Chapter 12 Energy Use and Conservation

Contents:

Tables

Figures

Example

652.1200 General

Energy cost for operating an irrigation pumping plant is a major concern to most irrigation decisionmakers. Many are taking a close look at their pumping installations to find ways to reduce operating costs. Some irrigators consider converting from medium to high pressure sprinkler back to surface irrigation systems to reduce or eliminate energy costs. Generally, this leads to a considerable reduction in water application uniformity with increased runoff, deep percolation, or both. Typically more water must be applied with graded surface irrigation systems than for sprinkler irrigation systems, and where the water is pumped from wells, an energy reduction by converting may not be realized.

To maintain an efficient operating pumping plant, modifications to the pump are generally necessary to reduce pressure head and increase flow. Many irrigators who use center pivot or linear move sprinkles are converting to low pressure application devices on their systems to reduce energy costs. Flow being pumped to the system remains the same, but pressure head is reduced. This may also require a modification to the pump. Reducing pressure by installing a valve between the pump and sprinkler heads does not reduce energy.

Because energy is an immediate cost, the irrigator is often more interested in reducing readily apparent energy costs than solving other important problems, such as poor water management for the full irrigation season or high seepage losses in the on-farm distribution system. Table 12–1 demonstrates typical seasonal water use and losses of sprinkler irrigation systems versus surface irrigation systems.

Properly designed and operated surface irrigation systems can provide good irrigation efficiencies. For example, adequately designed, operated, and well-managed level basin irrigation systems can have irrigation efficiencies of 85 to 90 percent. To maintain a high total farm water use efficiency using level basins, laser controlled field leveling, lined head ditches with good water control structures, adequate flow rate, and proper water and system management should be available and used. Proppperly designed, operated, and properly managed Low Energy Precision Application (LEPA) systems, can reach irrigation efficiencies of 90 to 95 percent. To obtain this efficiency with LEPA systems, adequate water management and cultural practices should be used to provide complete water infiltration where the system is used; i.e., no water translocation.

Although energy conservation is not a specific NRCS objective, it is a national objective assigned to other water conservation activities that are NRCS objectives. Finding ways to reduce energy consumption in conjunction with soil and water conservation measures can be a major selling point when recommending conservation measures.

Many irrigation pumping installations were designed and installed when energy costs were lower. Typically, the original installation was not as efficient as those installed today. Some installations were poorly designed or improperly installed in the first place. Many pumping plants have not been maintained properly and have significantly lower efficiencies than when originally installed. Length of irrigation sets, and thus pumping times, is frequently governed more by the irrigators schedule than by the needs of the crop. This leads to many pumping plant installations being much less efficient because of management than they could be.

Table 12–1 Sprinkler irrigation system vs. surface irrigation system water use and losses

	Moderate pressure sprinkler irrig. system (ac-in/ac)	Surface irrigation system (ac-in/ac)
Crop water requirement	20	20
Misc. spray losses @ 15%	4	0
Ditch seepage losses @ 15%	0	5.9
Surface system- DP & RO losses @ 40%	0	13.4
Sprinkler system- DP losses @ 10%	2.7	0
Total	**26.7**	**39.3**

Finding the most economical solution to these problems requires a multidisciplinary team approach. The irrigation decisionmaker is the most important member of the team. Pump and equipment dealers and manufacturers should be involved. Electric power companies and public utility districts are interested in electrical energy conservation. Electrical power conserved is new power not generated. The Extension Service has an energy conservation objective. Their team members have considerable specialized information and expertise that should be used to the fullest. NRCS needs to work closely with other members of the team using the planning process to provide good energy conservation alternatives.

Several manufacturers are named in the information in this chapter. NRCS endorsement is not implied. Names are used for illustration only.

652.1201 Reducing pump energy requirements

The major considerations for ways to reduce pumping energy are:

- Increase pumping plant efficiency
- Increase irrigation efficiency
- Proper irrigation scheduling (amount and timing)
- Reduce pressure (energy) requirements
- Conversion from pump to gravity
- Changing to another irrigation method or system

(a) Increase pumping plant efficiency

Pumping plant efficiency is the ratio of the amount of work done (output) by a pumping plant (pump and power unit) to the amount of energy required to do the work (input). A procedure to check pumping plants is included in Chapter 15, Planning and Evaluation Tools.

Pumps and many engines and motors are designed to operate under a narrow range of conditions. They should be operated within this range for best efficiency. Pumps and power units are subject to wear, so close attention to maintenance is required to sustain desirable pumping efficiency.

High efficient electric motors are designed to operate under a wide range of conditions (half to full load) with less than 1 percent spread in nominal efficiency. Typical nominal efficiency range is 94.5 to 95.0 percent under half to full load of a 3,600 rpm, 50 hp, high efficient electric motor. (See table 12–8.) Most manufactures are more than willing to provide performance information on their engines and motors.

(b) Increase irrigation efficiency

Irrigation efficiency can be increased in several ways. A well designed and managed irrigation system, should meet crop water design requirements, typically full crop ET across most of the field with minimum deep percolation and runoff. Distribution across the field should be uniform. Conveyance losses can be minimized by installing a ditch lining or pipelines. Leaks of any kind should be promptly repaired. The delivery system should be properly maintained to operate according to original design. The water user should strive for application efficiencies in excess of 80 percent with all irrigation methods. Chapters 5, 9, and 15 provide details on irrigation system evaluations.

(c) Proper irrigation scheduling (amount and timing)

Proper irrigation scheduling is applying water at the right time and in the amount to meet water needs. Needs can be for crop water needs or other uses, such as improved crop quality, crop heating or cooling, salinity management, or chemigation. Where the water supply is not limited, the greatest waste of water (and energy) is usually over irrigation. Excess water application reduces plant yield or biomass, limits the ability of soil to grow crops, wastes nutrients, and increases the potential for surface or ground water pollution.

In some areas, irrigation water managers are using up to 5 times as much water as locally published crop ET amounts indicate is adequate. Even a simple program of irrigation scheduling can greatly reduce this excessive use. Chapter 9, Irrigation Water Management, provides details on irrigation scheduling methods.

(d) Reduce pressure (energy) requirements

Low pressure sprinkler or spray heads are being used on most new center pivot installations. This saves energy. Some older systems are being retro-fitted to use low pressure heads. Conversion should be done with careful design to maintain overall efficiency. In many cases the pump must be modified or replaced to assure optimum energy use; i.e., trim the impellers to reduce pressure head. If the water source is a deep well, reducing pressure at the sprinkler nozzle may reduce total energy requirements very little. Too often pressure (and perhaps irrigation equipment) is changed without an associated change in management. This results in an even lower irrigation application efficiency. For example, installing LEPA sprinkler nozzles without making appropriate changes in soil, water, and plant management often reduces application uniformity. Energy requirements typically stay the same if a valve is used to reduce operating pressures on the sprinkler system. The pressure upstream of the valve is the same as before; therefore, total pressure head is the same.

Modifying pipe size, changing from high friction loss pipe to low friction loss pipe, changing field configuration, and using valves and fittings that reduce friction loss can reduce total pressure head requirements. This cost can be weighed against the savings in energy, recognizing that energy costs will most likely increase in future years.

(e) Conversion from pump to gravity

Many opportunities occur to wholly, or in part, convert from pump to gravity supplied pressure for sprinkler systems. Ditches generally must be replaced with pipelines; therefore, this is costly. However, long-term savings with energy used for pumping can be substantial. Each foot of elevation provides 0.433 pounds per square inch of pressure (or 1 lb/in^2 = 2.31 ft of head). In computing available head, pipeline friction loss must be subtracted from the elevation head. An additional benefit may be from the reduction of ditch seepage losses, improved water control, reduced labor, etc.

(f) Changing to another irrigation method or system

Changing the present irrigation method or system to another method or system can increase energy efficiency. An example is changing from a handmove sprinkler system to an automated furrow or border system. With proper site conditions, design, and management, surface systems can equal or exceed sprinkler system efficiencies. Detailed design and economic analysis generally are required to compare irrigation methods and systems.

652.1202 Energy source

Most pumping plants use electric motors, diesel engines, or natural gas engines as power sources. Occasionally liquid propane or gasoline engines are used. Most of the following information deals with electric and diesel powered units. If adequate electric power sources are located at or within a reasonable distance from the water source, electric power generally is the least costly form of energy. However, in rural areas where electrical power is generated from local coal fired, fuel oil or natural gas generators, natural gas engines are typically less costly to operate. In Southern States, natural gas is readily available in most rural areas.

Electric phase converters are available that allow three-phase motors over 10 horsepower to operate on single-phase power supply. However, they are costly to install and require some power to operate. The company furnishing electric power should be consulted before installation. Annual hours of use; i.e., irrigating only part season or when supplementing precipitation, need to be considered.

(a) Energy use criteria

Performance standards for an irrigation pumping plant can be expressed as performance standards or water horsepower-hours (wHp-hr) per unit of energy. These standards can be used to compare the cost of energy, as used in an efficient irrigation pumping plant, by different energy sources. Dollars per wHp-hr can also be used. With both, the energy cost for pumping an equal amount of water can be compared for various energy sources. For instance between a natural gas and an electric powered pump, if electric power is available.

Other nonenergy performance units include acre inches of water per unit of crop produced (water use efficiency), i.e., ac-in/ton of hay. Pumping cost per unit of crop produced, i.e., $/bale of cotton, and cost per water horsepower, i.e., $/wHp-hr, can also be used.

(b) Nebraska pumping plant performance criteria

Personnel at the University of Nebraska developed a set of performance standards for pumping plants (table 12–2). Comparison to the Nebraska criteria indicates how well the pumping plant is performing and can determine if excess energy is being used. Depending on the amount of energy used, a decision can be made regarding adjustments, repairs or replacement.

Nebraska pumping plant performance criteria represents the performance level that can be expected from a properly designed and maintained pumping system. It is a compromise between the most efficient pumping plant possible and the average pumping plant. Therefore, some pumping plants will exceed the criteria.

Nebraska criteria are expressed as the water horsepower (wHp) produced from a unit of fuel for 1 hour and can be represented in the units wHp–hr/unit of fuel. The performance of any pumping plant is represented by the same units. Performance is calculated by dividing the water horsepower produced by the fuel consumption of the pumping plant.

Water horsepower is a function of water volume output, pressure, lift or suction and pipe friction losses. It is the true work being accomplished by the pump. (More detail on horsepower calculations is contained in NEH, Part 623 (Section 15), Chapter 8, Irrigation Pumping Plants. Water horsepower, which does not include pumping plant efficiency, can be calculated by:

$$\text{whp} = \frac{(\text{flow, in gpm}) \times (\text{TDS, in ft})}{3{,}960}$$

where:

TDH (total dynamic head, in ft) = (lift, in ft) + (pipe friction loss, in ft) + (pressure head, in ft) + (velocity head, in ft)

Note: Pipe friction loss includes column or lift pipe losses in addition to friction losses from pipe and fittings downstream from well head.

$$\text{pressure head, } (\text{ft}) = (\text{lb / in}^2) \times (2.31 \text{ ft / lb / in}^2)$$

$$\text{pressure head, in ft} = (231) \times (\text{Pressure, in psi})$$

$$\text{velocity head, } (\text{ft}) = \frac{V^2}{2g}$$

where:

V = velocity of flow in pipeline, ft/s
g = acceleration of gravity at 32.2 ft/s/s
gpm = total pumping quantity, in gal/min
3,960 = units conversion, where gpm units are used

By comparing the pumping plant's performance to the criteria, a percentage rating results. This is accomplished by dividing the performance of the pumping plant by the performance criteria. For example, a diesel producing 75 wHp and burning 6 gallons per hour would have a performance of 12.5 wHp–h/gal (75 wHp/6 gal/hr).

Table 12–2 Nebraska pumping plant performance criteria

Energy source	bhp–h 1/ per unit of energy	wHp–h 2/ per unit of energy 3/	Energy units
Diesel	16.66	12.5	gallon
Gasoline	11.5 4/	8.66	gallon
Liquid Propane	9.20 4/	6.89	gallon
Natural gas	82.2 5/	61.7	1,000 cubic feet
Electricity	1.18 6/	0.885 7/	kilowatt-hour

1/ bhp–h (brake horsepower-hours) is the work being accomplished by the power unit (engine or motor) with only drive losses considered.
2/ wHp–h (water horsepower-hours) is the work being accomplished by the pumping plant, engine, or motor and pump.
3/ Based on 75 percent pump efficiency.
4/ Taken from Test D of Nebraska Tractor Test Reports. Drive losses are accounted for in the data. Assumes no cooling fan.
5/ Manufacturer's data corrected for 5 percent gear head drive loss with no cooling fan. Assumes natural gas energy content of 925 Btu per cubic foot. At 1,000 Btu per cubic foot, energy content uses 88.9 Hp-h per 1,000 cubic feet for natural gas. Btu per cubic feet can vary from season to season and from winter to summer.
6/ Assumes 88 percent electric motor efficiency.
7/ Direct connection, assumes no drive loss.

