for the uniformity testing procedure to follow. Alternatively, the NRCS's CPED model (Center Pivot Evaluation and Design) can simulate water distribution under center pivot and linear move sprinkler systems, however the CPED model assumes proper installation and operation of the sprinkler package. Sprinklers installed in the wrong positions or operated at a lower pressure than design should not be expected to perform as the CPED model predicts.

Figure 4.14 - Catch cans used to test sprinkler uniformity.

A CU rating of 90%-95% is considered excellent and would only require regular maintenance. Whereas, a CU of 85%-90% is considered good and would not need major adjustments; regular maintenance and inspection are required. When CU is at 80%-85% the system requires inspection and sprinkler package check, and at 80% or less the system requires sprinkler pressure adjustment and full maintenance of the whole package.

Plotting the results of a can test can help diagnose sprinkler problems. Figure 4.15 illustrates multiple problems. Section A exhibits normal variation in water application and despite the variation in catch can depths, the application uniformity is high. In Section B, a leak in a boot at one of the towers produces a spike in water application depth. In Section C the sprinklers were installed on the system in reverse order on two spans. This caused too much water application near the inside and too little toward the outside position of each span. In Section D the end gun was adjusted to rotate more than the sprinkler package design specifications; however, because the sprinklers on the main portion of the system were installed in reverse, the end gun actually contributed in a positive manner to the application depth of the last span and the overhang. All of these issues were found on one system and are easily fixed with little if any expense.

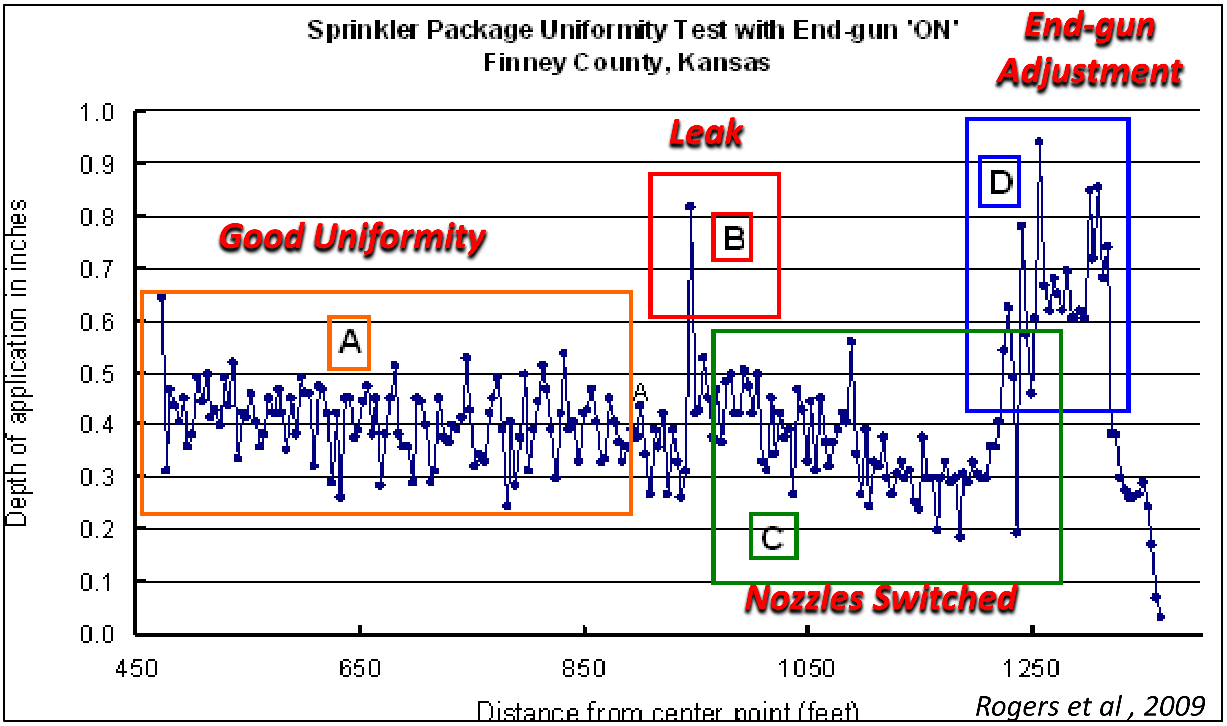


Figure 4.15 - Results of a catch-can test of uniformity for a center pivot in Kansas.

VI. Safety

Following safety procedures and guidelines is essential when conducting an irrigation energy audit. Both operator and equipment safety procedures must be followed. Multiple hazards are present around irrigation systems. Pumping systems have rotating drives. Electrical systems have components that can deliver fatal shocks. Water pressure is dangerous if a break should occur and water hammer can destroy equipment and is hazardous to operators and bystanders. Falling is a hazard when working on center pivot laterals and other equipment 10-15 feet above the ground. Often pump and equipment sites are poorly maintained with wet/muddy conditions presenting tripping and falling opportunities.

A. Personal safety

Safety around systems that are served by electrical power is of utmost importance. Insure that all electrical components are installed and operating correctly. Never work on electrical components unless the power supply is shut off. Use safety gear and equipment to protect yourself from shock. Use lockout disconnects to prevent inadvertent startup. Even a seasoned professional who had repaired irrigation systems in Nebraska for 20 years lost his life when he came in contact with live electrical wiring.

In 1993 a rural power company supplier conducted a series of electrical tests and inspections of electrically driven center pivot systems with electric pump motors. It showed that 37% were potentially hazardous due to a lack of a grounding conductor. Nearly 40% did not have a ground rod installed, and more than 50% did not have a fuse or means of disconnection. They also found loose connections, improper circuit and motor protection and deteriorated insulation.

Shortly after the 1993 tests the Nebraska State Electrical Inspector conducted a second series of inspections, which showed similar results. Of the 77 systems were inspected, 10 were classified as lethal, 38 as definitely hazardous, and the remaining 29 listed as potentially hazardous. The 10 listed as lethal systems had current flowing to ground at the time of the inspection or had almost killed someone shortly before the inspection was conducted. In all 77 systems, the National Electrical Code (NEC) had been violated.

Grounding is extremely important. All electrical equipment on the irrigation machine or associated with the irrigation machine is required to be grounded. This requirement is found in *Article 675* of the *National Electrical Code*. Proper grounding will insure that the electrical supply is de-energized if a fault occurs that can result in live power getting to the metal machine in these wet conditions. There are two types of grounding necessary for reliable and safe operation of an electrically powered irrigation machine -- system grounding and equipment grounding. Additional information on electrical standards is included in ASABE Standard S362, "Wiring and Equipment for Electrically Driven or Controlled Irrigation Machines”. A thorough discussion of electrical equipment and safety is included in Appendix J.

Insure that all moving parts including drive shafts have the proper shielding installed. This is especially important when installing torque meter test equipment. Wear eye protection during the test. Use hearing protection around internal combustion engines when running.

B. Equipment safety

An irrigation machine, such as a center pivot system, is an electrical challenge in that the electrical current must be moved over a long distance. According to Ohm’s law, because the wires have resistance, voltage drop will occur as the current travels the long distance from the source panel to the motor or other load. Lost voltage is lost energy. If the voltage is lower than optimum, a motor must draw additional current to develop the power required to move the irrigation machine. Excessive current not only increases the voltage drop, but it can result in motor overheating. To minimize the current flow, the motors must be operated at the highest voltage practical. This is why irrigation machines operate at 480 volts rather than 240 volts or 208 volts. Also, loads powered from a 3-phase source rather than a single-phase source draw 40% less current to develop the same power, although it takes three wires for 3-phase loads and two wires for single-phase loads. Insure that all electrical equipment is grounded and is protected from overload or faults by circuit breakers or fuses.

Suitable pressure air and relief valves should be installed on pipelines to prevent damage to pipes and equipment from water hammer surges.

Remove obstructions in the path of the irrigation machine. Center pivots are powerful and can easily climb over objects. Do not park a vehicle or service trailer in the path of a center pivot drive tower.

Make sure that engines have appropriate safety controls to shut off the unit due to loss of irrigation water, oil pressure, and engine temperature. Electric pumps also need a safety shut off from loss of water.

VII. Irrigation System Energy Summary

A. Pumping plant performance calculation

The pumping plant performance rating is calculated from the measurements obtained in the field test. The performance rating is not the same as energy efficiency. It is a comparison of the field test measurements to a standard pumping system that is operating at a relatively high efficiency.

The Nebraska Pumping Plant Performance Criteria was developed to provide an estimate of the amount of work that can be obtained from a unit of energy by a well-designed and managed pumping plant (Table 4.1). An average efficiency of 75% was used for the pump and drive. The overall performance of the engine/motor and pump system is expressed as water horsepower hours (WHP-hr).

Research at the Nebraska Tractor Test Laboratory has shown that efficient diesel engines produced about 16.7 BHP-hr of work per gallon of diesel and about 12.5 WHP-hr/gallon of diesel fuel. The performance of the engine and pumping plant systems can also be expressed as an efficiency, i.e., the ratio of the work done compared to the energy available in the fuel. Results show that a diesel engine is about 31% efficient and that the overall fuel conversion efficiency is about 23%.

Table 4.1 - Energy Content of Fuels and Work Performed by Irrigation Power Units.‡

	Average Energy Content		Nebraska Pump Plant Criteria			
Energy Source	BTU	HP-hr	Engine or Motor Performance HP-hr/unit	Pumping Plant Performance WHP-hr/unit†	Engine or Motor Efficiency %	Pumping Plant Conversion %
1 gallon of diesel	138,690	54.5	16.7	12.5	31	23
1 gallon of gasoline	125,000	49.1	11.5	8.66	23	18
1 gallon of LPG	95,475	37.5	9.20	6.89	25	18
1 mcf of natural gas	1,020,000	401	82.2	61.7	21	15
1 therm of natural gas	100,000	39.3	8.06	6.05	21	15
1 KW-hr of electricity	3,412	1.34	1.18	0.885	88	66

‡ Conversions: 1 horsepower = 0.746 kilowatts, 1 kilowatt-hour = 3412 BTU, 1 horsepower-hour = 2,544 BTU

† Assumes an overall efficiency of 75% for the pump and drive.

The pressure, lift, and water flow rate are combined to determine the water horsepower output of the pump. The horsepower output is compared to the measured pumping plant fuel consumption required to produce the horsepower. This value is compared to the expected fuel consumption to determine if the pumping plant is efficient. Fuel consumption exceeding the expected rate results in a performance rating below 100%. A fuel consumption rate below the expected rate results in a performance rating above 100%. The performance rating is not an efficiency rating but a rating comparing actual versus expected performance. Expected performance takes into account energy efficiencies for each component of the pumping system. The performance rating is calculated as follows:

- ✓ Calculate the total head (TH) or total dynamic head (TDH)
- ✓ Calculate water horsepower (WHP)
- ✓ Calculate pumping system energy use
- ✓ Calculate energy performance (EP)
- ✓ Calculate energy performance rating (EPR)

1. Total head (Total dynamic head)

Total head is the total of all head and pressure values for the irrigation system. It includes well lift, column friction loss, discharge pressure, and any other friction or head loss for well systems and pumping lift, suction loss, discharge pressure and any other friction or head loss for surface water sources. Pressure readings and friction loss in psi need to be converted to feet of head.

Column friction loss:

Friction occurs when water flows through pump column pipe as in any other type of pipe. The pressure gauge at the discharge measures the friction head loss downstream. However, the friction head loss in the column cannot be measured in the field. Therefore, the head loss must be obtained from the pump supplier. The head loss through the pump column must be added to the discharge head and lift to determine the total pumping head.

The head loss is greater in the pump column than for regular pipe. This is because the pump column also houses the lineshaft and oil tube which creates more friction in less cross section area.

Figure 4.16 gives the expected head loss per 100 feet of oil lubricated pump column given the column size, oil tube size, and flow rate (gpm). To determine the head loss for water lubricated pumps (no oil tube), use the 2" oil tube size for open lineshaft sizes to 1 1/2”. For open lineshaft sizes over 1 1/2", use the 2 1/2" oil tube size. Pump manufacturers have tabular values of column friction loss that can be used instead of Figure 4.16.

Example 4.4:

A pump is producing 1000. The pump column consists of 8 5/8" (8" nominal size) pipe, 150 feet in length (150 ft pump setting), and the lineshaft size is 1 1/2" with a 2 1/2" oil tube (8 x 2 1/2).

From Figure 4.16, the friction head loss is: 4 ft for 100 ft of column.
For 150 ft of column (4 ft * 150/100), column friction is 6 ft.

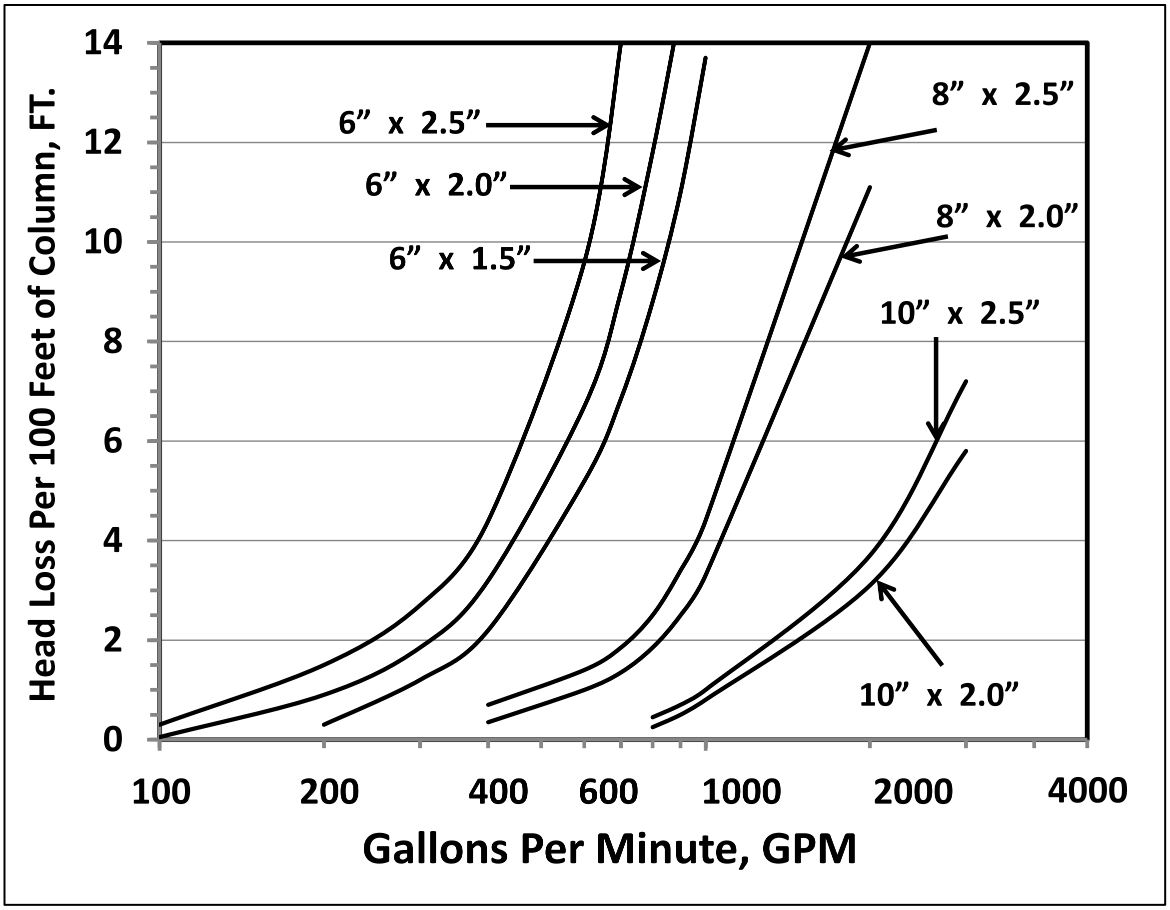


Figure 4.16 - Column friction loss for deep well turbine pumps.

Calculate total head:

Total head (TH) is the vertical lift (L) in feet from the pumping water level to the discharge pressure gauge plus the friction loss (H_f) in feet in a deep well pump column or on the suction side of a centrifugal pump plus discharge pressure reading (P) converted to feet of head.

$$TH = L + H_f + (P \times 2.31)$$

Example 4.5:

Pumping water level (L) is 100 ft, discharge pressure (P) is 55 psi, and column friction loss (H_f) is 6 ft (Example 4.4)

$$TH = 100 + 6 + (55 * 2.31) = 233 \text{ ft}$$

2. Water horsepower

Water horsepower is the amount of power that in applied to the water by the pumping plant. Water horsepower is the product of flow rate (R) (gpm) multiplied by the total head (ft) and divided by a conversion factor (3960) to get horsepower.

Calculate water horsepower (WHP):

WHP = Q * TH /3960

Example 4.6:

From Examples 4.4 and 4.5, flow rate (Q) is 1000 gpm and total head (TH) is 233 ft.

WHP = 1000 * 233 / 3960 = 58.8 WHP

3. Pumping system energy use

The amount of work produced per unit of energy depends on the source used to power the pump (Table 4.1). One gallon of diesel fuel will generate about 139,000 BTU of energy if completely burned. The energy content can also be expressed as the horsepower-hours of energy per gallon of fuel (i.e., 54.5 BHP-hr/gallon for diesel). Not all of the energy contained in the fuel can be converted to productive work. Electric motors have a higher conversion ratio. The difference between the input power and the output power is largely lost to heat from the power unit.

The actual pumping system energy use rate is the energy use per hour that is measured in the pumping plant audit test in kilowatts (KWh/hr) for electricity, gallons per hour (gph) for liquid fuel engines, and thousand cubic ft per hour (mcf/hr) for natural gas engines. The energy performance (EP) is the ratio of water horsepower divided by the energy consumption.

Calculate energy performance (EP):

Example 4.7:

The pumping system from Example 4.6 uses 73 KWh/hr of electricity.

EP = 58.8 WHP / 73 KWh/hr = 0.805 WHP / KWh

4. Energy performance rating

The energy performance rating (EPR) is the ratio of the actual energy performance divided by the standard performance criteria for pumping plants. The standard performance criteria are based on the Nebraska Pumping Plant Criteria (Table 4.1). The EPR is useful in evaluating how the pumping system performs with respect to a standard. It is not the efficiency of the pumping system.

Another performance rating that is useful is the ratio of the hourly energy rate use divided by the volume of water pumped per hour. This rating can be used to compare the energy effectiveness of systems in applying water. Furrow irrigation systems have a lower energy use per acre-inch of water applied than sprinkler systems because the operating pressure is lower.

Calculate energy performance rating (EPR):

Example 4.8:

EPR(%) = EP / performance criteria * 100

Performance criteria
Electricity: 0.885 WHP-hr/KWh/hr
Diesel: 12.5 WHP-hr/gallon
Natural gas: 61.7 WHP-hr/mcf
Propane: 6.89 WHP-hr/gallon
Gasoline: 8.66 WHP-hr/gallon

EPR = 0.805 / 0.885 * 100 = 94%

Water performance rating:

The water performance rating (WPR) is the ratio of the hourly energy use divided by the acre-inches of water pumped per hour.

Example 4.8:

From Example 4.4 with 1000 gpm and Example 4.7 with 73 KWh/hr of electric use:

Ac-in/hr = 1000 gpm / 453 gpm/ac-in/hr = 2.2 ac-in/hr

WPR = 73 / 2.2 = 33.2 KWh/ac-in

B. Irrigation energy cost calculation

The cost to pump irrigation water depends on the type of energy used to power the pumping unit. The cost to pump an acre-inch of water depends on:

- The water horsepower to pump the water
- The work produced per unit of energy consumed
- The performance rating of the pumping plant
- The cost of a unit of energy.

The pumping energy audit can be used to estimate the fuel cost savings that could be expected from various repairs or upgrades to the system.

The energy audit can also be used to determine cost savings of improved irrigation practices like irrigation scheduling. Four areas that could have significant energy cost savings include:

- Improved irrigation water management
- Converting from high pressure to lower pressure sprinklers
- Repairing or upgrading the pumping plant
- Converting to a different fuel source

Below are examples of each of these alternatives.

Given for examples: Center pivot irrigation system, 130 acres, deep well turbine pump with diesel engine, 800 gpm, 200 ft of total head, diesel fuel use is 4 gal/hr, 12 inches of water applied per year, 60 psi pivot pressure, fuel cost is $3.50/gal for diesel, and $0.11/KWh for electricity.

Calculate WHP:
WHP = 800 gpm * 200 ft / 3960 = 40.4 WHP
Calculate EP
EP = 40.4 WHP / 4 gal/hr = 10.1 WHP-h/gal
Calculate EPR
EPR = 10.1 / 12.5 * 100 = 80.8%
Calculate WPR
Ac-in/hr = 800 / 453 = 1.77 ac-in/hr
WPR = 4 gal/hr / 1.77 ac-in/hr = 2.26 gal/ac-in
Calculate operation hours/year
Hours = 130 acres * 12 in/yr / 1.77 ac-in/hr = 881 hours /yr
Calculate current fuel cost
Fuel cost = 881 hr/yr * 4 gal/hr * $3.50 /gal = $12,334 /yr

Example 4.9: Improved irrigation water management

Research throughout the Midwest and Great Plains has consistently shown water savings of one to two inches of water per year using improved irrigation water management. Improved water management uses soil moisture monitoring, ET information, and irrigation scheduling to maximize the effectiveness of rainfall and irrigation water applied without inducing water stress. Improving irrigation water management is, by far, the lowest cost energy conserving alternative since it involves very little "out of pocket" costs.

Calculate cost savings from improved irrigation water management using numbers from the example above:

Water saved per year = 130 acres * 2 inches/year = 260 ac-in/year
Cost savings = 260 ac-in/yr * 2.26 gal/ac-in * $3.50/gal = $2057 /yr

Example 4.10: Converting to lower pressure sprinklers

Current pivot pressure is 60 psi. Keep the flow rate at 800 gpm. Calculate the cost savings from converting to 30 psi.

Calculate new WHP using the numbers from the examples above:

Pressure reduced = 30 psi = 69.3 ft head
New total head = 200 – 69.3 = 130.7 ft
WHP = 800 * 130.7 / 3960 = 26.4 WHP

When converting to lower pressure, the pumping plant needs to be modified to match the new system head. It is assumed that the modified pumping plant will be upgraded to meet the Nebraska Pumping Plant Criteria of 12.5 WHP-hr/gal, saving even more energy cost.

Calculate fuel and cost savings

WHP savings = 40.4 – 26.4 = 14 WHP
Fuel savings = 14 WHP / 12.5 WHP-hr/gal = 1.12 gal/hr
Cost savings = 1.12 gal/hr * 881 hr * $3.50/gal = $3454 /yr

Example 4.11: Repairing the pumping plant

Repairing or modifying the pumping plant could improve the pump energy performance rating from 80.8% to 100% or greater.

Calculate the new fuel use using the numbers from the examples above:

Fuel use = 40.4 WHP / 12.5 WHP-hr/gal = 3.23 gal/hr
Fuel savings = 4 gal/hr – 3.23 gal/hr = 0.77 gal/hr
Cost savings = 0.77 gal/hr * 881 hr * $3.50/gal = $2374 /yr

Example 4.12: Converting from diesel to electricity

Converting to electric power is dependent on the availability of electric service and the cost for the service and new equipment. Keep in mind all of the advantages and disadvantages of each power source. Also it is assumed that the pump will be modified to meet the Nebraska Pumping Plant Criteria at the time the conversion is done.

Calculate cost savings from conversion using the numbers from the examples above:

Current fuel cost = $12,334 /yr
Electric energy use = 40.4 WHP / 0.885 WHP-hr/KWhr/hr = 45.6 KWh/hr
Electric energy cost = 881 hr/yr * 45.6 KWh/hr * 0.11 / KWhr = $4419 /yr
Cost savings = $12,334 - $4419 = $7915 /yr

Example 4.13: Complete system upgrade

A final example illustrates the energy and cost savings from multiple upgrades to the irrigation system and improved irrigation water management using numbers from the examples above:

Water management
Hours = 130 acres * 10 in/yr * 1.77 ac-in/hr = 734 hr/yr
New WHP for low pressure = 26.4 WHP
New electric energy use = 26.4 WHP / 0.885 WHP-hr/KWhr/hr = 29.8 KWh/hr
Electric energy cost = 734 hr/yr * 29.8 KWh/hr * 0.11 / KWhr = $2406 /yr
Cost savings = $12,334 - $2406 = $9928 /yr

C. Economic Feasibility

Two methods can be used to determine the economic feasibility of energy upgrades or repairs for an irrigation system. The first method is to calculate a simple **payback period**. The simple payback period does not consider the time value of money such as interest rates for investment. Payback period (PP) is calculated using the following equation:

PP = Initial investment/Annual cost savings

Example 4.14: Payback period

Consider Example 4.11 where annual cost saving is $2374/yr. If the initial investment to repair the pumping plant is $7400, then the payback period is:

PP = $7400 / $2374 = 3.1 years

The money that is feasible for making repairs or upgrades is determined by the length of the repayment period (n) and the annual interest rate (i). These values are used to compute the **series present worth factor** (PWF) using the following equation:

$$PWF = ((1+i)^{n} - 1) / (i * (1+i)^{n})$$

Table 4.2 gives series present worth factors (PWF) for typical repayment periods and interest rates. The breakeven investment is the value of the annual energy savings times the series present worth factor. The series present worth factor represents the amount of money that could be repaid at the specified interest rate over the repayment period. Example 4.15 illustrates use of the series present worth factor to determine economic feasibility.

Table 4.2 - Series Present Worth Factor (PWF)

Repayment Period, years	Annual Interest Rate					
	6%	7%	8%	9%	10%	12%
3	2.67	2.62	2.58	2.53	2.49	2.40
4	3.47	3.39	3.31	3.24	3.17	3.04
5	4.21	4.10	3.99	3.89	3.79	3.60
6	4.92	4.77	4.62	4.49	4.36	4.11
7	5.58	5.39	5.21	5.03	4.87	4.56
8	6.21	5.97	5.75	5.53	5.33	4.97
9	6.80	6.52	6.25	6.00	5.76	5.33
10	7.36	7.02	6.71	6.42	6.14	5.65
12	8.38	7.94	7.54	7.16	6.81	6.19
15	9.71	9.11	8.56	8.06	7.61	6.81
20	11.47	10.59	9.82	9.13	8.51	7.47
25	12.78	11.65	10.67	9.82	9.08	7.84

Example 4.15: Economic feasibility

1) Economics of repairing the pumping plant (Example 4.11)

   Estimated energy savings if meeting the Nebraska Pumping Plant Criteria = $2374 /yr

   If the interest rate is 8% and the irrigator wants to pay off the repair cost with energy savings in 3 years, the series present worth factor (PWF) from Table 4.2 is 2.58. The breakeven investment (I) to cover the repair cost is:

   I = $2374 * 2.58 = $6125

2) Economics of complete system upgrade

   Estimated energy savings from complete system upgrade = $9928 /yr

   For an interest rate of 8% and a longer repayment period of 10 years, the series present worth factor (PWF) is 6.71. The breakeven investment (I) where energy savings would cover the cost of the complete system upgrade is:

   I = $9928 * 6.71 = $66,617

   If the cost for the complete upgrade is less than $66,617 then the upgrade is economically feasible.

VIII. Troubleshooting

Well water level sensor gets stuck

Some wells have a close tolerance between the well casing and the pump column. This may make lowering the cable or tape difficult. Also when the pump is started or turned off, the cable or tape may be lodged.

If the cable should become lodged around the column or between the column and casing, do not apply enough excessive pull on the cable that could break it. If the cable should break, it could fall into the well where it would be drawn into the pump. One method to free the cable is to allow slack (10-20 ft) in the cable and apply a jerking movement to the cable. This may have to be done several times.

If the pump is running when the electrode is caught, shutting it off may release the cable. If the cable remains lodged, stop and start the pump using the engine clutch. This often shifts the pump column enough to free the cable. Starting and stopping is not recommended with electric motors or engines without a clutch.

Another method is to "tilt" the pump column away from the casing where the cable is suspected to be lodged. A hydraulic jack can be positioned between the pump base and the foundation and pressure applied. A small movement of the pump base will cause a large movement of the column further down the well. This will often free the cable.

When these methods fail, the cable can be cut well above the ground level and tied to the pump base. The cable must not be allowed to fall into the well. In time the cable may free itself.

No well access

It is possible that access into the well casing is not available. Usually an access port is located in the well discharge base. On wells with small casing, this port may not penetrate inside the casing. Where no hole is located, a 7/16 in hole can be drilled through the pump base. This hole can be tapped for a ¼ in pipe plug to plug the hole after use. Care must be taken not to drill into the water carrying section of the pump base (pump column). Some older wells may have access to the well casing under the well discharge head. A similar hole could be drilled there but must be plugged when finished. If it is not possible to measure well water levels, use the database of well logs to estimate water levels.

No information on pump

If the name plate is missing from the pump, information on the pump may be available from the owner or pump dealer. Another source of information is the state online database as part of the well log. Even if the pump nameplate is available, the pump may have been modified without noting it on the name plate. Thus, it is critical to ensure the model number of the pump impeller is accurate or it will be difficult to determine if the pump is operating appropriately or not.

Unable to turn auxiliary drive motors or end gun booster off

On some center pivot tower drive systems, the motors cannot be turned completely off without activating the safety shutdown. Set the tower drive speed as slow as possible to minimize drive motor impact on pumping system energy use. For special cases with the newer electronic pivot panels, contact the local supplier to solicit suggestions for settings to minimize erroneous energy use.

No information on power unit

When an engine curve cannot be located, a rough estimate of the continuous brake horsepower (BHP) can be calculated for naturally aspirated engines using the following equations:

Spark Ignition Engines:

BHP continuous = Engine displacement (cu-in) * RPM / 8000

Diesel Engines (no turbocharger):

BHP continuous = Engine displacement (cu-in) * RPM / 8700

No suitable water meter access

The water flow meter needs at least 5 to 10 pipe diameters upstream and 3 to 5 pipe diameters downstream for accurate readings. Some installations may not have this clearance near the pump site. A good alternative is to place the flow meter on the center pivot lateral pipeline at least 10 pipe diameters downstream from the pivot riser pipe and upstream from the first sprinkler nozzle. The ultrasonic flow meter should attach satisfactorily to the pipe as long as the lead wires are long enough to reach the ground for reading. Use caution when using a ladder to access the pipeline lateral as the pivot may move away from the ladder.

No suitable pressure gauge access

The pressure gauge should be attached to the main pipeline as close to the pump discharge as possible but should be downstream from any control valve. Usually, a port is available, however, a pipe bushing adapter may be needed to match the threads on the pressure gauge. It is advisable to have a supply of various fittings to match conditions in the field. If an access port is not available, choose a location on the pipeline at the same elevation as the pump discharge to tap into the pipeline. Use care in drilling the pipe so that the hole can be tapped to the correct thread size as the pressure gauge and also to the thread size of a suitable plug. This is best done using a combined drill-tap bit.

Multiple pumps serving one system

Where multiple pumps serve the same system, test each individual pump, if possible.

One pump serving multiple systems

Where one pumping system simultaneously serves more than one system, proceed as if there is one system, and take readings upstream from the branching to the individual systems. If the pipelines branch close to the pump discharge, flow measurements can be made on the individual systems and summed to get the total flow. Pressure readings should be taken upstream of the branching.

Digital electric meter

It may be difficult to get accurate readings of KWh on some of the electronic meters without running extended tests. Contact the local electric supplier for assistance with the multiplier used on the meter and how to collect instantaneous power use readings.

Single phase electric service or Variable Frequency Drive controls

Electric meter readings should provide accurate power usage values. If VFD or other load control startup features are used, allow the system to operate sufficient length of time for all parts of the system to stabilize. It is extremely difficult and expensive to record the power use at the outlet of a VFD due to the variation in frequency delivered by the controller. The only source of meaningful information is to monitor the meter on the delivery side of the VFD.

Electric outages or load control during test

An electrical outage during the test necessitates restarting the test. Be sure to let the system stabilize again after the system has been restarted. It is advisable to visit with the electrical supplier before conducting any test. If load control is scheduled during the test period, it may possible for the supplier to delay the load control until the test is completed.

Unexplained results or outcomes

Test results may produce values that are unrealistic for the field conditions. Be sure to check calculations first, and then attempt to identify which test readings may be erroneous. Repeat the test readings and compare to the initial values. Common sources of error include:

- ✓ Problems with measuring well water levels caused by cascading water or an oil layer on top of water in well.
- ✓ Errors in water flow measurement caused by pipeline turbulence.
- ✓ Inaccuracy in measuring fuel flow or reading electric meter.