Comparing this to the diesel criteria of 12.5 wHp-h/gal results in a rating of 100 percent:

$$\frac{(12.5 \text{ whp} - \text{hr/gal from pumping plant})}{(12.5 \text{ whp} - \text{hr/gal from criteria})} = 1.0 \text{ or } 100\%$$

This pumping plant has met the criteria. On the other hand if this plant had been consuming 8 gallons per hour of diesel, its performance would be 9.4 wHp–h/gal (75 wHp/8 gal/hr) and its performance rating would be 75 percent, (9.4 wHp–h/gal) divided by (12.5 wHp–h/gal). In this case the pumping plant would be performing below the criteria, using unnecessary fuel (2 gal/hr).

(1) Criteria versus overall efficiency

The performance rating should not be confused with the pumping plant's overall efficiency. They are not the same. Overall efficiency is the ratio of the energy output of the pump (water horsepower) compared to the energy used; whereas, the performance rating is the ratio of the performance level of a pump compared to the standard performance criteria. The performance rating from the criteria does, however, relate to overall efficiency of the pump. For diesels, a pumping plant with a performance rating of 100 percent equates to an overall efficiency of 23 percent (table 12–3). The above diesel pumping plant had a performance rating of 75 percent, however, it is not 75 percent efficient. Rather, if one wishes to base the performance on overall efficiency, the pumping plant would be considered 17 percent efficient (0.75 x 23% = 17%).

Table 12–3 Nebraska performance criteria vs. overall efficiency 1/

Energy type	Unit of energy	wHp-h per unit of energy	Performance rating (%)	Overall efficiency (%)
Diesel	gal	12.5	100	23
Propane	gal	6.89	100	18
Natural Gas	mcf	61.7	100	17
Electric	kWh	0.885	100	66 2/
Gasoline	gal	8.66	100	17

1/ Efficiency given for electricity is *wire to water* efficiency, which is calculated at the pump site. Liquid or gas fuel is based on average Btu values.
2/ Overall efficiencies vary from 55 percent for 5 horsepower to 67 percent for 100 horsepower.

Remember, performance criteria are basically an index so that pumping plants can be compared to one another. The performance rating can be used to rate the pumping plant on a scale of 1 to 100 with 100 meaning the criteria have been met. For those pumping plants that exceed the criteria, the index goes beyond 100.

(2) Using criteria to determine excess fuel consumption

Performance criteria are also useful for determining excess fuel consumption of a pumping plant. The operational pump performance rating is simply subtracted from 100, divided by 100, and multiplied by the present fuel consumption. The result is the fuel being used in excess of what the criteria recommend. For example, the diesel pumping plant illustrated earlier had a performance rating of 75 percent and was consuming 8 gallons of fuel per hour. The excess fuel consumption per hour would be 2 gallons per hour.

$$(100 - 75/100) \times (8 \text{ gal/hr}) = 2 \text{ gal/hr excess}$$

Table 12–4 shows comparative fuel use at various performance ratings. The criteria can also be used to determine what the fuel consumption would be for a new pumping plant designed to meet the criteria.

Water horsepower of the pumping plant is simply divided by the performance criteria to get the fuel consumption per hour. For example, suppose a new diesel-powered deep well turbine pumping plant is designed to meet the criteria and pump 1,000 gallons per minute from 150 feet with a discharge pressure of 80 pounds per square inch. The horsepower output would be 85 water horsepower. The calculated fuel use would be (85 wHp divided by 12.5 wHp-h/gal = 6.8 gal/hr). Fuel consumption can also be calculated for other design pressures to compare operating costs between different irrigation systems, such as high or low pressure center pivot. The criteria can even be used to compare the operating costs between different energy sources. Table 12–5 is a direct comparison, using this example for fuel consumption and with various fuels, of hourly costs for different energy sources.

Table 12–4 Comparative fuel use

Performance rating (%)	Multiplier for fuel use in excess of criteria
100	1.0
90	1.11
80	1.25
70	1.43
60	1.67
50	2.0
40	2.5
30	3.33
20	5.0
10	10.0

Table 12–5 Comparison of energy sources

	Fuel costs ($)	Hourly cost ($)
Diesel	1.00 / gal	6.80
Diesel	1.25 / gal	8.50
Natural Gas	2.70 / mcf	3.72
Natural Gas	3.00 / mcf	4.13
Natural Gas	3.50 / mcf	4.82
Natural Gas	4.00 / mcf	5.51
Electric	.04 / kWh	3.84 1/
Electric	.06 / kWh	5.76 1/
Electric	.08 / kWh	7.68 1/

1/ Monthly demand charges may be in addition to direct electrical energy use and will vary widely depending on electrical company.

Figure 12–1 displays the energy requirements for an efficient irrigation pumping plant for flows above 250 gallons per minute comparing various energy sources. It is shown as an example that an efficient pumping plant discharging 1,000 gallons per minute against a total lift of 300 feet requires about 85 kilowatt hours of electric energy. A diesel engine would use 6.9 gallons of fuel per hour, a propane engine 10.8 gallons per hour, natural gas engine 112.5 cubic feet per hour, and a gasoline engine 8.6 gallons per hour. Local fuel unit costs can then be applied to compare alternative energy uses.

Figure 12–1 Energy requirements for an efficient irrigation pumping plant (source: Bulletin 637, Cooperative Extension Service, University of Wyoming)

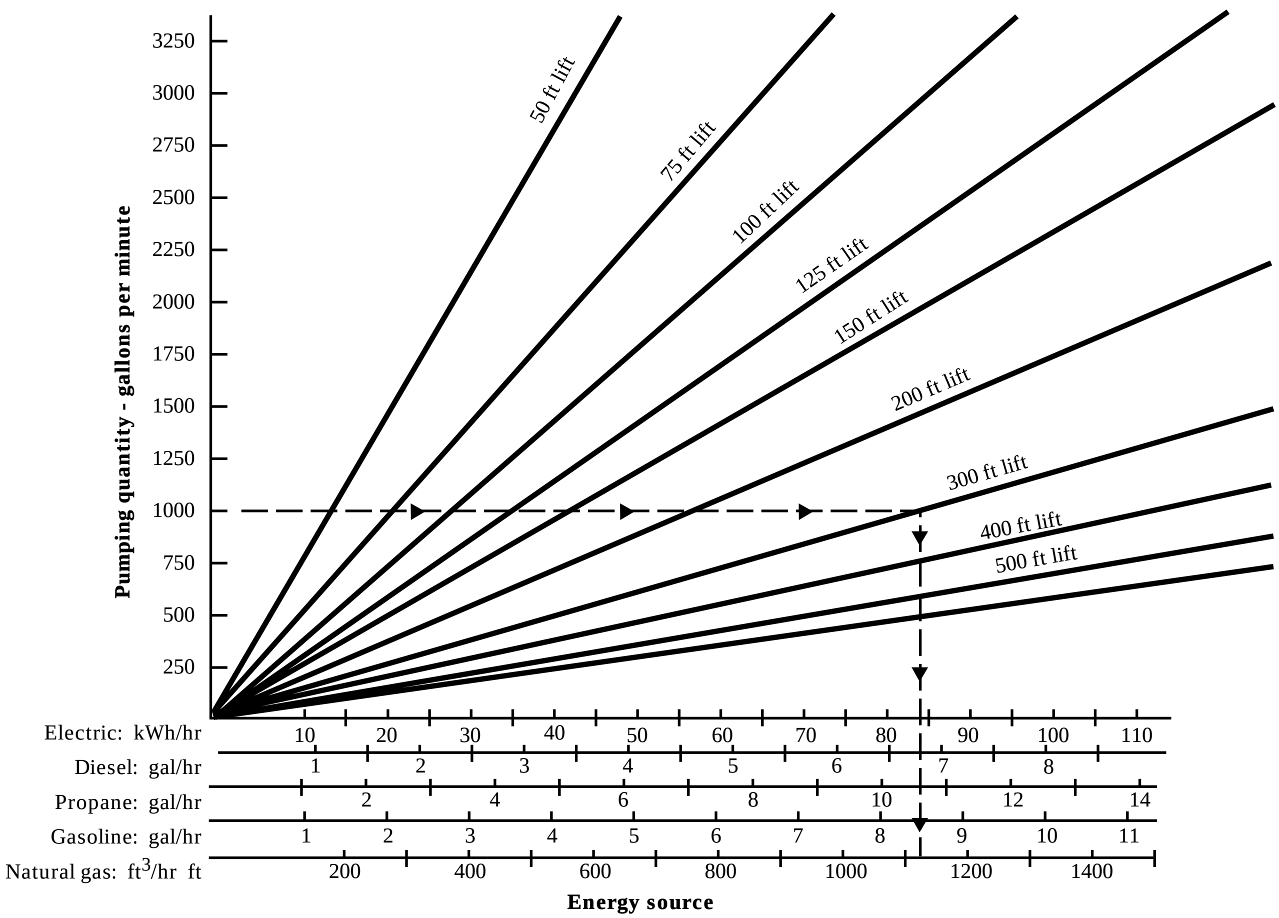


Figure 12–2 Electric power costs to pump an acre-foot of water against a head of 1 foot