Appendix A
Data Recording Sheets

Irrigation Management Evaluation

Owner Name ________________________________ County_________________________

Mailing Address______________________________ Zip Code ______________________

Phone Number ________________________ Date ___________________________

Legal Description ______________________ Lat., Long. ___________________________

Equipment Information:

Soil Water Sensors Installed YES _______ NO _______ Depths Monitored _________

Position of Sensor Installation(s) in Field ____

Information Accessed by HAND HELD METER or DATA LOGGER ____________________

Soil Water Holding Capacity Chart Available YES _______ NO _______

Soil Irrigation Trigger Points Identified YES _______ NO _______

Rain Gauge Used YES _______ NO _______ Location _______________________

ET_{gage} Used YES ______ NO _______ Location ______________________

Field Information:

Irrigation System Type ________________________ Estimated Efficiency, % __________

Number of Sets ___________ Acres Irrigated ____________ GPM per Acre __________

Soil Textures, % or acres Clay _____ Silt _____ Loam _____ Fine Sand _____ Sand ______

Soil Slope Category, % or acres A ______ B ______ C ______ D _____ E ______ F _______

Tillage Practices ________________ Crop Residue Cover, % _______________________

Crops Irrigated ______________________________ Peak ET Rate, in/day ____________

Field Data:

Soil Water Balance Calculated: YES _______ NO _______

Soil Irrigation Trigger Points Used: YES _______ NO _______

Evidence of Surface Runoff: YES _______ NO _______

Average Application Depth per Irrigation, inches ____________

Center Pivot Irrigation Management Evaluation

Owner Name ________________________________ County_________________________

Mailing Address______________________________ Zip Code _______________________

Phone Number _________________________ Date ___________________________

Legal Description ______________________ Lat., Long. ___________________________

Equipment Information:

Soil Water Sensors Installed _________________________ Depth Monitored _________

Position of Sensor Installation in Field _______________________

Information Accessed by HAND HELD METER or DATA LOGGER

Rain Gauge Used YES __________ NO _______

ETgage Used YES ______ NO _______

Field Information:

Center Pivot Estimated Efficiency, % _______ Hours Per Revolution______________

Acres Irrigated ___________ GPM per Acre ____________

Soil Textures, % or acres Clay _____ Silt _____ Loam _____ Fine Sand _____ Sand ______

Soil Slope Category, % or acres A ______ B ______ C ______ D _____ E ______ F _______

Tillage Practices ________________ Crop Residue Cover, % _________________

Crops Irrigated ____________________________________ Peak ET Rate, in/day ______

Field Data:

Percent Timer Setting Chart Available: YES _______ NO _______

Soil Water Balance Calculated: YES _______ NO _______

Soil Irrigation Trigger Points Used: YES _______ NO _______

Evidence of Surface Runoff: YES _______ NO _______

Average Application Depth per Irrigation, inches ____________

Irrigation Pumping Plant Performance Test

Name ______________________________ County________________________

Mailing Address______________________ Zip Code ______________________

Phone Number _______________________ Date _________________________

Legal Description ____________________ Lat., Long. ___________________________

Engine Information: Manufacturer __________________Engine Model No. ______________

Rated HP ______________ Engine RPM_____________

Pump Manufacturer __________________ Pump Model No. _____________________

No. of Stages ___________ Pump Setting____________ft Pump rpm_________________

Test Data:

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Pumping Water Level, ft						
Discharge Pressure, psi						
Flow Rate, gpm						
Energy Use Rate, unit/hr						
Pumping Plant Performance						

Energy Type	**Measured Unit**	**Factor**
Diesel	gal/hr.	495
Propane	gal/hr.	273
Electric	kW	35
Natural Gas	mcf/hr.	2443

Long Term Fuel Use Records: ___________ gallons per hour

Current energy cost per unit: ____________($/gal, $/kWh, $/mcf)

Current energy cost: 100-(_________) x _______Energy use rate x _________ Energy cost

100

Your Pumping Plant Performance

Total pumping head _______ x ____gpm ÷ ______Energy Use Rate ÷________Energy Factor

= ___________ % Performance Rating

Your Excess Fuel Use Rate

100- Performance Rating (%) x _____Energy Use Rate x $____ Energy Cost

= $ ____/hour

100

Your Potential Annual Fuel Savings

Hours of Operation_________ x $ ________ /hr excess cost

= $ _________ Potential energy savings per year

Center Pivot System Evaluation

Owner Name ________________________________ County________________________

Mailing Address______________________________ Zip Code _______________________

Phone Number ________________________ Date __________________________

Legal Description ______________________ Lat., Long. ___________________________

Equipment Information:

Manufacturer __________________________ Year _______

Sprinkler Manufacturer ___________ Sprinkler Model __________ Year _______

Position of Sprinkler ABOVE BELOW and _______ feet from the soil surface

Field Information:

Soil Textures, % or acres Clay _____ Silt _____ Loam _____ Fine Sand _____ Sand ______

Soil Slope Category, % or acres A ______ B ______ C ______ D _____ E ______ F _______

Tillage Practices ________________ Crop Residue Cover _____________

Surface Drains __________________ Surface Water Present YES _______ NO _______

Acres Irrigated ___________ GPM per Acre ____________

Crops Irrigated ____________________________________

Design Specifications:

Sprinkler Pressure ______________________ Sprinkler Spacing ______________________

Design Printout Available: Yes __________ No _________

Field Data:

Safety Equipment Present (PTO shield, gearhead cap, etc.): YES ______ NO ______

Overall Wire Condition: Excellent _______ Good ________ Poor _______

Wires Protected: YES _______ NO ________

Ground Wire Present and Connected: YES _______ NO ________

Pressure Gauge Present: YES ________ NO ________

Sprinklers Present and Operating: YES _______ NO ________

Pivot Pressure, psi _______________ End System Pressure, psi _______________

Catch Can Test Results CU _______ DU ________ (attach data sheets & calculations)

Sprinkler System Evaluation

Owner Name ________________________________ County_________________________

Mailing Address______________________________ Zip Code _______________________

Phone Number _________________________ Date ___________________________

Legal Description ______________________ Lat., Long. ___________________________

Equipment Information:

Sprinkler Pipeline/Gated Pipe Material ___________ Year Purchased ___________

Sprinkler Manufacturer _________________ Year Purchased ___________

Field Information:

Soil Textures, % or acres Clay _____ Silt _____ Loam _____ Fine Sand _____ Sand ______

Soil Slope Category, % or acres A ______ B ______ C ______ D _____ E ______ F _______

Tillage Practices ________________ Crop Residue Cover _____________

Surface Drains __________________ Surface Water Present YES _______ NO _______

Acres Irrigated __________________ GPM per Acre ____________

Crops Irrigated ____________________________________

Design Specifications:

Set Time __________ Sprinkler Flow Rate _______ Acres per Set _____________

Sprinkler Pressure ______________________ Sprinkler Spacing ______________________

Lateral Spacing ___________

Field Data:

Average Sprinkler Flow Rate ____________ Set Time, hrs ______

Delivery Line Flow Rate, gpm __________ Pipeline Velocity _________

Pressure Gauge Present: YES ________ NO ________

Leaky pipes: YES ________ NO ________

Sprinkler Pressure (Set 1), psi _____ Sprinkler Pressure (Last set), psi _______________

Catch Can Test Results CU _______ DU ________ (attach data sheets & calculations)

Pipeline Energy Evaluation

Owner Name ________________________________ County_________________________

Mailing Address______________________________ Zip Code _______________________

Phone Number ________________________ Date ___________________________

Legal Description ______________________ Lat., Long. ___________________________

Pump Information:

Pump Column Type OIL LUBED _______ WATER LUBED _________

Diameter of Pump Column, inches _______ Length of Pump Column, feet ___________

Flow Rate, gpm __________ Estimated Friction Loss, feet ____________

Delivery Line Information:

Pipeline material: PVC __________ Aluminum _____________ Steel __________________

Diameter of Pipeline, inches _____________ Length of Pipeline, feet _________________

Number of 90^o Elbows _________________ Number of Flow Through Tees __________

Number of 45^o Elbows _________________ Number of Butterfly valves _____________

Number of Directional Tee's ____________ Flow Rate, gpm __________

Estimated Friction Loss, feet ____________

Center Pivot Pipeline:

Pipeline material: Aluminum ___________ Steel _____________ Poly Lined ________

Diameter of Pipeline, inches ________ Length of Pipeline, feet _________________

Number of 90^o Elbows _________________ Number of Flow Through Tees __________

Number of 45^o Elbows _________________ Number of Butterfly Valves _____________

Number of Gate Valves ________________ Impeller Flow Meter ___________________

Chemigation Valve ______________ Flow Rate, gpm _______________________

Estimated Friction Loss, feet ____________

Field Data:

Field Elevation at Pump Outlet, feet ______ Field Elevation at Highest Point, feet _____

Pressure at Pipeline Inlet, psi ____________ Pressure at Distal End, psi ______________

Appendix B
Test Equipment and Specifications

Electric water level indicator (well sounder)

The water level indicator is used to find both static (non-pumping) and pumping water level in the well. The indicator, also known as an "electric sounder", works on the principle of electrical conductivity of water. The sounder uses a two-conductor cable with a weighted electrode on the end. When the electrode is immersed in the water, a circuit is completed and is indicated by a meter, digital display, light signal, or audible signal. The cable is marked along its length to indicate the distance to the water level. It may be necessary to interpolate readings between the cable markings to get an accurate water level.

Specifications:

The electric water level sensor should have:

300 to 500 feet of cable (more if deeper water levels are anticipated), extra cable should be available if needed

One or more weighted electrodes

Integral reel

Visual and/or audio sensor signal

Flexible and weighted sensing end

Suppliers:

Global WL500 Water Well Level Sounder w/400 foot cable ($850)

Solinist P@/N2/500ft (($1020)

Campbell Scientific Model CS450 Submersible Level Transmitter w/ 150 cable (±0.05% FS accuracy) $900

Tachometer

A tachometer is used to measure the speed (rpm) of pump and power unit. A non-contact optical tachometer is best for most conditions. A contact tachometer can be used to measure turbine pump and gear head speeds but may not be adaptable for engine drive shafts. The tachometer cannot be used to measure speed of submersible pumps since the pump is down the well. Use manufacturer's specifications for submersible pump speeds.

Specifications:

Operating range from 0 to 6000 rpm

Suppliers:

Shimpo Model DT-207LR-S12 ($350)

Electric meter

The electric energy use rate in kilowatts (KW) can be determined by using the existing utility or electric meter at the site. Modern utility meters are digital. Obtain instructions for reading the meter from the electric utility supplier using the correction factors and multiplier needed to determine power use.

Some electric utility companies have current and/or power transformers installed with their electric meters. This allows less current to flow through the meter. If they are used, observed power will need to be corrected to compensate for the transformer. If the observed power from the meter seems excessively low, check for the use of these transformers. Often the current transformer ratio (CTR) or the power transformer ratio (PTR) will be indicated on the meter face. If not, the utility should be consulted for the correct ratio. This ratio is multiplied by the observed power to determine the correct power.

KW = observed KW x CTR x PTR

If the electric meter is located an appreciable distance from the pump motor (>100 ft), the observed KW should be corrected for line loss. Consult the Pump Handbook article "Power Loss in Underground Electrical Feeders".

Although the utility meter is generally within ½ % accuracy, it can give erroneous readings. On electric pumping plants, a performance rating over 125% would indicate an error in measurement. A check on power using voltage and amperage should be made by a qualified electrician. Occasionally a wrong correction factor is listed or the meter has been damaged by a lightning strike. Seldom will a meter read high.

Reading:

Suppliers:

Handheld multimeters:

Biddle-Megger Model DCM340 Clampon/Multimeter ($190)
Fluke Model 337 TRMS AC/DC Clampon/Multimeter ($370)
B&K Precision Model 367A Clampon/Multimeter ($230)
Amprobe Model ACD-15 TRMS-PRO Clampon/Multimeter ($200)

Torque meter

A torque meter is required to measure the power output of internal combustion engines. It is attached to the output shaft of the engine and generally requires a specially made shaft kit to accommodate the meter mounting.

Specifications:

Operating range should exceed the largest engine that would be tested

Suppliers:

Honeywell Model 1228-10K (for up to 500 hp engines) w/connection cable ±1Hp ($5300)
Honeywell Model 1248-20K (for up to 900 hp engines)

PTO Shaft kits (Custom Made)

Series 41

30 inch hookup for 36 inch standard drive shaft
42 inch hookup for 48 inch standard drive shaft

Series 48

30 inch hookup for 36 inch standard drive shaft
42 inch hookup for 48 inch standard drive shaft

Series 55

30 inch hookup for 36 inch standard drive shaft
42 inch hookup for 48 inch standard drive shaft

Fuel flow meter

An accurate measurement of fuel flow is needed for liquid fueled engines. A coriolis type electronic meter is preferred. As an alternative, a system that weighs the fuel can be used.

Specifications:

Suppliers:

Coriolis Mass Flow Meter ($5700)
RH03-T1-P1-PMO-MO-A1-N
w/ RHE07-2-NN-N Transmitter
Purchased from: *Environmental Compliance Technologies, INC.*

120# portable scale w/ propane, diesel fuel, ethanol cans and connection hoses ($600)

Pressure gauge

Pressure gauges are used to measure the discharge pressure at the pump outlet. Pressure gauges may also be used to check system operating pressure. A vacuum gauge is used to measure the suction lift of a centrifugal pump.

Specifications:

Pressure gauges should be obtained with operating ranges of: 0 to 3 psi, 0 to 30 psi, 0 to 100 psi, and 0 to 200 psi, and -30 inches Hg to 0 vacuum.

Obtain high quality gauges, preferable liquid filled.

Alternatively, obtain a digital pressure gauge that has selectable ranges for the above pressures.

Fittings that adapt the pressure gauge port to other sized pipe openings.

Suppliers:

Manually read

Dwyer Model 7000B Spiralhelic Direct Drive Gauge ($150)

Pressure Transducer

Omega Model PX209-015G5V Pressure Transducer (0.25% FS) $200
Aschcroft Model G17M0242F2200 (±0.05% FS accuracy) $175
Dwyer Model 628-12-GH-P1-E4-S1 (± 1.0% FS) $134

Water flow meter

Water flow must be measured to evaluate the pump and system efficiency. An ultrasonic flow meter is preferred. A Collins type flow device may be used as an alternative. Flow must be measured in a section of the pipeline that has a uniform flow regime.

Specifications:

Flow measurement should be accurate to less than 1% error.

Suppliers:

Ultrasonic flow meter ($7250)

FUJI Portiflow-X, Model FUJI-FLCS1 Transit Time w/PC cable and software

w/ FUJI UFM 2 MHZ, Model FUJI-FLD12 Small diameter 2-16"

Model ST900-048 T-Mike Programmable wall thickness meter

Portable generator

A portable generator is needed where 110 volt power is not available at the site. The generator is used to operate power tools and some of the measuring equipment such as the torque meter. Many electric powered installations do not have 110 volt power available.

Specifications:

1.8 KW gasoline powered AC/DC generator

50 ft electric cord

DC/AC inverter 750 watt

Suppliers:

Data logger

A data logger can be used to record various electronic measurements used in the test on a more continuous basis. The torque sensor, fuel meter, tachometer, pressure transducer and water level indicator can be recorded using this transducer. In addition, weather variables such as barometric pressure, air temperature and humidity can be recorded using a data logger.

Supplier:

Campbell Scientific CR100 with enclosure ($1500)

Rugged laptop computer

A laptop computer can be used to query the data logger once per 5 minute interval to download the data recorded on a more frequent basis. In addition, the water meter readings can be saved directly to the computer during extended testing intervals.e

Miscellaneous tools

Hand tools

Full set of wrenches and sockets to 1.25 in

Full set of wrenches and sockets to 32mm

Cordless drill/driver combination (≥18V)

Assortment of drill bits up to ½ in to fit the drill

Channel lock pliers (several sizes)

Flat blade and Phillips screwdrivers (multiple sizes)

Pipe wrenches (multiple sizes)

Vise Grips
Hammers (claw and 3-pound)
Adjustable wrenches
Assorted punches
Assorted cold chisels
Assorted files
Thread tapping set
Hacksaw
Electric impact wrench

Other

Extension ladder to safely reach center pivot pipeline, at least 13 feet
30 in x 60 in table

Supplies

Assortment of small pipe fittings, bushings, couplings, tees, elbows, and valves in sizes from ¼ inch through 1 inch
Teflon tape or pipe compound
Penetrating lubricant
Rags/paper towels
Hand cleaner

Safety equipment

First Aid kit
Eye protection
Hearing protection
Electrical Safety Clothing and Gloves
Insect repellent
Tic-Tracer or electric current sensor
Rubber gloves
Rubber boots
Gloves

Tool storage and transport

A vehicle or trailer should be available for storing the equipment and transporting it to the field site. The unit should be vented to atmospheric pressure. A four-wheel drive van or pickup with a tool topper body is recommended to provide access to remote and wet field sites. The vehicle can also house a "porta potty".

Appendix C
Irrigation Systems and Equipment

Surface irrigation

Surface irrigation (gravity, flood) is the oldest form of irrigation. Surface irrigation distributes the water by moving it over the land surface. Water infiltrates into the soil as it moves over the land. Types of surface irrigation include:

- Furrow irrigation where water flows down furrows between crop rows (Figure B.1). The furrows should have a uniform, constant slope from the head to the tail end of the row.
- Border irrigation where water application is confined between raised soil borders. Borders have a constant slope from the head to the tail end of the field.
- Level border irrigation is similar to border except the field is level and water is confined on all four sides.

Figure B.1 - Gated pipe irrigating furrows.

Sprinkler irrigation

Sprinkler systems are used to meet a variety of objectives. Sprinkler irrigation systems may consist of an individual sprinkler or a group of sprinklers installed along a lateral pipeline. Sprinklers operating as a group must provide overlap among individual distribution patterns to produce uniform water application along the lateral pipeline and between lateral positions.

Depending on the type of installation, sprinkler systems are operated in one of the following ways:

- Remain stationary (solid set).
- Periodically moved by hand or mechanically (side roll or hand move).
- Continuously moved around a pivot in a circle (center pivot).
- Continuously moved along a closed or open water supply (linear move).
- Continuously moved along a travel lane (traveler).

Refer to Sprinkler Irrigation Systems for descriptions of sprinkler irrigation equipment.

Sprinkler system management

Each sprinkler system has advantages and disadvantages that best suit it for certain conditions, and management of the irrigation system should take advantage of the inherent features of the chosen sprinkler system. Design of the system uses the best information available to achieve the best results. Poor management can, however, accentuate undesirable features and result in unsatisfactory operation. No system can achieve the desired objectives if the operational management defeats the design of the system. Likewise, no level of management can correct faults in a design that renders the sprinkler system unsuitable for the site.

The design of the sprinkler system should minimize the potential for negative outcomes such as runoff, deep percolation, excessive evaporation, under-application, and excessive energy use. Fine-tuning of the operation is required to assure that the system functions as intended. Often modifications in operating procedure are needed to achieve high efficiency and uniformity. For example, if runoff occurs in areas of a center pivot system, it may be necessary to change tillage practices, add furrow dikes, or reduce the application depth.

It is good practice not to fill the soil profile completely with water at each application. Leaving some capacity to store rain fall often reduces the total seasonal water required and the potential for leaching of water and nutrients below the root zone. Because of limited soil water-holding capacity, some very sandy soils may not allow the flexibility of reserving soil water storage for rainfall.

Some areas with low-capacity water supplies may preclude full irrigation. Deficit irrigation may change the management scheme of the irrigation system. Maximizing the application efficiency may dominate the operation.

Whenever possible, operate the sprinkler system during favorable periods such as when winds speeds are low and evaporation potential is minimal. This is especially important for high-pressure sprinkler systems such as travelers or high-pressure center-pivots. Most sprinkler irrigation designs, however, require full-time operation during periods when water use is high and rainfall is lacking.

Sprinklers that malfunction along with normal wear and tear on the nozzles cause the system water application uniformity to decrease with time. Systems that pump sand or have poor quality water will have the most severe declines in water application uniformity over time. A good management practice is to walk beside the system while it is operating to verify that each sprinkler is functioning. Some nozzles may be partially plugged with debris. Walking beside the system closely enough to view the operation of each sprinkler or nozzle will help identify these problems. Encourage the owner to monitor and record operating pressure during the season and from year to year to spot potential problems early. Lower than normal pressure or consistent sand deposits in the trap at the end of the system could indicate well and pump problems.

Center pivot

Center pivots are the most popular and widely used irrigation today (Figure B.2). The center pivot is a self-propelled moving system that rotates around a center or pivot point. Center pivots are adapted to meet many field sizes, shapes, soils, terrain, and management objectives.

Figure B.2 - Center pivot sprinkler irrigation system.

A center pivot making a complete circle irrigates an area equal to the area of a circle with a radius equal to the wetted length of the system. Towers support the lateral pipeline and structure and are driven by electric or hydraulic motors on two or more wheels. Moving away from the pivot point, each tower must travel a greater distance to make a revolution. Likewise, each section of the machine going outward from the center irrigates more acres. Thus, more water must be discharged in outer sections of the pivot lateral. Combining the increasing number of irrigated acres with a decreasing amount of application time means that the outer portions of the system have the greatest water application rate.

The pivot lateral pipelines can be a variety of sizes with most systems either 6- or 6 5/8-inch pipe. The most common center pivot systems operate on quarter-section sized square fields irrigating 125 to 130 acres. Corner units are optional attachments to the end of the center pivot lateral to irrigate a larger portion of the corners or to avoid obstacles at field edges.

The operating pressure for the center pivot system must consider the friction loss in the pivot lateral, elevation changes, and the required pressure for the sprinklers at the outer end of the lateral. Water is discharged along the center pivot lateral with most water discharged at the outer sections because most of the land area is covered under them. However, friction loss is less than if all the water were discharged from the end. Friction loss in the center pivot lateral can be estimated by taking 54% of an equivalent length of pipeline with all the discharge at the end. A typical 1,300-foot center pivot will have a friction loss of 8 to 15 psi.

The outside tower controls the speed of the system. A system of alignment controls keeps the other towers in line between the end tower and the pivot point. The water application rate for the system is governed by the length of the lateral (area covered) and the sprinkler package type. The depth of water application is based on the water application rate and the revolution time. The water application rate for the center pivot is the same for a given flow rate regardless of rotation speed.

A center pivot sprinkler package must match sprinkler operating characteristics with the field conditions. A vast array of different types and configurations of sprinkler packages is available to meet different goals. A detailed discussion of sprinkler characteristics is presented in Chapter 5 of Sprinkler Irrigation Systems. Refer to Center Pivot Irrigation Management Handbook for a detailed discussion of center pivot sprinkler packages and their application. Field-based information is required to accurately select a sprinkler package. Failure to collect and evaluate key field information could result in an inefficient irrigation system. Soil survey information showing soil mapping units is available from the Natural Resources Conservation Service.

Center pivot systems often use a large volume sprinkler (end gun) at the far end of the pivot to help irrigate more area in the corners of a field. On low-pressure systems, an auxiliary pump is used to boost the water pressure to the end gun by 20 to 40 psi. This may require up to a 5 BHP (brake horsepower) booster pump. The uniformity of application under this unit usually will be much less than that under the main lateral sprinklers. Wind and the angle of the gun rotation can influence water application significantly.

Most center pivots are designed to apply water with an application uniformity of 90% or greater. Sprinklers that malfunction and normal wear on the nozzles may cause the application uniformity of the system to decrease with time. If possible, check each nozzle for correct nozzle size and position against the computer printout provided when the system was new. Watch the system respond when filling the lateral line at startup. Water may be entering the system too rapidly if the system flexes up and down or jolts when water reaches the end. This symptom indicates water hammer in the pipeline. Systems with long delivery pipelines are most susceptible to water hammer problems. A throttling valve at the pump or a gradual increase in pump speed will help reduce the potential for water hammer problems.

Be sure safety features such as pressure relief valves, automatic pressure shutoffs, engine monitoring switches, vacuum relief valves, and chemigation safety equipment are installed and working properly. Closely follow manufacturers' recommendations for maintenance, and make any needed repairs. The system should be equipped with safety shutoffs to stop the pump and pivot operation due to low pressure conditions, and if the pivot lateral ceases to move for an extended time. Provisions for shutting off an end gun along field boundaries are required.

Linear move

The linear-move system is mechanically similar to the center pivot, but instead of traveling in a circle, the system travels in a straight line across the field (Figure B.3). Water can be fed into any point along the system but usually is at an end or the center. Some systems follow a ditch and take water directly from the ditch while others are supplied by a hose supplied by a buried mainline with risers. Linear-move systems generally have their own power source mounted at the main drive tower. If water is obtained from an open ditch, a motorized pump is mounted at the drive tower.

Figure B.3 - Linear move sprinkling system with drop nozzles.

Linear-move systems can have as few as two towers, or they can have multiple towers that can cover more than 300 acres. Some linear systems are towable so they can irrigate more than one field. They also can be fixed on one end and pivoted wet or dry to move them to a second side of a field.

The linear system is best suited to rectangular or L-shaped fields with a length/width ratio of at least 2:1; that is, the lateral travel distance is more than twice the irrigation lateral length. The system is not well adapted to fields with extreme rolling terrain because it can cause alignment problems.

The drive mechanisms can be electric or hydraulic motors at each tower which are generally powered by an engine mounted on the machine. A power unit for the water pump also may be needed. Linear-moves have a guidance system to maintain the direction of travel which can be a buried cable, a groove in the soil or a GPS.

Many sprinkler packages are available with sprinklers and mounting configurations similar to those on center pivots. Sprinklers on linear moves are the same size throughout the length of the system. The water application rate (unlike the rate with a center pivot) generally quite low and is the same from one end to the other.

Pipe size on linear systems depends on the system's capacity and lateral length. A center-feed system can use smaller diameter lateral pipe than an end-feed system of the same capacity and length due to the lower friction loss in the center-feed. Calculated friction losses are similar to those in solid set and hand move laterals rather than those with center pivots.

Evaluation of linear moves that use a water supply ditch will present different issues because of the traveling power unit along with the possibility of multiple power units.

For flexible-hose systems, select a hose diameter that minimizes friction losses. With flexible hoses, the length traveled will be about twice the length of the hose. Hoses may be any reasonable length depending on system capacity. Larger systems may use two hoses. Water is supplied to the hoses with buried pipe and appropriately sized risers. If the hose is too long, friction loss can be excessive, and the drive tower may have difficulty pulling the hose. For those reasons, a shorter hose may be used with risers spaced more closely.

When the system completes a pass across the field, the machine should return to the starting point prior to beginning another water application event. This travel scheme should be minimize wheel tracks and uneven watering. Irrigations should be scheduled to avoid exceeding the allowable soil water deficit and to prevent over-watering that can leach nutrients.

The alignment controls and safety shutoffs for linear systems are similar to those for center pivots. Usually, the two outside towers control the travel speed of the linear system. They travel at a preset speed, and an alignment system on each tower keeps each tower in line. The guidance system overrides the preset speed to alter the speed of one end tower versus the other as necessary to maintain the alignment.

Traveling Gun

Traveler systems use a large volume sprinkler with a nozzle mounted on a cart that travels along a lane across the field (Figure B.4). Travelers are available in many nozzle sizes that discharge from less than 25 gpm to more than 500 gpm. All travelers require relatively high pressure with operating at pressures of 60 to 120 psi. Thus, travelers use more energy for pumping than other systems.

A traveler can be used on a variety of crops, field sizes, and shapes. A traveler irrigation system consists of five components:

1. A large-volume gun sprinkler.
2. A cart for the sprinkler.
3. A hose.
4. A reel to hold the hose.
5. A drive system.

It works best on long, level fields with straight rows. However, they are popular because of their flexibility to cover irregular shaped fields not suitable for center pivots. Travelers are portable and can be move between fields.

The most common traveler is the hose-tow type that uses a hard polyethylene hose mounted on a hose reel trailer. The hose supplies water to the sprinkler and also pulls the sprinkler through the field. The hose reel is stationary during an irrigation run. The reel is powered by a water turbine or auxiliary engine to wind the hose. Any length of hose can be unrolled to irrigate varying lane lengths. Hose lengths are generally less than 600 ft to minimize friction losses.

The large volume sprinklers can cover wetted diameters from 100 to 550 ft. To achieve adequate uniformity, travel lanes are spaced at 50 to 60% of the sprinkler wetted diameter.

Refer to MWPS 30 Sprinkler Irrigation Systems for more information on traveling guns.

Figure B.4 - Traveling gun carriage and cart.

Solid set

A solid-set system has sprinklers and complete pipe system covering an entire field (Figure B.5). Because of the high cost, solid-set systems normally are used on high-value crops. Many systems are designed to be multipurpose, supplying irrigation, frost protection, crop cooling, or chemical application. Solid set irrigation can be used to irrigate the entire field at one time or sequenced through multiple sets covering portions of the field.

Solid-set systems typically use low output sprinklers to give application rates of 0.20 inch per hour or less. Pipeline sizes should optimize lateral line sizes to minimize friction loss while, at the same time, minimizing costs. Pipeline size should be selected to limit friction loss to less than 20% of the sprinkler design pressure. For example, for a 50 psi sprinkler, limit the pressure difference between the first and last sprinkler on the line to 10 psi (0.2 x 50). Many times it may be possible to lay out the mainlines and laterals so that friction losses are equalized throughout the system.

Figure B.5 - Solid set sprinkler system.

Hand move

Hand move systems irrigate one section of a field using movable pipe and sprinklers. Then the pipe and sprinklers are moved to another set of the field. Sprinkler size and placement are similar to solid set; however, some hand move systems use large gun sprinklers. Lateral pipelines can use various materials including aluminum, PVC, and polyethylene. Hand move systems have a low initial investment for smaller irrigation operations, but are more labor intensive compared to the solid set, center pivots or linear systems.

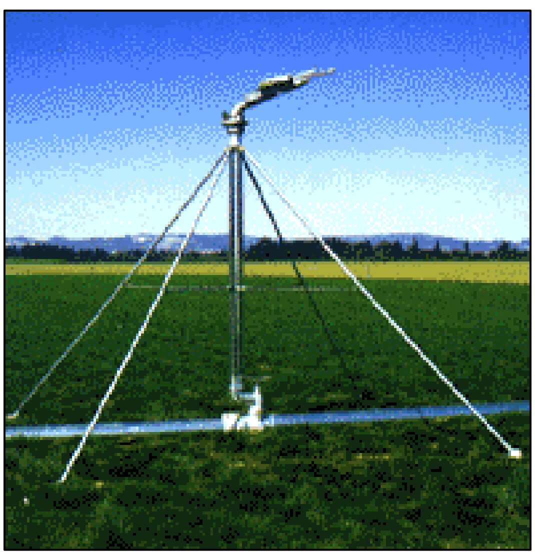
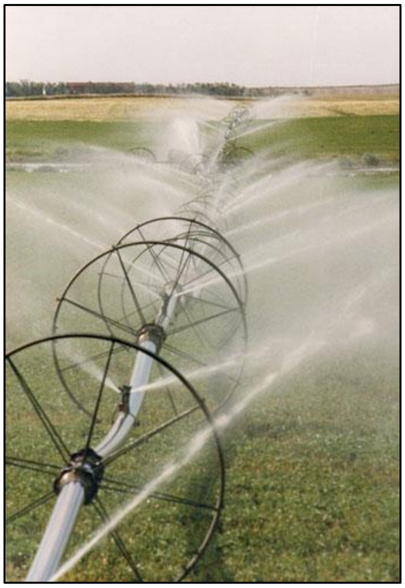


Figure B.6 - Hand move big gun sprinkler.

Hand-move systems often are designed for one to three moves per day. Hand-move pipe is impractical to use on large areas or with tall crops such as corn. Since the system can irrigate with a variety of sprinklers and spacings, it can be designed to meet almost any field shape and requirement, including soil intake rate and topography.

Side roll



Side roll (wheel move) uses an aluminum pipe as the axle for a number of wheels. The system is stationary while irrigating one set. Then the lateral is rolled sideways to the next set, sequencing in that fashion across the field. The wheels are spaced 30 to 40 feet apart with the sprinklers midway between the wheels. Wheels are available in diameters ranging from 4 to 10 feet to provide clearance for different crop heights. Normally, an engine mounted on a driver unit moves the lateral.

Side rolls can be used on any low-growing crop such as vegetables, potatoes, soybeans, forage crops, sod, and cereal grains. They are best suited to relatively level fields that are square or rectangular. Rolling topography makes alignment difficult. Sprinkler and lateral spacing should be carefully chosen to ensure an efficient water distribution.

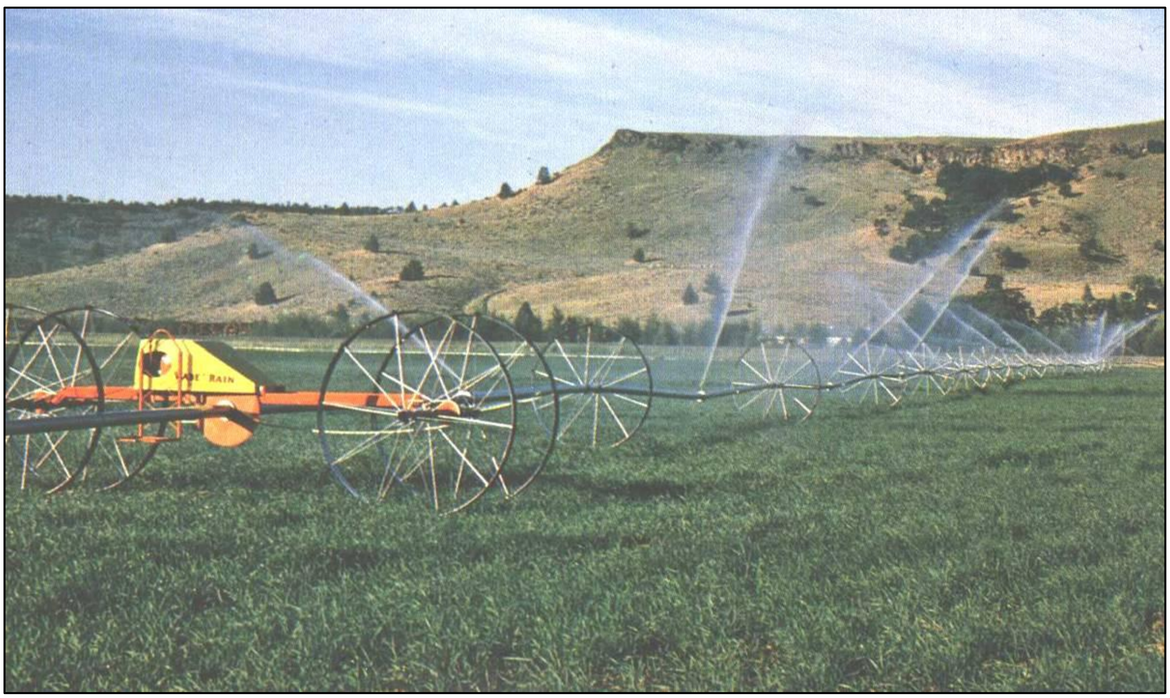


Figure B.7 - Side roll sprinkler system.

Drip and micro irrigation

Drip (trickle) irrigation involves placing small tubes along and near plant rows. Small emitters are mounted along the tube to deliver water to the plants. Drip irrigation is, by design, low flow and low pressure. Figure B.8 illustrates the layout of a drip irrigation system. The laterals are tubes or tapes that are attached to a manifold. The manifold, in turn, is fed by a mainline that receives water from the pumping station. The pumping station includes pumps, power units, filters, and the necessary piping and fittings to plumb the system.

Emitter flow rate is generally between 0.4 – 2 gallons per hour (gph). Water used in drip and microspray irrigation must be clean, without debris that could clog the emitters. Filters are used to prevent clogging, and chemigation is used to prevent bacterial growth from plugging emitters as well.

Drip irrigation is very efficient since evaporation is low and uncropped areas do not receive water. Drip irrigation is often used in specialty crops like potatoes, broccoli, lettuce, peppers, melons and other vegetables or in fruit, tree and vine crops. Drip lines can either be used for a single season or installed for multiseason use.

Advantages

1) Useful on steep terrain
2) High uniformity with excellent maintenance and design.
3) Systems are versatile and can be used on varying field shapes and size.
4) Runoff is not an issue but can be if over watered.
5) Fertilizers can be applied evenly to the plant roots without having to wet foliage.
6) The root zone can be kept moist which allows improved uptake of important nutrients that are concentrated at the soil surface.

Disadvantages

1) Evaporation and wind can be an issue for microsprays that cover large areas.
2) Du can decrease quickly if proper maintenance and use are not performed.
3) Water availability must be reliable unless groundwater is used to supplement.
4) Initial installation energy and operation costs are higher in drip/microspray. However, energy is saved over time if the system efficiency is high, fertilizer application can be reduced, and yields can improve.
5) Salts can build up at the soil surface under drip/microsprays. Sprinkler irrigation may be needed every few years to flush out the excess salts.

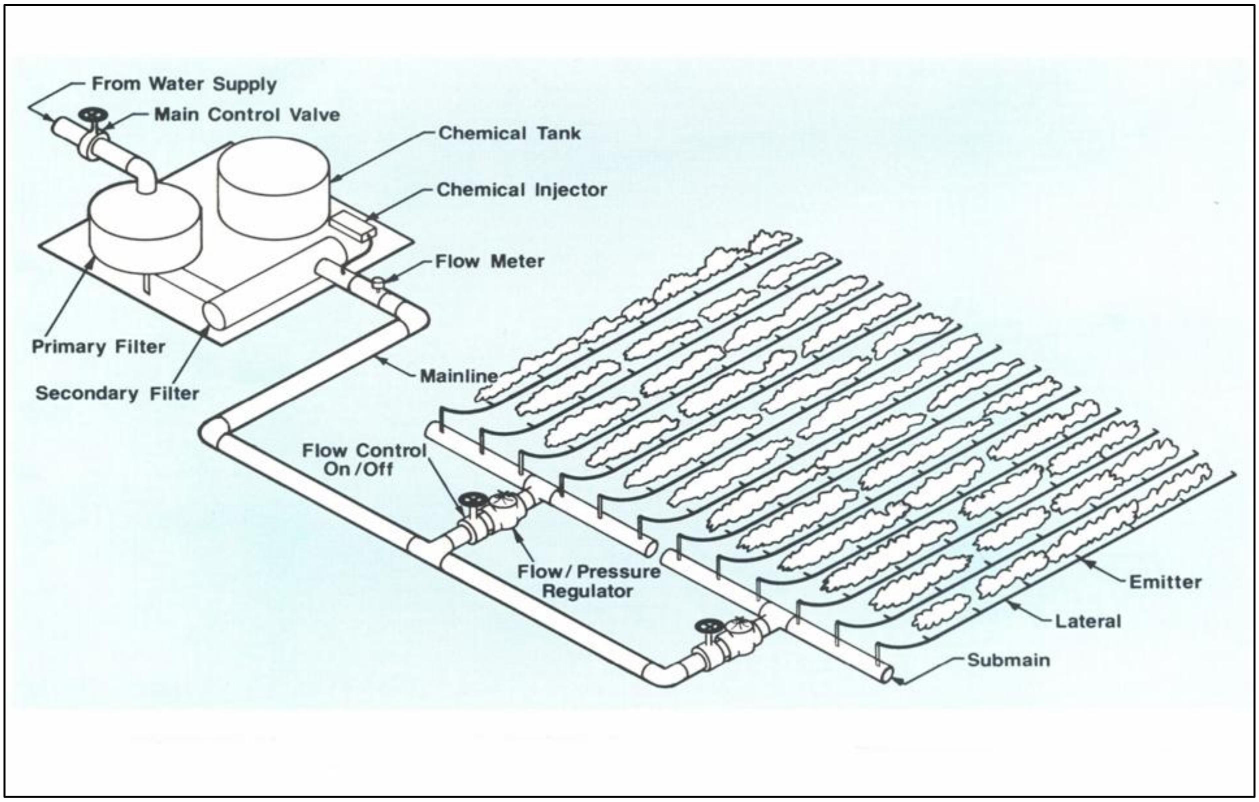


Figure B.8 - Layout of drip irrigation system.