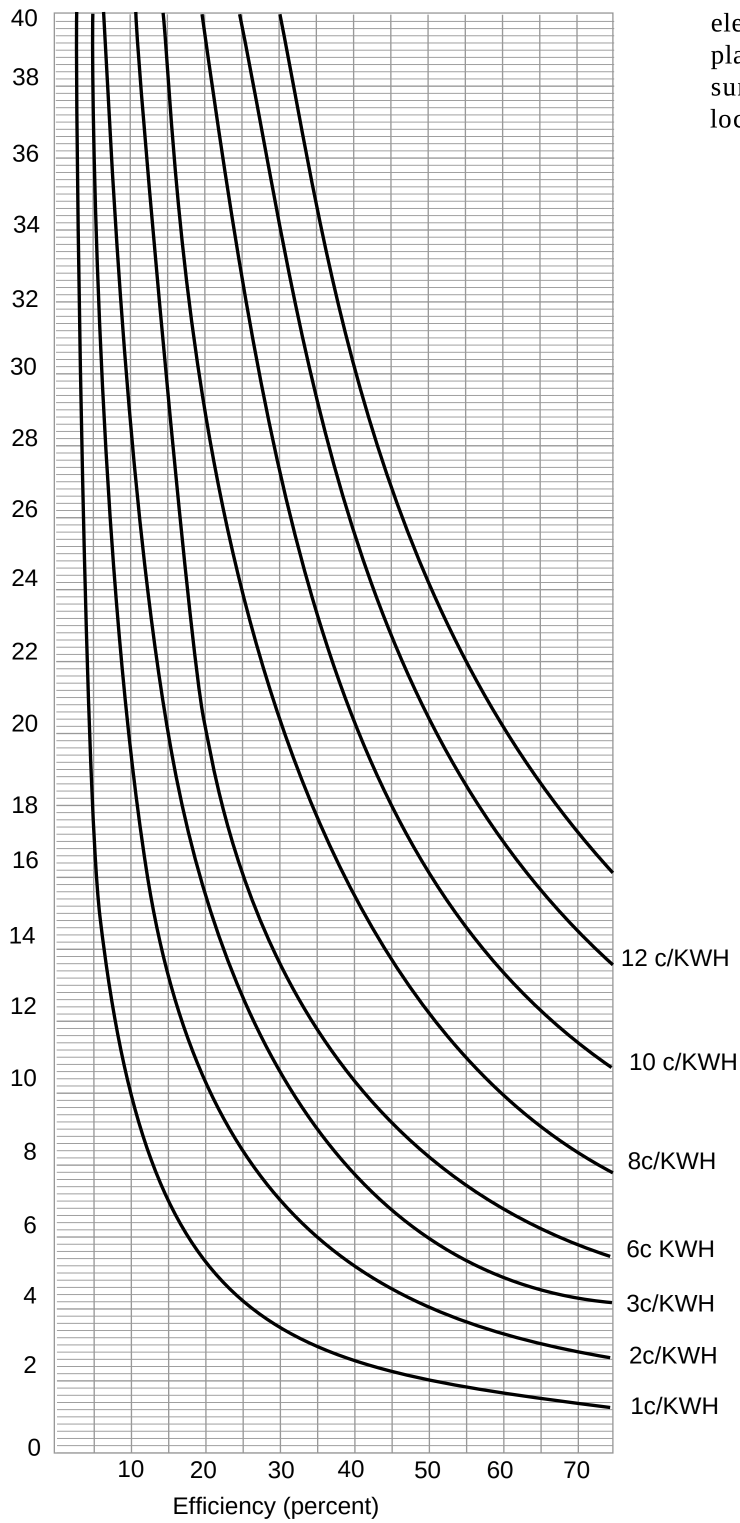
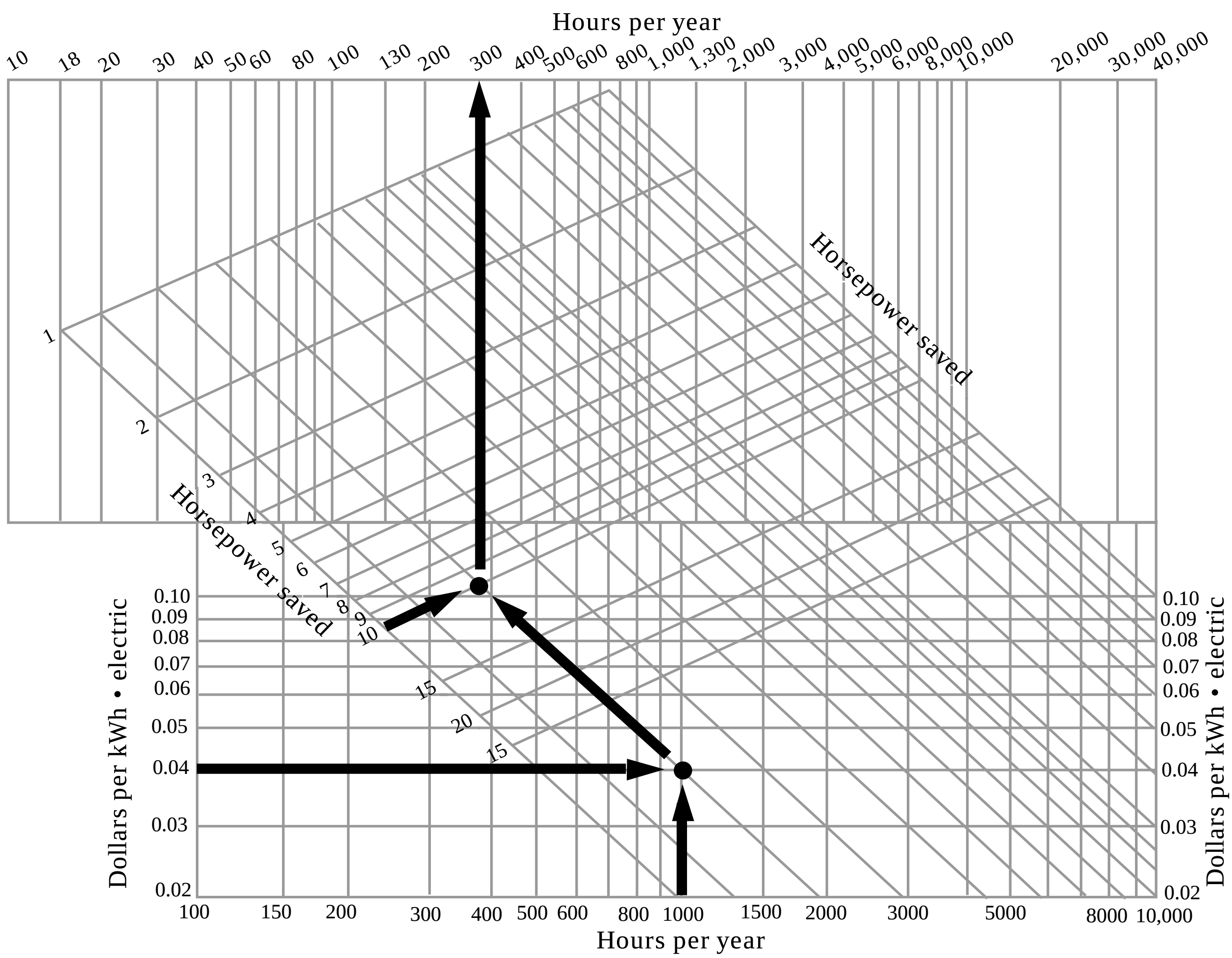


Figure 12–2 shows relationship of electric pumping plant efficiency versus cost (cost per acre-foot per foot of head in dollars or cents) of pumping for various electrical rates. It vividly displays effect of a pumping plant operating at poor efficiency. It does not include surcharges, such as for demand charge, applied by local electric companies.

Figures 12–3 and 12–4 display effects of decreased horsepower requirements resulting from reducing total pressure head requirements. This may be from decreased pumping lift, reduced friction losses with modifications to the pipelines (i.e., suction pipe, mainlines, submains, and lateral) and fittings (i.e., elbows, reducers, enlargers, valves), or decreased operating pressure (i.e., conversion from high pressure to low pressure).

Figure 12–3 Horsepower saved converted to dollars saved in a year using electrical energy (courtesy of Cornell Pump, Portland, OR)



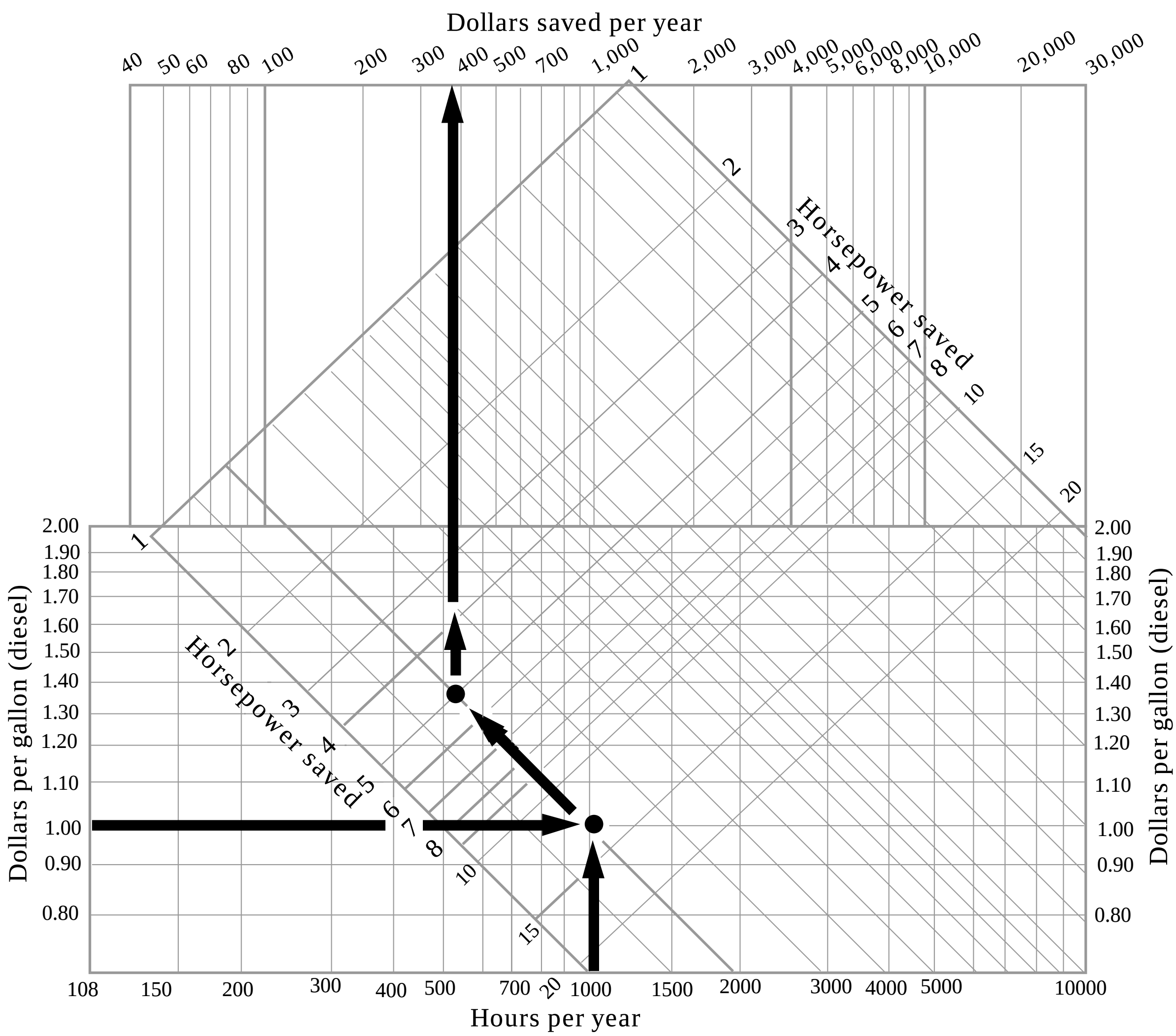
Example:

Cost of electric power = $.04 / kWh
Hours of pumping, annually = 1,000 hr
Calculated horsepower saved = 10 hp

Therefore:

Savings of $300 per year would result in pumping plant operation.

Figure 12–4 Horsepower saved converted to dollars saved in a year using diesel fuel (courtesy of Cornell Pump Company, Portland, OR)



Example:
Diesel fuel cost = $1.00/gal
Hours of pumping, annually = 1,000 hr
Calculated horsepower saved = 5 HP

Therefore:
Savings of $380 per year would result in pumping plant operation

(c) Reading watt-hour meters

A quick and easy way to determine energy input to an electric pump is to use revolutions per unit time of the small revolving disc on the watt-hour meter and calculate horsepower usage. The formula at the bottom of this page is used to convert meter readings to kilowatt energy use and horsepower. These multipliers may vary, depending on local application, and checking with local electric company is necessary.

652.1203 Irrigation pumping plant design considerations

Irrigation pumps are commonly used to lift water from one elevation to a higher elevation or to add pressure to the water. Handy information bulletins to determine energy use, methods to reduce energy use from pumping plants, selection of pumps, and pump performance are readily available from pump manufacturers and many university Cooperative Extension Services.

Pump and power unit should be carefully matched to the irrigation system flow requirements and Total Dynamic Head (TDH). Both characteristics should be accurately determined. This may involve measuring flows in an existing system. A detailed description of pump characteristics and hydraulic calculation procedures are contained in NEH Section 15, Chapter 8, Irrigation Pumping Plants.

$$\text{kW} = \frac{(3.6) \times (\text{meter disc revolutions}) \times (\text{meter constant, Wh}) \times (*)}{(\text{time, in seconds})}$$

$$\text{hp} = \frac{\text{kW}}{0.746}$$

where:

kW = kilowatts used by the electric motor
Wh = watthour meter constant, used to convert to kilowatt hours used
hp = horsepower
* = Where installations use a high rate of electrical energy, the electric company will install meters that only put a small part of the energy used through the meter. Current Transformer Ratio (CTR) of 200:5 (40 multiplier), 400:5 (80 multiplier), 800:5 (160 multiplier), or 1,600:5 (320 multiplier) can be used. A Potential Transformer Ratio (PTR) of 5:1 (5 multiplier) can also be used. ***Note:*** Both CTR and PTR can be used at the same installation. Ratios are multiplied by the observed kW calculation to determine the correct kW, as follows:

actual kW = (observed kW) x (CTR) x (PTR)

Almost all pumps have moving parts that require some type of lubrication to prevent wear. In some instances the bearings are lubricated and sealed a the time of manufacture. In others oil or grease must be added periodically or continuously, and even water itself may be used as the lubricant. Where water is pumped from wells using oil lubricated shafts, a layer of oil several inches thick often accumulates on the water surface.

Sediment in irrigation water causes wear of any pump. Propeller and centrifugal pumps handle a reasonable amount of sediment, but require periodic replacement of impellers and volute cases. Turbine pumps are more susceptible to damage because of the sediment in the water. Deep well turbine pumps can be costly to inspect for excessive wear. Positive displacement pumps must be used only with sediment-free liquids. Fertilizer and chemical injection pumps are typically positive displacement pumps and can provide the required accurate control of injected chemicals.

(a) Pump characteristic curves

Pump characteristic curves, sometimes called pump performance curves or head capacity curves, display the relationship between head (pressure) produced and the water volume pumped. Because of their mechanical nature, pumps have certain well defined operating properties. Pump characteristic or performance curves are available and essential for determining pumping plant requirements.

Data for these curves are developed by testing a number of pumps of a specific model. A set of curves or tables is prepared that represents the specific operating condition for each impeller and pump model. Field offices rarely have copies of all possible pump curves for all pumps used in their area. Generally, though, the majority of pumps in an area are of few makes, types, and models that are handled by local dealers. An effort should be made to obtain pump curves for these pumps from suppliers or from the manufacturer. Typically, they are readily available.

Performance of pumps changes with time. Since they are mechanical devices, they wear, and the rate of wear is dependent on the amount and kind of sediment pumped. Replacement of the impeller, wear rings, or even the entire bowl assembly may be required when wear has become excessive. The best way to evaluate an installed pump's performance is to do a field pump test described in Chapter 9, Irrigation Water Management. The field test should provide information needed for decisions on pump repair or energy reduction.

Performance curves are typically available for every make, model, and size pump commercially manufactured. However, it may be difficult to obtain performance curves for older pumps and for pumps where the impellers are used in the same pump, a performance curve is prepared for each size impeller. With multiple impellers (i.e., deep well turbine pumps), head developed by each impeller (stage) is accumulated. Speed of rotation also affects impeller performance.

A prerequisite to selecting the right pump or analyzing an existing pump is knowing how to read pump characteristic curves. Each manufacturer's curve looks a little different, and each type of pump has a slightly different set of curves. Most common characteristic curves provided by manufacturers and typically included on most pump performance curves are:

- Total dynamic head (ft) versus discharge (gpm)
- Efficiency (%) versus discharge (gpm)
- Input power (bhp) versus discharge (gpm)
- Net positive suction head (ft) versus discharge (gpm)

Normally, the NRCS technician only provides a head/capacity requirement, i.e., 900 gpm at 150 foot head, for dealer and owner pump selection. More detailed information is provided for better understanding, and to allow specific pump evaluation.

The following section illustrates how to read typical pump performance curves for each major type pumps used to pump irrigation water.

(1) Single speed centrifugal pump

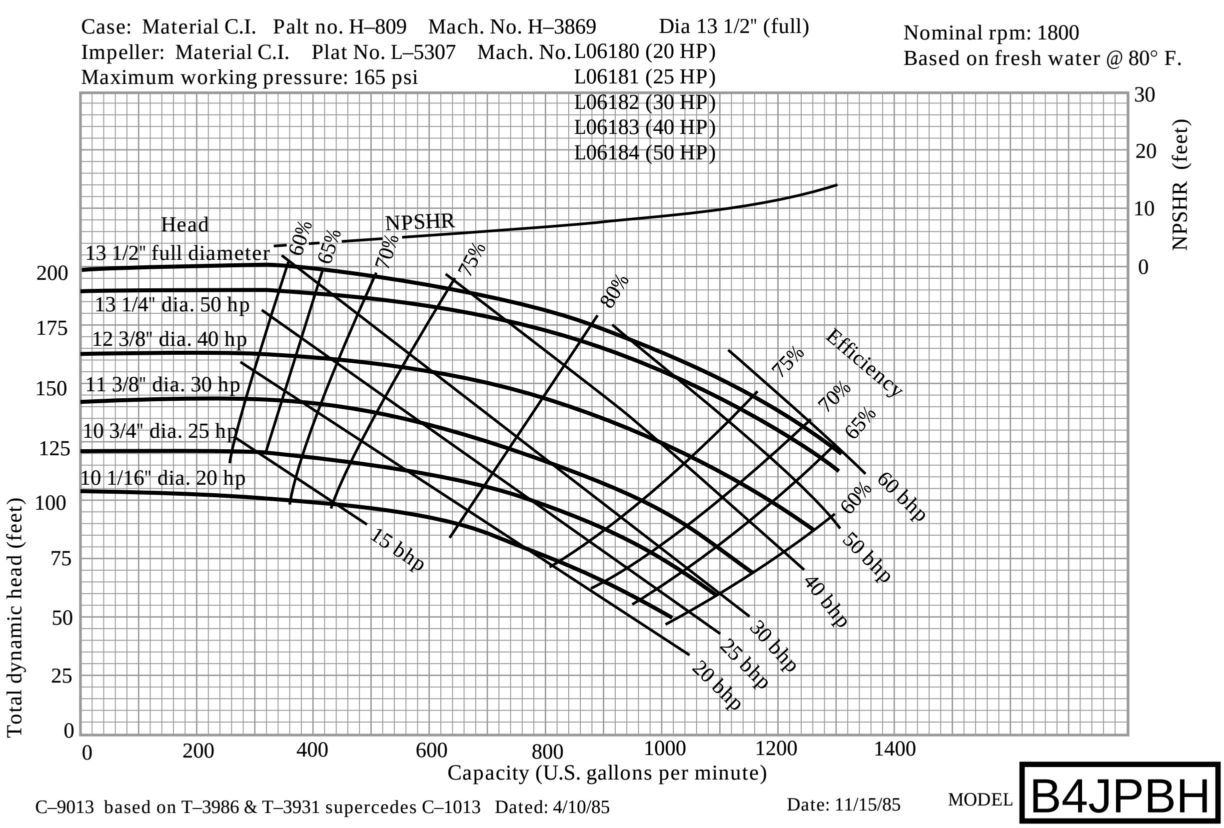
Figure 12–5 illustrates a set of curves for a single speed centrifugal pump. This type pump is driven by a 1,760 rpm electric motor. Four factors, all related to discharge capacity in gallons per minute, are shown on the chart. They are:

- total dynamic head
- pump efficiency
- brake horsepower
- net positive suction head

The first three curves display the effect of different impeller diameters. For example, if a pump was required to deliver 900 gpm at 150 feet of TDH, read the chart as follows:

Enter the left side with TDH of 150 feet and the bottom at 900 gallons per minute. The intersection of these two is just above the 12 3/4-inch diameter impeller curve. Therefore, the next larger impeller must be used, which is 13 1/4-inch diameter. At a TDH of 150 feet, this pump puts out about 1,040 gallons per minute. If pump discharge is limited with a valve to 900 gallons per minute, TDH raises to 170 feet of head, and efficiency is read at 900 gallons per minute on the efficiency curve as about 78 percent (read left efficiency scale). If pump discharge is not limited with a valve, efficiency for 1,040 gallons per minute is read as 77 percent. Brake horsepower is about 50. Maximum allowable net positive suction head (NPSH) is about 6 feet. (Suction head exceeding this causes operation problems and loss of efficiency.) If the increased TDH is unacceptable, exact head/discharge can be obtained by trimming the impeller diameter. Energy used will reduce accordingly.

Figure 12–5 Single speed centrifugal pump (courtesy of Berkeley Pump Company)



If the higher flow rate is selected, friction loss in the pipeline also increases. Recalculation of friction losses is necessary. An Irrigation System Performance Curve (friction loss vs. capacity) can be plotted or overlaid onto the pump characteristic curve. The pumping plant operates where the two curves cross (intersect).

Pumps shown in the curve are for standard 30-, 40-, and 50-horsepower sizes. If the brake horsepower require is slightly over a standard size motor, consult the motor manufacturer to see if overload is acceptable. Otherwise, use the next larger motor.

A flow of 1,040 gallons per minute is not the design flow of 900 gallons per minute. You must now decide to accept this or look at the alternatives. The alternatives are:

- Use the next size smaller pump and accept lower flow.
- Look for another brand or model pump that better fits the conditions.
- Reduce TDH to about 137 feet by increasing pipe sizes or reducing output pressure, then go to the smaller 40-horsepower pump.
- Increase the TDH by closing a valve slightly until a discharge of 900 gallons per minute is reached. This action is not energy efficient; however, it can be most practical where discharge is to be limited.

Pump selection is always a select, recalculate, and retry compromise to find the most efficient pump that best fits the desired conditions.

(2) Multispeed centrifugal pumps

Figure 12–6 illustrates a set of curves for a single impeller size multispeed centrifugal pump. Multispeed pumps are generally driven by an internal combustion engines. Curves shown are head, brake horsepower, and pump efficiency versus capacity curves.

Design head/discharge should be located to the right of peak pump efficiency. As wear occurs, pump efficiency increases giving a higher life span efficiency than if designed for absolute peak efficiency initially. For example, if a pump is to deliver 1,100 gallons per minute at 60 feet TDH, find the rotations per minute and horsepower required.

Enter the left side with TDH of 60 feet and the bottom with 1,100 gpm. Read required shaft speed of pump as slightly above 1,800 rpm, bhp as about 21 horsepower, and efficiency as about 80 percent. Note that this performance is based on a suction lift of 15 feet. Less suction lift should be used at higher elevation to maintain performance. Table 12–6 displays practical static suction lift.

Total suction lift equals static lift plus friction loss in suction pipe, elbows, and foot valve plus velocity head. The example is for 900 gallons per minute with 6-inch diameter welded steel suction pipe, elbow, foot valve; a 5,000-foot elevation, and maximum water temperature of 80 °F.

Given:

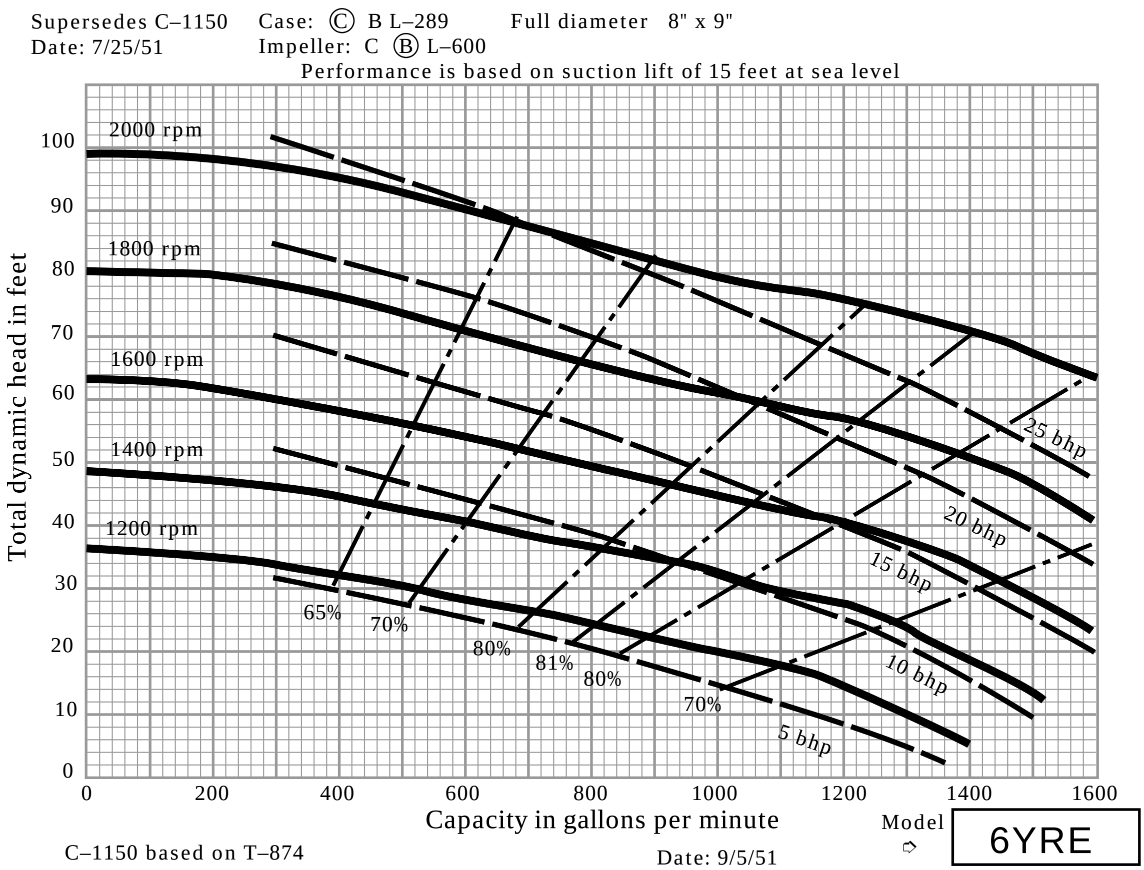
Static lift (water surface to eye of pump inlet)	=	15.4 ft
Friction loss (calculated)	=	5.2 ft
Velocity head (calculated)	=	.6 ft
Total	**=**	**22.18 ft**

Table 12–6 Practical static suction lift

Elevation (ft)	Maximum theoretical suction lift 1/ (ft)	---- Practical static suction lift 2/ ---- at various water temperatures 60 °F (ft)	70 °F (ft)	80 °F (ft)	90 °F (ft)
Sea level	34.0	23.4	23.2	23.0	22.6
500	33.4	23.0	22.8	22.5	22.2
1,000	32.7	22.4	22.4	22.0	21.8
1,500	32.1	22.0	21.9	21.6	21.4
2,000	31.5	21.6	21.5	21.2	20.9
3,000	30.3	20.8	20.6	20.4	20.1
4,000	29.2	20.0	19.9	19.6	19.3
5,000	28.1	19.2	19.1	18.8	18.6
6,000	27.0	18.5	18.3	18.1	17.8

1/ Maximum theoretical lift of water at 50 °F and lower.
2/ 70 percent of theoretical maximum.