Microspray/Microsprinklers are small sprays that are installed near the target crop. This type of system is used in crops that have shallow roots covering a large area or plants that are spaced far apart, such as walnut trees, because the sprays cover a larger area compared to drip.

Figure B.9 - A microspray system placed close to a tree.

Appendix D
Irrigation Water Management

Irrigation water management involves monitoring soil water conditions, determining crop water needs, and scheduling irrigations to maximize water use efficiency while minimizing water losses. Irrigation water management requires timely application of the right amount of water. Competition for water, high pumping costs, and concerns for the environment are making good water management more important.

Center Pivot Irrigation Management Handbook is a comprehensive resource for irrigation water management. Contact the University of Nebraska – Lincoln and Michigan State University Extension for more information and assistance or look for educational information on the internet at: http://water.unl.edu/web/cropswater/home

Soil water

Measuring soil water detects if there is a water shortage that can reduce yields or if there is excessive water application that can result in water logging or leaching of nitrates below the root zone. Measuring soil water also can build an awareness and knowledge of each irrigated field that is invaluable for planning and management.

Monitoring soil water levels is required for effective irrigation water management since every year provides different growing conditions for the crop. Many tried and proven methods of estimating or measuring soil water are available. The method selected depends on a variety of factors such as accuracy, cost, and ease of use.

Soil water concepts and terms

Soil water levels can be expressed in terms of soil water content or soil water potential (tension). Soil water content most commonly is expressed as percent water by weight, percent water by volume, or inches of water per foot of soil. Other units such as inches of water per inch of soil also are used.

Water content by weight is determined by dividing the weight of water in the soil by the dry weight of the soil. It can be converted to percent by multiplying by 100%. Water content by volume is obtained by multiplying the water content by weight by the bulk density of the soil. Bulk density of the soil is the relative weight of the dry soil to the weight of an equal volume of water. Bulk density for typical soils usually varies between 1.5 and 1.6. Inches of water per foot of soil is obtained by multiplying the water content by volume by 12 inches per foot. It also can be expressed as inches of water per inch of soil which is equivalent to the water content by volume. By determining this value for each layer of soil, the total water in the soil profile can be estimated.

Soil water potential describes how tightly the water is held in the soil. Soil tension is another term used to describe soil water potential. It is an indicator of how hard a plant must work to get water from the soil. The drier the soil, the greater the soil water potential and the harder it is to extract water from the soil. To convert from soil water potential to soil water content requires information on soil water versus soil tension that is available for many soils.

Water in the soil is classified as either available or unavailable water. Available water is defined as the water held in the soil between field capacity and wilting point (Figure D.1). Field capacity is the point at which the gravitational or easily drained water has drained from the soil. Traditionally, it has been considered as 1/3 bar tension. However, field capacity for many irrigated soils is approximately 1/10 bar tension. Wilting point is the soil water content where most plants would experience permanent wilting and is considered to occur at approximately 15 bars tension.

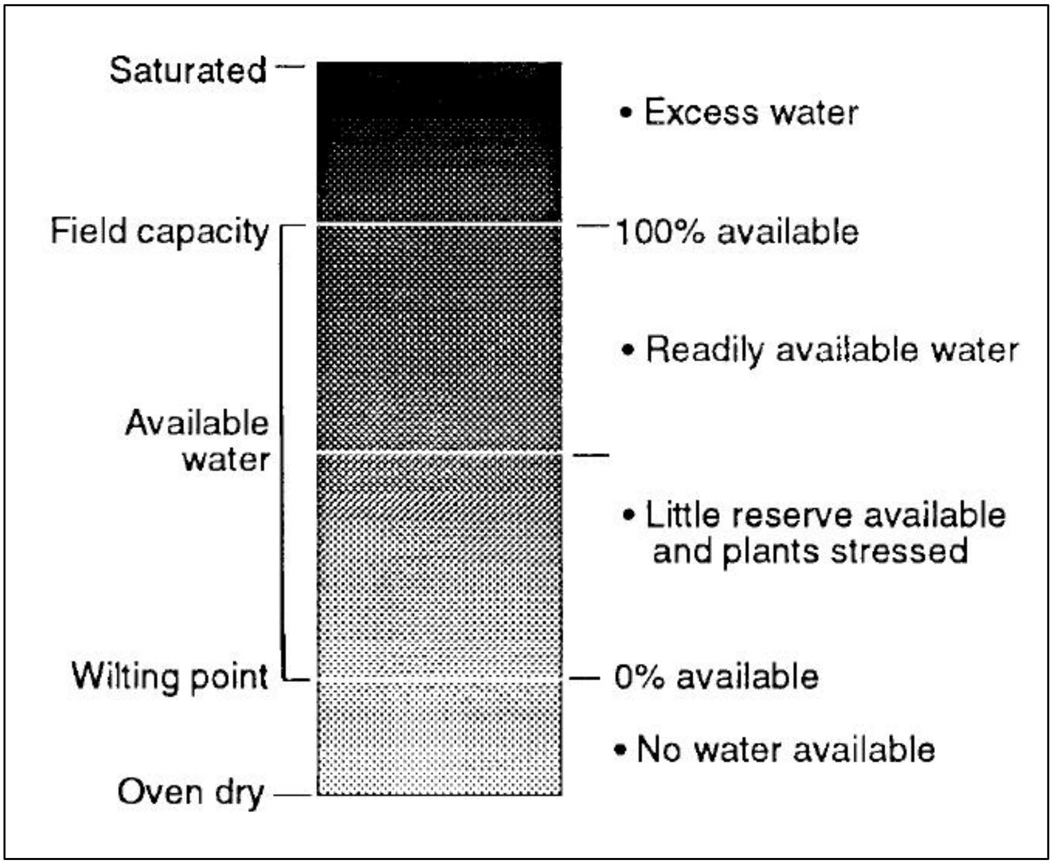


Figure D.1 - Soil water levels.

Table D.1 gives common ranges of available water for soil textures. Readily available water is that portion of the available water that is relatively easy for a plant to use. It is common to consider about 50% of the available water as readily available water. Even though all of the available water can be used by the plant, the closer the soil is to the wilting point, the harder it is for the plant to use the water. Plant stress and yield loss are possible after the readily available water has been depleted.

Table D.1 – Available soil water.

Soil Texture	Inches of Available Water per foot
Fine sands	0.7-1.0
Loamy sands	0.9-1.5
Sandy loams	1.3-1.8
Loams	1.8-2.5
Silt loams	1.8-2.6
Clay loams	1.8-2.5
Clays	1.8-2.4

Methods of measuring soil water

Soil water can be measures or estimated in a variety of ways ranging from the simple, low cost hand-feel method to more accurate and expensive neutron probe units. For most irrigation water management applications, even a low cost, economical method is better than entirely foregoing soil water measurement.

Electrical resistance blocks: A meter is used to read the electrical resistance blocks installed in the ground. The blocks come in a variety of configurations with two electrodes imbedded in a porous material. Meters are generally portable and are intended for use in reading a large number of blocks throughout one or more fields. More recently, various automated systems are being used to monitor blocks in the field.

Water moves in and out of the block in equilibrium with the soil water content. Meter resistance readings change as water in the block changes which, in turn, is an indication of changes in the amount of water in the soil. The manufacturer usually provides calibration to convert meter readings to soil tension or soil water potential.

Proper installation is important for reliable readings. Good soil contact with the block is essential. Follow manufacturer's and Extension Service guidelines for installation and use of the blocks and reading equipment.

Resistance methods are suitable for most soils, and the readings cover most of the soil water ranges of concern to irrigation management. Gypsum blocks tend to deteriorate over time, and it may be best to use them for only one season. Problems may occur with highly sandy, acid or saline soils.

A widely used version of an electrical resistance block is the Watermark Sensor. These sensors measure soil water potential indirectly through electrical resistance between two electrodes, similar to gypsum blocks. However, Watermark Sensors use a granular matrix similar to fine sand with a porous ceramic external shell, surrounded with a synthetic membrane to protect against deterioration. The matrix includes some gypsum to act as a buffering agent is soils with low pH. The Watermark Sensors can be read by a handheld meter, or connected to a data logger for continuous measurement and remote sensing.

Tensiometers: Tensiometers are a sealed, water-filled tube with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. The tensiometer is filled with water and the porous tip is buried in the soil to the desired depth (Figure D.2). Tensiometers have been called mechanical roots since they provide an indication of how hard it is for the plant to get water from the soil.

Tensiometers measure soil water potential or tension. Water in the tensiometer will come to equilibrium with water in the soil. Readings are an indication of the availability of water in the soil. Readings are in centibars (1/100 of a bar). A reading of 100 is equal to 1 bar of tension. Tensiometers generally are effective only at less than 85 centibars of tension, because the partial vacuum will be broken allowing air to enter the ceramic tip or the water in the tube separates. The usable range from 0 to 85 centibars, however, is the most important range for irrigation management of the more sandy soil textures.

Properly installed and maintained, the tensiometer provides an accurate measurement of soil tension. It is not suitable where soil tension routinely exceeds 85 centibars. Even though portable units are available, tensiometers are normally planted or installed at one location for the duration of the irrigation season. Tensiometers do not directly give readings of soil water content. To obtain soil water content, a water release curve (water content versus soil tension) is needed.

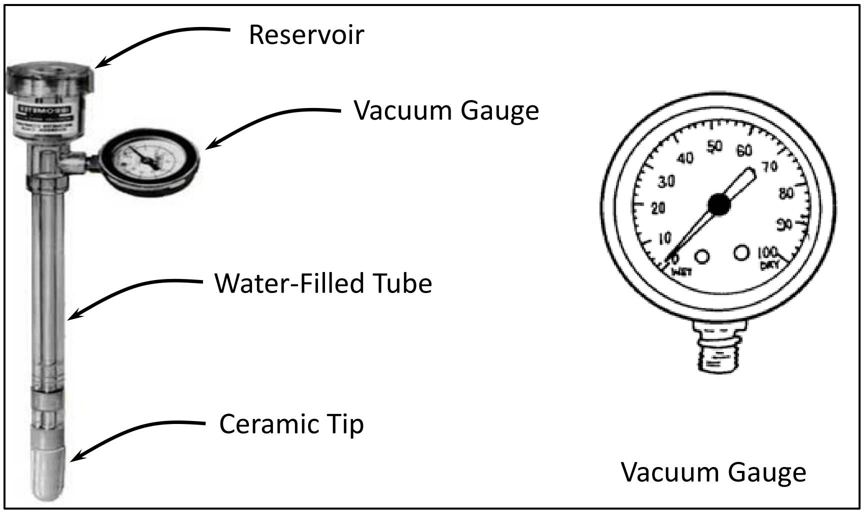


Figure D.2 - Tensiometer.

Probe and hand-feel method: A soil probe is used to sample the soil profile. Soil water content is evaluated by feeling the soil with your hand by squeezing the soil between your thumb and forefinger. Then a chart is used to judge relative water content levels. One benefit of the hand-feel method is that numerous and different locations throughout the field as well as several depths in the soil profile can be sampled during each visit to the field.

This method is only an estimate and lacks scientific basis. Accurate measurement is not possible, but rather the method is an art developed over time with extensive use. Another measurement method is really needed as a reference, especially during the learning period.

The feel method requires no investment other than a soil probe. Effective use, however, does require more time and judgment than other, more quantitative methods.

Time domain reflectometry (TDR): TDR is a newer technology based on sensing the dielectric constant of the soil which is dependent on the soil water content. The equipment consists of an electronic meter connected to two rods placed into the ground. The instrument sends an electrical signal through the soil and the rods serve as the transmitter and receiver. Both portable and fixed units are available.

Capacitance probes: Capacitance probes are installed into tubes in the ground. The nonradioactive probe can be fixed or portable. An electronic meter senses the amount of water in the soil based on its electrical properties.

Gravimetric sampling: Sampling and drying involves collecting soil samples from various depths and locations in the field. Weights of the wet samples are recorded, the samples are oven dried, and dry weights are recorded. This provides values of soil water content by weight. Available soil water and soil tension can be determined if water release information and bulk density are known for the soil. This method gives an accurate measurement of soil water and is the basis by which all other methods are calibrated. It does not provide immediate feedback of soil water content, it is time consuming, and it can be messy.

Neutron probe: The neutron probe is an electronic instrument with a radioactive source that is lowered into an access tube installed in the soil. The neutron probe indicates soil water by detecting hydrogen in soil water. A counter reads the number of neutrons that are reflected by the hydrogen in the soil. This number is then used to calculate the soil water content. Neutron probes require special licensing and training. The equipment is also expensive.

Portable Measuring Devices: Several types are available for estimating soil water content. Most have electronic meters and use either resistance or capacitance technology. Some use the same principle as a tensiometer. Portable soil water probes serve much the same purpose as the hand-feel method. They provide the flexibility of being able to sample many locations throughout the field. They may be most useful in providing relative readings of soil water content within or between fields rather than providing an accurate measurement of soil water. Another method such as tensiometers or resistance blocks is needed as a reference to calibrate the instruments.

Field installation of soil water sensors

To best determine soil water conditions for the full soil profile, place sensors at multiple depths in the root zone. For soils without restrictive layers, about 70% of the roots are in the top 50% of the root zone. Table D.2 gives normal rooting depths for common crops. These are the rooting depths for mature crops. Root development progresses at a similar rate to top growth. Install sensors early enough in the season to make them useful for scheduling any irrigation. Install at least two sensors at each site except for shallow-rooted crops or shallow soil underlain by gravel. Place the sensors at 1/3 and 2/3 of the crop rooting depth. For example, with corn, sensors would be placed at about 12 to 18 inches and 24 to 36 inches.

Use the shallow sensor to judge when to start irrigating. Use the deep sensor to determine how much water to apply. If readings of the deep sensor rise faster than the shallow sensor, apply more water with each irrigation. If readings of the deep sensor remain wet, then there is more chance for deep percolation of water and nutrients. For row crops, place the sensors between plants in the row. Avoid locations where field or irrigation equipment could damage the sensors. Select a uniform area and make an effort not to disturb or compact the soil near the sensors.

Identify the depth of the sensors to insure correct recording by the person reading them during the season. Mark the locations well using flags and/or stakes. When using blocks, identify the lead wires and attach them to the stake.

Table D.2 – Crop rooting depths.

Crop	Rooting Depth Feet
Corn	4-6
Alfalfa	2-3
Soybean	2-3
Potato	3-4
Field Beans	2-4
Sugar Beets	2-4
Pasture	1-2
Sorghum	3-4
Turf	1
Annual vegetables	1-2
Small fruits	1-2
Asparagus	2-3

Select at least two sites in each field (four is preferable), one near the start of the irrigation cycle and one near the end of the irrigation cycle. Use two sites for each crop where more than one crop is in the same field. Where there is more than one soil texture, place sensors in the dominant soil textures. Avoid locations that are low areas, tops of hills, beneath the coverage of the end gun of a center pivot, under the first tower of a center pivot, near the edges of fields that may get uneven irrigation, or any other area that is not representative of the field.

Put each sensor site where it will be accessible from a road or trail. It is very important to place sensors where they can be found easily for reading, especially as the crop matures. Put markers or flags in the row and on the side of the held. Reduce foot traffic around the sensors to minimize soil compaction. Do not locate the sites too far from field roads so that extra effort is required to find and read the instruments.

Scheduling with Soil Water Instruments

Soil water measurement is an integral part of any irrigation scheduling program. Soil water readings can be used by themselves to schedule irrigations, but they are most valuable when used in combination with other methods of scheduling such as a simple checkbook method or a computer model. Soil water readings can determine initial soil water balances and update those balances throughout the irrigation season.

Where the soil water readings are the basis for scheduling irrigations, take readings at least once every two days. Where the readings are used to update other scheduling methods, reading once or twice per week may suffice. Record all readings (Figure 6). The soil water readings, along with rainfall and irrigation amounts and crop condition, can help in management and future planning.

Soil water instruments measure current water levels in the soil and cannot predict future readings. It is possible for soil water readings to change rapidly during high water-use periods, from one day to the next, for example. Crop water use can be especially high on hot, windy days. Unless all of the field can be irrigated in one day, start irrigations before the sensors call for water.

Use soil water readings to schedule irrigation so the irrigation cycle can be completed before crop stress occurs. Table 3 gives guidelines for irrigating using tensiometers and resistance blocks. Starting irrigations early is important during periods of high water use or critical growth stages to prevent excessive depletion of the soil water reserve. Since most irrigation systems do not have enough pumping capacity to keep up during times of high water use, the soil water reserve helps get through those periods.

During periods of lower water use and after rainfall, it is especially important to monitor the soil sensors. Stop irrigation when both the shallow and deep readings indicate the soil water is near field capacity. Because crop demands and sensitivity to water stress are often lower early and late in the season, it may be possible to deplete more soil water at those times without loss of crop yield. This will allow more effective use of rainfall and minimize leaching of chemicals and nutrients below the root zone. Irrigation water application may be terminated after it is determined that adequate soil water reserves are available for the crop to mature.

Crop Water Use

An understanding of crop water use and the factors affecting it is important to irrigation water management. We need to know why crops use water and what factors affect the rate of water use. Knowing crop water use for the crop helps manage the irrigation system accordingly.

Evapotranspiration (ET)

Evapotranspiration (ET) for a crop is the transfer of water in the form of water vapor from crop surface to the atmosphere. There are two components to ET: evaporation from the soil or plant leaves and transpiration from plants. During transpiration, water is taken up from the roots of the plant and moved to the leaves. Small openings in the leaf tissue called stomata allow water vapor to pass from the plant to the atmosphere. The transpiration of water cools the plant and maintains the productivity of photosynthesis. This results in a direct relationship between transpiration and yield. Although we are mainly concerned with transpiration, it is difficult to separate it from evaporation so the two components are often measured or calculated together.

Since the primary reason for transpiration is to cool the plant, it is to be expected that climatic conditions are the driving forces behind the rate at which plants transpire. Air temperature and solar radiation are the two primary factors in the rate at which transpiration occurs. As air temperature and solar radiation increase, so does transpiration. Wind speed and humidity also affect ET. Other factors that affect ET include soil water availability, crop type and stage, irrigation regime, and tillage practices.

Leaving crop residue can have a significant effect on evaporation of water from the soil surface. In a University of Nebraska study, it was found that in plots with residue removed it would take 1.5-2.5 inches more of irrigation to achieve the same yield as plots with residue on the surface. Also, at the end of the growing season, the plots with residue on the surface contained 1.5 inches more water in the top 4 feet of soil than the bare plots. This means that the residue on the soil surface could save 3-4 inches of irrigation compared to bare soil.

Calculating ET involves collecting detailed weather data including solar radiation, air temperature, wind and humidity. Water use of a crop in a specific field is difficult to calculate. Automatic recording weather stations are used throughout much of the irrigated regions to provide data for calculating ET. A more simple method for measuring crop ET uses an atmometer.

Irrigation Scheduling

Irrigation scheduling is the process of meeting the crop needs for water with irrigation while making the best use of rainfall. Keeping a water balance for the soil involves subtracting crop water use and adding water from rainfall and irrigation. Then projections of future water use are used to plan and manage irrigation applications.

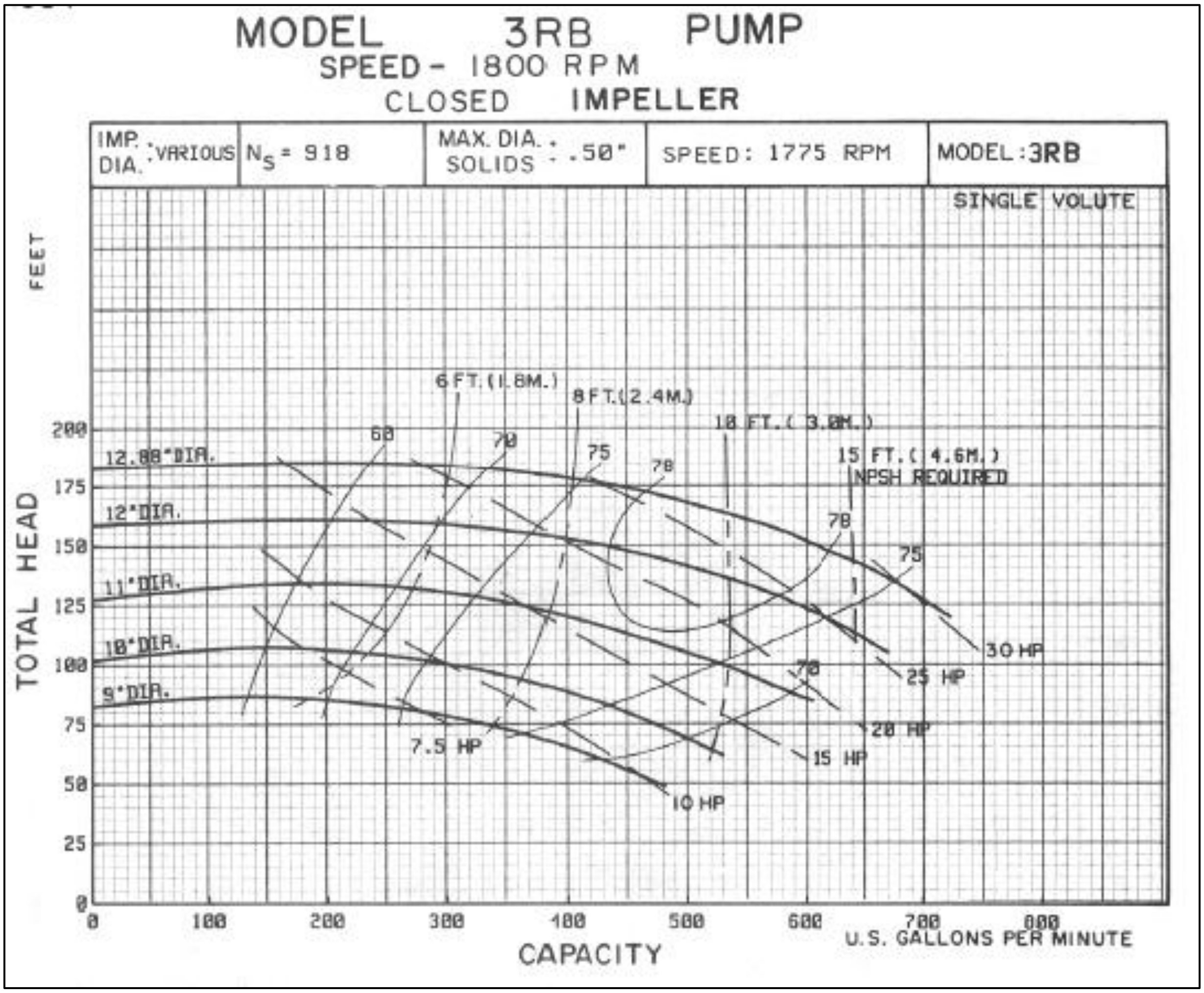
A variety of methods are used to schedule irrigations including keeping a log of the soil water balances similar to a checkbook or using a computer spreadsheet for record keeping. Some producers have detailed computer software to gather data, calculate ET, and project future irrigation needs. Still others contract with consultants to handle the task of irrigation scheduling. The important thing is that a method be used and records kept. This enables optimizing use of the water and energy resources. Irrigation scheduling can help conserve water and energy, minimize pollution of surface and ground water, and produce optimum crop yields. Efficient scheduling of irrigation water applications gives the highest return for the least amount of pumping dollars.

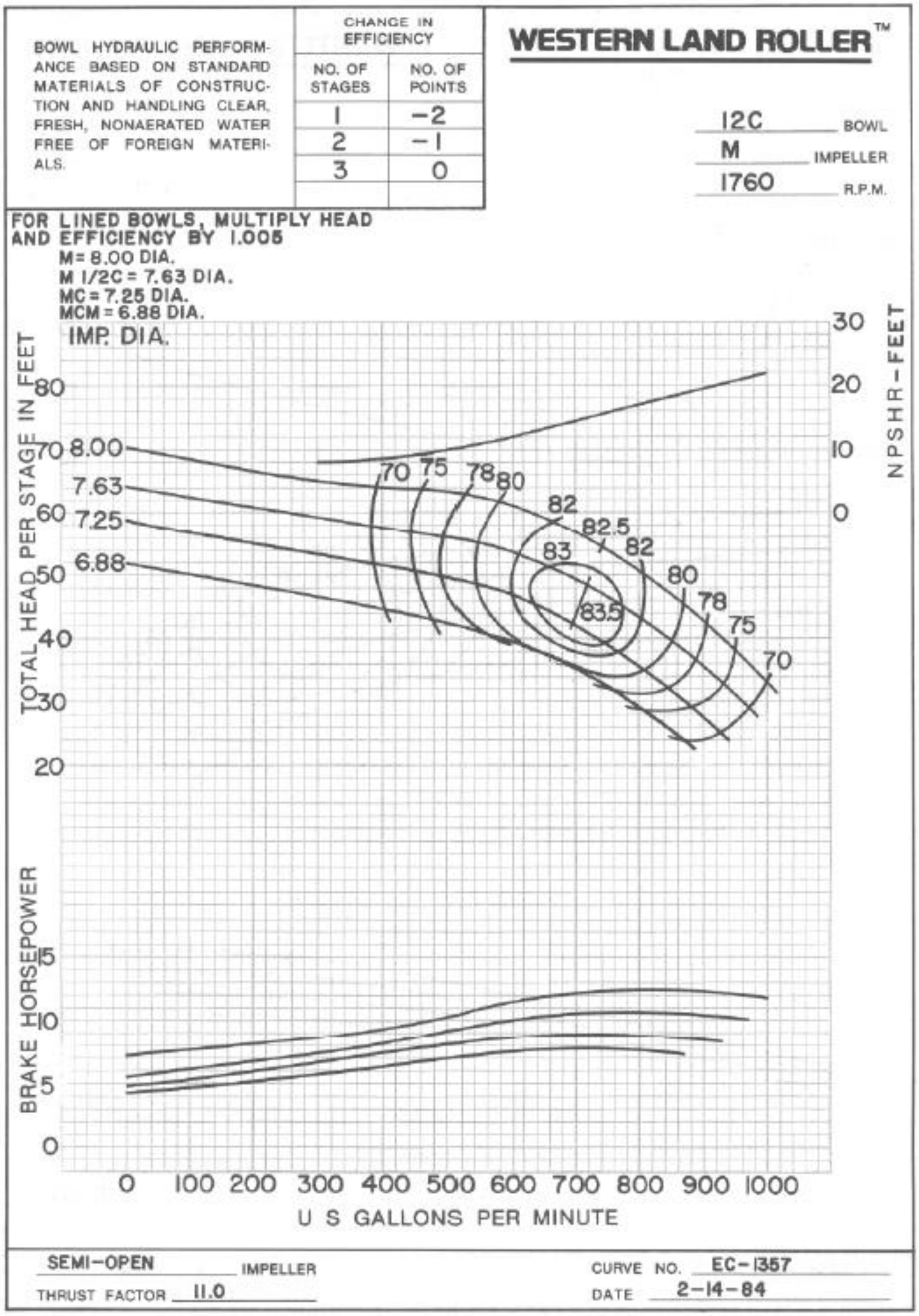
Appendix E
Pump and Power Unit Performance Curves

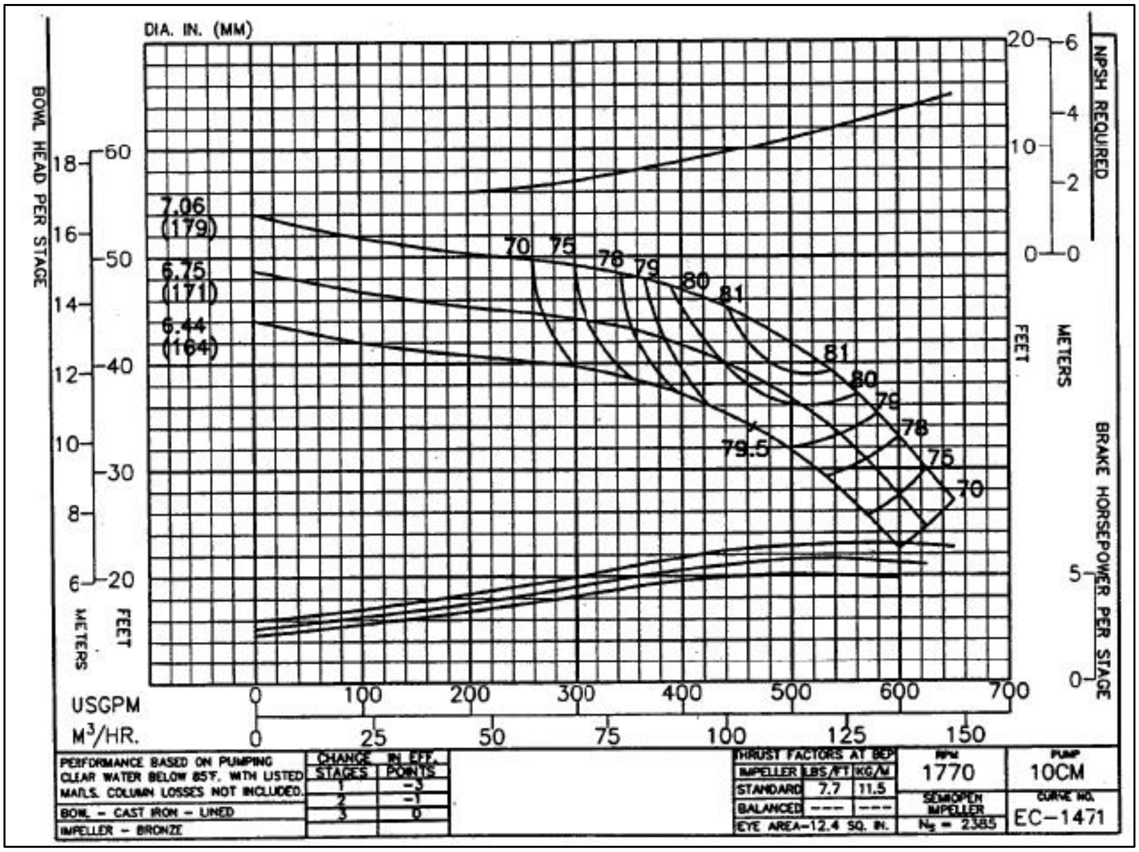
Irrigation pumping plants need to be designed and maintained to achieve high energy efficiencies. Field research by the University of Nebraska – Lincoln has found that few pumping plants meet the Nebraska Pumping Plant Criteria. For a thorough discussion of pumping plant design, consult the following references: MWPS Sprinkler Irrigation Systems, Center Pivot Irrigation Management Handbook, and Design and Operation of Farm Irrigation Systems. See the following online resource for pump curves:

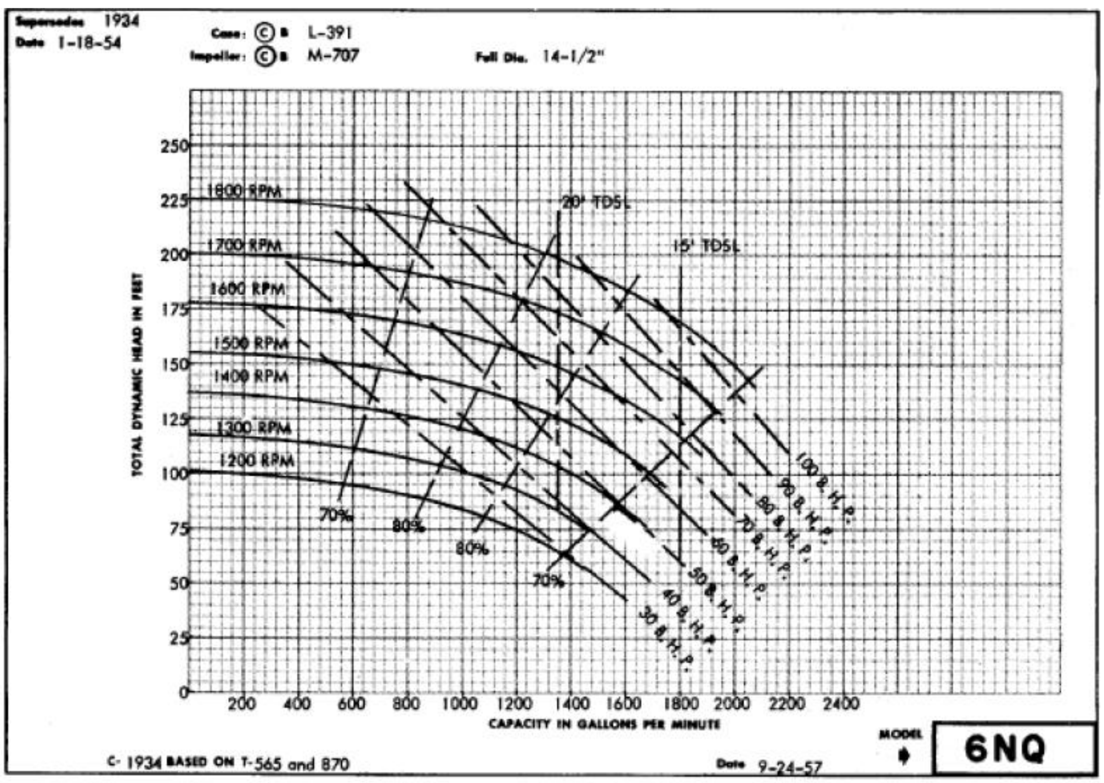
http://www.wcc.nrcs.usda.gov/ftpref/wntsc/Pump%20Curves/

Example Pump Curves:

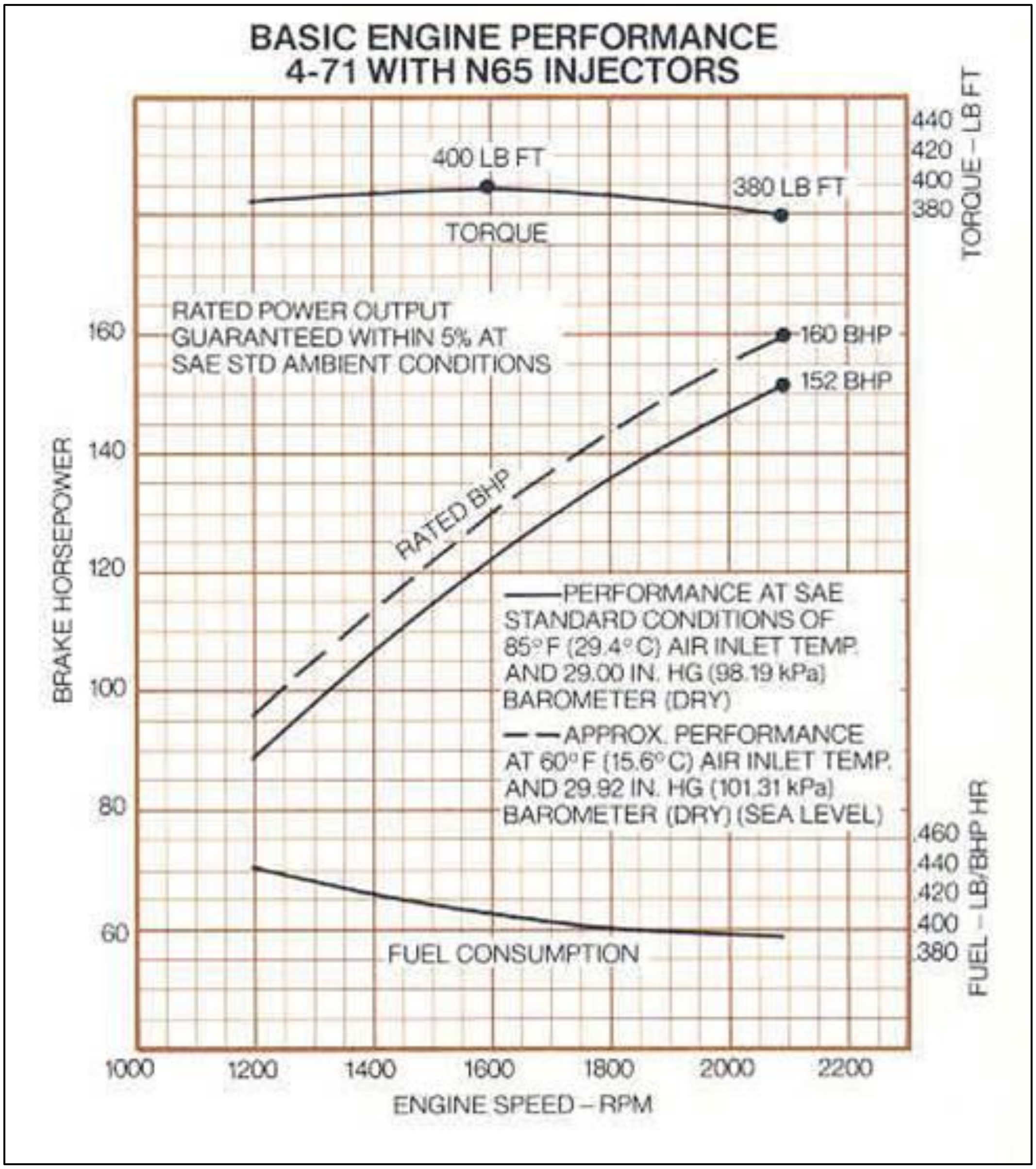


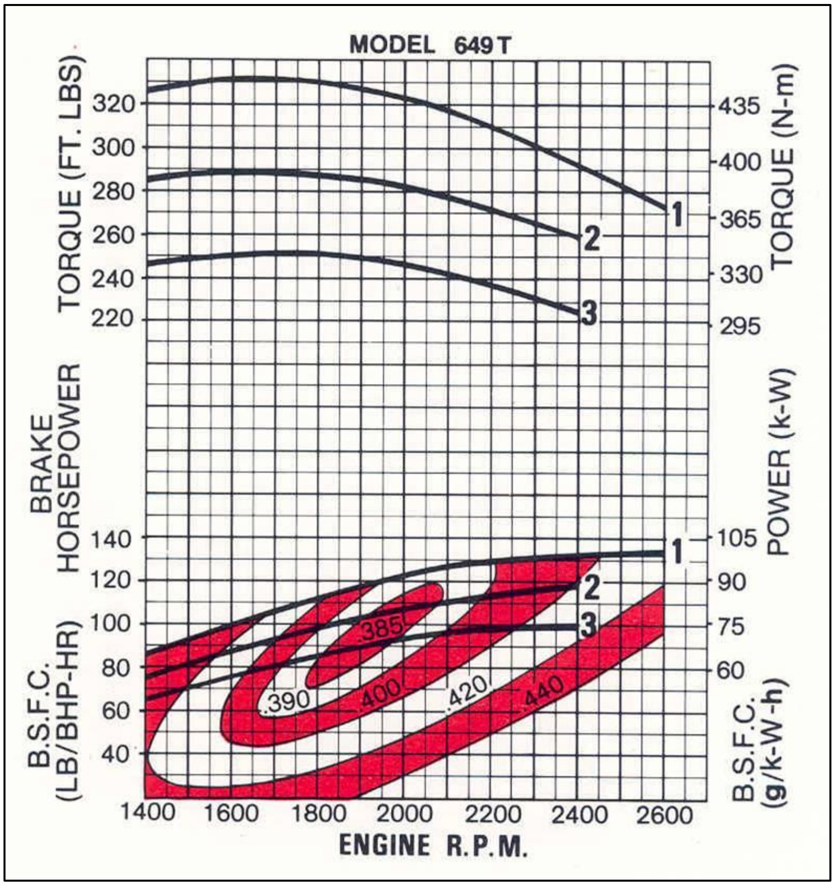

BOWL HYDRAULIC PERFORMANCE BASED ON STANDARD MATERIALS OF CONSTRUCTION AND HANDLING CLEAR, FRESH, NONAERATED WATER FREE OF FOREIGN MATERIALS.
CHANGE IN EFFICIENCY
NO. OF STAGES
NO. OF POINTS
1 −2
2 −1
3 0
WESTERN LAND ROLLER™
12C BOWL
M IMPELLER
1760 R.P.M.
FOR LINED BOWLS, MULTIPLY HEAD AND EFFICIENCY BY 1.005
M= 8.00 DIA.
M 1/2C = 7.63 DIA.
MC = 7.25 DIA.
MCM = 6.88 DIA.
IMP. DIA.
TOTAL HEAD PER STAGE IN FEET
NPSHR-FEET
8.00
7.63
7.25
6.88
70 75 78 80 82 82.5 82 83 83.5 80 78 75 70
BRAKE HORSEPOWER
U S GALLONS PER MINUTE
0 100 200 300 400 500 600 700 800 900 1000
SEMI-OPEN IMPELLER
THRUST FACTOR 11.0
CURVE NO. EC-1357
DATE 2-14-84


DIA. IN. (MM)
7.06 (179)
6.75 (171)
6.44 (164)
BOWL HEAD PER STAGE
NPSH REQUIRED
BRAKE HORSEPOWER PER STAGE
USGPM
M³/HR.
PERFORMANCE BASED ON PUMPING CLEAR WATER BELOW 85°F. WITH LISTED MATLS. COLUMN LOSSES NOT INCLUDED.
BOWL – CAST IRON – LINED
IMPELLER – BRONZE
THRUST FACTORS AT BEP
EYE AREA–12.4 SQ. IN.
RPM 1770
PUMP 10CM
SEMIOPEN IMPELLER
CURVE NO. EC–1471


Supersedes 1934
Date 1-18-54
Case: L-391
Impeller: M-707
Full Dia. 14-1/2"
TOTAL DYNAMIC HEAD IN FEET
CAPACITY IN GALLONS PER MINUTE
1800 RPM
1700 RPM
1600 RPM
1500 RPM
1400 RPM
1300 RPM
1200 RPM
20' TDSL
15' TDSL
C- 1934 BASED ON T-565 and 870
Date 9-24-57
MODEL 6NQ

Example Power Unit Curves




MODEL 649T
TORQUE (FT. LBS)
320
300
280
260
240
220
435
400
365
330
295
TORQUE (N-m)
BRAKE HORSEPOWER
140
120
100
80
60
40
105
90
75
60
POWER (k-W)
B.S.F.C. (LB/BHP-HR)
B.S.F.C. (g/k-W-h)
1
2
3
.385
.390
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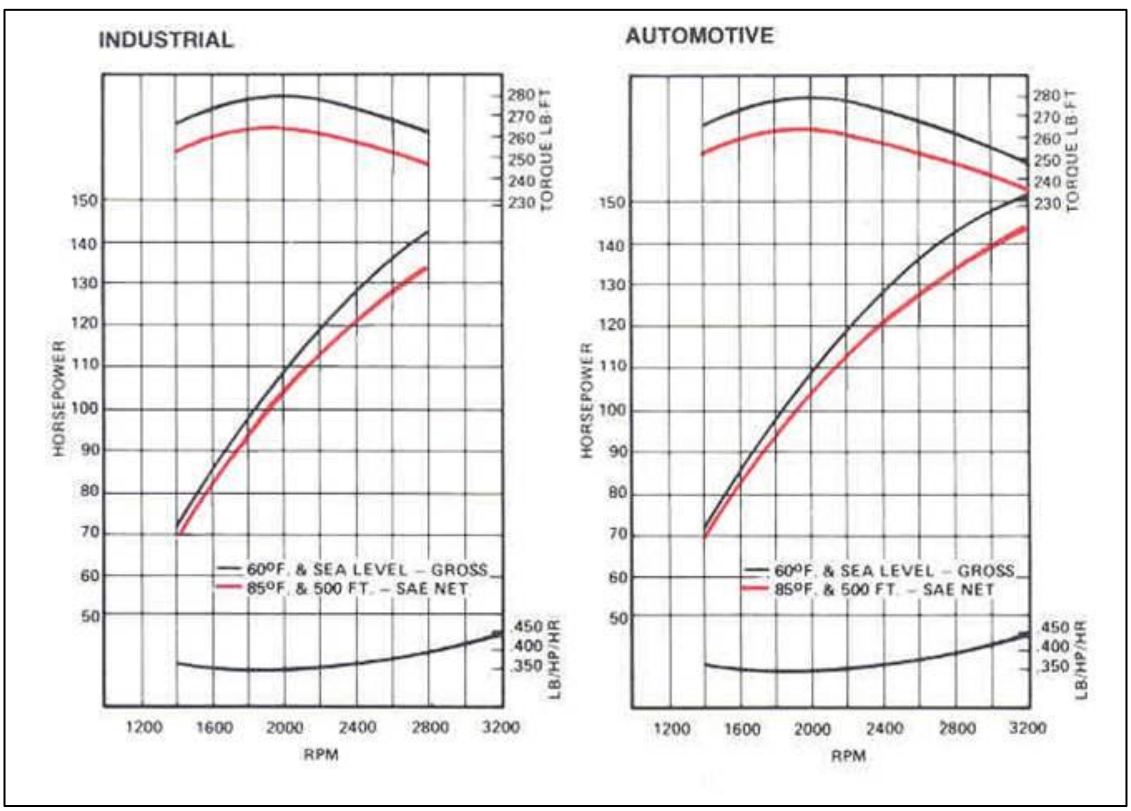
.440
1400
1600
1800
2000
2200
2400
2600
ENGINE R.P.M.


INDUSTRIAL
AUTOMOTIVE
HORSEPOWER
TORQUE LB-FT
280
270
260
250
240
230
150
140
130
120
110
100
90
80
70
60
50
60°F. & SEA LEVEL – GROSS
85°F. & 500 FT. – SAE NET
.450
.400
.350
LB/HP/HR
1200
1600
2000
2400
2800
3200
RPM

Appendix F
Measuring Water Flow

Flow measurement is an essential element of irrigation management. The water flow rate is used to calculate how much water is applied during each irrigation and the total water applied for the season. These values enable calculation of the cost for irrigation when combined with values of energy use. Flow meter readings can also be used to monitor changes in irrigation applications that could signal impending equipment problems.

Many types of flow meters are available for pressurized piped systems. In general, meters for most irrigation systems are velocity meters. Positive displacement meters are generally used for smaller pipe sizes.

Table E.1 - General Guide for Selecting Type of flow Meters.

Type of Flow meter	Conditions of water	Pipe sizes (in)	Pressure loss	Typical accuracy (%)	Required length of straight pipe up and down stream of meter	Cost
Paddlewheel	Clean water	0.5 to 36 or more	Low	± 1% to 2% of full scale	Requires a straight run of pipe before and after the meter, depend on manufacture.	Low to medium
Ultrasonic	Clean water or sewage water	1 to 60 or more	none	± 2% of full scale	10 and 5 times the inside diameter of the pipe respectively	Medium to high
Propeller	Clean, relatively free of sediments	2 to 96	Low	± 2% of reading	From 5 to 10 and from 1 to 2 of diameters respectively	Low to high depend on size
Venturi	Viscous Liquids , dirty and clean water	2 to 40	Low	± 1% of full scale	Manufacture recommendations	Medium to high depend on size
Orifice	Clean, relatively free of debris	1 to 40	High	± 2% to 4% of full scale	Manufacture recommendations	Low

Table E.2 – General costs for water meters.

Specifications	Cost $
Propeller flow meter	3,000 - 6,000
Venturi Shunt/Proportional meter	3,000 to 7,000
Paddle Wheel meter	2,000 - 5,000
Ultrasonic meter	6,000 – 7,000

Ultrasonic flow meter

Ultrasonic flow meters are attached to the outside of the pipeline. They adapt to a broad range of pipe diameters and pipe materials. They require that the pipe thickness be known, but some units have a sensor that measures pipe thickness. Installed properly, ultrasonic flow meters are accurate to within 1%. The digital readout with the flow meter provides both instantaneous and accumulated flow measurement.

Ultrasonic meter set up is simple, and suitable on a wide variety of pipe sizes or materials including steel, plastic, concrete, cast iron, and aluminum.

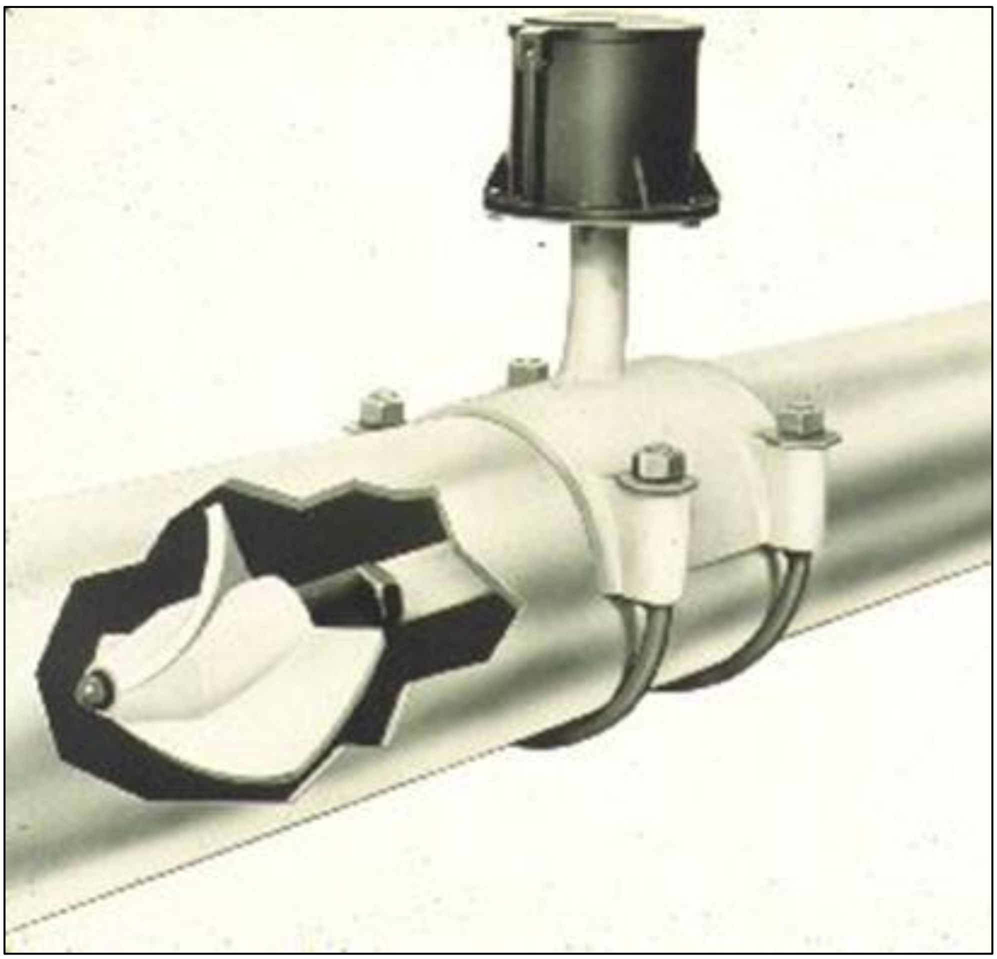
Ultrasonic meters have sensing elements clamped external to the pipe, one upstream and the other downstream. The signal is sent both directions to get the time differential. Two basic sensing methods are generally used, Doppler meters and time-of –travel meters. Doppler meters measure the frequency shifts caused by liquid flow. A signal of known frequency is sent into the liquid to be measured. Because the liquid causing the reflection is moving, the frequency of the returned pulse is shifted. The frequency shift is proportional to the liquid's velocity.

Time-of-travel meters have transducers mounted on each side of the pipe. The configuration is set so that the sound waves traveling between the devices are at a 45 degree angle to the direction of liquid flow. The speed of the signal traveling between the transducers increases or decreases with the direction of transmission and the velocity of the liquid being measured.

Propeller meters

Propeller meters are the most common type of meter in use for measuring water at the source in pressurized water delivery systems. The basic unit consists of a rotating propeller mounted in the pipe with a meter for measuring the rate of pumping and the volume of water pumped. Although in some designs propeller and turbine meters look almost identical and operate on the same axial rotor principle. The revolutions of the propeller are counted and the rate and volume measured. The rotational speed is a direct function of flow rate and can be sensed by magnetic pick-up, photoelectric cell, or gears. Propeller meters are relatively accurate and meet the needs of many users.

Major concerns with propeller meters are wear on the bearings and turbidity in water causing excessive wear on the propeller or plugging of bearings with sediment. Propeller meters are not recommended when water is dirty and contains abrasive material such as sand. A rule of thumb is that the impellers on a pump have to be replaced often, and then propeller meters are probably not the best choice due to abrasive wear on the meter propeller. Propeller meters can be equipped with electronics devices.



Collins Flow Meter

Equipment:

Collins Flow Gage
Support Equipment
- Electric drill
- ¼" drill bit
- 7/16" drill bit
- ¼" NPT pipe tap
- ¼" pipe plugs
- Center punch
- Dry wall seam tape
- Tools – knife, screwdriver, adjustable wrench
- Ruler

Description:

The Collins Flow Gage, (a pitot flow device) is one method of determining the flow rate in gallons per minute (gpm) of the water being pumped. This method measures the average flow velocity in the pipe. Given the pipe size and velocity, flow rate can be computed (A x V = Q).

The Collins Flow Gage is very versatile. It can be installed in any size pipe having a wall thickness of at least 1/16". Dismantling the pipe system is not necessary as is required with a propeller flow meter.

Two 7/16" holes must be drilled and tapped across from each other into the irrigation pipe. The pitot tube is installed using these holes. The pitot tube has two opposed orifices built in. The forward orifice (facing the water flow) measures the pressure in the pipe and the impact force due to the water movement. The higher the velocity the greater the impact. The trailing orifice (facing downstream) measures only the pressure in the pipe. A manometer indicates the pressure differential between the two orifices. The pressure differential is converted directly on the measuring scale into velocity (feet/second).

Water flow does not have constant velocity throughout the cross-section of the pipe. Flow velocity will tend to be higher near the center and lower at the side wall. Therefore, to find the average velocity, the orifices in the tube must be placed a certain distance from the center line of the pipe. This value is calculated as 0.353 x the inside pipe diameter. Two velocity measuring points are therefore necessary – one on each side of the center line of the pipe. This is known as the two-point test.

The pitot tube must be reversed (rotated ½ turn) and two more measurements taken at the same measuring points. This is necessary because of a slight misalignment of the orifices in the tube. Four velocities result. These four velocities are averaged to determine the average velocity. The two-point test provides a quick and accurate test in most conditions. When water flow is turbulent or inverted, a ten-point test provides better accuracy. This test requires ten velocity measuring points representing equal flow areas of the pipe section. The measuring points are: 0.158 x ID, 0.275 x ID, 0.354 x ID, 0.420 x ID, and 0.475 x ID from the pipe center line. There are five points on each side of the center line (Figure 2).

In Nebraska field tests, the two-point test has shown an average gpm deviation of 1.5% from the ten-point test. In most cases the two-point test is adequate. A ten-point test should be run when the pitot tube is placed closer than three feet from a valve, tee, elbow, or check valve; or when more than ½ ft/sec deviation is noticed from one side of the pipe to the other side.

The following instructions are for the two-point test. Equipment installation and operation are the same for both the two-and ten-point test. Additional ten-point test instructions follow the two-point instructions.

<u>Equipment:</u>

Locating and drilling the holes:

1) Locate a section of pipe near the pump which has few obstructions such as check valves, cooling coils, or elbows. Two small holes will be drilled in this pipe section. This location should be at least three feet downstream from any obstruction <u>if possible</u>. Select the longest possible distance from any of the above.

    <u>Note:</u> The pipe wall thickness must be at least 1/16" thick in order to tap the holes. Aluminum pipe <u>is not</u> adequate. The steel discharge pipe downstream from the pump is usually the best location for the holes.

   The Collins flow tube can be installed in the dogleg or stand pipe of many pivot systems. Check to make sure the pivot design does not contain a conduit running inside the stand pipe. Other pivots may also use the stand pipe as a bearing assembly for the pivot and the Collins cannot be installed.

2) The two holes must be placed directly across from each other. To find the correct position of these holds, follow this procedure.
   - a) Tear off a length of tape long enough to wrap around the pipe so it will have an overlap of at least 2 inches.
   - b) Wrap the tape around the pipe at the location where the holes are to be drilled. The tape ends should overlap each other at the top of the pipe and line up with each other along the edges.
   - c) Using a sharp knife, cut across the overlap in the direction of the pipe.
   - d) Remove the tape. The tape should now be the length of the circumference of the pipe.
   - e) Place the two ends of the tape together and fold the tape in half. Fold the tape in half one more time. The tape should now be divided into fourths.
   - f) Again wrap the tape around the pipe so that the ends meet at the top of the pipe. The ends should line up perfectly.
   - g) Use a piece of adhesive tape to secure the paper tape ends together.
   - h) Locate the two folds of the tape on the sides of the pipe (one on each side).
   - i) Using a center punch, mark the pipe at the point where the folds cross the center line of the tape (both sides of the pipe).
   - j) These two marks must be directly across from each other.
3) Use a ¼" drill bit to drill through the pipe at the two center punch marks.
4) Use a 7/16" drill bit to enlarge the ¼" holes to the proper size for the tap. Be sure to drill squarely.
5) Tap these two holes using a 1/4"-18 National pipe thread size tap. Use a lubricant on the tap. A 7/16" 8-point socket can be used with a 3/8" drive ratchet to drive the tap. If the tap begins to turn hard, reverse direction 1 turn, and then continue. Be sure to tap squarely.

Important: Only tap into the pipe about halfway on the tap. Tapping too deeply may make the threads too large to use a pipe plug to seal the holes after the test.

An alternative to the ruler is a length of stiff wire with a hook bent at one end. Insert the wire until the hook stops at the inner edge of the pipe and mark the other end with a pencil. Use a common ruler

Installation of the tube:

1) Locate the tube in the kit. It will consist of a tube with two threaded packing glands and two "stop clamps" (split brass bars with two screws). On one end of the tube is an alignment bar. Never loosen or remove this bar.
2) Remove one of the stop clamps and one packing glad.
3) Insert the tube into the pipe so that the tube protrudes through both holes.
4) Screw the packing glad (on the tube) into the pipe and tighten by hand.
5) Slip the remaining packing glad on the tube and screw into the remaining hole. Tighten by hand.
   Note: If the holes were drilled and tapped properly, steps 4 and 5 should not be difficult. If not, you may need to drill another set of holes.
6) The tube ends must be located an equal distance from each side of the pipe. Notice that there is a mark near both ends of the tube. Using the ruler, move the tube until the mark on each end of the tube is the same distance to the side of the pipe. The tube is now centered within the pipe.
7) Position the tube so that the alignment bar is parallel with the pipe.
8) From the chart included with the Collins, determine the "stop clamp" setting and the gpm factor, using the inside pipe diameter found earlier.
9) Position the stop clamp on the tube using the stop-clamp setting distance. This distance is measured from the outermost portion of the packing glad to the edge of the stop clamp facing the pipe. Repeat for the opposite side of the pipe using the remaining stop-clamp. Tighten both clamps.

Setting up the meter (manometer)

1) Remove the manometer from the box. Close all valves on the manometer.
2) Set the manometer in a vertical position and secure the meter.
3) Connect one hose from the manometer to one end of the tube in the pipe. Connect the other hose to the other end of the tube. Hose clamps may be necessary to secure the hose.

Running the test:

1) The engine and pump should be allowed to run long enough to warm up and stabilize the irrigation system.
2) Open the four bottom cock valves on the manometer and allow water to flow out for a few moments to remove all air in the hoses. Close the two bottom valves.
3) Water should rise in both glass tubes. If not, open the top valve on the left side of the manometer and allow the water to rise into both tubes. Close the valve when both water levels can be seen.
4) If the water rises to the top in any one of the glass tubs so it cannot be seen, follow this procedure.

- Make sure both upper valves on the manometer are closed.
- Connect the tire pump found in the kit to the top of the manometer on the right side.
- Open the right valve.
- Pump air into the manometer until the water level in both tubes move about half way down.
- Close valve and remove tire pump.

5) At this point, notice that the water level is not the same in both glass tubes. This is normal and indicates that the Collins Flow Gage is working properly.
6) Move the tube, installed in the pipe, until the stop-clamp butts against the packing glad. Be sure the alignment bar is still parallel with the pipe.
7) Notice that the center section of the manometer has a numbered scale. It also slides up and down.
8) Slide the center section up until the "0.0" line is at the same level of the lowest water level in one of the glass tubes.
9) The higher water level in the other tube will correspond with some number on the scale. Record this number on the data worksheet for the first velocity reading.
10) Rotate the alignment bar and tube 180º or ½ turn. The stop-clamp should still be in the same position. Notice that the water level in the manometer is changing. Allow it to stabilize and take a reading as in Steps 8 and 9. Record as the second velocity.
11) Pull the alignment bar and tube to the other side of the pipe. The stop-clamp should butt against the packing gland. Again, make sure the alignment bar is parallel with the pipe.
12) Take a reading as in Steps 8 and 9. Record as the third velocity measurement.
13) Again, rotate the alignment bar and tube 180º (1/2 turn). The water levels in the glass tubes will switch. Allow the levels to stabilize and record the final velocity reading.
14) Calculate the flow rate (gpm) using the data worksheet.
15) Remove tube assembly from the pipe in reverse order. Plug the two pipe holes with ¼" pipe plugs.

Ten-Point Test

The ten-point test varies in the number of points checked (10 vs 2) and where the stop clamps are positioned. The gpm factor does not change for the same pipe size.

To set the Collins pitot tube up for the ten-point test, calculate the following settings:

1) 0.475 D where: D = inside pipe diameter (inches)
2) 0.055 D
3) 0.121 D
4) 0.200 D
5) 0.317 D

Step 1 After centering the tube, set the stop clamps at 0.475 D and slide to the packing glad stop.
Stop 2 Pull tube out the required distance calculated above for the remaining four readings.
Step 3 Repeat for other side of pipe.
Step 4 Reverse tube and repeat above.
Step 5 Add readings and divide by 20 to obtain average velocity. Multiply by gpm factor to determine flow rate (gpm).

Note: A 6-inch steel rule graduated in 1/10" and 1/100" works best for measurements.

Appendix G
Pipelines

Pipe materials

Irrigation pipes are most commonly made from aluminum, steel, polyethylene (PE) or polyvinyl chloride (PVC) material. Many sizes and pressure ratings are available in each of the materials. For the specifics of a given pipe product and size options, consult the respective manufacturer's technical manuals. Chapter 7 of Sprinkler Irrigation Systems contains information on pipe sizes, wall thickness, pressure rating in addition to procedures for calculating friction loss.

Aluminum pipe is light and portable. It is useful for temporary installation of a main line or for hand-move sprinkler lateral systems. Several types of couplers and latch assemblies are used on aluminum pipe. The ring lock coupler is the most popular and offers the greatest pressure rating. Aluminum pipe is not buried.

Steel pipe can withstand very high pressure (150 psi and higher depending on pipe wall thickness). Because of its strength, it is used on systems with a large lift or on those with a high pressure requirement. Generally expensive in small sizes, steel pipe may be the most economical alternative for large pipes. It is available in many diameters and in 20- to 30-foot lengths. Steel pipe sections generally are welded together, but rubber gasket joints are available. Welded joints, especially when buried, should be coated or painted to protect them from rusting. Painting the entire pipe, including fittings, above ground can reduce rust.

Polyethylene (PE) plastic pipe is furnished most often in rolls of black tubing 50 to 200 feet in length and available in a limited number of pressure ratings and diameters under 5 inches. PE is normally used for buried submains or mainlines in small acreage systems.

Polyvinyl chloride (PVC) plastic pipe is the most commonly used material because it is generally the lowest cost material. PVC is lightweight and has minimal friction loss. Lengths of 20 to 40 feet are most common, with various end configurations for easy installation. PVC pipe is used mainly for underground applications because most PVC pipe loses strength when exposed to sunlight. However, some PVC compounds have been specially formulated to be durable for surface applications and are used as a substitute for aluminum pipe, especially in solid-set laterals and gated pipe.

PVC is available in several diameters and pressure ratings to allow selection of the most economical pipe for an application. The pressure rating assigned to a given pipe is a function of wall thickness, outside diameter, and the type of PVC compound used in manufacturing the pipe.

PVC pipe is available in two size designations: plastic irrigation pipe (PIP) and iron pipe size (IPS). IPS is plastic pipe with the same outside diameter as iron pipe so that iron pipe fittings can be used. The outside diameter for PIP pipes is always smaller than the IPS pipe for a similar nominal pipe diameter. Likewise, the inside diameter for a PIP pipe of similar size and pressure rating always is smaller than IPS pipe.

Most PVC pipe products are sized to fit industry accepted Standard Dimension Ratios (SDR) that describe a pipe's pressure design class rating and its maximum allowable operating pressure for that pipe. Standard dimension ratio is simply the ratio of the outside pipe diameter to the thickness of the wall. SDR ratings are a guideline for allowable operating pressure.

Pipeline fittings and accessories

Pipelines are the major component of a water delivery system but the pipeline itself must have appropriate fittings, connections, and associated devices to deliver and control the water as intended. Several pipeline accessories, for example water flow meters, are available to help an operator better manage the irrigation system (Figure F.1).

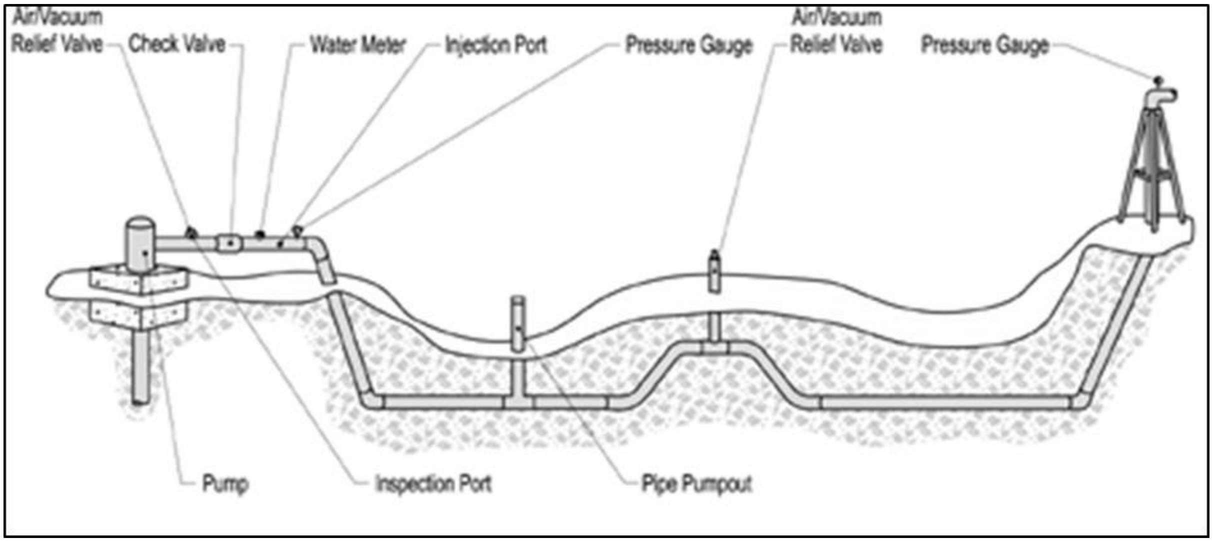


Figure F.1 – Cross-section diagrams illustrating valve locations for pipelines.

Fittings and accessories produce friction losses like pipelines. When determining the total friction losses for a pipeline system, include pressure losses from accessory valves and fittings to ensure the irrigation pump is sized appropriately. Friction loss data for a given accessory or fitting are best obtained from the respective manufacturer's literature. The losses for an individual valve or fitting may seem small, but over an entire system, the total loss may be substantial.

Valves are installed in a pipeline to either control the amount of flow or to protect the pipeline. A flow control valve should be installed in the pipeline near the pump. In some cases this valve may be used for continuous control, but more importantly, it can be used to reduce the rate of flow into a pipeline during startup until all air is purged from the line. Trapped air can cause water hammer and surges that produce high pressures to damage the pipeline. For the most efficient operation, the control valve should be fully open once the pipeline is up to pressure; pumping against a partially closed valve causes a pressure drop, which wastes energy and increases operating costs.

Check valves prevent the reverse flow of water. Placed between the pump and the pipeline, they prevent the backwards flow of water after shutdown that may cause damage to the system.

Trapped air reduces the capacity in a water line and can result in water hammer; thus, as a pipeline is filled, air must be purged from the line. In a similar manner, air must be allowed to enter a pipeline as it drains to prevent pipe collapses due to a vacuum. To meet these needs, provide an air/vacuum relief valve between the pump discharge and the check valve on well installations to allow water to freely flow back into the well when the pump is shut off.

In addition, provide air/vacuum relief at all high points and at the end of the pipe. Some irrigation pipelines may require the addition of a continuous air release valve at the high points to remove trapped air during operation.

Water hammer

Water hammer is the conversion of flowing energy in the water to elastic energy that causes a series of negative and positive pressure waves to move up and down the pipeline until friction damps the energy or until rupture occurs. Water hammer can be caused by closing a control valve too quickly in a flowing pipeline or filling a pipeline too quickly as it becomes fully pressurized. Water hammer surges in irrigation pipelines are similar to the banging that occurs in household pipes except that the result of water hammer is much larger in irrigation lines and can be very damaging. Uncontrolled water hammer can explode pipelines, burst pumps, and blow pivots apart. Water hammer adds to the normal operating pressure of the system. Without proper precautions, water hammer pressures can exceed 400% of the normal operating pressure of a system and exceed the pressure rating of a pipe. Negative water hammer pressure also is possible and can collapse pipelines. To prevent water hammer, many irrigation systems are installed with a manually or automatically controlled flow throttle valve near the pump to minimize flow rate during startups thus reducing water hammer risks.

Water hammer surge potential is the potential of a given installation to create a situation where water hammer can occur. The length of irrigation pipeline is one indicator of water hammer surge potential. Short pipelines have less water hammer surge potential than longer pipelines.

For example, a producer is pumping water at a rate of 1,000 gpm with an irrigation system that includes a pipeline with a long straight stretch (2,000 feet) between the pump and an elbow (changes direction). If the pump stops operating for whatever reason, water rushes to the elbow, creating a positive pressure surge at the elbow. If the elbow, pipeline, or connection does not rupture, then the increasing positive pressure created at the elbow will eventually stop the movement of water rushing towards the elbow and will cause the water to reverse directions towards the pump.

The result of the water rushing towards the pump will create a suction or negative water hammer at the elbow. Once water arrives at the pump, the positive pressure will cause the water to stop and reverse direction towards the elbow again. The water oscillating between the elbow and pump will eventually lose energy and dampen to a stop.

Other factors that affect water hammer are pipe size and water flow rate (velocity) changes, and whether air is trapped in the pipeline.

Pipeline water velocity is directly related to flow rate and, thus to water hammer. Recommendations are that water velocity be less than one foot per second when filling pipelines. Maximum velocity once the line is full should be less than five feet per second.