Figure 12–6 Multispeed centrifugal pump (courtesy of Berkeley Pump Company)



Reference to table 12–6 indicates maximum practical suction lift for 5,000-foot elevation equals 18.8 feet. Therefore, the pump will probably not operate properly and cavitation would probably occur. Alternatives include:

- Lower pump to reduce static lift.
- Enlarge suction pipe and improve configuration of elbows and foot valve to reduce friction loss.
- Reduce discharge.

Alternative considerations and procedures are similar to those described under single speed centrifugal pump.

(3) Vertical turbine pump

Figure 12–7 illustrates a set of three curves for a single stage of a single size enclosed impeller turbine. This pump is driven by an electric vertical motor at 1,770 rpm. Total dynamic head, brake horsepower, and pump efficiency are shown on the chart. Also shown is a chart giving factors to change efficiency as stages are added.

Often, a single-stage pump does not produce enough head to overcome the required lift or discharge pressure of an irrigation system. Vertical turbine pump stages (bowls) can be added in series. By doing this, the head capability is increased. The head-capacity curves and horsepower capacity curves are additives at a given discharge. Head and horsepower are doubled if a second bowl is added to a first bowl; three stages would triple the head produced and horsepower required.

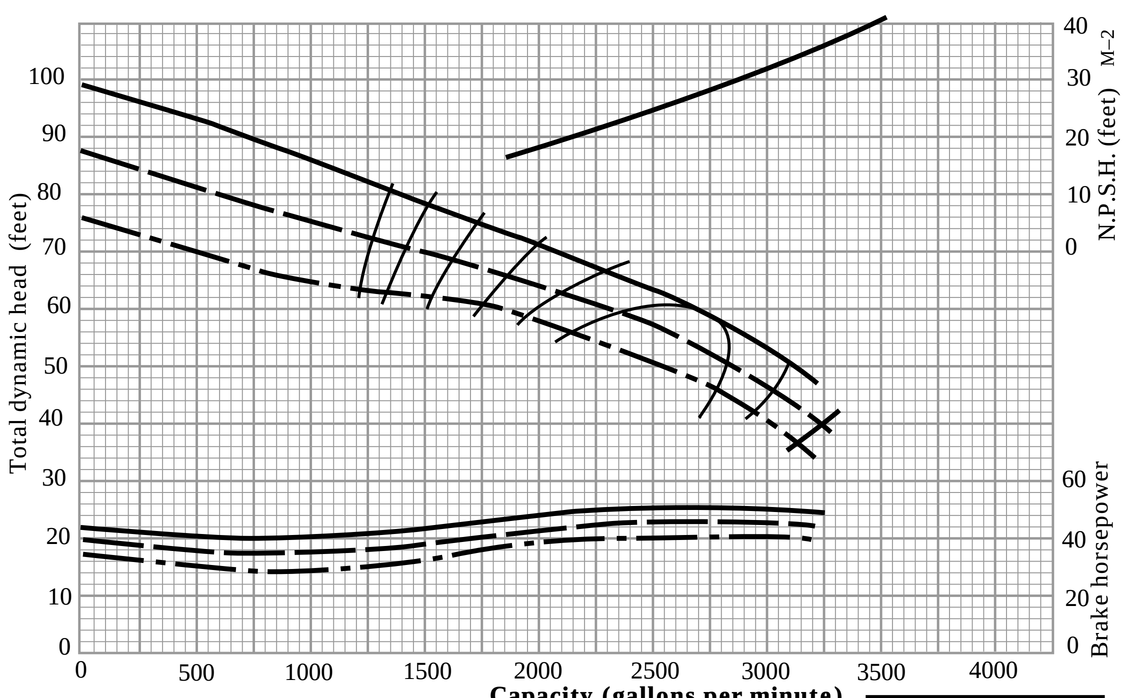
Figure 12–7 Vertical turbine pump (courtesy of Berkeley Pump Company)

	Bowl	Impeller
Material	C.I. Porc.	Brz.
Part No.	L–452	L–622
Mach. No.	L–2034	L–622
Diameter	13–3/8" O.D.	(see table)

Letter	Impeller Diameter
A	8–3/4" x 10–7/8" Full
B	8–3/16" x 10–1/4"
C	7–9/16" x 9–11/16"

Based on T– 3258, **Test of** 4 **stage pump**
2971–1 **Performance for 1 Stage pump**
Adjust efficiency for stages used:

Stages	4	3	2	1
Points	0	–1	–2	–5



C–7216 Issue date: 5/24/74 (Supersedes C–7216 Dated 7-2-73) 1770 RPM **MODEL 1403 HH**

Staging turbine pumps can change efficiency. Efficiency corrections are shown in a table on the curve. In figure 12–7 the peak efficiency of the pump is given as 82 percent. According to the correction chart, a one-stage pump would be corrected by 5 percentage points (82–5 = 77%), and a three-stage pump would have –1 correction (82–1 = 81%).

Procedures for reading curves are otherwise the same as for the centrifugal pumps.

(4) Vertical mixed flow pumps

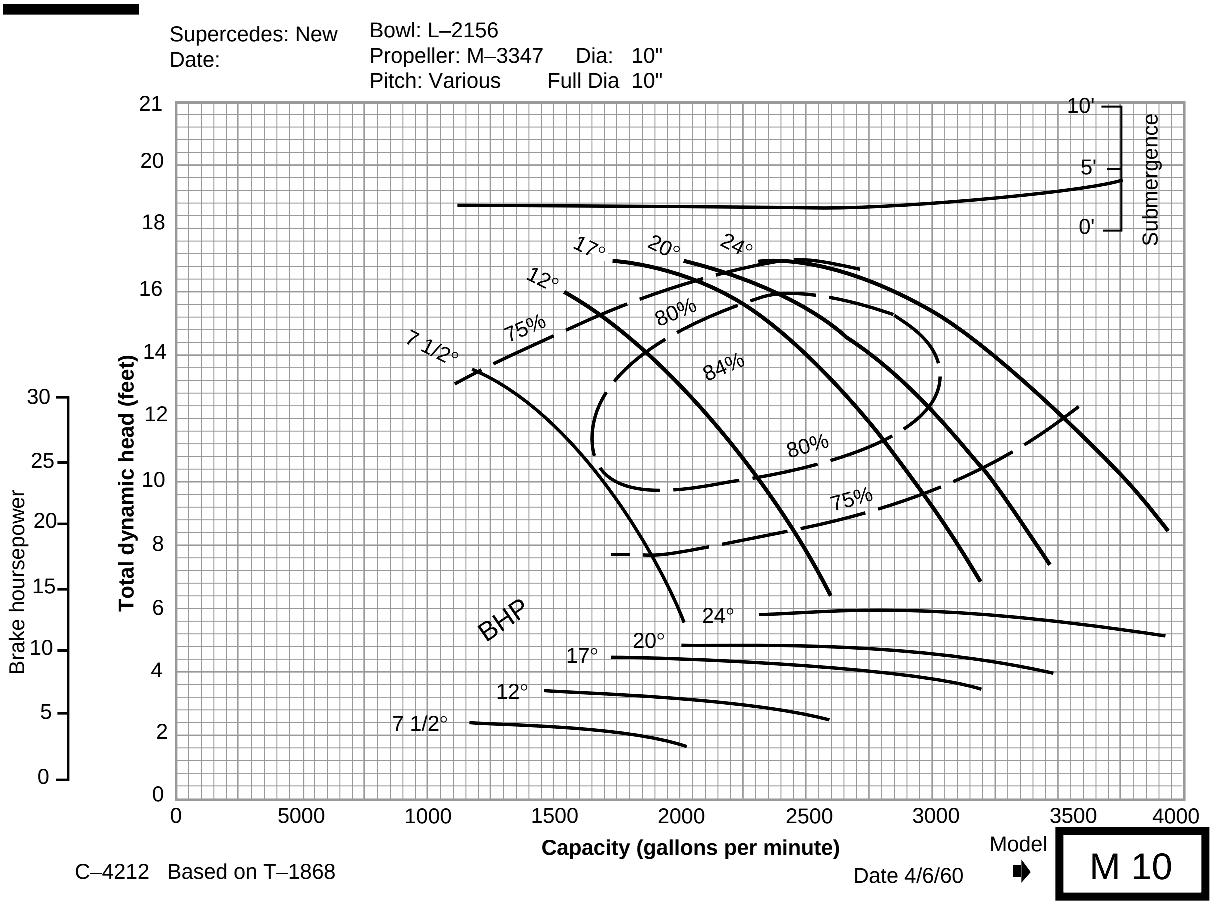
Figure 12–8 illustrates a curve for a 1,180-rpm electric motor driven, low-head, mixed-flow, pump. This pump is often used for lifting water from a stream to a ditch, one ditch to another, or boosting from a ditch into a surface system pipeline. Total dynamic head, brake horsepower, pump efficiency, and minimum submergence curves are shown.

The impeller (cross between propeller and turbine type) can be obtained in several configurations or pitches (7.5 to 24 degrees). Different pitches provide different head/capacity characteristics. Generally, the steeper the propeller pitch, the more brake horsepower required. Pitches are shown as five TDH and BHP curves.

Maintaining minimum pump intake submergence is critical. Therefore, sump (pump well) characteristics become critical with this pump. See figure 12-12 for recommended pump sump dimensions. Follow the manufacturer's recommendations carefully when designing the sump.

Pump performance curves are read the same as centrifugal pump curves.

Figure 12–8 Vertical mixed flow pumps (courtesy of Berkeley Pump Company)



(b) Pumping plant installations

Pumps, motors, engines, and all appurtenances should be installed on a raised, firm foundation and be adequately shaded. All electrical cable, fittings, and control panel should be tight and adequately grounded, and the area should be free from standing water. For gasoline, diesel, natural gas, and propane powered engines, all hose connections should be tight with zero leaks.

For centrifugal pumps, installations should provide:

- Concrete slab foundation for a solid support of motor and pump and allow proper alignment of drive shaft. Do not secure pump and motor to the foundation. Allow the unit to seek its own position.
- Supports for suction and discharge pipes close to the pump.
- Adequate size pipe and fittings to prevent cavitation and minimize friction losses.

For vertical turbine pumps, installations should provide:

- Concrete slab foundation around the well head and pump base to provide support for gear head, engine, or motor and allow proper alignment of pump drive shaft.
- Maintain proper lubricant levels in gear head and pump shaft.
- Provide for adequate pump impeller submergence.
- Adequate size discharge pipe in the well.
- Adequate well capacity

For submersible pumps, installations should provide:

- Corrosion resistant cable support for pump motor, electric cable, and pipeline.
- Adequate size discharge pipe in the well.
- Adequate pump impeller submergence.
- Adequate well capacity.
- Proper size electric wire or cable from motor to control box.

Safety control devices should be considered standard installation items. Lightning protection devices are considered and installed according to manufacturer's recommendations. Pressure control switches should be provided to allow pumping plant shut-off should sudden pressure drop at downstream side of pump occur. Typical examples are a break in a pipeline or a control valve failure. Water level control sensors in pump sumps can provide pump shut-off should the water source be interrupted. This device prevents pumps from operating with no water. Electric surge protectors should be considered to help protect electric panels and motors from lightening

(c) Electric motors

Electric motors should be carefully matched between load and electrical supply conditions. To do otherwise results in wasted power and higher than required initial installation and maintenance costs.