Air pockets in a pipeline can cause water hammer when the air is compressed and moves along the pipeline. Pipelines that have been shut down for even a few minutes often will have air in them due to vacuum relief valves. It is very important to have air release valves where needed along pipelines to safely discharge trapped air.

Manufacturers usually provide a surge pressure rating for pipes that is determined by using an ASTM standardized test. This test procedure includes subjecting the pipe to high pressures to determine when the pipe will burst. The manufacturer usually publishes the surge pressure rating along with other pipe specifications.

Buried pipelines require special knowledge and experience to assure proper installation and operation. For example, concrete thrust blocks may be needed at certain locations to transfer the thrust to undisturbed soil in the trench and keep the pipe from moving or breaking. Buried PVC pipes greater than 4 inches that are drained before freezing usually need at least 30 inches of cover to protect them against machinery loading. Working with an experienced installer and supplier is the best choice when using buried pipelines.

Information on pipeline selection is provided in MWPS 30 Sprinkler Irrigation Systems.

Appendix H
Air Line Method for Measuring Water Level

The air line method is a simple and accurate method for determining both static and pumping water levels. The air line can be made of copper, galvanized steel, nylon, or plastic pipe. The diameter must be small enough for clearance into the well and is usually 1/4 or 5/16 inch. If flexible plastic or nylon is used~ a weight on the end is necessary so it will hang vertically. Also, the weighted end will help prevent the pipe from wrapping around the pump column.

The length of the pipe must be known. Check records to determine the length of a previously installed air line. For accurate measurement, the minimum required submergence or depth of water above the end of the pipe is 15-20 feet. The end of the pipe should be at least two feet above the inlet to the pump.

At the base of the pump, the upper end of the air line is fitted with a pressure gauge and an air snifter valve. The air snifter valve is similar to the valve stem of a tire. The pressure gauge should be selected to match the anticipated water level conditions. For accurate measurement, the full scale reading of the pressure gauge should not be more than four times the minimum submergence. For example, if the expected minimum submergence is about 25 feet or 11 psi, a pressure gauge with a 40 psi maximum range would be necessary. The nearest gauge sold in this instance is 0-30 psi, since a 0-60 psi range gauge would exceed the recommended maximum. Pump testers should use a calibrated gauge to verify accuracy of the original gauge. The addition of a manual valve as shown in Figure E.1 is optional. The manual valve can be used to regulate air flow so that pressure surges do not damage the pressure gauge.

All fittings must be air tight. Use sealing compounds during assembly. A bicycle tire pump or other source of compressed air is necessary for operation. The equipment necessary for the air line system can be easily constructed from parts from local plumbing suppliers.

Operation

As air is pumped into the submerged air line, via the snifter valve, the pressure rises until all water has been forced out of the pipe. At this point the pressure in the air line is in equilibrium with the column of water above the end of the pipe. The pressure reading will no longer increase as air is pumped into the system. Once the pressure has stabilized the pressure reading is taken.

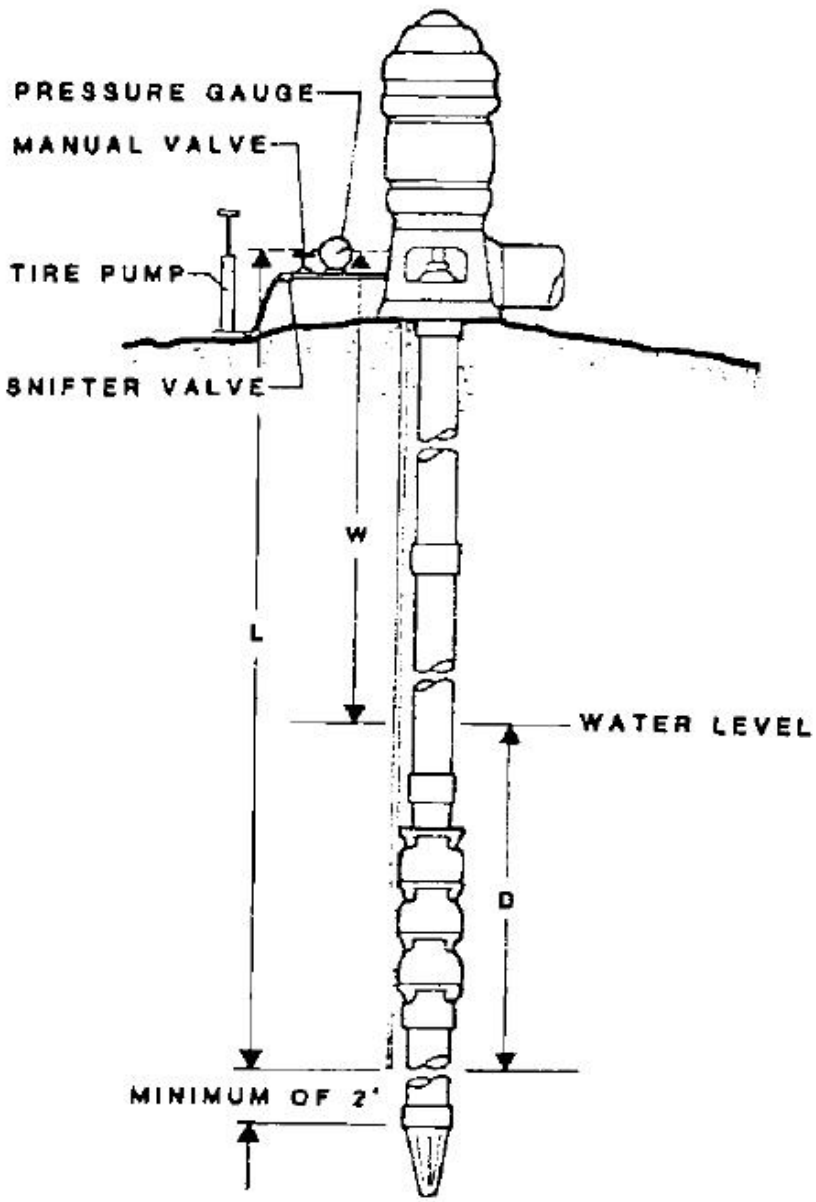
The water level in the well is equal to the length of the pipe (L) minus the depth of submergence (D) (See Figure E.1). If the pressure gauge is calibrated in psi (pounds per square inch), the depth of submergence is obtained by multiplying the gauge reading by 2.31, i.e. 1 psi equals 2.31 feet of water. Thus, if the gauge reads 11 psi, the depth of submergence of the end of the air line is 25.4 feet (11 x 2.31 = 25.4). If the length of the air line is 140 feet, then the water level is 114.6 feet (140 -25.4 = 114.6).

Some pressure gauges are calibrated in feet of water head. In that case, the water level is obtained directly by subtracting the gauge reading from the length of the air line. Also, there are special gauges available with adjustable dials that will indicate water levels directly. They must be set to indicate the appropriate air line length before use. The worksheet below can be used for recording the data and doing

Example Well

1. Length of air line (L) 140 feet
2. Pressure gauge reading 11 psi
1. Depth of submergence of the air line equals psi x 2.31 = 25.4 feet
2. Water level in well equals the air line length minus the depth of submergence =114.6 feet

Air Line Installation



Appendix I
Weighing Method for Measuring Fuel Use

Internal Combustion Fuel Use

Measuring fuel use by weighing the fuel at the start and end of the test periods is an alternative to using a coriolis meter. Accuracy is less than with the coriolis meter and setup requires having auxiliary fuel storage. The description below is for diesel engine tests. Similar procedures can be used for propane and gasoline and are discussed in Technical Irrigation Pumping Plant Test Procedure Manual.

Equipment:

5 gallon fuel cans (modified for test)
Platform scale
Stopwatch
Fuel hoses
Misc. fittings

Description:

Fuel consumption is determined by weight. The quantity of fuel used over a time interval is weighed. The net weight of fuel used is converted to gallons. The net gallons used per the time interval equals the gallons per hour.

A five-gallon fuel can, modified for a supply line near the bottom of the can, works well for test purposes. A return fuel fitting is also necessary which can be placed at the top of the can. Provisions should be made to allow filling of the can between tests if necessary. A platform beam scale is recommended as the weighing device.

Equipment Set-up:

Note: It is important when switching from the diesel supply tank to the fuel can that all air is removed from the hose and fittings. Air in the fuel line can cause the engine to stall and may require repriming of the fuel system. If this happens, consult the engine's owner's manual for correct priming procedures.

1) Fill the fuel can with diesel. Keep the fuel can contents from being contaminated with water or dirt.
2) Most diesels will have a fuel supply to the engine and a return fuel to the tank. Both need to be used with the fuel can since the return fuel is not used by the engine.
3) Connect the supply line from the bottom of the fuel can to the engine, or use the existing supply line and connect it to the fuel can. A supply of miscellaneous fittings is helpful since fuel connections are not standardized.
   Important: Bleed air from these lines by allowing diesel fuel to run free through the line before making the connections
   Important: The supply line must not bypass the final fuel filter.
4) If the engine has a return line, connect it to the top fitting on the can, or use the hose from the fuel can return and connect it to the return line fitting on the engine.
   Note: The return line may be placed into the fill spout of the fuel can if the can is not modified for return fuel.
5) Loosen fill cap on the can to allow air to enter.
6) Place the scale on a hard level surface. A piece of plywood may be used for this. Protect the scale from wind if possible. Wind will make reading of the sensitive scale difficult.

Determine the fuel use:

1) The engine and pump should be allowed to warm up and stabilize before beginning the test.
2) Select the proper range on the scale to accommodate the weight of the fuel can and contents.
3) When the scale stabilizes, start the stopwatch. Record the weight.
4) Allow the engine and pump to run long enough for a minimum of five pounds of diesel to be used. The more diesel used will result in a more accurate measurement. However, be careful not to allow the fuel can to go empty.
6) Record the weight and time.
7) Calculate the fuel use rate.

Start Weight – Stop Weight = Net Weight of Fuel

Net Weight of Fuel/7.05 lbs/gal = Net gallons

Average weight of No. 2 diesel per gallon. Actual weight may vary between 7.01 and 7.1 pounds per gallon.

Net Gallons/time (hours) = gallon/hour

8) Reconnect the fuel and return lines after the test. Again, make sure the air in the lines is bled off.

Appendix J
Electrical Technical notes

Electrical Tech Note — 216

Biosystems & Agricultural Engineering Department
Michigan State University

Electrical Shock and Safety

Prevention of electrical shock begins with being especially careful when there is a danger of making contact with energized conductors. Always remember that prevention of electrical shock is more important than damage to equipment or facilities. For example, if some electrical equipment falls into a wet area, resist the temptation to retrieve the equipment. Think first of the potential shock hazard, disconnect power, then retrieve the equipment. Do not attempt to retrieve the equipment before disconnecting power.

Avoid working where accidental contact with energized conductors can occur. Sometimes trained personnel find it necessary to work around energized conductors. It is reported that the majority of fatalities due to shock occur by making contact with 120 volts. Even much lower voltages can be fatal. When it becomes necessary to work near energized conductors, it is important to understand how the body can become a part of a circuit. Figure 216.1 shows a person making contact with a piece of equipment with exposed metal where an internal fault in the wiring has resulted in the frame being in contact with an internal 120 volt conductor. Since many electrical systems are grounded to the earth, the person completes a path between the equipment and the earth resulting In a current flow through the person's body.

Electrical Current Causes Shock: Electric shock in humans and animals is the result of current flow through the body or a part of the body. The body produces electrical current flow to control body activities. Electrical current from external sources may pass through the body on occasion and go unnoticed because the current level is below the threshold for perception at the nerve endings where perception can occur. Perception as well as damage to body tissue is the result of excessive levels of current flow and length of time of exposure. Exposure to an electrical current for a fraction of a second may cause pain, while exposure to that same level of current over a longer period of time may result in damage to the body. The concept is similar to touching a hot object. A quick touch reveals the object is hot. Contact for a longer time may result in damage of the skin. A level can be reached, however, when even a short exposure causes damage.

Body Path Resistance: The amount of electrical current that will flow through the body of a human or animal depends upon the resistance of the body current path and the voltage. The resistance of the body path consists of the resistance of the body and the contact resistance of the body with conductive surfaces as illustrated in Figure 216.1. Electricians wear insulating gloves and stand on insulating surfaces when working near live conductors to create a very high contact resistance that limits body current flow to an insignificant level. The major part of the electrical resistance of the body is through the skin. When dry, the skin has a resistance in the tens of thousands of ohms. When wet, such as standing in a swimming pool, the resistance of the body path can be less than 1000 ohms. When body resistance is very low, only a few volts can result in perception.

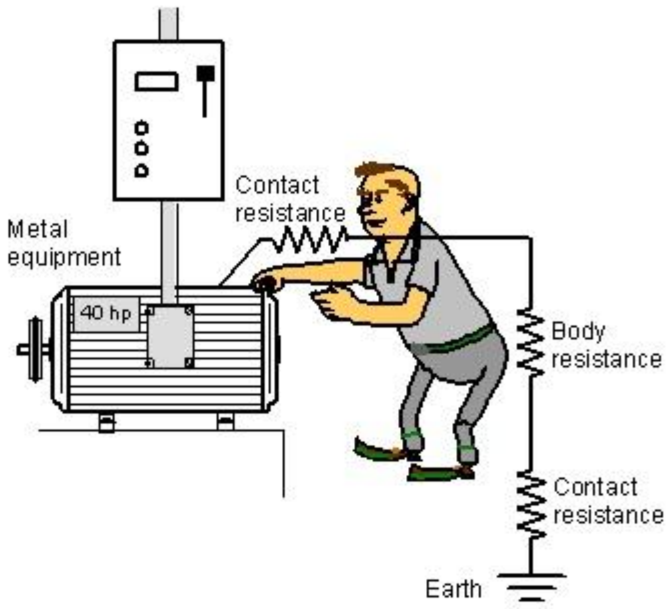


Figure 216.1 An internal fault in equipment can result in contact between a live conductor and the frame of equipment. When a person or animal makes contact with the equipment a circuit is created where the current level depends upon the voltage on the equipment and the resistance of the path through the person or animal.

In situations where working around exposed energized conductors is unavoidable, steps must be taken to make sure the body does not complete a circuit. When standing on a concrete or other conductive floor surface, the person who may become exposed to contact with energized conductors should stand on a layer of insulating material. Also it is important to avoid making contact with conductive surfaces such as concrete walls or metal equipment. When applying pressure, make sure a slip will not result in losing balance and falling into energized parts. Also when applying pressure, avoid grasping objects such a metal pipe in order to apply pressure. It is important to think about the path current will travel if accidental contact occurs. Make sure the chest is not in the path between potential entry and exit of current during accidental contact. It is also important to work in such a way that if the body does become part of a current path, a person does not become frozen in such a way that contact cannot easily be broken. An example of a dangerous practice is holding onto a metal object with one hand while cutting a potentially live conductor with pliers in the other hand. If a shock should occur, the person may be unable to let-go of the object and the pliers.

Effects of Continuous AC Current on Humans: Humans are highly variable as to what may occur when exposed to electrical current. Frequency (cycles per second or Hertz) of alternating current is a factor. It is important to understand that the body of humans and animals is affected by only small fractions of an ampere. The unit of measure of electrical current flow is the ampere. One ampere is a large quantity when it comes to shock, therefore, thousandths of an ampere or milliamperes (mA) is the common unit of measure. It takes 1000 mA to equal one ampere. Table 216.1 gives values that are for continuous exposure to 60 Hz alternating current when a person is working and not particularly aware that shock may occur. The values of current in Table 216.1 are considered to be lower levels for the stated result. For difficult breathing, or heart fibrillation, the chest is a part of the current path. Perception can occur for some humans below the level stated. Pain generally occurs for most humans above the level stated, although there may be difficulty distinguishing between being startled and pain.

There are many factors that must be considered when determining effects of electrical current on humans and animals that go well beyond threshold levels. Table 216.1 is intended only as a general guide to create an awareness for the purpose of encouraging safety when working with electrical equipment or working in a situation where a person may make contact with energized conductors or equipment.

Table 216.1 Human exposure to continuous 60 Hz alternating current through the body and the lower threshold levels generally required to result in the states effect.

Perception	1 mA
Ground-fault circuit-interrupter trips	5 mA
Pain	8 mA
Let-go	15 mA
Difficult breathing	20 mA
Fibrillation of the heart	30 to 50 mA

Purpose of Equipment Grounding: The purpose of equipment grounding is to provide a conductive path from the exposed frame of metal equipment back to the electrical source that is of low enough resistance to prevent humans and animals from being exposed to damaging levels of current. Ideally the equipment grounding conductor will carry ample current to quickly cause the overcurrent device (fuse or circuit breaker) to open and de-energize the circuit. Frequently the fault condition is of such high resistance that enough current will not flow to open the overcurrent device. It is under these conditions that equipment grounding is especially important. In this situation, the equipment grounding conductor will carry enough current to prevent the voltage on the equipment from getting to high enough level to cause harm to humans and animals. Figure 216.2 illustrates a case of what is known as a high resistance fault in a piece of equipment where the equipment grounding conductor is not present. A dangerous level of voltage is present on the equipment and human or animal contact can result in serious injury or death.

In Figure 216.2 the overcurrent device does not open since the contact between the live wire and the equipment frame is at a level of 100 ohm. For this example the frame of the equipment is at 120 volts at the time the person makes contact. Figure 216.3 is an electrical circuit diagram of the situation illustrated in Figure 216.2. For this example the resistance of the path through the person is assumed to be 5000 ohm. The current level through the person in this example is 23 mA which is at a dangerous level depending upon the length of time of exposure.   The total resistance of the current path through the person is 5110 ohm. For a discussion of how to analyze such a circuit refer to *Tech Note 215*.

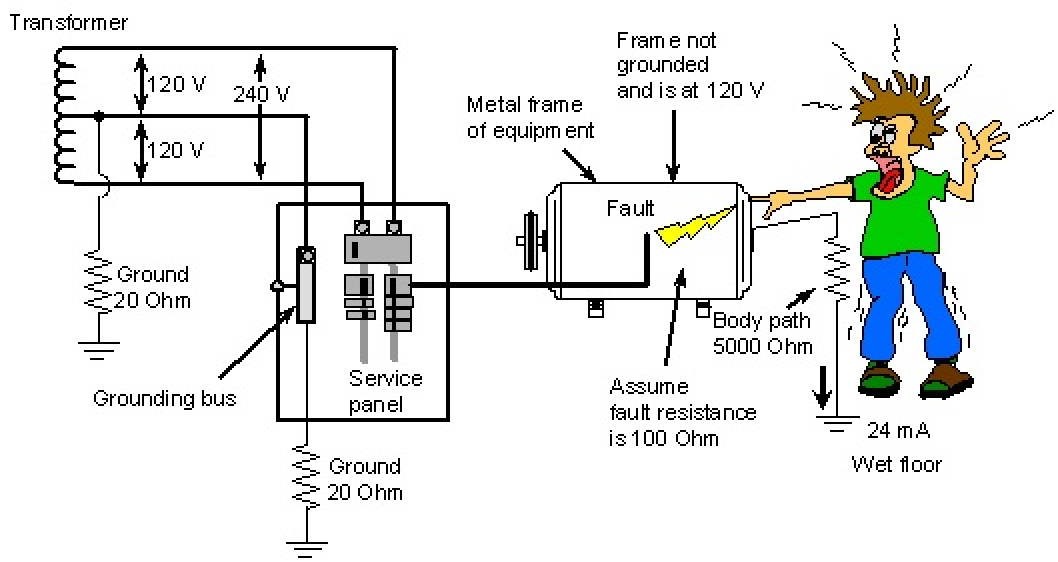


Figure 216.2 An internal fault has occurred in the equipment allowing contact between the live conductor and the frame of the equipment. When the person touches the equipment and completes a path to earth enough current can flow to cause serious injury or death. A safety equipment grounding conductor is not connected to the frame of the equipment in this case.

Essential for electrical safety is the equipment grounding wire that is required by electrical codes to be connected from the exposed metal frame of equipment to the grounding point or grounding bus at the main electrical service panel. The neutral wires for 120 volt circuits are also connected to this same equipment grounding bus. This grounding bus is shown in Figure 216.2 and Figure 216.4. Note that in Figure 216.2 the grounding wire to the equipment is missing thus not available to serve it's purpose of protecting a person or animal from a serious shock. Note in Figure 216.4 that a grounding wire is run from the service panel grounding bus to the frame of the equipment. The equipment in both cases is subjected to the same internal electrical fault where a hot wire is making contact to the metal frame. The equipment grounding wire in this case offers a 1 ohm path for fault current to flow back to the service panel grounding point as compared to a 5000 ohm path through the person. There is still a small current flowing through the body of the person, but in the case of Figure 216.4 the current level is only 0.2 mA and is below the level of human perception.

Current through person = 120 V / 5110 Ohm= 0.023 A = 23 mA

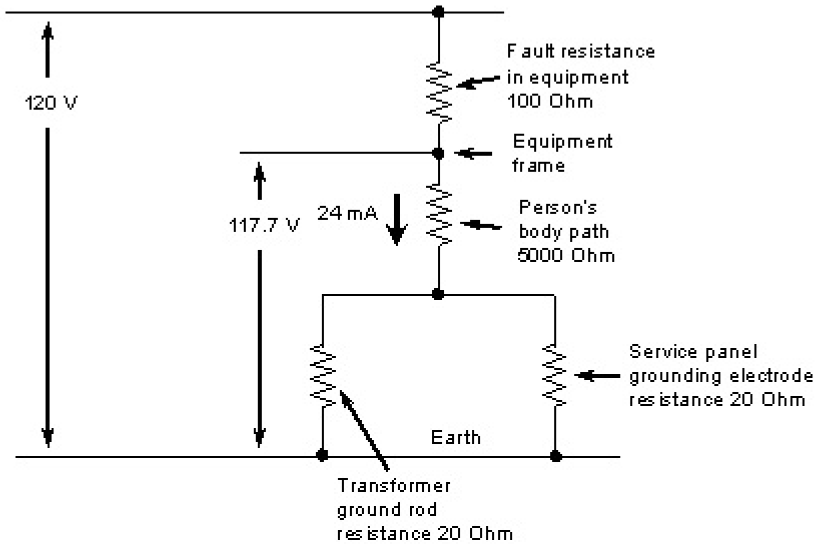


Figure 216.3 This is an electrical circuit diagram of the shock situation depicted in the previous illustration which can be used to determine the level of current that potentially will flow through the person's body if contact with the equipment occurs.

The electrical circuit for the case depicted in Figure 216.4 is shown in Figure 216.5. Compare the circuit of Figure 216.5 with that of Figure 216.3 and note that the only difference is the addition of the 1 ohm ground wire from the frame of the equipment to the grounding bus of the service panel. In this case the current flowing on the grounding wire is not enough to trip the circuit breaker. In most cases the circuit breaker will trip when a fault in the equipment occurs. Note that the current through the person's body in this case is only 0.2 mA.

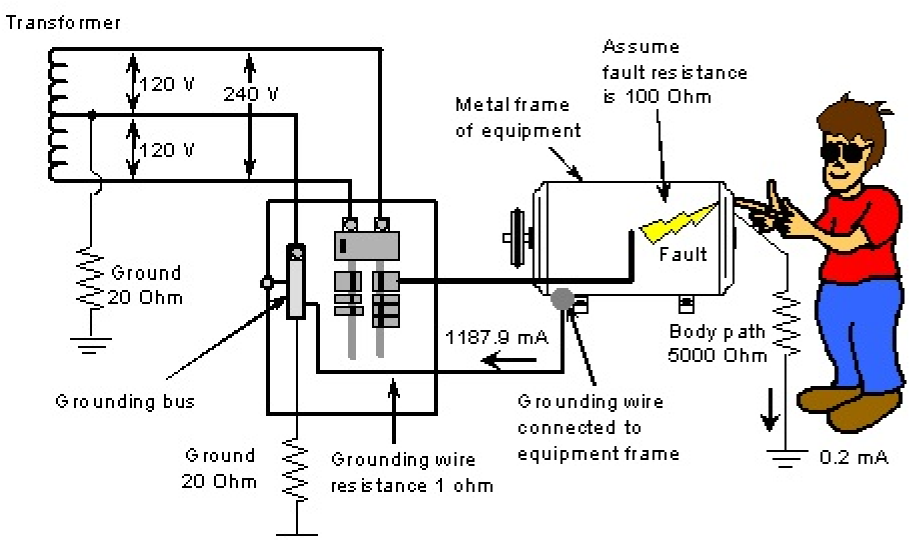


Figure 216.4 With an equipment grounding wire connected to the frame of the equipment the fault current flows back to the source on the equipment grounding wire thus preventing the person touching the equipment from receiving a serious electrical shock.

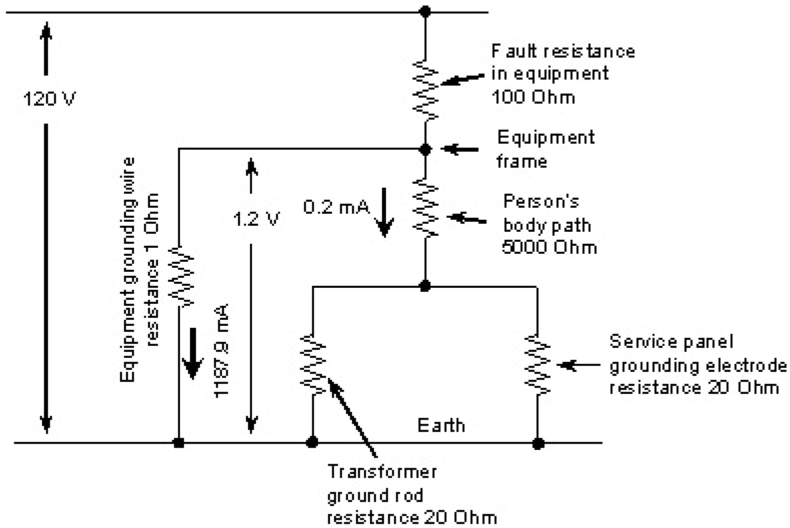


Figure 216.5 This is the same circuit diagram as Figure 216.3 except an equipment grounding wire with a resistance of 1 ohm is connected between the frame of the equipment and the grounding bus of the electrical panel. The majority of the fault current flows safely back to the source on the equipment grounding wire preventing serious electrical shock to a person touching the equipment.

The total resistance of the circuit of Figure 216.5 is 101 ohms which results in 1188.1 mA total current flow with a 120 volt fault to the frame of the equipment. Remember that in this case the hot wire contact to the frame is at a resistance of 100 ohms. In most cases the fault resistance is much lower resulting in enough current flow to immediately trip the circuit breaker. In the case of Figure 216.4 and Figure 216.5 there will be 1.2 volts between the equipment frame and the earth resulting in only 0.2 mA current flow through the body of the person.

Ground-Fault Circuit-Interrupters: Ground-fault circuit-interrupters (GFCIs) are required by electrical codes to be installed in many potentially wet locations where exposure to dangerous levels of voltage may occur and humans can become a part of the current path. A ground-fault circuit-interrupter functions by measuring the current in the conductors to see if there is any leakage. Table 216.1 shows that these devices trip when they sense that more than 5 mA is returning to the source by some path other than the circuit conductors. Since the leakage may be through a person, the GFCI will open the circuit and de-energize the conductors.

Conclusions: The level of perception of an electrical sensation for humans is about 1 milliampere (1/1000 ampere), and there is a narrow range between this perception level and a serious shock. The purpose of an equipment grounding wire connected from the grounding point of the electrical service panel to the exposed metal frame of equipment is hopefully to trip the circuit breaker or blow a fuse in case of an electrical fault. If, however, the fuse does not blow or the circuit breaker trips a purpose of the equipment grounding wire is to hold the voltage of the exposed frame of equipment to such a low level that a person or animal will not receive a serious shock. This is especially important in wet areas and around swimming pools. Since equipment grounding wires can become broken, corroded, or otherwise damaged, a device known as a ground-fault circuit-interrupter is required to be installed on many circuits serving equipment in wet areas. The ground-fault circuit-interrupter senses whether current is flowing in a path other than the circuit wires and disconnects power to the circuit when the fault level exceeds 5 mA.

Electrical Tech Note — 219

Biosystems & Agricultural Engineering Department
Michigan State University

Single-Phase, 120/240 Volt, 3-Wire Electrical System

Electrical power is delivered to customers by means of distribution lines with at least one wire operating at several thousand volts as measured to the earth. The utility installs a transformer near the customer location to convert the high distribution voltage to a level that is safe and convenient for the customer. Typical electrical equipment and appliances sold in the United States operate at 120 volts with larger appliances such as clothes dryers and electric ranges operating at 240 volts. Since equipment and appliances in the home operate at 120 volts or 240 volts, it was necessary for the electrical system to provide both voltages.

Center Tapped Transformers: A transformer is used to convert the high voltage of the distribution line to 240 volts for the typical residential customer. If the secondary winding of the transformer has a wire connected to the center of the winding, the voltage between that winding and either of the other two windings will be 120 volts. This is illustrated in Figure 219.1. Concern over lightning damaging the electrical system and equipment by striking a wire or near a wire lead to the grounding of this 3-wire electrical system to the earth. Electrical codes require the common wire (center wire) to be grounded to the earth. By grounding the common wire, there will be two wires not grounded and they are referred to as the ungrounded wires. The ungrounded wires are frequently called the hot leg A and leg B. In a 3-wire single-phase electrical system such as the one shown in Figure 219.1, the common wire is called the neutral.

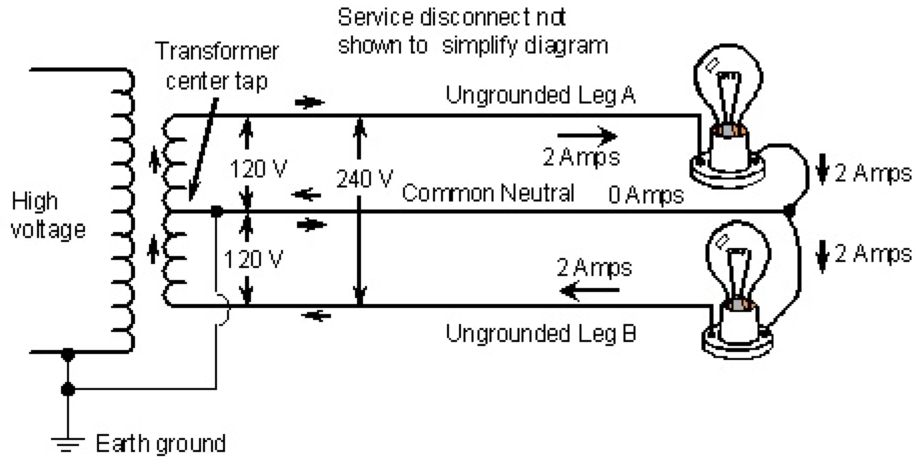


Figure 219.1 A 3-wire electrical system is created by attaching a center tap wire to the secondary winding of a transformer thus producing 120 and 240 volts.

Since there is 120 volts from the center tap wire to either of the other wires, the center tap wire was called the common. If two identical 120 volt loads are connected one to each of the ungrounded wires from the transformer, the current flow measured on the common wire is zero. In this condition the 120 volt loads are considered to be balanced. The current flow on the common neutral is the difference between the current flow on the two ungrounded wires.

Single-Phase 3-Wire Electrical Panels: To provide maximum safety, the *National Electrical Code* requires that a means be provided to disconnect power from the two ungrounded conductors as they enter a building. The electrical code calls this the main service disconnect. It is usually the main circuit breaker in the electrical panel of the building. This is illustrated in Figure 219.2 where the three electrical wires from the utility transformer are shown entering the electrical panel. The ungrounded conductors are attached to the main circuit breaker, and the neutral conductor connects to a neutral terminal block in the panel. The utility is required to connect the neutral conductor to a ground rod in the earth at the transformer. The electrician installing the service in a building is required to ground the neutral conductor to the earth at the service of the building. This connection is usually made to a metal water pipe entering the building or to a ground rod driven into the earth to a depth of not less than 8 ft.

Circuit breakers attach to the electrical panel in such a way that they connect to metal conducting bars called bus bars. There are two bus bars in a single-phase electrical panel, one for each of the ungrounded conductors entering the panel. These bus bars are not energized unless the main circuit breaker is turned on. There are two types of circuit breakers that can attach to a single-phase panel. A single-pole circuit breaker attaches to just one of the energized bus bars. A 120 volt circuit originates from a single-pole circuit breaker. It takes two wires to make a single-phase circuit, and the other wire originates at the neutral terminal block. This is also illustrated in Figure 219.2. If a circuit is wired with electrical cable, the black wire attaches to the circuit breaker and the white wire attaches to the neutral terminal in the panel.

A two-pole circuit breaker is used to power a load that requires 240 volts. In this case there generally is no neutral involved. The electric range and electric clothes dryer circuits are exceptions. The circuit breaker attaches in such a way that it makes contact with each of the two ungrounded bus bars. When the circuit breaker is turned on, there will be 240 volts between the two output terminal screws. Safety grounds are required for all circuits in addition to the insulated circuit wires, but they are not shown for the circuits in Figure 219.2.

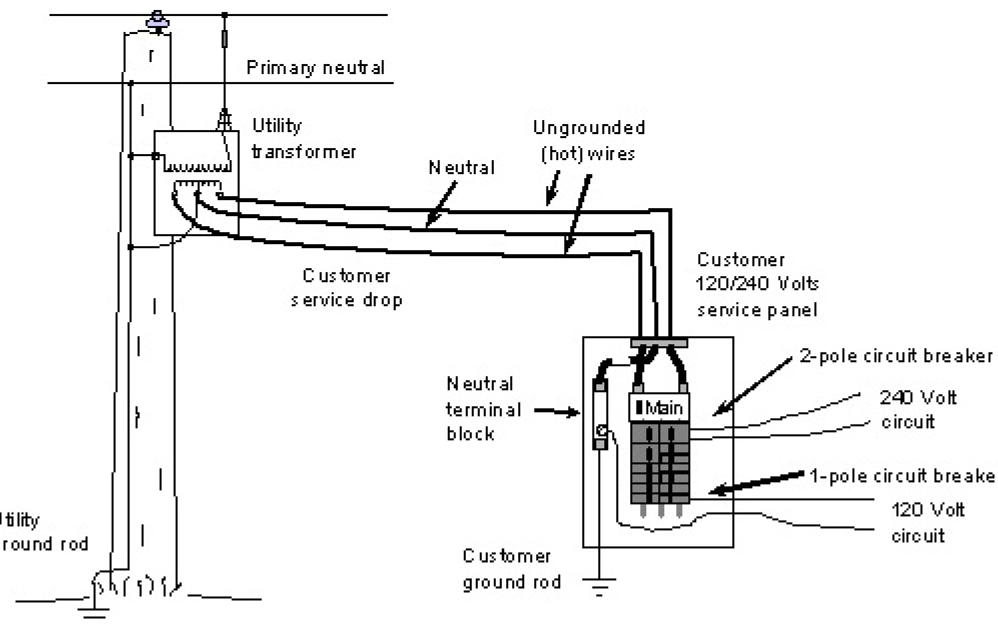


Figure 219.2 The two ungrounded wires from the utility transformer connect to the main circuit breaker and the neutral conductor connects to the neutral terminal block. A 240 volt circuit originates with a 2-pole circuit breaker, and a 120 volt circuit originates at a 1-pole circuit breaker with the other wire connected to the neutral.

Electrical Tech Note — 220

Biosystems & Agricultural Engineering Department
Michigan State University

Three-Phase Electrical Systems

Electrical power is commercially produced with a generator that has three windings each producing electrical current that is 120° out of phase with the other phases as shown in Figure 220.1. Voltage is changed using transformers that have a set of windings for each phase. This can be done with one transformer with three windings or using three individual transformers. There are two ways these transformer windings can be connected depending upon the requirements of the load to be served. This *Tech Note* discusses the different types of 3-phase electrical systems and their applications. Single-phase power can be obtained by connecting to any two of the wires of a 3-phase electrical system.

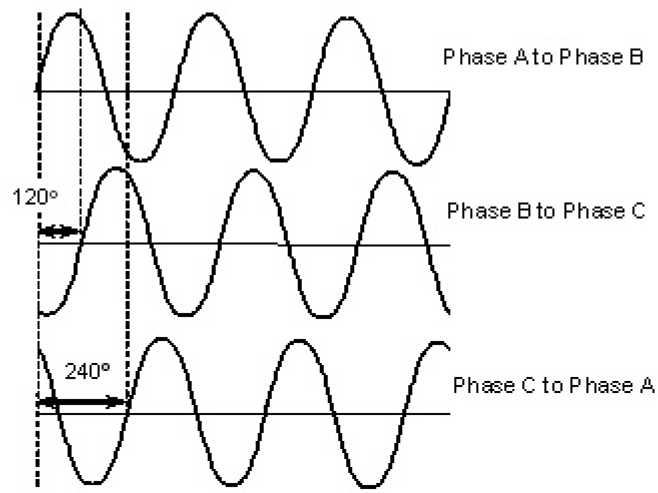


Figure 220.1 There are three ungrounded wires for a 3-phase electrical system and the voltage between each set of wires will be a sine wave, each off-set by 120°.

Connecting 3- Phase Transformer Windings: There are only two ways the windings of a 3-phase transformer can be connected. They can be connected in a loop as shown for the primary side of the transformer of Figure 220.2. Making a diagram of this type of connection results in an equilateral triangle that looks like the Greek letter *delta*. This is called a *delta* connection. The other way to connect a set of 3-phase windings is to connect one side of each winding together with the other pointing out like the spokes of a wheel. A diagram of this connection looks like a three-pointed star or if arranged correctly it will look like the letter **Y**. This type of connection is named for the letter **Y**, but it is spelled *wye*. Whether a 3-phase transformer has the windings connected wye or delta will depend upon the type of electrical system needed and the voltage requirements of the loads to be supplied. When the transformer windings are connected wye, there is usually a common wire (neutral) connected to the common winding point giving a 4-wire 3-phase system. In the following diagrams of 3- phase electrical systems, only the secondary winding of the transformer will be shown. There is a primary winding for each secondary winding and it is not required to be connected in the same manner as the secondary winding.

For most applications, a special 3-phase electrical panel is required which will have a 3-pole main circuit breaker and three bus bars — one for each phase. Typically the phases are named A, B, and C. The electrical code requires the lettering to be from the left conductor in the panel to the right conductor. It is a good idea to mark the service and feeder phase conductors with colored tape or label them with letters. When working on a 3-phase electrical system, care must be taken not to reverse any phase conductor or motor rotation will be reversed.

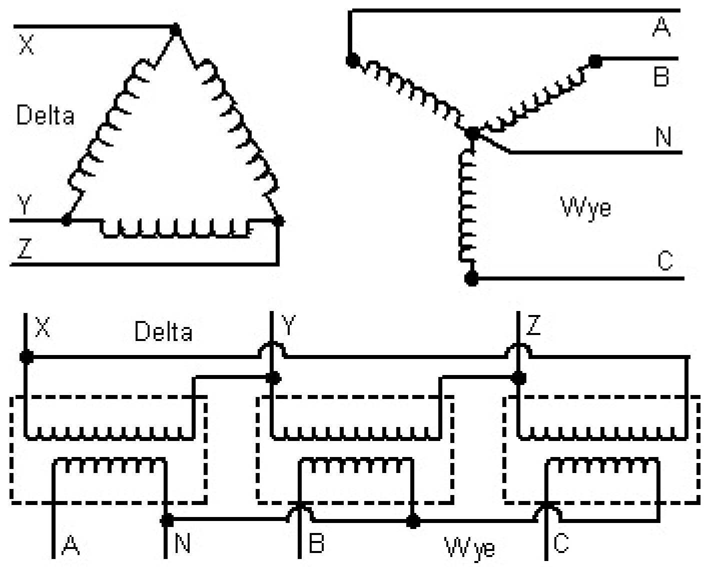


Figure 220.2 Three individual transformers are used to change the voltage of a 3- phase electrical system with the windings in this case connected in a delta on the primary side and a wye on the secondary side.

Loads such electric motors of equal horsepower rating draw less current when operating from a 3-phase supply than a single-phase motor operating at the same voltage. The 3-phase motor will have three supply conductors while the single-phase motor will have two supply conductors. Single-phase motor current will be approximately equal to 3-phase motor current times 1.73. Power in a single-phase circuit is equal to the voltage times the current times the power factor. Refer to Equation 220.1. In a 3-phase circuit power is equal to 1.73 times the voltage times the current times the power factor as shown in Equation 220.2.

Single-Phase

$$\text{Power} = \text{Volts} \times \text{Amps} \times \text{power factor} = E \times I \times pf \qquad \textbf{Equation 220.1}$$

3-Phase

$$\text{Power} = 1.73 \times \text{Volts} \times \text{Amps} \times \text{power factor} = 1.73 \times E \times I \times pf \qquad \textbf{Equation 220.2}$$

Three-Phase 208/120 Volt, 4-Wire Wye: A 3-phase, 4-wire wye electrical system is ideal for supplying buildings that have many circuits operating line to neutral such as lighting and general-purpose receptacle outlets. With this type of system, there are three ungrounded conductors and the neutral or common conductor originating at the point where the three transformer secondary windings are connected. A 3-phase, 4-wire, 208/120 volt electrical system is illustrated in Figure 220.3. In the case of a wye electrical system, the voltage between any two phase conductors is 1.73 times the voltage from phase-to-neutral. The voltage in one transformer winding is 120° out of phase with the voltage in any adjacent winding. As a result, the voltage across each winding cannot be added arithmetically. To find the phase-to-phase voltage of a wye electrical system given the phase-to-neutral voltage, multiply the phase-to-neutral voltage by 1.73 as shown in Equation 220.3. To find the phase-to- neutral voltage of a wye electrical system given the phase-to-phase voltage, divide the phase-to-phase voltage by 1.73 as shown in Equation 220.4.

Wye electrical systems only

$$\text{Phase-to-phase voltage} = 1.73 \times \text{Phase-to-neutral voltage} \qquad \textbf{Equation 220.3}$$

$$\text{Phase-to-neutral voltage} = \text{Phase-to-phase voltage} \,/\, 1.73 \qquad \textbf{Equation 220.4}$$

If the major load in a building is electric motors and electric discharge lighting, then the most practical 3-phase, 4-wire electrical system to use is a 480/277 volt wye system. The phase-to-phase voltage is 480 volts and by dividing this by 1.73 the phase-to-neutral voltage will be 277 volts. Electric discharge lighting ballasts are commonly available to operate at 277 volts. The electrical system will look exactly the same as shown in Figure 220.3 except the 120 volts is replaced with 277 volts and the 208 volts is replaced with 480 volts. The panel and circuit breakers must be rated for this higher set of voltages.

Three-Phase, 240 Volt or 480 volt, 3-Wire Ungrounded Delta: In cases where the only load to be supplied is electric motors or similar 3-phase loads, a delta 3-wire electrical system is satisfactory because a neutral conductor is not needed. The electrical code permits such a system to operate without a direct connection to ground. The 3-phase delta 3-wire system can supply power at 240 volts or it can supply power at 480 volts depending upon the need. Figure 220.4 illustrates a 480 volt, 3-wire, ungrounded delta 3-phase electrical system. Note at the transformer there is no connection to ground. At the service panel the electrician is required to install a ground which is only connected to the service panel enclosure. Supplying a load with this type of electrical system involves installing a 3-pole circuit breaker and running three phase conductors. An equipment grounding conductor must also be run for safety. If a 120 volt circuit is needed for lights and receptacles, then an additional single-phase transformer will need to be installed to step the 240 or 480 volts down to 120 volts.

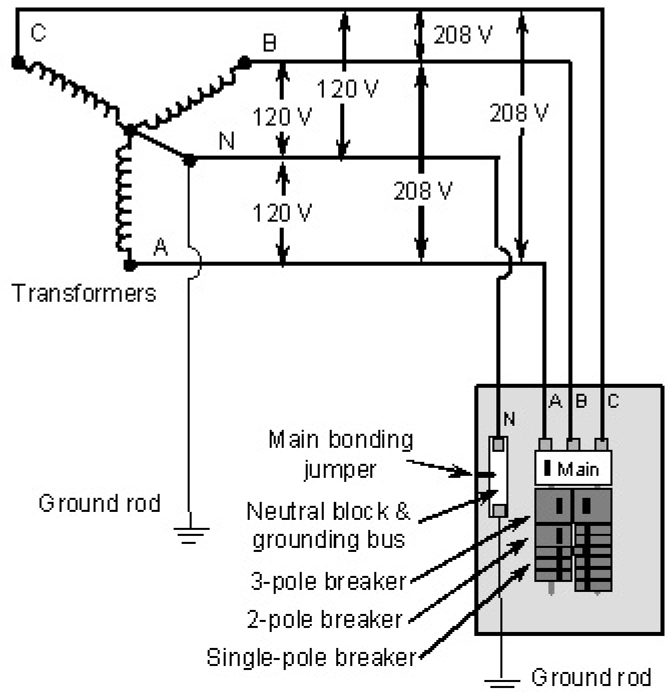


Figure 220.3 A 208/120 volt, 4-wire, 3-phase wye electrical system, common for commercial buildings, provides single-phase power at 120 and 208 volts and 3-phase power at 208 volts. The wye electrical system can also operate at 480/277 volts.

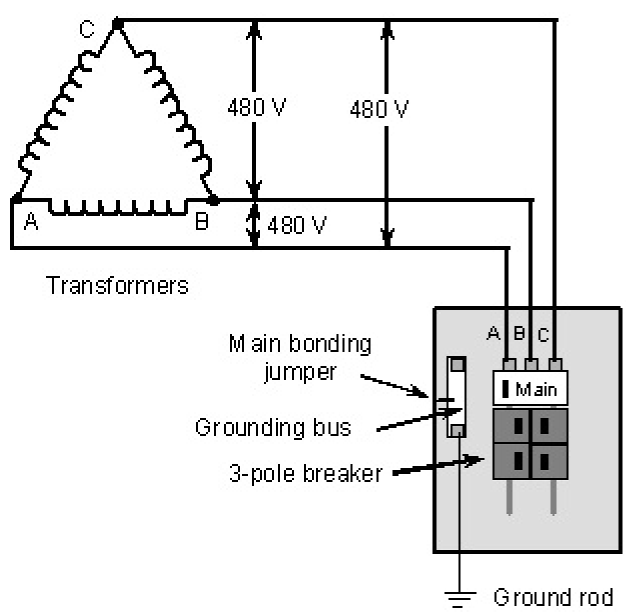


Figure 220.4 A 3-phase, 3-wire, ungrounded delta electrical system operating at 480 volts (sometimes 240 volts) is suitable for applications where most of the load to be served is electric motor load and similar 3-phase loads such as electric heaters.

Three-Phase, 240 Volt, 3-Wire Corner Grounded Delta: The 3-phase, 3-wire, delta corner grounded electrical system is used generally for the same applications as the ungrounded delta system except the transformer windings are grounded. This system can operate either at 480 volts or at 240 volts. Figure 220.5 shows a corner grounded, 3-wire, 3-phase system operating at 240 volts between phase conductors. The utility grounds one of the phase conductors at the transformer. This is called the grounded phase conductor by the electrical code and is required to have a white marking. This is a phase conductor, not a neutral. It usually terminates at a grounding bus in the main service panel, and the electrician is required to ground this conductor to the earth at the service panel. Only two of the phase conductors are required to have overcurrent protection. The grounded phase conductor is not permitted to have overcurrent protection unless it is a circuit breaker that also opens the other phase conductors. A load such as an electric motor is wired the same as other motor circuits except one phase conductor will originate at the grounded phase terminal of the service panel and the other two phase conductors will originate at a circuit breaker. In addition to the three phase conductors, an equipment grounding conductor is also required. The grounded phase conductor is not permitted to serve as the equipment grounding conductor.

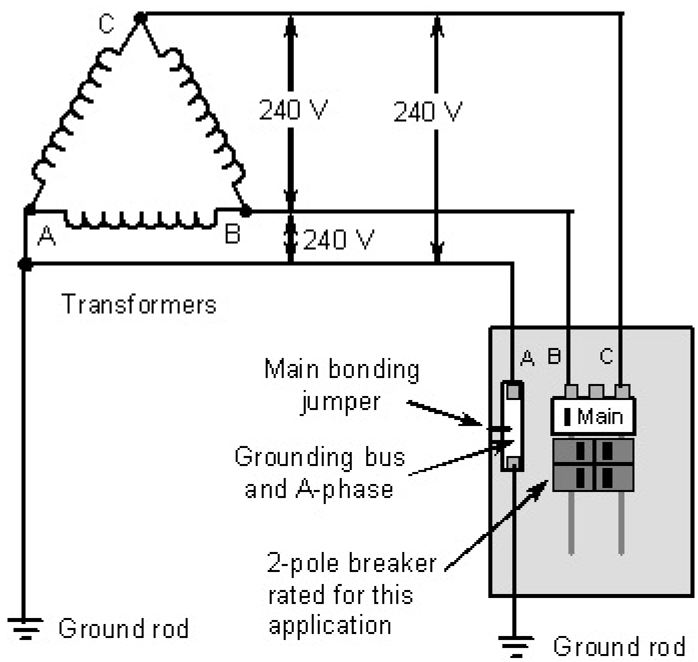


Figure 220.5 A 3-phase, 3-wire, delta electrical system is permitted to have one phase grounded. The grounded phase conductor is not permitted to have overcurrent protection. It is required to be grounded at the transformer by the utility and at the service panel by the electrician. This system operates at 240 volts between phase conductors. The system is also permitted to operate at 480 volts between conductors.

Three-Phase, 240/120 Volt, 4-Wire Center-Tap Grounded Delta: There are some applications where 3-phase power at 240 volts is desired, and also single-phase power at 120 volts and at 240 volts. All three requirements can be met by one set to transformers connected in a delta with a center-tap to one of the transformers as shown in Figure 220.6. This type of electrical system is used for many farm and small commercial applications. When a load such as an electric motor is supplied, a 3-pole circuit breaker is installed in the service panel. Single- phase 240 volt loads can be supplied using a 2-pole circuit breaker, although the circuit breaker must be rated for this type of application. Single-phase 120 volt loads can be supplied using a single-pole circuit breaker — but there is a caution. With this system there will be 120 volts from the neutral to two phase conductors, and 208 volts from the neutral to the other phase conductor. The electrical code calls that phase conductor the phase with the higher voltage to ground. Electricians generally call that phase the high leg or the wild leg. Do not install any single-pole circuit breakers in the panel connected to the high leg. The electrical code requires the high leg to be the center phase (B phase) and be marked with orange tape or paint everywhere it is visible. This is a very versatile system, but caution must be taken to prevent misuse of the high leg. Reference to the required marking of the high leg of a 3-phase, 4-wire, 240/120 volt electrical system is found in *Section 110.15* of the *National Electrical Code*.

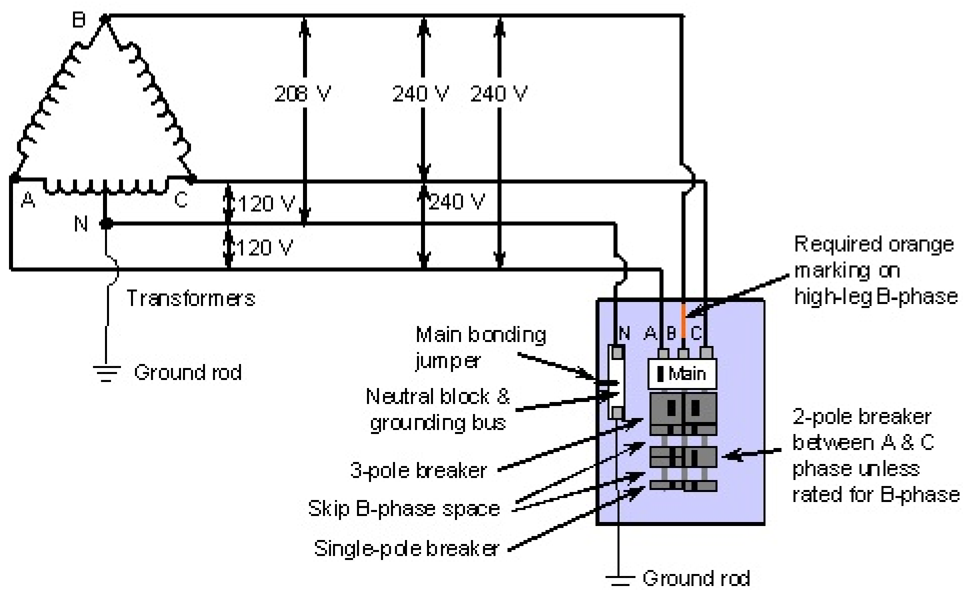


Figure 220.6 A 240/120 volt, 4-wire, 3-phase delta electrical system provides single- phase power at 120/240 volts and 3-phase power at 240 volts. One phase has a higher voltage to ground and that phase must be identified with an orange marking.

Open Delta 3-Phase Electrical Systems: All of the delta 3-phase electrical systems previously described can be operated with one of the primary phase conductors missing. One example of this type of electrical system is shown in Figure 220.7. Note that the electrical system in Figure 220.7 looks exactly like the one in Figure 220.6 except one of the transformers has been removed. One advantage of this type of system is that the utility is able to provide 3- phase power to a customer even when one of the phase conductors of the primary distribution system is not available.

Utility electrical distribution of primary power in many parts of the country is done with what is known as a multi-grounded wye electrical distribution system. The three windings of the utility substation distribution transformers are connected in a wye configuration with the common point of the wye connected to the earth by means of an extensive grounding electrode at the substation. The distribution wires supplying power to customers are three ungrounded (hot) phase conductors on insulators and a neutral wire generally not mounted on insulators. There is a grounding electrode such as a ground rod connected to this primary neutral wire at every customer transformer location and often at poles between customer locations. When a customer is supplied single-phase power, the primary winding of the transformer is connected to one of the primary phase conductors and to the neutral conductor. Refer to *Tech Note 219* for a description of a single-phase connection. For a 3-phase connection to a multi-grounded distribution line three individual single-phase transformers are generally used with each transformer primary connected to one of the primary phase wires and the other terminal of each transformer connected together and to the primary neutral as well as to a grounding electrode. This is illustrated in Figure 220.8. When a 3-phase delta electrical system is supplied from a 3- phase wye distribution line it is possible to provide the customer 3-phase electrical power as shown in Figure 220.7 with one of the transformers removed. Two transformers are used rather than three transformers as shown in Figure 220.7 and Figure 220.9. This is called an open delta connection. More about utility electrical distribution can be found in *Tech Note 225*. The delta systems shown in Figure 220.4 and Figure 220.5 can also be operated open with one transformer removed.

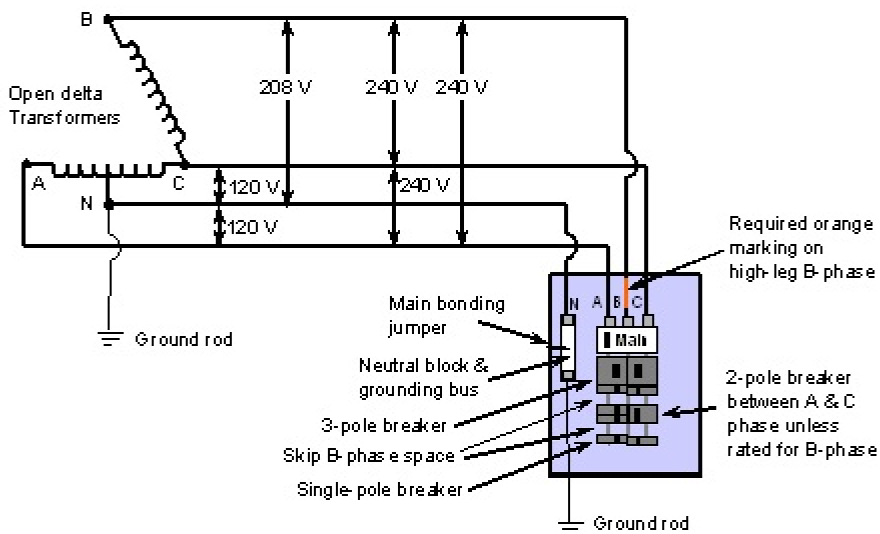


Figure 220.7 The utility can provide 3-phase power to a customer with an open delta system when one of the distribution system phase conductors is not available. This system is the same as in Figure 220.6 except one transformer has been removed.

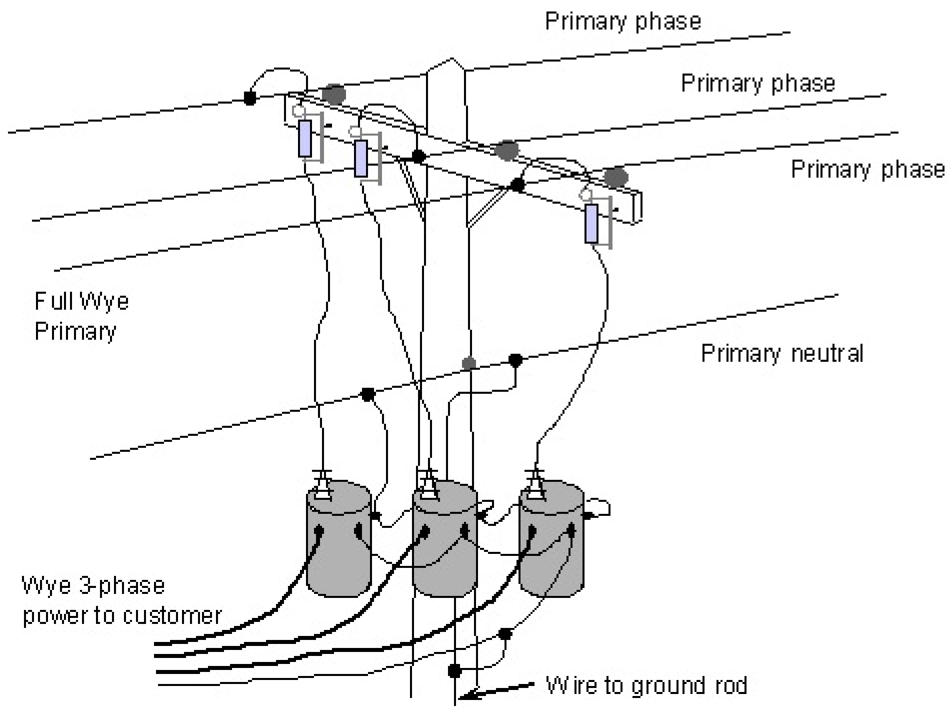


Figure 220.8 The utility primary distribution line has three phase conductors and a grounded neutral wire. Note that one primary terminal of each transformer is connected to a different phase conductor and the other primary terminals of each transformer are connected together, connected to the primary neutral wire, and also connected to a grounding electrode.

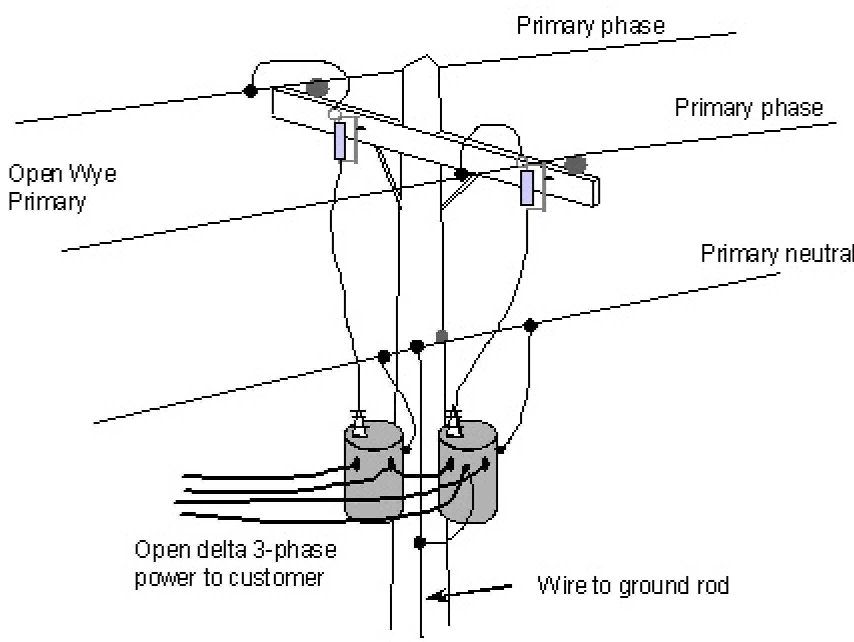


Figure 220.9 The utility primary distribution line has only two phase conductors and a grounded neutral wire. One primary terminal of each transformer is connected to a primary phase conductor and the other primary terminal of the two transformers is connected together and connected to the primary neutral as well as to a grounding electrode. This is called an open delta connection.

Conclusions: Utility electrical power is generated and distributed as 3-phase, 60-Hz, alternating current where both single-phase power and 3-phase power can be provided. The transformers that change the voltage at various points along the system can be connected in only two configurations, as a delta or as a wye. Depending upon the requirements of the customers, the utility can provide electrical power as single-phase or as 3-phase in a variety of standard nominal voltages. Single-phase power can be provided as 120 volts, but most single-phase power is provided with a center-tapped transformer that provided both 120 volts and 240 volts. The wye 3-phase transformer configuration generally provides power at 208 volts between phases and 120 volts from phase-to-neutral, or different transformers can be used that provide power at 480 volts between phases and 277 volts from phase-to-neutral. If only 3-phase power is needed it can be provided with a delta configuration at either 240 volts or at 480 volts. A different set of transformers is needed for each of these voltages. Because this is a delta configuration the system can be operated as an open delta using only two transformers. Some farm and commercial customers may want 3-phase power at 240 volts and also single-phase power at 120/240 volts. By providing a center-tap to the secondary winding of one of the delta transformers both of these requirements can be provided with the same system as a 4-wire delta 240/120 volt, 3-phase system.

A copy of the latest edition of the *National Electrical Code* can be obtained from the National Fire Protection Association, One Batterymarch Park, Quincy, MA.

Biosystems & Agricultural Engineering Department
Michigan State University

Grounding, Bonding, and Equipotential Grids

Electrical systems that commonly supply power to areas accessible to the general public are grounded to limit the maximum voltage that may occur and to minimize adverse effects from lightning. This means that one wire of the electrical system serving a building accessible to the general public is grounded to the earth. Theoretically there is no voltage difference between the floor upon which a person stands and the grounded wire of the electrical system. Because there is resistance in conductors, and because wiring and equipment can fail, sometimes there is a difference between a grounded wire and the adjacent earth or floor. This Tech Note is intended to discuss grounding of electrical systems, the terminology associated with electrical grounding, and some of the grounding techniques used to protect humans and animals from harmful as well as annoying electrical shocks and tingles.

All circuits of electrical systems are required to have an effective equipment grounding conductor run to every outlet, appliance, and equipment supplied. This conductor may be a wire or it may be the metal of pipes and enclosures that are a part of the electrical circuit. The purpose of this grounding conductor is to act as a barrier between a person or animal and exposure to live power that can be harmful. Figure 228.1 shows a single-phase circuit breaker service panel typical of the type that supplies power to a dwelling.

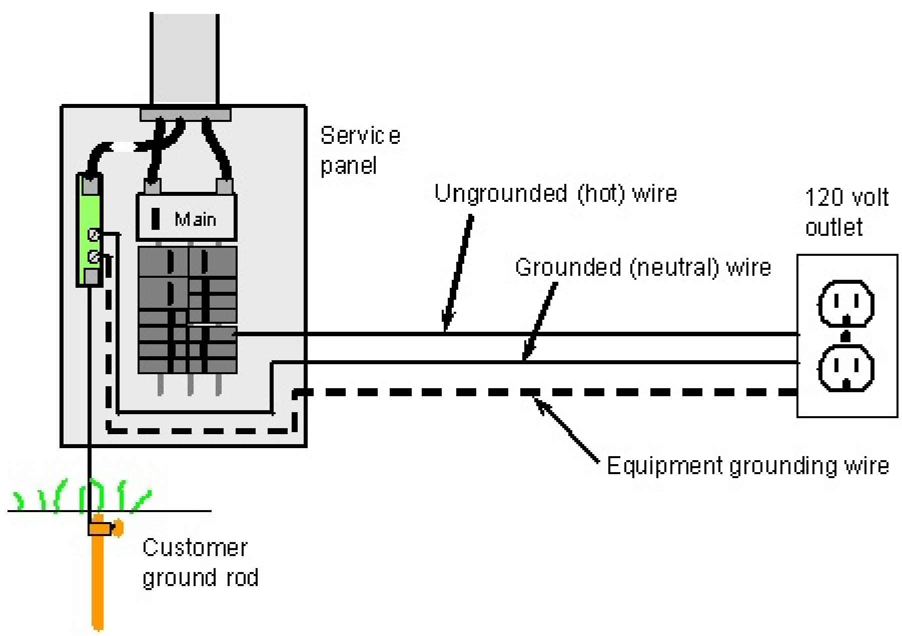


Figure 228.1 A 120 volt circuit supplied from a single-phase service panel has an ungrounded (hot) wire, a neutral wire (grounded) and a safety equipment grounding wire.

A typical single-phase electrical service panel like the one shown in Figure 228.1 has two ungrounded or hot wires supplying the service panel. There is 240 volts between the two hot wires, but only 120 volts between each hot wire and the grounded wire which is called the neutral. The diagram shows the wires that are required to supply a 120 volt receptacle. There is an insulated hot wire (usually a black wire), an insulated neutral wire (must be the white wire), and a safety equipment grounding wire which is either bare or has green insulation. Notice that the equipment grounding wire and the neutral wire both terminate at the same location in the service panel. If something goes wrong and the equipment a person is holding develops a voltage, the equipment grounding wire will carry the fault current safely back to the service panel. If the equipment grounding path is broken or not present, the fault current can flow through the person to the earth or floor, possible causing serious injury.

When a person or an animal feels an electrical sensation, what they are feeling is the flow of current through the body or a portion of the body. Dry skin has a fairly high resistance and it takes a higher voltage to cause a perceptible level of current than if the skin is wet. It only takes a fraction of a milli-ampere (mA) of current (less than 0.001 ampere) for human perception when a person is aware of the possibility of an electrical exposure. Usually it takes about 1 mA of current to get the attention of a human when unaware of an electrical exposure. At a level of 5 mA through a portion of the human body, the shock is generally not pleasant and in some cases is at a level where it may begin to be harmful. The ground-fault circuit- interrupter receptacle required to be installed in many dwelling locations and for all outside 120 volt receptacles trips off the power at a level of 5 mA.

Types of Grounding: One type of grounding is called *system grounding*. This is the intentional grounding of an electrical system to the earth at the service panel. Electrical systems are grounded, usually to the earth, to limit the voltage due to lightning, line surges, or unintentional contact with higher voltage lines. Electrical systems are also grounded to stabilize or fix the level of voltage that can develop under normal conditions between the earth and electrical conductors. A large wire, usually bare copper, runs from the neutral terminal of the service panel to a connection to the earth. One type of earth connection is a metal rod or pipe driven into the earth. The electrical code describes other acceptable ways of making this connection to the earth.

Another type of grounding is called *equipment grounding* and is also shown in Figure 228.1. It connects the metal frames of equipment likely to become energized to a common grounding point which in most cases is the neutral terminal at the service panel. The basic purpose of this equipment grounding conductor is to allow enough current to flow under fault conditions to cause the operation of an overcurrent device such as a fuse or circuit breaker which then de-energizes the circuit. Another purpose of equipment grounding is to limit the voltage on conductors or equipment being contacted by personnel when fault current is flowing. Fault current may flow for a few seconds before the overcurrent device opens the circuit. Or, the fault current may not be sufficient to de-energize the circuit. Under these circumstances, the purpose of the equipment grounding wire is to prevent the voltage exposed to people and animals from getting high enough to cause injury.

Definitions: Terminology associated with the subject of grounding can be confusing. It is important to understand these terms. A *grounded conductor* is an insulated conductor that is intentionally grounded to the earth at the service panel. The electrical code calls it the grounded circuit conductor. For most electrical systems it is the neutral wire. Even though it is grounded to the earth at the service panel, it carries circuit current. An equipment *grounding conductor* is one that connects to exposed metal of the electrical system and to frames of equipment. This conductor does not carry circuit current. It's purpose is to conduct fault current in the event of a problem with the electrical system where a person or animal may become exposed. Most circuits will operate without the equipment grounding wire, but safety is compromised. Even though the equipment grounding wire is not a circuit conductor, some equipment will not operate properly without an equipment grounding connection.

A *fault* is a condition where the electrical current is flowing outside of the intended path. A *ground fault* occurs when there is contact between a circuit conductor that carries current and the earth or the frame of equipment. If this ground fault is to an ungrounded wire (hot) usually the fuse will blow or the circuit breaker will trip. This ground fault can be from the neutral wire in which case the circuit may continue to operate, unless the circuit is protected with a ground-fault circuit-interrupter (GFCI). In that case the GFCI will detect the ground fault and trip off the circuit. A *short circuit* is a fault where current travels directly from one conductor to the other such as when an electrical cable is pinched or penetrated by a screw or nail.

A *voltage gradient* is a difference in voltage across a surface of some material. The gradient voltage can be measured by touching two points on the surface with a voltmeter. Voltage gradients of concern may exist across the surface of high resistance materials such as the earth, a concrete floor, or fresh water such as a fountain or swimming pool water. Utility as well as customer wiring systems are generally grounded to the earth and there will likely be some small amount of current flowing through the earth. Currents flowing through the earth can cause detectable voltage gradients across the earth. Typically a small voltage gradient can be measured across the earth within a few inches of a service panel ground rod. People and animals can sometimes detect these voltage gradients as a slight tingle, but in extreme cases an annoying shock can occur. Within the fenced-in areas near utility equipment, voltage gradients can rise to harmful levels and utility personnel are trained to work safely within these areas.

A *touch potential* is a voltage across a human or animal's body when making contact with metal or another conductive surface. Generally a touch potential is from a hand to the earth such as illustrated in Figure 228.2 for this utility worker. But, small current flowing in the earth can in some cases create small touch potentials around equipment that can be detected by people and animals. A cow at a farm may feel a tingle due to a small touch potential when drinking from some water fountains as illustrated in Figure 228.2.

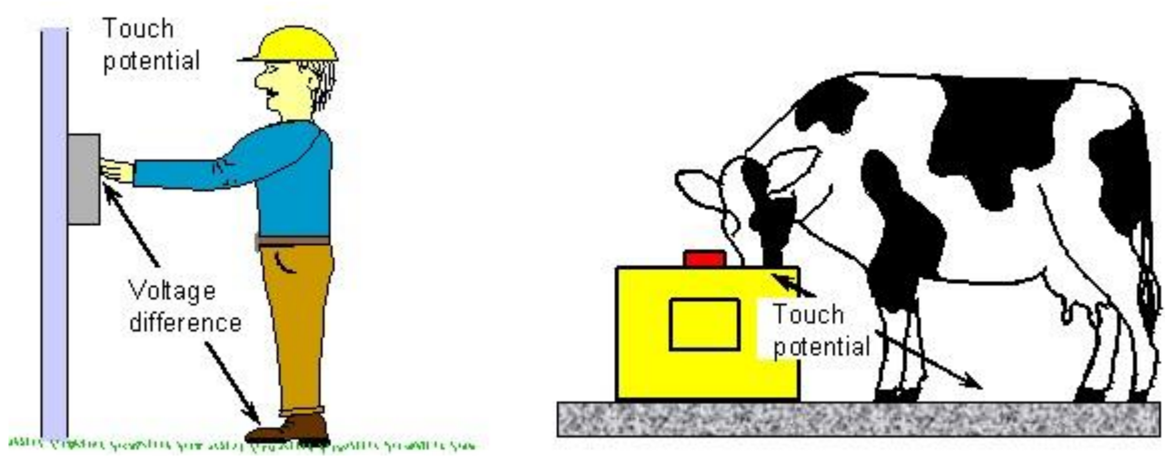


Figure 228.2 Voltage gradients in the earth or floor can result in the floor being at a different potential than exposed metal equipment resulting in a touch potential.