Table 12–7 lists standard electric motor sizes and speeds available, and electric current phase used to operate 10 horsepower or larger three-phase motors with single-phase current.

Table 12–7 Electric current phase required for standard electric motor sizes 1/

Motor hp	3,600 rpm	1,800 rpm	1,200 rpm	900 rpm	720 rpm	600 rpm
1	1,3	1,3	1,3			
1.5	1,3	1,3	1,3			
2	1,3	1,3	1,3			
3	1,3	1,3	1,3			
5	1,3	1,3	1,3	1,3		
7.5	1,3	1,3	1,3	3		
10	1,3	1,3	3	3		
15	3	3	3	3		
20	3	3	3	3		
25	3	3	3	3		
30	3	3	3	3		
40	3	3	3	3	3	3
50	3	3	3	3	3	3
60	3	3	3	3	3	3
75	3	3	3	3	3	3
100	3	3	3	3	3	3
125	3	3	3	3	3	3
150	3	3	3	3	3	
200	3	3				
250	3	3				
300	3	3				

1/ 1 = single-phase electric current, 1ϕ
3 = three-phase electric current, 3ϕ.

(1) Maximum size

Motors are designed and constructed at either single- or three-phase electric current. In most areas, a 10-horsepower motor is the maximu size that can be powered directly with single-phase current. Local utility companies may further limit the maximum size to 7.5 horsepower.

(2) Phase converters

Single-phase motors can be used to operate larger horsepower motors if a phase converter is used. Two most common types of converters are an auto transformer-capacitor converter (for horsepower to 100) and a rotary converter (for up to 200 horsepower motors or groups of motors). Converters are expensive, and a 2 percent or greater energy loss occurs when using them.

Rural electric power companies generally limit converter size because of the limited power line capacity the amount of current required during startup. Electric motors require three to five times running amperage for startup. Maximum motor size may be limited to 15 horsepower in some cases. A check with the local electrical company will address these concerns.

(3) Three-phase electric motors

Electric motors are rated according to their brake horsepower. Typically, this is the horsepower output that can be continuously delivered, as rated by the manufacturer. Electric motors can develop more horsepower than shown on the nameplate; however, loading above the nameplate horsepower can cause excess motor heating. Heat reduces motor life because heat accelerates the breakdown of motor insulation and other components. Three-phase motors do not require a starting mechanism; thus, they have fewer moving parts than do single-phase motors.

Some motors have a service factor (SF). Most three-phase motors used for irrigation have a service factor of 1.15. The service factor allows short-term loading above the brake horsepower rating without seriously affecting motor life, as long as good heat dissipation is maintained. Generally, service factor loading should not be used for continuous power. It is intended to be a safety factor.

An electric motor is not 100 percent efficient. Some energy is lost in converting electrical energy into mechanical energy. Electric motor efficiency is typically 80 to 95 percent. Larger motors are more efficient than smaller motors. Also a small motor's efficiency is highest at 3/4 load. Table 12–8 displays nominal efficiencies for standard and high efficient motors. To avoid overloading, it may be advantageous to use the next larger electric motor. Operating any electric motor below its rated load capacity decreases the electric to mecahnical energy efficiency.

Table 12–8 Nominal efficiencies for standard and high efficiency electric motors (courtesy of Marathon Electric, Wausau, Wisconsin)

Horse-power	Standard efficiency motor nominal efficiency (%)			High efficiency motor nominal efficiency (%)		
	full load	3/4 load	1/2 load	full load	3/4 load	1/2 load
3,600 rpm, 460 volt						
5	84.0	86.0	84.5	89.5	89.5	88.5
10	84.0	85.0	82.0	91.7	92.4	91.7
20	86.5	86.5	83.5	92.4	92.4	92.4
30	87.5	87.5	85.5	93.6	94.1	93.6
40	91.0	91.0	89.0	94.1	94.1	93.6
50	91.7	91.7	91.0	94.5	95.0	94.5
75	93.6	93.6	92.4	95.0	94.5	95.0
100	94.1	94.1	93.0	95.4	95.4	95.0
150	93.6	93.0	91.7	95.4	95.4	95.0
1,800 rpm, 460 volt						
5	85.5	83.5	81.5	—	—	—
10	87.5	88.5	87.5	—	—	—
20	89.5	90.2	89.0	92.4	93.0	93.0
30	89.5	88.5	80.5	94.1	94.1	94.1
40	90.2	89.5	88.0	94.5	94.5	94.5
50	91.0	91.0	90.2	94.5	95.0	94.5
75	93.0	93.0	91.7	95.4	95.8	95.8
100	92.4	93.0	92.4	95.8	95.8	95.8
150	94.1	93.6	92.4	96.2	96.2	95.8

Motor speed (rpm) is rated at no load and full load. The difference between no load and full load speeds for three-phase motors is small. For example: 1,800 rpm at no load and 1,760 rpm at full load. Motor speed is controlled by cycles per second of alternating current.

(d) Internal combustion engines

Engines generally operate more efficiently when used at 75 to 100 percent of their continuous rated horsepower. The manufacturer's recommendation for loading should be followed. If internal combustion engines are to operate efficiently, a good maintenance program should also be followed.

The horsepower rating applicable to a pump engine is the continuous horsepower available at the output shaft. It is common practice for engine manufacturers to list power ratings without cooling fans (and other required accessories), which can consume 5 to 8 percent of engine power. When a radiator cooled engine is used, this loss or extra power use must be taken into account. Attachments can be obtained that circulate irrigation water to cool the engine and thus eliminate fan energy loss. Engine efficiency can be changed as much as 5 percent with some engine modifications.

Altitude, humidity, and air temperature affect engine power output. For naturally aspirated (nonturbocharged) engines, it is standard industry practice to derate engine power output by 3.5 percent for each 1,000 feet above a 500-foot altitude and 1.0 percent for each 10 °F above 85 °F.

(e) Pump installation

A flow meter, or other water measuring device, and a properly operating pressure gauge should be installed at each pump site to monitor pump operation. This information can be invaluable for determining when pump efficiency is starting to drop so that corrective actions can be taken. Typically a 5 percent drop in pressure or volume output is a signal that pump (or well) maintenance should be considered. A sudden drop in line pressure could indicate a break in the pipeline or other abrupt change in system. A position change of the distribution or application system can also cause a pressure variation at the pump; i.e., a pivot lateral moving from a downhill position to an uphill position. A flow (rate and volume) meter can be of great value for making some water management decisions.

Foot valves on suction pipelines prevent backflow from occurring when the pump is shut off. Without a foot valve, the suction pipe is drained each time the pump is shut off, allowing the pipe to be filled with air. When air enters the suction side of the pipeline, generally due to improper installation, flow is restricted. Air in the pump can also cause cavitation to accelerate pump wear. Higher velocities (3 to 5 ft/s) tend to move suspended air through the pipeline. Backflow prevention valves and air-vacuum release valves located just downstream of pump discharge should also be considered. They help prevent reverse flows through the pump and potential collapse of discharge pipelines, especially where pumping uphill. All these devices just discussed should be considered a part of any pump installation.

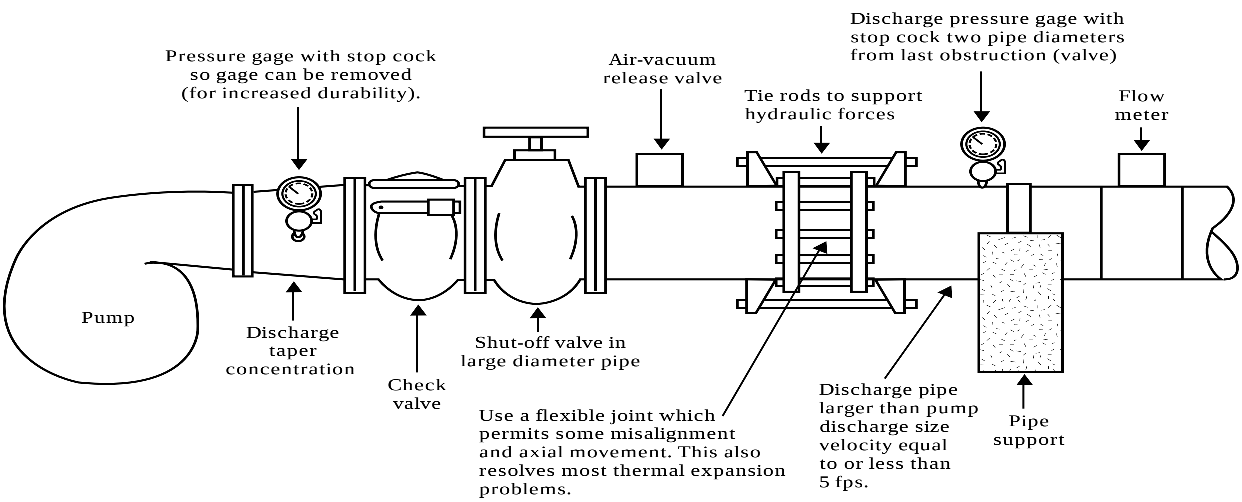
How a pump is installed can significantly affect overall operating efficiency. Unfortunatly many installations are not adequately installed. The following specific information relates to individual pump types.

(1) Centrifugal pumps

Centrifugal pump suction pipeline must be free of air leaks and must not have high points that can cause air accumulation or restricted flow. Also pump priming is difficult when suction pipline air leaks are excessive. Figure 12–9 illustrates pump installation considerations. Figure 12–10 illustrates priming arrangements and foot valve needs for centrifugal pumps.

Figure 12–9 Installation considerations for centrifugal pumps (courtesy of Cornell Pump Company)

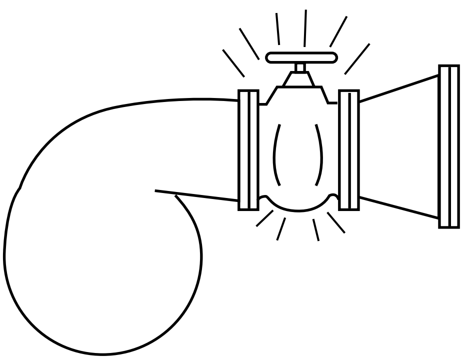
Discharge piping—Good practice



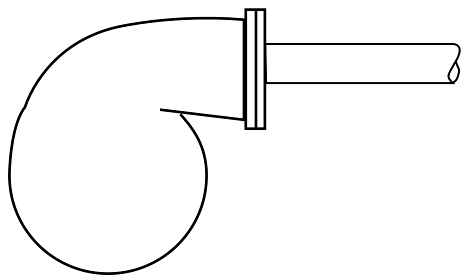
Note: A vacuum gage on the pump suction side can indicate whether the intake screen is becoming plugged. A pressure gage will not work since pressure on the pump suction side is negative.

Figure 12–9 Installation considerations for centrifugal pumps—Continued

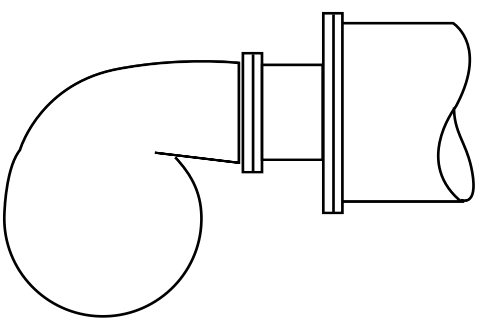
Discharge piping—Poor practice



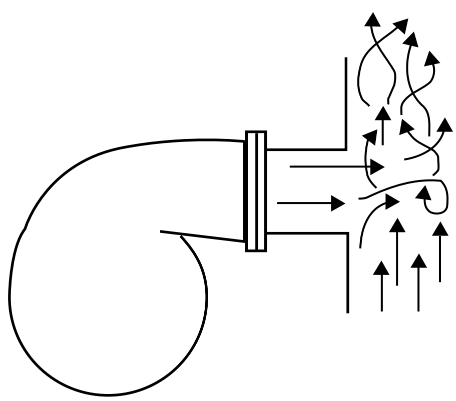
Do not design a system to operate with the discharge valve partly closed.