A *step potential* is a voltage across a human or animal's body while standing on the earth or some other surface such as a concrete floor. A voltage gradient across the surface of the earth or floor will result in a difference in voltage between a human's or animal's feet. A step potential is illustrated in Figure 228.3. Rarely does a human detect a step potential unless standing on a wet surface with bare feet such as near a swimming pool. If some electrical equipment develops a fault causing an excessive leakage of current into the earth, a voltage gradient will most likely develop in the earth or floor near the equipment and a noticeable step potential can be detected by animals such as the cow in Figure 228.3.

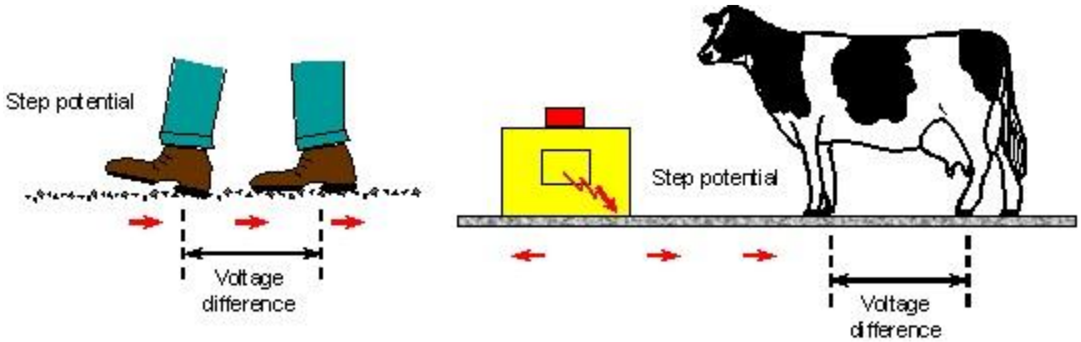


Figure 228.3 A voltage gradient across the surface of the ground or floor, called a step potential, can expose a person or animal to a difference in voltage between feet.

An **equipotential bonding grid** is intentionally installed metal elements such as wire, rods, or conductive coatings in the floor, earth, or across the surface with the intention of reducing or eliminating difference of voltage. Metal elements installed in a concrete floor and bonded to exposed metal above the floor will eliminate a difference in voltage between the floor and the exposed metal. The purpose of an equipotential bonding grid is to eliminate or reduce to insignificant levels touch and step potentials for humans and animals. An equipotential bonding grid is illustrated in Figure 228.4 where metal reinforcing mesh embedded in the concrete floor is bonded to the metal that can be touched be humans or animals.

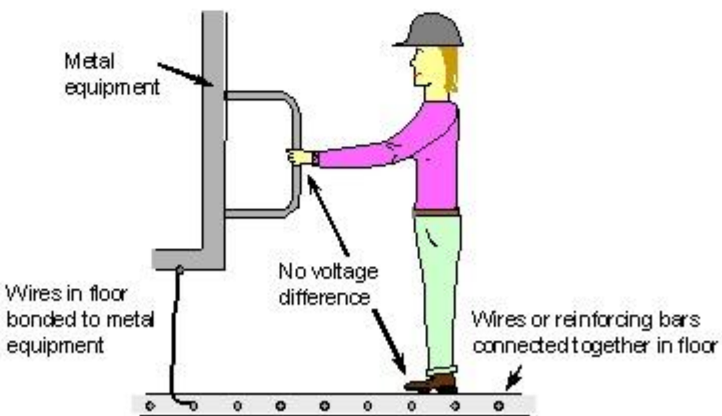


Figure 228.4 Reinforcing metal installed in a concrete floor and bonded to exposed metal above will result in an equipotential bonding grid where there is little or no difference in voltage between the floor and the exposed equipment.

Electrical *bonding* is the intentional connecting together of metal or conductive parts of an electrical system. The grounding path created by metal tubing or conduit may be interrupted by a section of nonconductive conduit. For example, to provide flexibility for adjustments, there may be a short length of flexible nonmetallic conduit inserted in a run of metal conduit supplying power to a motor, appliance, or equipment. A copper bonding wire , sometimes called a bonding jumper, is used to connect sections of metal conduit together to form one continuous low resistance path all the way from the service panel to the equipment.

Importance of Equipment Grounding: All equipment required to be grounded is to be connected back to the service enclosure. If equipment grounding is omitted or becomes ineffective, there will not be an effective ground-fault circuit path and the exposed metal of the equipment may develop a voltage that potentially can be dangerous to humans and animals. If the equipment where a fault occurs is making contact with the earth, such as the sump pump in Figure 228.5, current will flow into the earth.

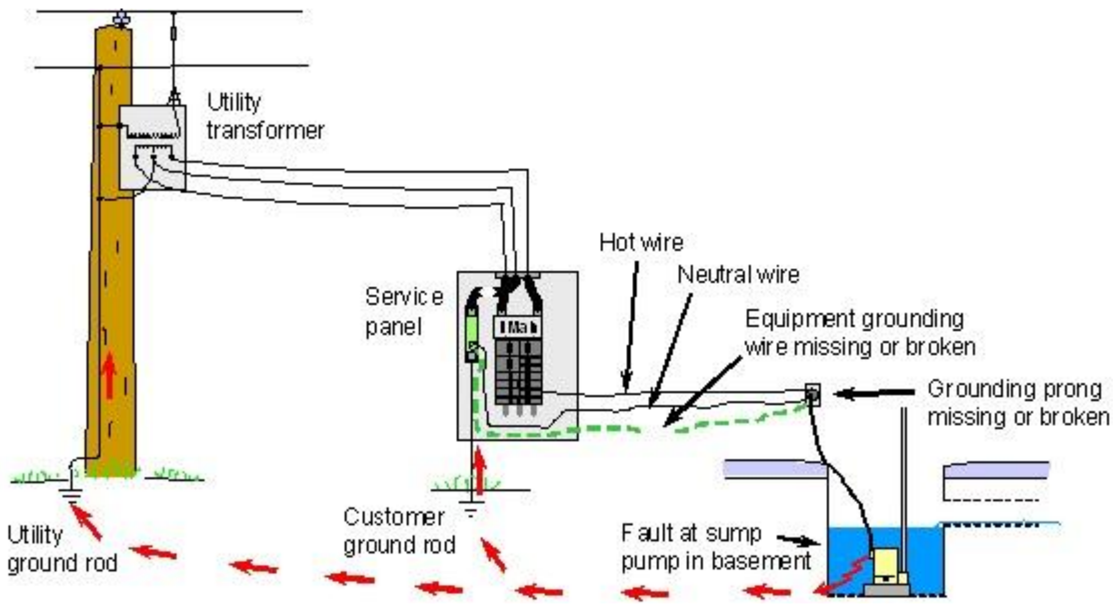


Figure 228.5 A fault in equipment that is not grounded may result in an earth current that can cause an objectionable or even dangerous voltage to occur in the surrounding area.

Electrical current flow completes a circuit from the source to the load or point of a fault and back to the source. Contrary to the belief of some individuals, current from an electrical system generally is not seeking the earth. Because electrical systems are often required to be connected to the earth, the earth can become a conductor. Electrical current goes to the earth to seek a path back to the source. Generally the source is the transformer that produces the voltage. Current that goes into the earth will eventually exit the earth at one or more points to get back to the source. Since there is resistance between the earth and a grounding electrode, there will be a voltage set up between the earth and the grounding electrode when current flows on this path. This is called neutral-to-earth voltage and is illustrated in Figure 228.6. Neutral-to-earth voltage creates touch potentials and sometimes detectable levels of step potentials.

This neutral-to-earth voltage is a difference in voltage between some metal object that is grounded to the electrical system and the adjacent earth. Neutral-to-earth voltage can be measured by touching a piece of metal equipment or the service panel grounding wire as in Figure 228.6 with the other probe connected to a short metal rod driven into the earth out in the yard. Best results are obtained by using a digital voltmeter. This voltage is caused by a small level of current (usually a small fraction of an ampere) flowing to earth or from the earth to the service panel neutral terminal.

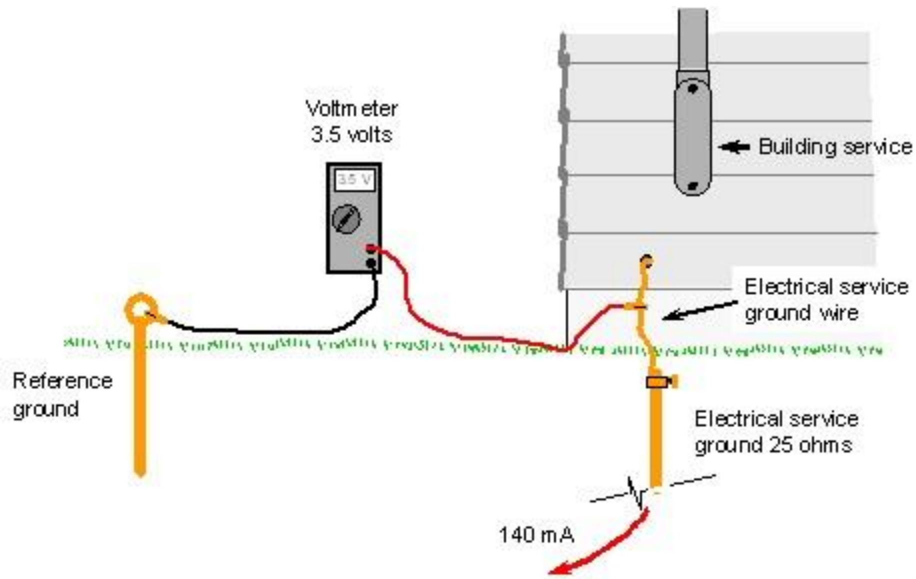


Figure 228.6 Neutral-to-earth voltage can be measured with a digital voltmeter by touching the equipment or the service panel grounding wire with one meter probe and measuring to a rod pushed into the earth out in the yard.

Earth Gradients and Ground Currents: Since utility and customer electrical systems are grounded to the earth at multiple locations, the earth acts as a parallel path to the grounded conductor. Usually the resistance through the earth is so high the current flowing in the earth is very small and of no consequence. The lack of a grounding conductor to equipment that is making contact with the earth can result in a significant level of current flowing in the earth. This current flows through the earth in the local area seeking a path back to the source transformer. A high resistance in a neutral conductor of the customer or utility due to a corroded splice or an undersized wire for the load can result in a voltage drop along the wire that increases the neutral current flow in the earth.

Most of the resistance of a path through the earth is located at the grounding electrode where the electrical system makes contact with the earth. Electrical codes indicate that the resistance to earth should be kept as low as practical, and below 25 ohms if possible. Since low resistance of a grounding electrode is dependant upon the resistivity of the earth at that location, low resistance in many places is not possible to achieve. According to the Ohm's law, current flow across a resistance will result in a voltage difference. The product of current and resistance is voltage. This is illustrated in Figure 228.6 where 140 milliamperes (0.14 amperes) is flowing into the earth at a ground rod that has a resistance-to-earth of 25 ohms. A voltmeter connected to the grounding wire and connected to the earth about 10 ft from the ground rod will measure about 3.5 volts caused by this current flow. A person or animal standing on the earth and touching the grounding wire will have a voltage across the body.

The voltage will be less the closer a person or animal stands to the ground rod. This difference in voltage in the earth is called a gradient. Usually this gradient is so small it cannot be detected. In recent years it was discovered that livestock on farms and people in swimming pools can detect this gradient or neutral-to-earth voltage.

Equipotential Grid: An equipotential bonding grid is the intentional installation of metal in the earth or floor near exposed metal equipment with the purpose of making the earth or floor at the same electrical potential as the exposed metal equipment. The theory is that a person or animal near the equipment will not experience a detectable voltage difference across the body by touching the equipment (touch potential). This is illustrated in Figure 228.2 and Figure 228.4. Equipotential bonding grids are required by the Code to be installed in some agricultural locations, at permanent swimming pools, and near electrical equipment associated with some artificial bodies of water.

A typical means of creating an equipotential grid in the floor of a livestock area is illustrated in Figure 228.7. Sheets of reinforcing metal are put in place prior to pouring a concrete floor. The sheets consist of steel wire factory welded at each wire crossing point. The sheets of reinforcing steel are fastened together with tie wires to form an electrical bond between the sheets. This method of bonding the reinforcing metal is acceptable by the electrical code. A copper wire connected to one of the reinforcing sheets is required to be connected by means of a pressure connector or exothermic welding. This copper wire is required to be size 8 AWG or larger. In the case of a permanent swimming pool with conductive poured walls and floor, this connection is to the equipotential bonding grid wire in the concrete. The wire is to be solid copper wire not smaller than size 8 AWG. As this copper wire emerges from the concrete it should be protected from damage by a nonmetallic conduit sleeve. Rigid nonmetallic conduit provides a durable corrosion resistance means of protecting the copper wire. This wire is then connected to all of the other metal equipment associated with the swimming pool. Bonding the wire directly to the grounding conductor of the exposed equipment is recommended. Make sure this bonding connection is not in such a location that it will experience physical damage or corrosion.

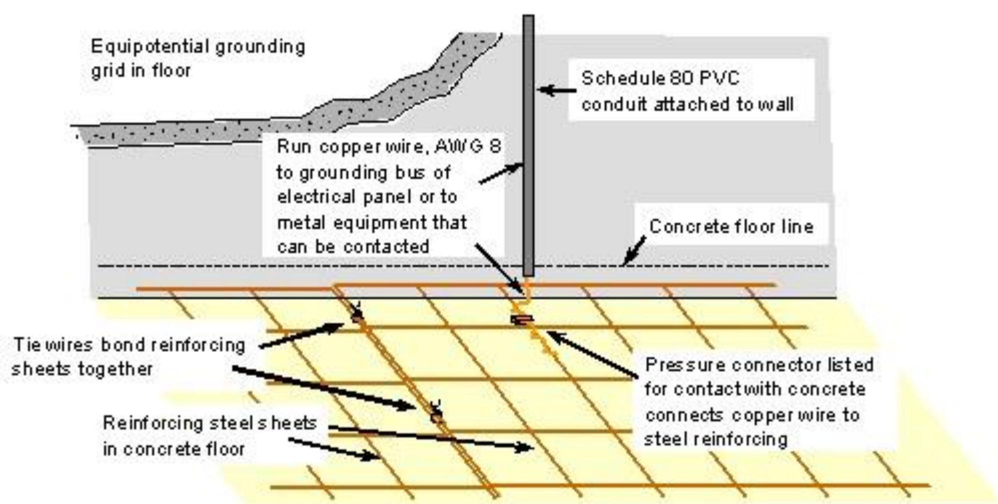


Figure 228.7 A typical means of establishing an equipotential grid is to insure that reinforcing bars or wire mats installed in concrete floors are connected together and a wire brought out of the concrete for connection to exposed metal equipment or to the grounding bus of the electrical supply panel.

Electrical Tech Note — 320

Biosystems & Agricultural Engineering Department
Michigan State University

Variable Frequency Drives

A variable frequency drive (VFD) is powered with 60 Hz alternating current and provides a 3-phase alternating current output with a frequency that can be varied. A VFD can be operated from a single-phase 60 Hz supply or from a 3-phase 60 Hz supply. The input alternating
current supply is rectified and filtered to produce direct current. The direct current is then inverted to form a 3-phase alternating current at the desired frequency that can be the same or different than the 60 Hz input power. The power circuit contains a rectifier and filter to convert alternating current to direct current, and an inverter to convert direct current back into alternating current at the desired frequency. An electronic controller receives feedback from the system being powered as well as monitors and controls the power to the 3-phase induction motor being driven. Figure 320.1 is a block diagram of the basic components of a variable frequency drive unit.

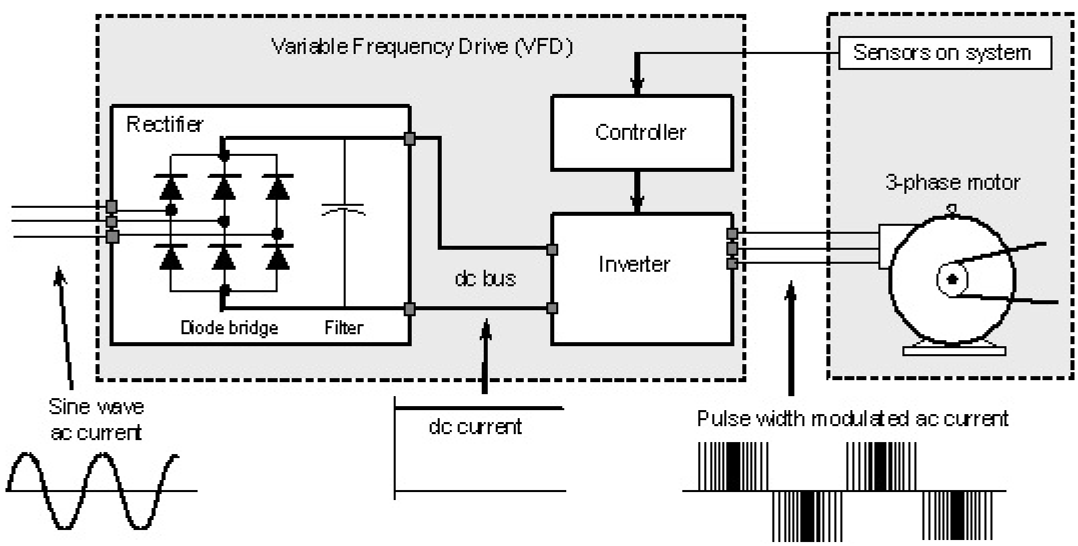


Figure 320.1 A variable frequency drive (VFD) rectifies the input 60 Hz alternating current into direct current, and using a device called an inverter, produces an alternating current output at the desired frequency to supply a 3-phase induction motor.

Induction Motors: The most common electric motors in use are induction motors that have a basically constant shaft rotation. Powered from a 60 Hz supply, a common 4-pole induction motor will have a full-load shaft rotation of from 1725 rpm to 1740 rpm. The shaft speed will decrease somewhat when the motor is heavily loaded and it will speed up when the motor is lightly loaded. With a 60 Hz supply, a magnetic field is produced by the windings in the outer frame (stator) of the motor that turns exactly at 1800 rpm for a 4-pole motor. This rotating magnetic field induces a current to flow in an aluminum structure within the rotor often referred to as a squirrel cage because of it's appearance. The induction motor derives it's torque by the strength of the rotating magnetic filed in the stator and the magnetic field induced into the rotor squirrel cage. For this to occur the rotor must turn at from 3% to 4% slower than the stator magnetic field when operating at full load. An induction motor is considered to be basically a constant speed motor with the shaft speed dependent upon the frequency of the alternating current supply.

Why Vary Frequency to a Motor: Many electric motors are used to power loads where the power required is highly variable. The motor must be sized to supply the maximum power demand, and much of the time it is operating at less than it's power rating. The efficiency of an electric motor to convert electrical power to mechanical power decreases rapidly when the motor is not working at nearly full load. For many applications, the motor is operating at full load, but the system being powered has a way of releasing excess power that is not needed. An example is a pneumatic system where the need for air-flow is highly variable, but the pump must be continually operating and maintaining a constant pressure. A pressure release valve in the system regulates the pressure when the pump and motor are applying more power than is needed. Systems of this type are common and waste huge amounts of energy. If the induction motor is powered by a variable frequency drive (VFD), the motor shaft rotation can be constantly adjusted to the speed required for optimum operation of the system. Sensors on the system control the speed of the motor and thus the power supplied to the system. The power output of a motor is directly proportional to the shaft speed (rpm) of the motor. Equation 320.1 can be used to determine the horsepower required when the torque (ô) is in pound-feet (lb-ft).

$$horsepower = \frac{2 \times \pi \times \tau \times rpm}{33{,}000}$$

A 3-phase induction motor is relatively inexpensive and maintenance free compared with most other types of motors. They are basically constant speed motors based upon the frequency of the input alternating current. However, if the supply frequency is increased the motor shaft rotation (rpm) will increase and will decrease as the supply frequency is decreased. The variable frequency drive (VFD) is a device that converts the 60 Hz supply to some other frequency for the purpose of varying the shaft rotational speed of an induction motor.

Output Waveform: The output voltage supplied to the induction motor by the variable frequency drive (VFD) is an alternating waveform at a desired frequency, but it is usually not a sine wave which is the case with the input voltage to the drive unit. Three-phase induction motors when designed for the purpose do not require a supply that is a sine wave. These motors can operate effectively from alternating waveforms of other types. This simplifies the design of drive units and helps control cost. A popular variable frequency drive provides an output by the method of pulse width modulation (PWM). The output on each phase is a repetitive pattern of positive and negative pulses with varying width with the pattern repeated at the desired frequency. Older motors not designed to operate with these waveforms may be subject to premature failure. Use only motors specifically rated for operation with variable frequency drives. Figure 320.2 is a representation of appearance of the output waveform of one of the phases from a pulse width modulation type variable frequency drive.

Motor Overheating: Electric motors are designed with internal fans and sometimes external fans to remove heat from the windings and rotor. When the rotor slows, cooling is reduced and the motor may be prone to overheating. This is less of a problem for 3-phase induction motors specifically designed for operation from a variable frequency drive. The *National Electrical Code* in *Article 430* requires some method be provided either in the motor or in the drive unit to detect motor overheating.

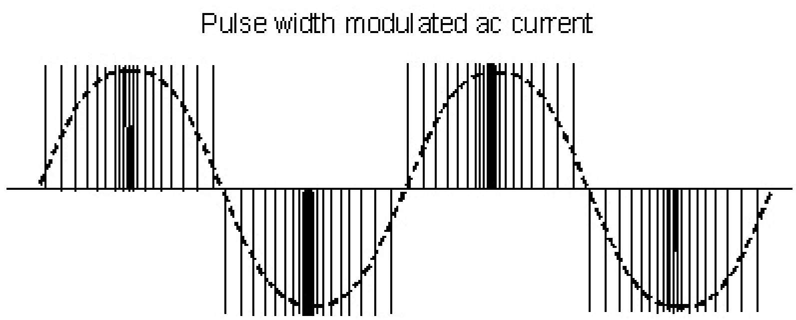


Figure 320.2 A common variable frequency drive (VFD) produces an output waveform that consists of a repetitive pattern of positive and negative pulses with varying pulse width. This method is known as pulse width modulation (PWM).

Back-up protection: The variable frequency drive unit contains electronic circuitry that is more prone to failure than an ordinary line-voltage mechanical motor starter. When used to power a system where high reliability is necessary, some means of back-up, or drive unit by- pass is recommended. If the power supply to the variable frequency drive (VFD) is 3-phase, then a by-pass switch can be installed so that the motor can be operated at normal speed directly from the 3-phase supply. A one-line diagram showing the arrangement of a by-pass switch is shown in Figure 320.3. Please note that a single line represents all three phase wires of the electrical system.

Single-phase applications: Variable frequency drives are intended to supply power to 3-phase induction motors. The input supply can be single-phase, but the output to the motor is always 3-phase. For a single-phase application, the equipment that will be supplied must be converted to 3-phase. The existing single-phase equipment must be replaced. The existing single-phase equipment can sometimes be retained as a back-up system in case of failure of the variable frequency drive unit. Most variable frequency drive units are capable of being operated from a single-phase supply except that the rectifier section of the drive unit must work harder to supply the same output power derived from a 3-phase supply. When operating a motor with a variable frequency drive supplied from a single-phase power supply, check with the drive unit manufacturer for the proper rating. When operating from a single-phase supply, the drive unit will usually not be able to supply a load greater than 65% of the 3-phase rating of the unit.

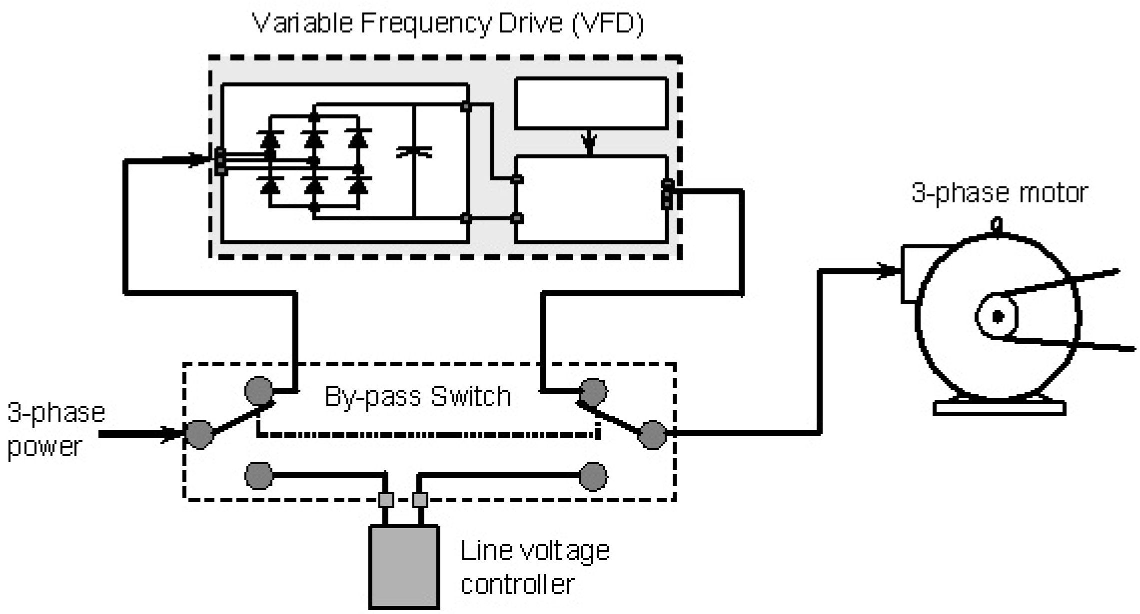


Figure 320.3 A by-pass switch can be installed that allows the motor to be operated directly form the 3-phase supply while completely isolating the drive unit from power so that it can be services with the system remaining completely operational.

Energy Savings: The energy required to operate some systems can be cut to less than half by operating the motor with a variable frequency drive rather than running the motor at full speed from a conventional line-voltage controller. The amount of savings depends upon the sytem and hours of operation. An analysis conducted by a qualified energy auditor can determine the potential energy savings, the estimated conversion cost, and the investment pay-back period. There may even be tax incentives and rebate payments available to help offset the conversion costs. Start by contacting the electric utility or an agency providing energy audit services.

Phase Converters

A phase converter is a device that permits a 3-phase electrical load to be operated from a single-phase supply. Most frequently, the 3-phase device supplied is an electric motor. In some locations the serving utility may not be able to cost effectively provide 3-phase power to a customer. In these cases, the customer must find an alternative method of providing 3-phase power to meet te requirement of the load. Sometimes 3-phase power is available to the customer, but the need for 3-phase power at the customer's facility may be only limited and not practical to rewire the facility. For whatever reason, there are cases where there needs to be a means of occasionally being able to operate a 3-phase load from a single-phase supply. A phase converter makes such operation possible. It is important to understand the different types of phase converters and the principles of operation of the entire phase converter circuit. Rules for installing phase converter circuits are found in *Article 455* of the *National Electrical Code*® (*NEC*®)[1].

Single-Phase and 3-Phase Current: A diagram of a 3-phase load supplied from a single-phase supply is shown in Figure 322.1. Note there are only two wires supplying the phase converter, and there are three wires between the phase converter and the load. If there are only two single-phase wires, the current flowing on them will be higher than on the three wires to the load. If there are no losses at the phase converter, <u>the ratio of single-phase current to 3- phase current will be 1.73 to 1</u>. There will be losses in the phase converter that result in more single-phase current flow into the phase converter than is required to supply the load. These losses vary depending upon the design and type of phase converter. The *NEC* uses a ratio of 2.5 to 1 for single-phase current to 3-phase current.

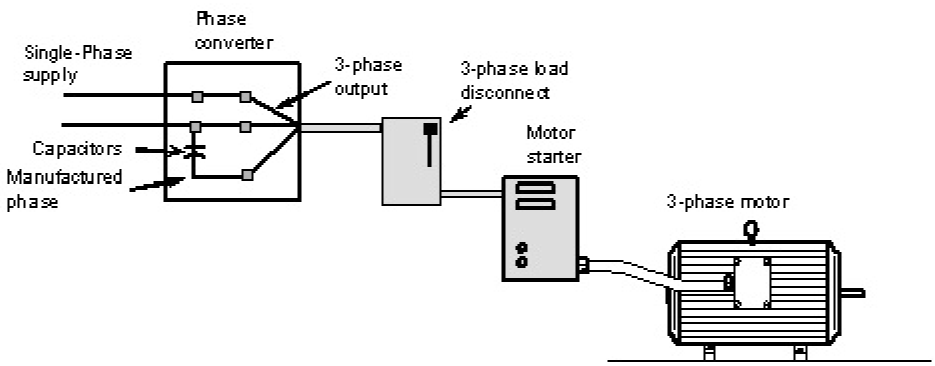


Figure 322.1 Two wires supply the phase converter and 3 wires supply the load from the phase converter. The theoretical current ratio of single-phase current to 3-phase current is 1.73 to 1, but considering system losses the ratio is more like 2.5 to 1.

One of the 3-phase wires between the phase converter and the load is called the *manufactured phase*. Two of the wires to the 3-phase load are solidly connected to the input single-phase wires as shown in Figure 322.1. The manufactured phase is connected to the input single-phase wires through a capacitor or through a capacitor and an inductor. This manufactured phase is required by the *NEC* to be identified by a distinctive marking. The *NEC* prohibits single-phase loads from being connected to the manufactured phase. A typical single- phase load would be a motor control circuit for a motor starter as illustrated in Figure 322.2. Make sure when connecting the control circuit (generally single-phase circuits) that it is connected between the two phase wires that have a direct connection to the input single-phase wires. If this procedure is not followed, it is possible for control system component failure to occur. The voltage between the manufactured phase and either of the other phase conductors may not remain constant through the operation of the equipment, and control system malfunction or failure may occur.

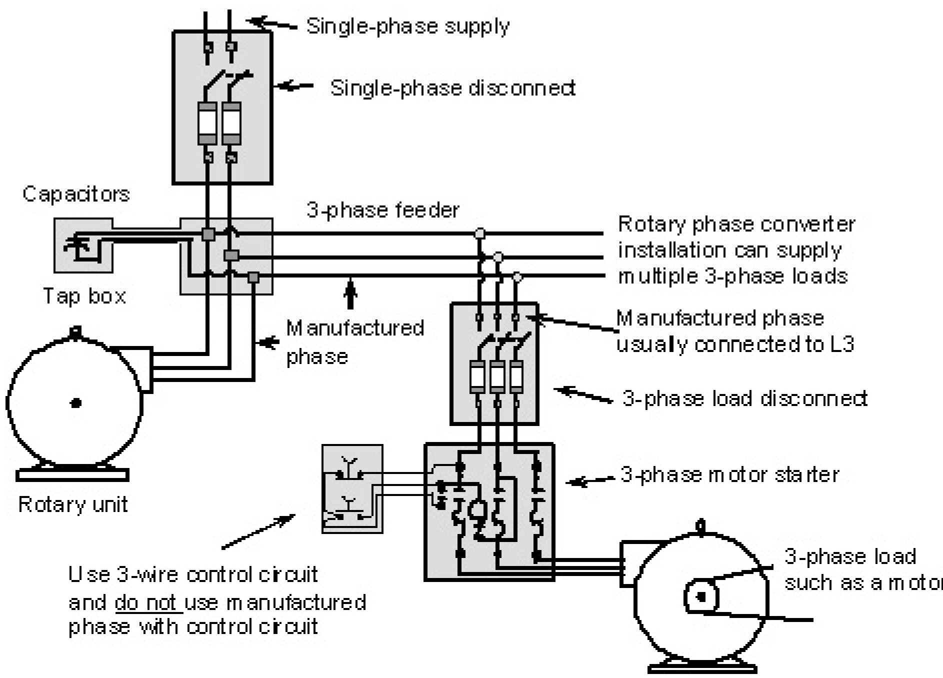


Figure 322.2 A rotary phase converter usually consists of a separate rotary unit and capacitor panel. The manufactured phase originates at the phase converter and is not permitted to supply any single-phase loads such as motor control circuits.

How a Phase Converter Works: The current flowing in the three wires of a 3-phase electrical system are out-of-phase of each other by 120E (shifted by 5.56 ms). There are three windings in a basic 2-pole 3-phase motor, and when current is supplied to each winding, a magnetic field is produced in the motor that rotates at synchronous speed. When the same motor is supplied with single-phase power, the current in one wire is in-phase with the current in the other wire. This current flows through two of the 3-phase motor's windings and a non-rotating magnetic field is produced. This is illustrated for a 3-phase motor with wye connected windings in Figure 322.3. By connecting a capacitor between one of the input wires and the unused lead of the motor, a current will flow through the third winding that is out-of-phase with the current in the other two windings. This connection is also illustrated in Figure 322.3. If the correct capacitance is chosen for the motor and load, the current through the motor windings will be similar to the case where the motor is energized with true 3-phase power.

Generally a higher level of capacitance is needed for starting the motor than for running. It is common to have a starting circuit that inserts extra capacitors that are taken out of the circuit once the motor reaches full rpm. Supplying a 3-phase motor from a single-phase supply does generally result in some reduction of starting torque as compared to operating the motor from a 3-phase electrical supply. Powering a hard starting load such as a compressor with a 3-phase motor and phase converter is not recommended unless approved by the phase converter manufacturer.

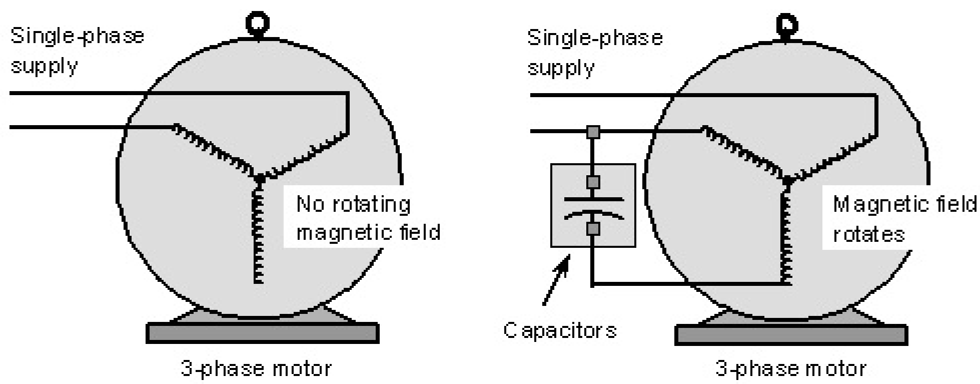


Figure 322.3 A 3-phase motor will not start if energized from a single-phase source, but a third phase can be produced by connecting the unused winding lead of the motor to one of the single-phase lines through a bank of capacitors.

Types of Phase Converters: Phase converters are of two types, static and rotary. Both allow operation of a 3-phase load from a single-phase supply. Cost, circuit simplicity, and flexibility at adapting the system to different applications are key factors when choosing a system. A *static* phase converter does not have any moving parts except perhaps in some cases a solenoid that may be used to connect extra capacitors during starting. A simple static phase converter is similar to the one shown in the diagram of Figure 322.1. Some static phase converters will have an autotransformer, as shown in Figure 322.4, to help stabilize the voltages supplied to the motor. As the load on the motor changes, the voltages between the different phase combinations may not be stable, and the autotransformer helps to correct this problem.

Static phase converters are sized to match one specific motor. A 5 horsepower static phase converter can only provide power for a 5 horsepower 3-phase motor. There is a difference in the performance of phase converters from different manufacturers. Generally the full horsepower rating of the 3-phase motor cannot be expected when operated from a static phase converter. It is not uncommon to only get 60% to 80% of 3-phase motor horsepower when operated with a static phase converter. The performance of some static phase converters may be higher. This means a 3-phase motor may need to be oversized for the load because it’s horsepower must be derated when operated using a static phase converter. Check the phase converter manufacturer recommendations to determine if horsepower derating is necessary, and if so, the level of derating that must be applied.