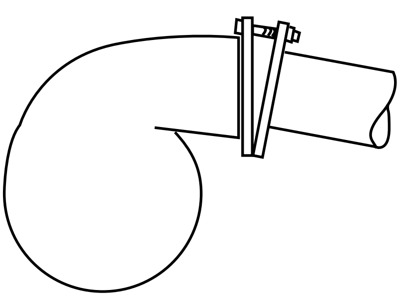
Do not use small discharge valves, piping and fittings. This adds to friction loss.

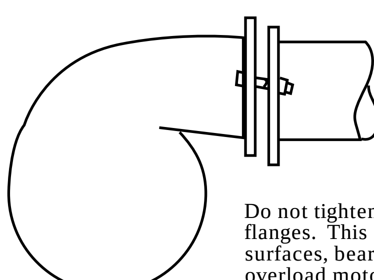


Valve on small diameter pipe



Avoid discharging at a right angle into a manifold flow. A Y connection in the direction of flow is preferred.



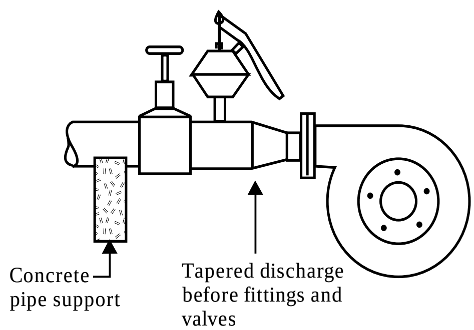


Do not tighten bolts on misaligned flanges. This can damage wear surfaces, bearings, coupling, and overload motor, and can create other problems.

Figure 12–9 Installation considerations for centrifugal pumps—Continued

Discharge and suction fittings—Good practice

Discharge fittings



Suction fittings

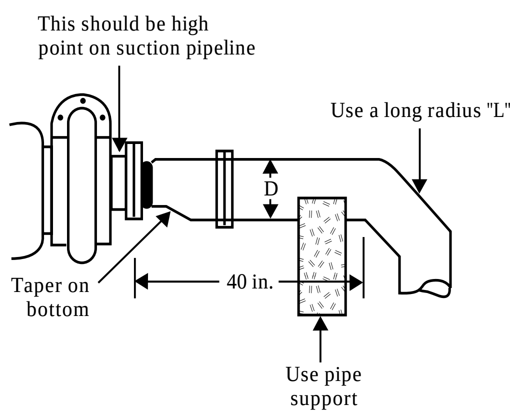
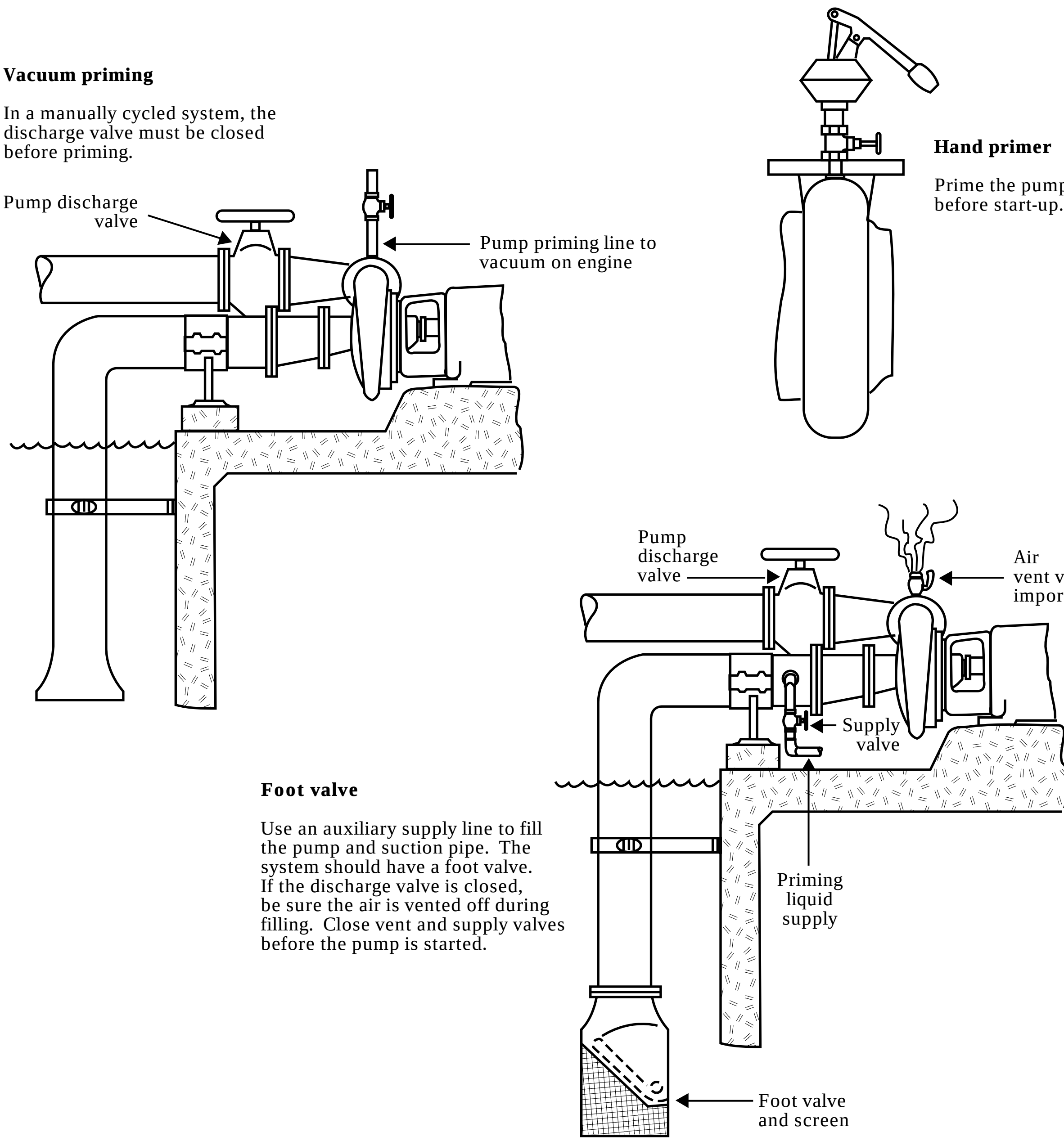


Figure 12–10 Priming arrangements for centrifugal pumps (courtesy of Cornell Pump Company)



***(i) Change of performance*—**Altering the speed or impeller diameter of a centrifugal pump changes the performance of the unit. Rules relating performance with change in speed and for change in diameter apply for all types of centrifugal pumps. Example 12–1 illustrates these rules.

A constant diameter impeller:
- Pump capacity varies directly as speed.
- Head varies as the square of the speed.
- Horsepower input varies as the cube of the speed.

At constant speed:
- Capacity varies directly with the impeller diameter.
- Head varies as the square of the impeller diameter.
- Horsepower varies as the cube of the impeller diameter.

Rules for impeller diameter are used in a similar way. By computing the performance of the pump at a number of points along its characteristic curve, a new set of curves can be plotted. These curves typically agree fairly close with actual pump performance curves and can be sufficient for planning purposes.

Standard diameter impellers for centrifugal pumps can be trimmed (reducing impeller diameter) to meet a specific head requirement. Impellers are trimmed to reduce operating pressure and energy requirements. Trimming is more cost effective than replacing the pump. However, the amount of impeller trim which occur and still maintain good pump performance is limited. Manufacturers can provide performance curves for the newly trimmed impeller.

Although horizontal shaft centrifugal pumps are most common, a vertical shaft, or vertical shaft and submerged pump volute can be used. Submerged vertical shaft centrifugals operate similar to vertical turbines.

Example 12–1 Change of performance rules

Given:
A pump delivering 500 gpm at 1,150 rpm and 50 ft head requires 10 hp.

Determine:
Capacity, head, and power input of this unit if motor speed is increased to 1,750 rpm.

Solution:
New capacity is in the same ratio as the speeds:

$$\frac{1,750}{1,150} \times 500 \text{ gpm} = 760 \text{ gpm}$$

New head is in the same ratio of the speeds squared:

$$\frac{1,750^2}{1,150^2} \times 50 \text{ ft} = 116 \text{ ft}$$

New horsepower is the ratio of the speeds cubed:

$$\frac{1,750^3}{1,150^3} \times 10 \text{ hp} = 35 \text{ hp}$$

(2) Propeller/mixed flow pumps

The sump in which a propeller or mixed flow pump is installed must be a part of the pumping plant design and installation. Figure 12–11 displays important sump dimensions versus flow. Figure 12–12 displays sump dimensions nomenclature and pump arrangement.

The sump entrance must be large enough to pass the design discharge to the pump(s) without restrictions. Velocities within the sump from the entrance toward the pump should be less than 1 foot per second. The shape and dimensions of the sump should be such to supply an even distribution of flow to the suction intake of the pump(s). Improperly designed or installed sumps (pump wells) can seriously affect pump performance. Improper sump design can result in the formation of vortexes, turbulence, and high or misdirected velocities—any of which can seriously affect performance. Vibration, excessive noise, surging, cavitation, excessive wear on shaft and bearings, reduced capacity, and excessive load on the pump motor can result. See NEH, Part 623 (Section 15, Irrigation), Chapter 7, Irrigation Pumps, for additional information and example layouts including sump dimensions versus flow for single and multiple pump installations.

Figure 12–11 Sump dimensions versus flow for vertical propeller pump installation

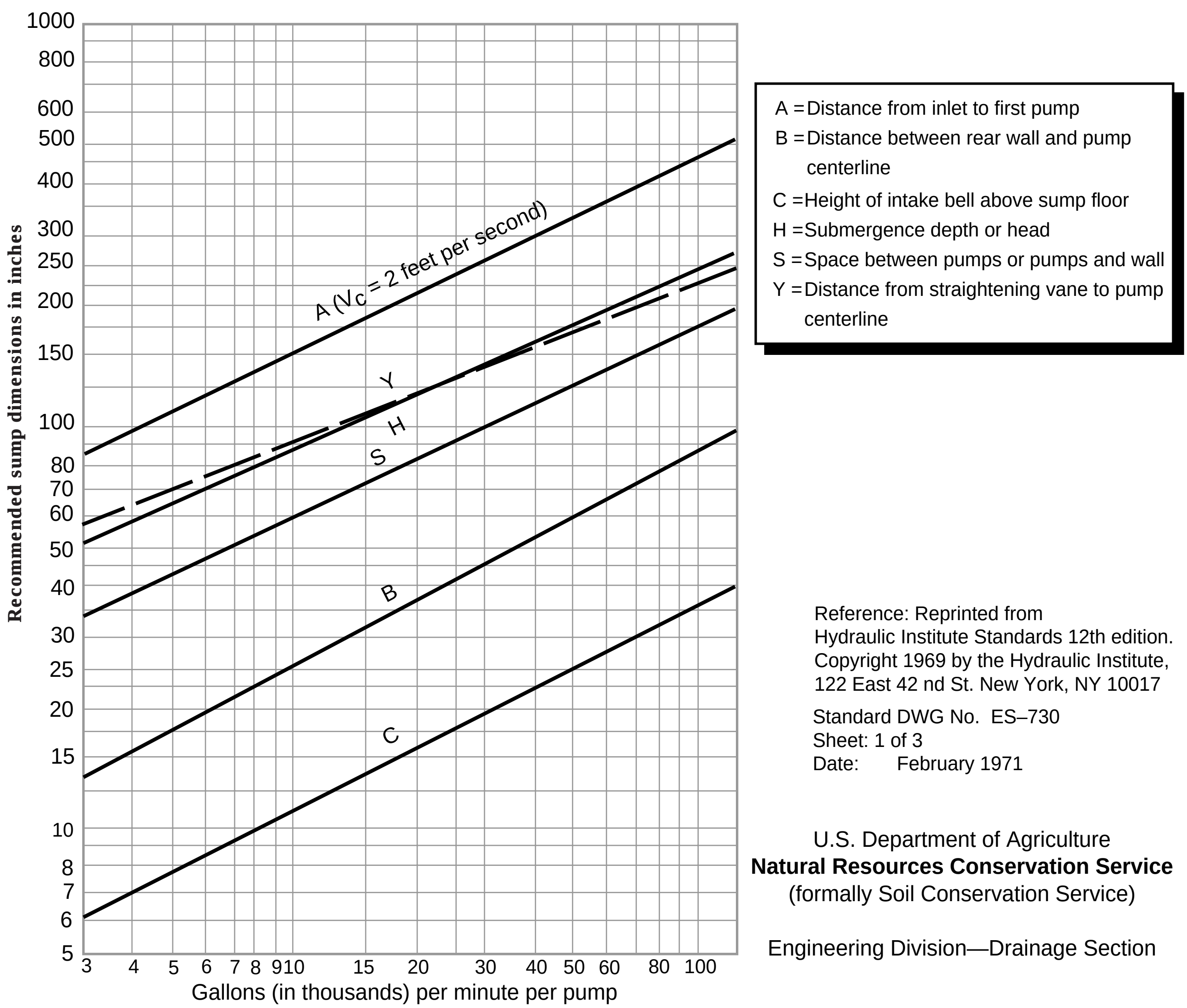
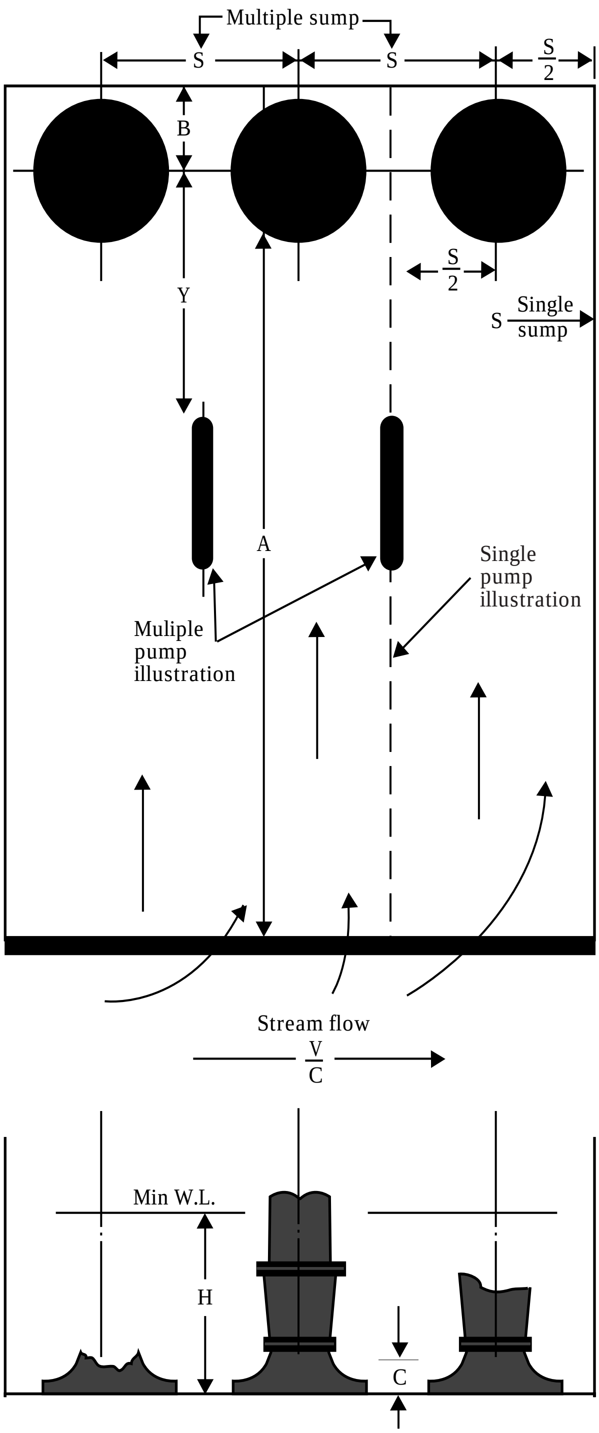


Figure 12–12 Nomenclature for sump dimensions and pump arrangement for vertical propeller pump installation



652.1204 Pipeline efficiency

Energy is required to offset friction loss in a pipeline. Friction loss in a pipeline increases approximately in proportion to the square of the pipeline water velocity. Flow rate and pipe size both affect velocity. Pipe material also affects friction loss. Energy required can be reduced by increasing pipe size, reducing flow rate, changing pipe material, or any combination of these.

Table 12–9 displays estimated friction loss for various combinations of pipe sizes (4- to 12-inch diameter), flow rates (100 to 2,000 gpm), and pipe material (steel, aluminum, and plastic). If a more accurate friction loss is necessary, use tables that provide for varying inside diameters, wall thickness and varying friction coefficients.

Table 12–9 Pipe friction loss comparison table for welded steel, aluminum, and plastic pipe

Gallons per minute	4-inch steel	4-inch alum.	4-inch plas.	6-inch steel	6-inch alum.	6-inch plas.	8-inch steel	8-inch alum.	8-inch plas.	10-inch steel	10-inch alum.	10-inch plas.	12-inch steel	12-inch alum.	12-inch plas.
	Pipe (ft/100-ft of pipe)														
100	1.25	.81	.55	.17	.11	.08									
150	3.00	1.73	1.18	.36	.23	.16	.09	.06							
200	4.39	3.65	2.01	.62	.42	.28	.15	.10	.07	.05					
300	9.47	6.35	4.27	1.32	.92	.60	.32	.21	.14	.11	.07	.05	.05	.05	
350		8.32	5.43	1.73	1.16	.79	.43	.28	.19	.14	.09	.06	.06		
400		10.74	7.39	2.31	1.50	1.02	.55	.37	.25	.18	.12	.09	.08	.05	
450			9.24	2.77	1.85	1.27	.69	.45	.32	.23	.15	.11	.10	.06	
500			11.55	3.47	2.31	1.55	.83	.55	.39	.28	.18	.13	.12	.08	.05
550				4.11	2.66	1.85	.99	.66	.46	.33	.22	.16	.13	.09	.06
600				4.85	3.19	2.19	1.18	.79	.54	.39	.25	.18	.17	.11	.07
650				5.54	3.70	2.54	1.39	.90	.63	.46	.30	.21	.19	.13	.09
700				6.47	4.27	2.89	1.62	1.04	.72	.53	.35	.24	.22	.15	.10
750				7.39	4.85	3.35	1.80	1.16	.82	.60	.39	.28	.25	.16	.11
800				8.32	5.54	3.70	2.02	1.27	.89	.68	.42	.31	.28	.18	.13
850				9.24	6.12	4.16	2.31	1.50	1.03	.76	.51	.35	.32	.21	.15
900				10.16	6.93	4.62	2.54	1.67	1.16	.84	.55	.39	.35	.23	.16
950				11.55	7.39	5.20	2.82	1.85	1.35	.95	.61	.43	.39	.25	.18
1000					8.32	5.66	3.07	2.02	1.40	1.06	.65	.48	.43	.28	.19
1050					9.01	6.24	3.35	2.25	1.50	1.12	.74	.51	.46	.31	.21
1100					9.93	6.93	3.70	2.54	1.65	1.24	.81	.56	.51	.33	.23
1200					11.55	8.09	4.39	2.72	1.96	1.46	.95	.66	.60	.39	.27
1300						9.24	5.08	3.44	2.28	1.69	1.11	.76	.71	.46	.31
1400						10.51	5.89	3.81	2.59	1.96	1.25	.88	.81	.52	.37
1500							6.58	4.39	2.93	2.19	1.47	1.00	.92	.60	.42
1600							7.39	4.97	3.29	2.54	1.60	1.12	1.04	.67	.46
1700							8.32	5.54	3.70	2.77	1.85	1.27	1.16	.76	.52
1800							9.24	6.12	4.13	3.10	2.08	1.39	1.29	.84	.57
1900							10.16	6.81	4.62	3.47	2.31	1.55	1.46	.95	.65
2000							11.32	7.39	5.08	3.80	2.54	1.70	1.59	1.04	.69

652.1205 Alternative energy reduction devices

(This section was from information in Irrigation Pumping Plants, University of California, Davis, CA, 1994.)

When it is desirable to reduce total dynamic head and pump discharge, using the existing motor and pump, variable or adjustable frequency drives for electric motors are available. These devices allow the rotations per minute (rpm), or speed, of the motor to be reduced. Horsepower is also reduced. The drive consists of a converter that changes AC power to DC power and an inverter that changes DC power into adjustable frequency AC power. As the frequency of the power is decreased, the power to the motor and the motor rpm are both reduced. This decrease in motor rpm can substantially reduce the pump horsepower demand since the pump horsepower demand is proportional to the pump rpm cubed. A small change in rpm then causes a significant change in pump horsepower demand. Figure 12–13 shows that reducing the rpm by about 20 percent reduces horsepower demand by about 50 percent. Reducing the rpm from 1,770 down to 1,400, for example, decreases the horsepower demand of a 100-horsepower pump to 50 horsepower.

The pump output, capacity, and the total dynamic head, is also determined by the rpm. The capacity is proportional to the rpm, while the total head is proportional to the rpm squared. Figure 12–13 also illustrates these relationships. For example, a 20 percent reduction in rpm decreases the pump capacity by 20 percent and the total head by nearly 38 percent.

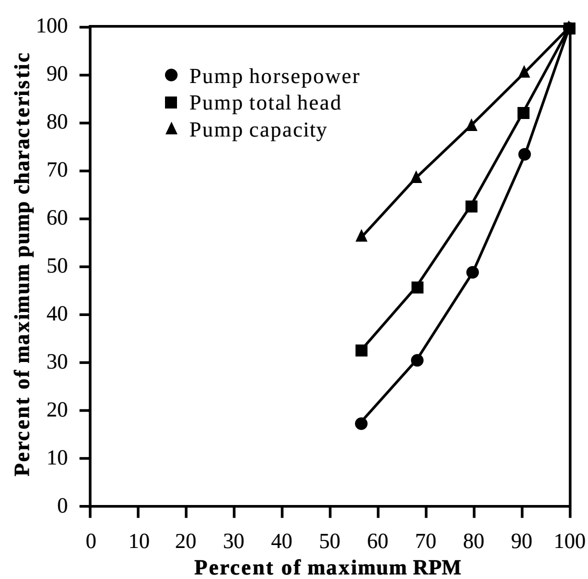
Because of these relationships, adjusting the pump rpm may not yield the same total dynamic head and discharge capacity obtained under a throttled (partly closed valve downstream of pump) condition. The actual total head and capacity at a particular rpm depend on the impeller design, which defines the relationship between total head and pump capacity.

Variable frequency drives must be protected from adverse environmental conditions, including dampness, dust, and extremes in temperature and altitude. One manufacturer recommends installations where ambient air temperature is maintained between 14 and 122 degrees Fahrenheit, humidity is maintained below 90 percent, and the elevation is below 3,300 feet.

Variable frequency drives can also affect the efficiency of the pumping plant. The lower the rpm, the less efficient the motor and the variable frequency drive. Down to about 50 percent of the maximum rpm, the drive efficiency may decrease only slightly, but at lower rpm's the efficiency of the drive falls dramatically. Manufacturers can supply characteristic curves for specific diameter and width impellers at reduced rpm's.

Variable speed drives eliminate energy waste caused by a throttled pump by producing a discharge similar to that of a throttled pump, but at a lower horsepower. The economic affect of these devices depends on the decrease in horsepower demand, operating time, electric energy costs, and cost (purchase, installation and maintenance) of the variable speed drive. The benefit of the variable speed drive is the savings in annual electric energy cost, which amounts to the difference in energy costs between the constant rpm operation and the reduced speed operation. Permanent required pressure (energy) is less costly and preferred.

Figure 12–13 Ratio of pump characteristics to pump rpm



652.1206 Other energy sources for pumping water

Wind has been widely used for many years as a power source to provide domestic and livestock water. It can also be used for direct pumping of irrigation water or to generate electric energy to power electric motors for pumping. Where wind is intermittent, water can be pumped to storage reservoirs where it can then be available for irrigation when needed. Area and crops irrigated should be balanced against total water supply available including conveyance and storage losses.

Solar energy using photoelectric cells can be used to charge batteries for electric motor operation or can be used to directly operate electric motors. The size of the energy generation system for both wind and solar power can vary widely depending on requirements for water capacity and operating head.

Hydraulic rams (sometimes called hydro-ram pumps) are devices for pumping water using the water's kinetic energy. Typically, a smaller flow rate (delivery) is raised to a higher elevation by using kinetic energy from a higher flow rate (supply). Maintenance is generally low, and the useful life is long. However, only a few manufacturers produce these devices.

Air pumps can be used to raise water. Intermittent bubbles of air are released at the inlet of a vertical small diameter pipeline. As the bubble raises to the surface, a small quantity of water is carried above the bubble.

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