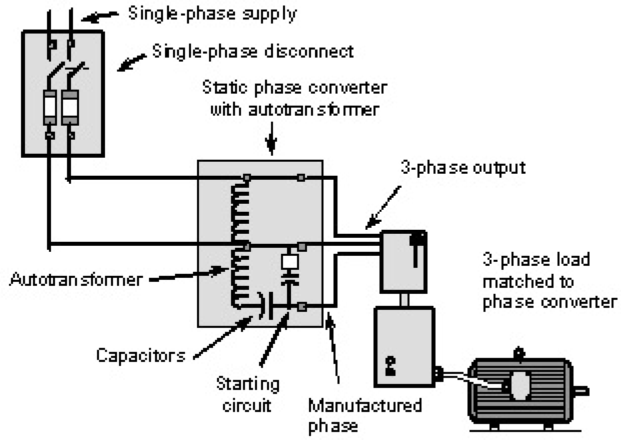


Figure 322.4 Some static phase converters use an autotransformer to help insure stable voltages to the 3-phase motor leads.

A *rotary phase* converter uses a 3-phase motor as a rotating transformer to produce the third phase. No load is extracted from the rotary unit, sometimes referred to as the idler motor. The rotary unit has two leads energized from the single-phase supply, and power is supplied to the third lead through a bank of capacitors. An advantage of this type of phase converter is that it is not required to be matched exactly to the load. There will be a maximum single load rating and a minimum load rating for the rotary phase converter. As long as any one load is sized between these two values, the phase converter can be used to power the load. Another advantage of the rotary phase converter is that it can supply several 3-phase loads simultaneously. It is generally necessary to start the loads individually. This can be done manually, or automatically using time delay relays. A rotary phase converter circuit supplying several motors is illustrated in Figure 322.5.

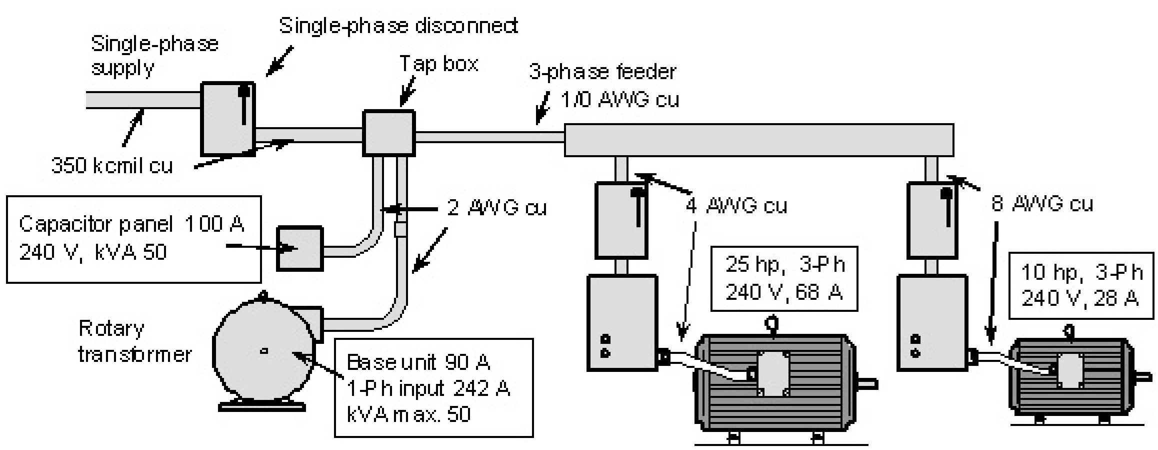


Figure 322.5 A rotary phase converter consists of a rotary unit and a bank of capacitors that convert single-phase power to 3-phase power. A rotary phase converter is capable of supplying several 3-phase loads simultaneously.

There is a caution with a rotary phase converter. The rotary unit must be started and up to full rpm before any loads can be applied. This would mean the rotary phase converter must be protected from momentary power interruptions that would shut down the system. One way to protect the phase converter in case of a momentary power interruption is to operate all 3-phase loads through a magnetic starter with a 3-wire control circuit. A 3-wire control circuit will automatically stop and require restarting if there is a power loss. Another method is to provide a time-delay restarting circuit.

Ratings of Phase Converters: A static phase converter must be sized for a specific motor. The nameplate on the phase converter will give the input single-phase full-load current. As directed in the *NEC* the minimum size input single-phase conductors are to have an ampere rating not less than 1.25 times the input full-load current marked on the nameplate.

A rotary phase converter is capable of supplying several loads simultaneously. The nameplate is required to state the largest single load the phase converter is capable of supplying. Additional loads are permitted to be added but not to exceed the maximum kVA rating of the phase converter as stated on the nameplate. A general rule is to assume one horsepower is equal to one kVA. A problem unique to the rotary phase converter is that the rotating unit must be carrying sufficient current to build a strong enough magnetic field for proper operation. The nameplate of a rotary phase converter unit will state the minimum kVA load that is required for proper operation. A phase converter nameplate meeting the requirements of *NEC* is shown in Figure 322.6 along with a nameplate for a separate phase converter capacitor bank. Sometimes the capacitors and the rotary unit are supplied as one complete unit. For the larger units, the rotary unit and the capacitors are supplied separately and connected at a tap box as shown in Figure 322.4.

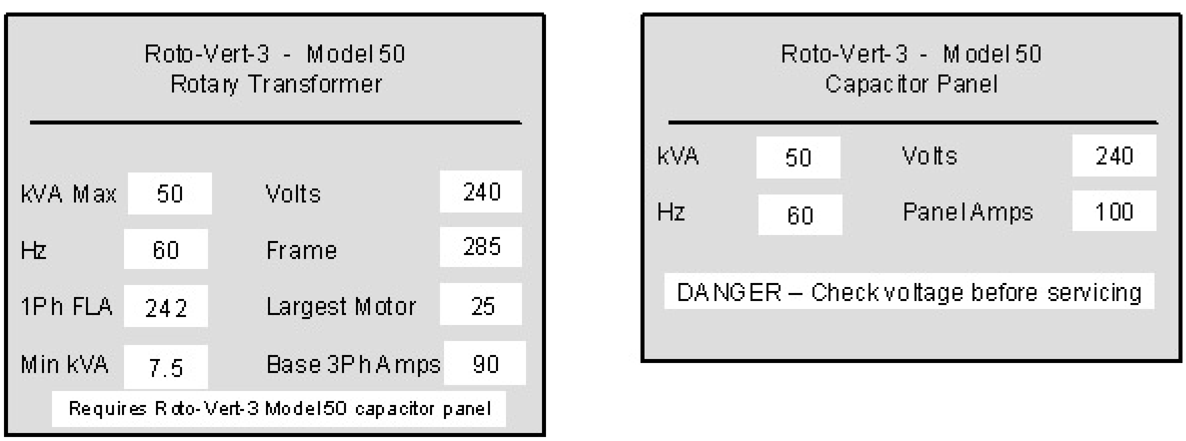


Figure 322.6 The nameplate of the rotary unit of a phase converter is required to supply the maximum total kVA 3-phase load that can be supplied, the single maximum kVA load that the unit is capable of starting and the minimum kVA total load required for proper operation. In addition the maximum output 3-phase current and the maximum input single-phase current is required to be provided. The nameplate on the right is for the separate capacitor bank required for the rotary unit.

Electrical Tech Note — 339

Biosystems &Agricultural Engineering Department
Michigan State University

Lightning Protection[1]

Lightning strikes to the ground can endanger people, animals, and property. It is important to know what to do during a thunderstorm. The best protection is to be inside a steel framed building. When inside a wood framed building, stay away from plumbing and metal appliances. If caught out in the open, crouch down near the ground away from any lone tall object such as a tree. An automobile with a metal roof offers good protection. The probability of damage to buildings can be reduced while increasing the effectiveness of the building as a lightning shelter by installing proper lightning protection for the building. Cloud-to-ground lightning is an electrical discharge between a thundercloud and the earth, and the purpose of a lightning protection system is to provide a good path from the high point of an object to the earth preferably on the outside of the building. Lightning can cause damage from a direct hit to a structure, and it can cause transient surges in wiring leading to buildings. As illustrated in Figure 1, a proper lightning protection system should protect from both sources of lightning damage by providing lightning and surge current a safe path to ground.

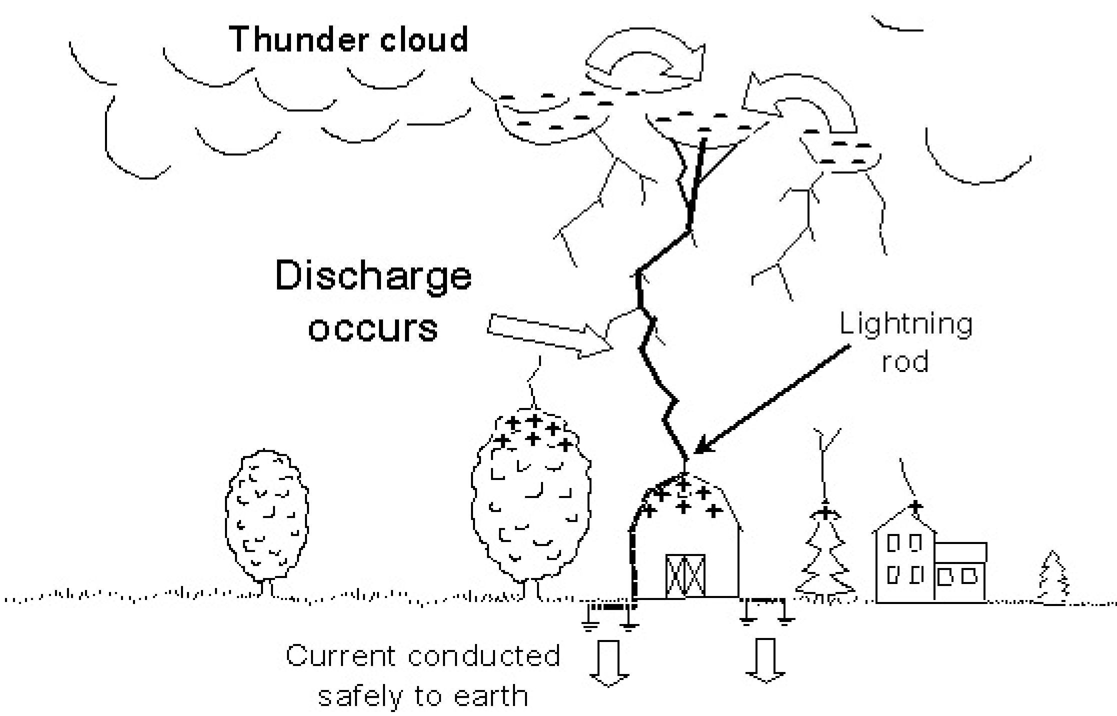


Figure 1. The purpose of a lightning protection system is to provide a safe path to ground for lightning and surge current.

Causes of Lightning: Turbulence and wind shear within a cloud can lead to a separation of electrical charges. Generally the lower portion of a thunder cloud develops a negative charge and the upper portions develop a positive charge. This is shown in Figure 2. As the energy level builds up between oppositely charged regions of a cloud, or the cloud and earth, a voltage builds up between these regions, reaching into the hundreds of millions of volts. Normally air is a good insulator, but with the voltage difference at such a high level the air ionizes (becomes electrically conducting) and when a path is established, usually the shortest distance, electrical current flows to equalize the charge. When the current flow is between the cloud and the earth the contact of the lightning bolt may be to the highest object such as a tree, tower, or building. The lightning current is trying to get to the earth, and the purpose of a lightning protection system is to give it an easy path. If a path is not provided, the lightning will seek a path that may cause considerable damage to property or harm to people and animals. Lightning current can enter a building in search for a path to earth. People standing near metal objects or plumbing within the building may become part of the lightning current path.

Here is how a typical lightning bolt develops. When the build-up of charge creates sufficient voltage between the cloud and the earth to overcome the resistance of the air, a leader begins to develop usually in a downward direction from the cloud in segments that are about 150 ft long. This is a narrow path in which the air has become ionized. Every few micro-seconds (a micro- second is one millionth of a second) another segment is added to the leader. Sometimes the leader branches out in several directions. This leader proceeds downward towards the earth, and when it is within a few hundred feet of the earth, tall objects on the ground often begin to send out a leader to join the one coming down from the cloud. The air above these objects can actually glow in an effect called corona. When these leaders join, an electrically conducting path has been established between the cloud and the earth and a massive return stroke of current follows this path. This current increases rapidly to a peak then decreases more slowly with the stroke taking usually no more than about one ten-thousandth of a second. If one stroke does not completely deplete the cloud of it's charge, several strokes may follow the same path. Much of the time there are several strokes to a single lightning event, but they occur so rapidly that a person only sees one bolt. On occasion the time between strokes is long enough to be perceived and a flashing effect can be observed. This current typically reaches peak levels in the tens of thousands of amperes. Materials on the ground that are in the circuit path must be capable of conducting this high level of lightning current or damage will occur.

Protecting Buildings: Lightning protection for a building includes air terminals on the high points of a building, properly sized and installed connecting cables, and a grounding electrode system that makes a low resistance connection to the earth. The electrical system for the building must also have good grounding and it must also be connected to the separate grounding system for the lightning protection. In addition a surge arrester connected to the wires entering a building also helps prevent surges produced in outside wiring from entering the building and causing damage to appliances and equipment.

A typical small building with a sloped roof is shown in Figure 3. **Air terminals** should extend a minimum of 10 inches above the objects they are intended to protect. An air terminal should be installed on all high projections such as silo roofs and chimneys. For a continuous roof ridge, air terminals should be space not more than every 25 feet. Air terminal minimum diameter is 5/8 in. When installed on a flat surface, the minimum height should be increased to 12 in. but not in excess of 24 in.

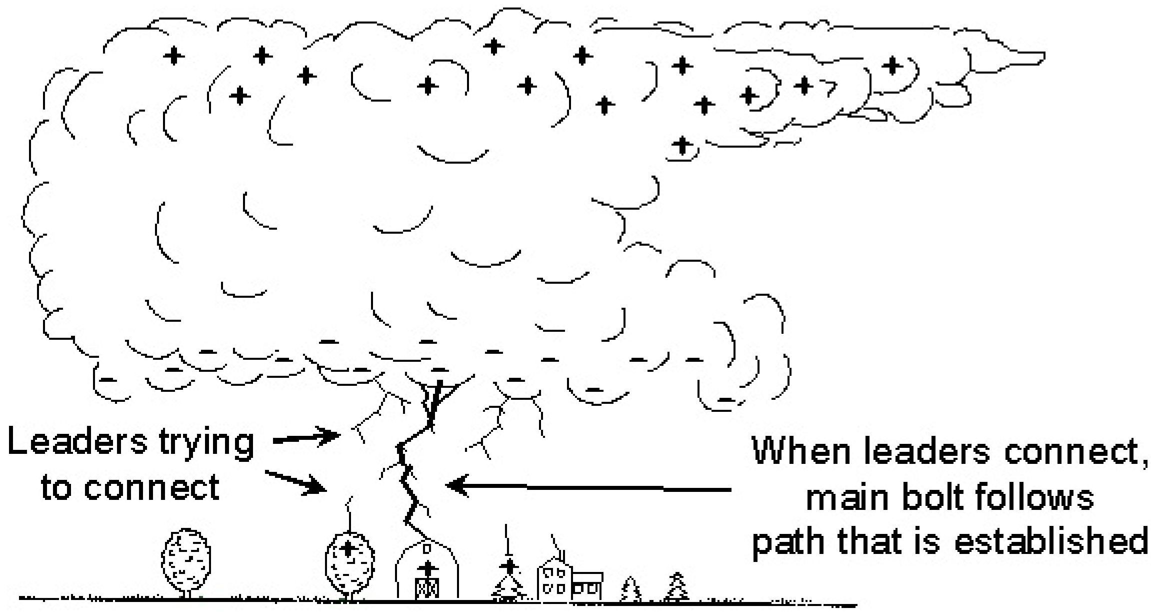


Figure 2. A leader extends down from the cloud to an object on the ground to complete a path for the main return stroke which can be in the tens of thousands of amperes.

A **grounding electrode** should be established at least at diagonal corners of the structure. Where buildings are of larger size (more than 250 ft in perimeter), additional grounding electrodes should be provided. It is recommended a down-wire and grounding electrode be provided every 100 ft where practical. A main conductor should be run from one grounding electrode, over the building connecting to each air terminal along the way and terminating at the other grounding electrode. Connect to individual isolated air terminals by tapping a branch conductor onto the main conductor and running to the air terminal. Keep these runs as short as practical. If the building is served with a metal underground water piping system, it should be bonded (electrically connected) to the lightning system grounds. The electrical system grounds should also be bonded to the lightning system grounds. If ground rods are to be used to make the connection to the earth, standard ground rods are 8 ft in length. Ground rods should be driven to their full depth and a wire attached with a clamp that is suitable for direct burial. It is recommended that each earth connection consist of not less than two ground rods spaced at least 8 ft apart.

If a building is previously equipped with a lightning protection system, check to see if the connections to the grounding electrodes are in good condition. It is not uncommon to find down- wires corroded at the point where they enter the earth or somewhere below the earth. If an existing grounding electrode consists of only one ground rod, it is recommended another be added spaced not closer than 8 ft from the original ground rod.

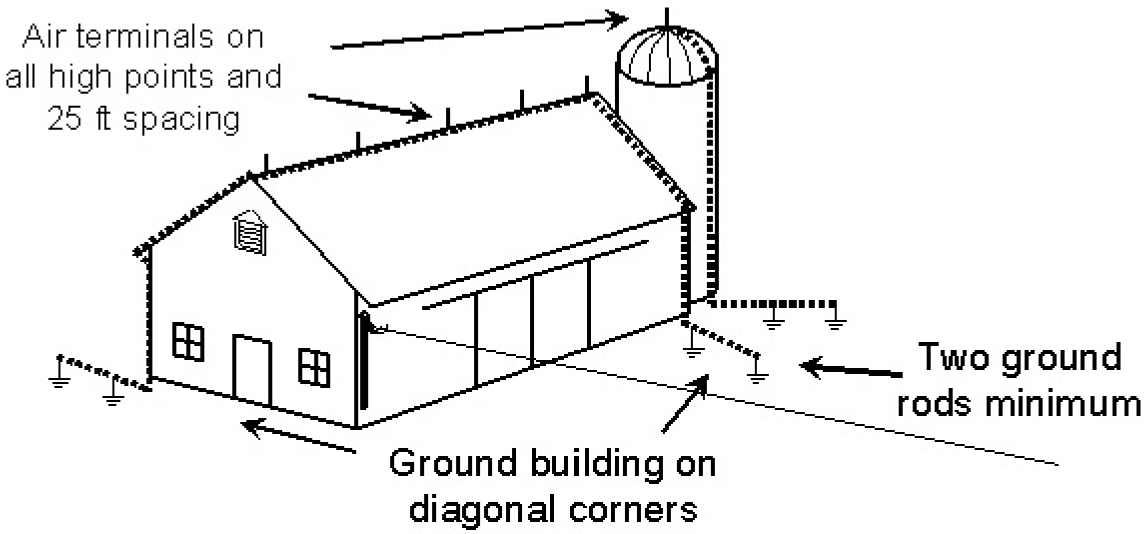


Figure 3. Attach air terminals to the roof ridge and other high points and connect them to grounding electrodes opposite corners of the building with a main connecting wire.

Connecting wires are used to join the air terminals together and to the grounding electrodes. All of the components of a lightning protection system for a building should be connected together to form one complete system. Do not connect some air terminals to one grounding electrode and some to another grounding electrode. There should be at least two independent paths from every air terminal to a grounding electrode. An exception is an isolated air terminal tapped to a main line conductor. The connecting wires are typically stranded copper, copper coated steel, or galvanized steel. These connecting wires need to be corrosion resistant and of adequate size to carry the current of the lightning bolt. A good reason for having multiple grounding electrodes and multiple paths is to divide the lightning current so it can be directed to earth more easily. It is recommended that the main line wires be not smaller than copper with a weight of 187 pounds per 1000 ft. This translates into a size 2 AWG copper wire. Radial runs off the main wire to individual isolated air terminals can be size 6 AWG copper wire, and it is recommended these runs not exceed 15 ft in length.

Isolated metal objects exposed on the surfaces of buildings in particular should be connected to the lightning protection system. Metal gutters and down spouts are one example. Another might be a metal track for a barn door especially if the barn door is metal. A side flash can occur between the conductors of the lightning protection system and an adjacent object. This side flash can harm a person standing close to the object or it can ignite a fire. It is not practical to bond all metal objects to the lightning system, but give some consideration to those metal objects that may become a part of a lightning path to earth. A size 6 AWG copper wire can be used to bond to isolated metal objects. It is best to keep the lightning system wires separated from metal conduits and metal enclosures of the electrical system by a distance of not less than 6 ft except at a point where the two systems are intentionally bonded. This will help to prevent side flashes between the two systems.

What is a Zone of Protection? It may not be necessary to provide a lightning protection system on all buildings if located next to a tall object that has been provided with lightning protection. Figure 4 illustrates the distances and heights that are considered to be protected by an adjacent object. If a building or tall object is properly protected, than the zone of protection extends out from the base of the object in all directions a distance equal to the height of the building or object. The probability of a lightning strike is low out to a distance of two times the height of the building. This does not necessarily mean a person or animal is safe within this zone of protection during a thunderstorm. A side flash from the protected building or a voltage gradient in the earth at the time of a direct strike can stall create a hazard for persons and animals.

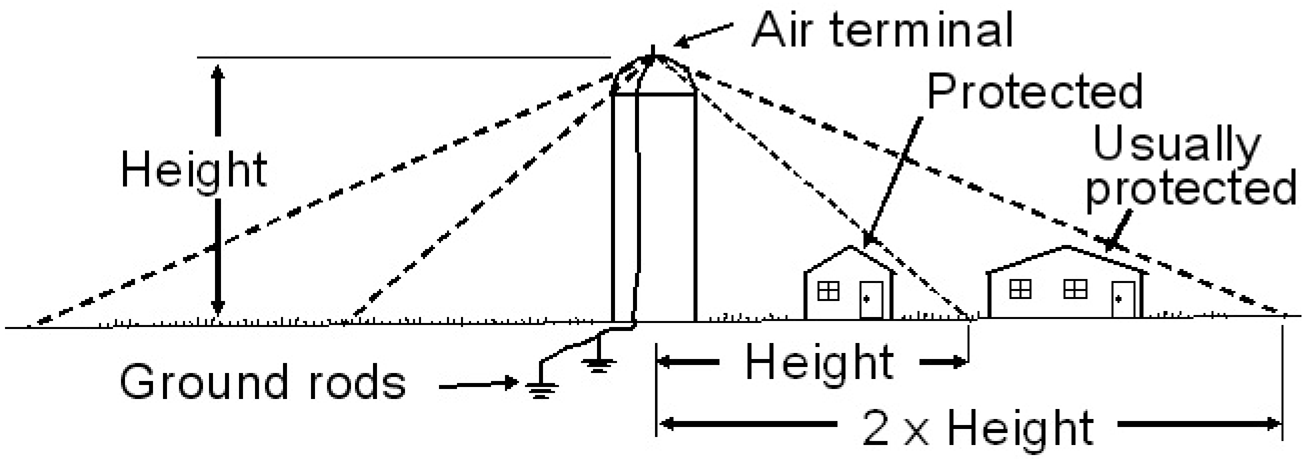


Figure 4. Tall objects with a lightning protection system provide a zone of protection to some adjacent buildings and objects.

Surge Protection: Lightning can strike an electrical power wire in the local area or next to a wire and set up a surge that travels down the wire in all directions searching for a path to earth. These surges can enter buildings and damage wiring and equipment. Individual pieces of equipment may be equipped with it's own surge protection, but that protection may not be adequate to handle a major surge entering the building through the wiring. A surge protector can be installed by an electrician at the point where the electrical wires enter the building in a manner similar to that shown in Figure 5. A common type of surge protector used for this purpose is called an MOV (metal oxide varistor). The surge protector is connected to each of the ungrounded (hot) wires that enter a building and also to the grounded conductor (neutral). A surge approaching a building on the wiring will be in the form of a voltage pulse of very short duration and much higher than the normal power voltage. The metal oxide in the protector is sensitive to high voltage, but not to the normal voltage. When this metal oxide is exposed to extremely high voltage, it changes from an insulator to a conductor and shorts the surge directly to the neutral where it has a direct path to the earth through the electrical system grounding electrode. As soon as the voltage returns to normal the metal oxide returns to being an insulator. A good grounding electrode for the electrical system is essential for proper operation of a surge arrester. If a surge arrester is installed, make sure the adequacy of the electrical system grounding is checked and improved if necessary.

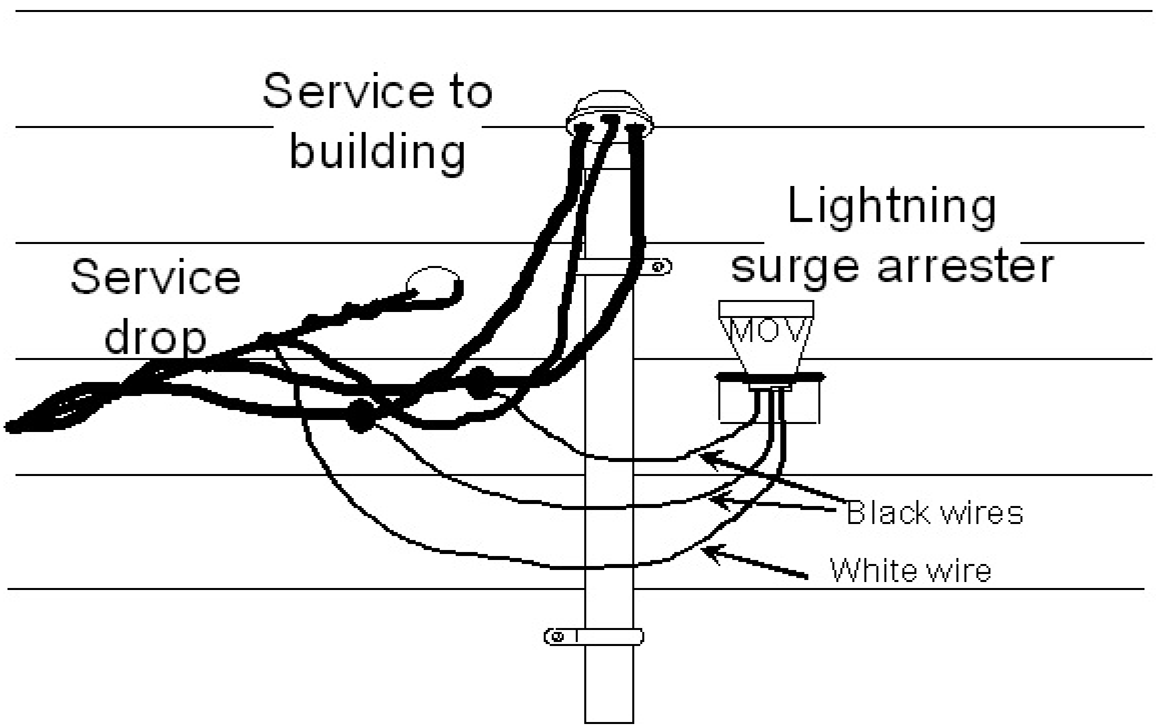


Figure 5. A surge arrester installed at a service entrance to a building provides a direct path to ground for a lightning produced high voltage surge that may try to enter a building electrical system.

Conclusion: Lightning is an important and essential part of the earth's ecosystem, but it sure can be destructive at times. It is sometimes hard to figure out why some locations seem to be more prone to lightning strikes to earth than others. Very tall objects are frequently targets because they represent a shorter path from cloud to earth. Injury, damage, and fires are usually the result of lightning not being able to find a quick and easy path form the point of contact to an object and the earth. A good lightning protection system helps to provide that path, thus reducing the probability that damage will occur or harm will come to persons or animals.

Glossary

Acre-inch (ac-in): The volume of water covering an area of one acre by one inch deep.
Area irrigated (acres): The surface area to be irrigated.
Application depth: The depth of irrigation water applied during one irrigation event or cycle. The net application depth is the depth of water applied after losses due to application efficiency are subtracted from the water that is pumped.
Artesian aquifer: An aquifer where the water formation is confined between restrictive layers and the static water level rises above upper confining layer.
Aquifer: A water-saturated geologic structure (ground water system) that yields water to wells at a sufficient rate that the wells can serve as practical sources of water.
Brake horsepower (BHP): The power output of the engine crankshaft required to drive a pump.
Cavitation: The formation and collapse of low-pressure vapor cavities in a flowing liquid, often resulting in serious damage to pumps, propellers, etc.
Center pivot: A self-propelled system consisting of a lateral mounted on A-frame towers that rotate around a center pivot point. Sprinklers are mounted along the lateral.
Centrifugal pump: A pump consisting of a rotating impeller enclosed in a housing and used to impart energy to a fluid through centrifugal force.
Crop water use: Water consumption by the crop and soil, also called evapotranspiration (ET). Generally expressed as a rate of inches/day or total inches/year.
Deficit Irrigation: Irrigation management with a supply of water less than the seasonal ET requirements of the crop. Relies on stored soil water in the root zone to provide the difference and requires filling the root zone soil profile to field capacity before or early in the growing season.
Deep-well turbine pump: A pump having one or more stages, each consisting of an impeller on a vertical shaft, surrounded by stationary and usually symmetrical guide vanes in a pump bowl assembly. Power is delivered to the impeller by a shaft, and a column carries the water upward.
Drip or micro irrigation: Drip irrigation is a method that applies a low volume of water at low pressure to individual plants.
Drawdown: The dropping of the water level when water is pumped from a well.
Efficiency: the ratio of the output of a system divided by the input of a system.
Evaporation: The process where liquid water is converted to a gas. In irrigation, evaporation is considered to be when water is evaporated from the soil or plant surface.
Evapotranspiration (ET): The combination of water transpired from the plant and evaporated from the soil and plant surfaces.
Friction head: The energy required to overcome friction caused by fluid movement through pipes, fittings, and valves. Friction is affected by pipe size, pipeline length, and pipe material.
Gallons per minute (gpm): The volumetric flow rate.
Head (feet): A measure of water pressure in feet of water where 1 psi = 2.31 ft of water.
Horsepower (HP): Term used to quantify the power requirement of the irrigation system.
Impeller: The rotating component of the pump that develops head and moves water through the pump.
Irrigation efficiency (%): The ratio of the amount of water stored in the soil divided by the total amount of delivered to field.
Irrigation scheduling: The management practice use plan irrigation water applications by monitoring soil water and crop water use to project irrigation applications.

Irrigation uniformity: The measure of how evenly water is distributed over the field, calculated as a CU or DU.

Irrigation system capacity: The rate at which an irrigation system can apply water to a given land area, generally expressed as gallons per minute per acre.

Kilowatt (KW): Unit of power used for electricity. Equal to 1.34 HP.

Maximum practical suction lift (MPSL): An estimate of the lift required to move water on the suction side of the pump.

Net positive suction head (NPSH): The pump manufacturer's specified suction head at sea level, ft.

Power: The rate of performing work. Power for irrigation systems is generally provided by electric motors or internal combustion engines.

Pressure (psi): The pressure energy necessary in the irrigation system to operate the distribution system at the design pressure.

Pump affinity laws: Physical properties of pumps that are governed by relationships of speed/diameter to the flow rate, head, and horsepower output of the pump.

Pump column: The pipeline that carries the water the pump bowls in a well to the surface.

Pump curve: A graphical representation of the performance of a pump with regard to flow rate, head and efficiency.

Pump impeller: The rotating part of a pump that increases dynamic head for a given flow rate.

Pumping lift (feet): The sum of the static lift and the drawdown.

Pumping plant performance rating (%): The ratio of energy efficiency of a pumping plant to an industry standard.

Pumping water level: The water level in a well or surface water source while the irrigation system is a the normal condition.

Specific capacity (gpm/ft): The relationship between discharge rate divided by drawdown for a well.

Suction head (feet): The head that is needed to move water from the supply into the inlet of a centrifugal pump.

Submersible pump: A turbine pump with a submersible electric motor that is located below the water level in the well.

Total head (TH) (feet): The head required to pump water from its source to the point of discharge and is the sum of the total lift, friction head, pressure head, and other losses. Also commonly called Total Dynamic Head (TDH).

Traveler or traveling big gun: An irrigation system that uses a large volume sprinkler which is self-propelled across the field.

Variable frequency drive (VFD): Controls used to vary the electrical frequency, used to vary the speed of a pump.

Velocity head: The energy of water in motion.

Water application efficiency (E_A): The ratio of the average depth of irrigation water stored in soil during irrigation to the average depth of irrigation water pumped.

Water flow rate: The quantity of water available and/or needed per minute, per hour, or per day, expressed as gpm, cfs, or ac-in/hr.

Water hammer: The sharp rise in pressure that occurs with sudden changes of water flow in the system.

Water horsepower (WHP): Useful work done by a pump, which is a function of pump discharge, total head, and pump efficiency.

Written pole motor: Electric motor with low starting current draw using single phase power.

List of Symbols

π : pi, often used as 3.14
A: area
ac: acre
ac-in: acre inches
ac-in/hr: acres inches per hour
ASABE: American Society of Agricultural and Biological Engineers
ASTM: American Society for Testing Materials
BHP: brake horsepower
BTU: unit of energy, British thermal unit
C: coefficient
cfs: cubic feet per second
CP: center pivot
CPED: Center Pivot Evaluation and Design software
CU: coefficient of uniformity
D: diameter
DU: distribution uniformity
E: efficiency
E_a: application efficiency
E_{evap}: evaporation
E_d: drive efficiency
ELT: elevation factor, feet MSL
E_p: pump efficiency
EP: energy performance
EPR: energy performance ratio
e_s: vapor pressure of water, feet
ET: evapotranspiration
ft: feet
fps: feet per second, velocity
°F: degrees Fahrenheit
gal: gallon
gpm: gallons per minute, flow rate
gph: gallons per hour, flow rate
GPS: Global Positioning System
H: head, feet
H_{atm}: atmospheric head
H_e: elevation head, feet
H_f: friction head, feet
H_l: lift, feet
HP: horsepower
H_s: suction head, feet
H_v: velocity head, feet
I: interest rate
ID: inside diameter
in: inches

IPS: iron pipe size
KW: kilowatts
KWh: kilowatt hours
L: length, feet
lb: pound
L_{eff}: effective length
L_{eq}: equivalent length
MWPS: Midwest Plan Service
MPSL: maximum practical suction lift, feet
mcf: million cubic feet (natural gas)
NEC: National Electric code
NPSH: net positive suction head, feet
NRCS: Natural Resources Conservation Service
OD: outside diameter
P: pressure, psi
PE: polyethylene pipe
PIP: plastic irrigation pipe
PP: payback period, years
psi: pounds per square inch
PVC: polyvinyl chloride pipe
PWF: present worth factor
Q or **q**: flow rate
RPM or **rpm**: revolutions per minute
SC: specific capacity of well, gpm/ft
SDR: standard dimension ratio of pipe, pipe diameter divided by wall thickness
sq ft: square feet
TDH: total dynamic head, also TH
TG: traveling gun
TDR: time domain reflectometry, ultrasonic flow meter
TDSL: total dynamic suction lift, feet
TH: total head, also TDH
V: volts
V or **Vel**: velocity
VFD: variable frequency drive
WHP: water horsepower
WPR: water performance ratio

References

Books

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Web pages and online materials

Several web sites have been referenced in the manual. Use these for additional information on irrigation energy use. Other valuable information is available by using web search engines. These are not listed here because they are continually updated and links are often broken.