The Agricultural Pumping Efficiency Program has been extended through 2008 as a PG&E Customer Energy Efficiency offering, funded through the Public Purpose Programs Charge under the auspices of the California Public Utilities Commission. Information pertaining to APEP contained in this pamphlet may be outdated. Please call APEP at 1.800.645.6038 or log on to www.pumpefficiency.org for current information regarding eligibility, educational seminars, pump tests and incentives for pump retrofits. Eligibility now extends to agricultural, large turf and municipal (including tertiary-treated water) water pumping customers with PG&E electric or natural gas accounts. Residential, commercial, industrial process, primary sewage and secondary sewage pumps are ineligible.

Agricultural Pumping Efficiency Program
Reducing Energy Use and Energy Costs

This book is published by the Agricultural Pumping Efficiency Program ("APEP" or "Program"). The Program was developed and is managed by the Center for Irrigation Technology on the campus of California State University, Fresno. The Program is funded by the Public Goods Charge that is paid by California utility ratepayers under the auspices of the California Public Utilities Commission.

The Program is intended for agricultural water pumpers using electricity or natural gas for energy. This book presents concepts and practices that can help reduce energy use, the total energy bill and improve overall resource efficiency.

IMPORTANT!
The Program may be terminated or modified without notice. The Program has a limited budget. Applications for retrofit/repair rebates or pump tests are accepted on a first-come, first-served basis until available funds are allocated or the ending date of the program, whichever comes first - visit www.pumpefficiency.org or call (800) 845-6038 for more information.

California consumers are not obligated to purchase any full fee service or other service not funded by this program. This program is funded by California utility ratepayers under the auspices of the California Public Utilities Commission.

Los consumidores en California no estan obligados a comprar servicios completos o adicionales que no esten cubiertos bajo este programa. Este programa esta financiado por los usuarios de servicios públicos en California bajo la jurisdiccion de la Comision de servicios Publicos de California.

The Center for Irrigation Technology

The Center for Irrigation Technology (CIT) developed and manages the Agricultural Pumping Efficiency Program. CIT is dedicated to advancing water and energy management practices and efficient irrigation technology. Located on the campus of California State University, Fresno, CIT functions as an independent testing laboratory, applied research facility and educational resource to both the public and private sectors. For more information, check the CIT link at www.pumpefficiency.org or call (800) 845-6038 or (559) 278-2066.
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The Agricultural Pumping Efficiency Program

The Agricultural Pumping Efficiency Program ("APEP" or "Program") is a comprehensive effort to improve energy efficiency in California's irrigated agriculture. The Program achieves these goals by:

1. Helping to install and maintain high-efficiency irrigation pumping plants in the field.
2. Helping to manage those pumping plants correctly.

The APEP offers:

1. Education
   Educational seminars concerning pumping plant specifications and maintenance, crop water requirements, and water management are presented throughout the state. The education message has four components, all of which are covered in this book:
   a. Know how to specify an efficient pump.
   b. Know how to maintain an efficient pump.
   c. Know how much water needs to be pumped.
   d. Know how much water has been pumped.

2. Technical Assistance
   Program personnel are available to help in locating pump efficiency testers, completing a pump retrofit/repair incentive rebate application form, or to answer general questions about pumping plant design and use. Please note that the Program does not offer site-specific engineering services. That is, we cannot help you design and install a specific pumping plant.

3. Pump Efficiency Tests
   Rebates for pump efficiency tests are paid directly to participating pump test companies. Tests are available for working, electric- or natural gas-powered agricultural water pumps. Note that tests are not available to fulfill requirements of any public or quasi-public agency or in relation to a real estate transaction.

4. Incentive Rebates for Pump Retrofits and Repairs
   Incentive rebates are available to individuals for retrofit/repair of working electric- or natural gas-powered agricultural water pumps. There are several important eligibility factors for incentive rebates. You are encouraged to talk to a Program representative. Complete information is provided in the APEP application or online at www.pumpefficiency.org.
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Agricultural Pumping Efficiency Program

Introduction

How Can a Company or Group Participate?

The Program is actively seeking partners to present the message of pumping efficiency to California agriculture. We can be part of one of your scheduled short courses or other events. You can also be part of one of our scheduled seminars. The Program message can be presented in whole or in part, and over any time frame – from one hour to two days (we prefer at least a two-hour time block).

In addition to the four main education components discussed previously, we can present concentrated sessions on various subjects such as variable frequency drives, obtaining and interpreting a pump efficiency test, seasonal irrigation scheduling, and evaluation of irrigation system performance. Call us if you have a specific topic of interest.

APEP Resources

The Agricultural Pumping Efficiency Program has a variety of resources available at no charge.

1. Regional Offices and Toll-Free Assistance

The Program maintains offices throughout the state and provides toll-free assistance.

- Main Office - (800) 845-6038
- San Joaquin Valley - (800) 352-0434
- Northern California - (866) 333-8938
- Southern California - (866) 333-8939
- Central Coast - (866) 473-0847

2. Web Sites

The Program maintains on-line resources that can provide valuable information on water and energy savings.

- www.pumpefficiency.org
  The Program web site provides summaries of all program components, a calendar of upcoming events, application forms, phone numbers, contact information, and a knowledge base. Here you can type in a word or phrase and a list of technical papers will be presented that pertain to that word or phrase. For example, you may type in “irrigation efficiency.” Several papers will be presented that define irrigation efficiency, tell how it can be measured in the field, and how you can improve your efficiency.

- www.wateright.org
  This interactive web site provides the tools to develop site-specific, seasonal irrigation schedules. The site also contains educational material and reference data on water and energy management including CIMIS crop water use data.

3. Seminars

APEP offers seminars throughout California. Most of these seminars come to you via the Mobile Education Centers. Others are provided at fixed sites. Dates and locations of upcoming events are listed on the web site or you can call one of the offices to find out when a seminar will be presented in your area. All seminars are free of charge.

- On-Site Seminars with Mobile Education Centers (MEC)
  The Program brings educational seminars to farmers in the field using two Mobile Education Centers. These are enclosed trailers with self-contained pumping plants. They are used to introduce the basic concepts of pump performance and how to specify and maintain an efficient pump. They travel around the state and are used to present educational seminars of various lengths and on different subjects.

- Seminars at Pump Demonstration Facilities in Fresno and Chico
  Demonstration and calibration facilities are located at California State University, Fresno and California State University, Chico. These facilities are located next to fields so they can be used to demonstrate irrigation efficiency concepts as well as pumping efficiency.
4. Written Materials
The Program distributes several types of written materials including this book and the *Pumping Energy Calculator*. Individual brochures are available providing summary discussions of pump efficiency, flow meters, irrigation planning, specifying an efficient pump and education. Call one of our offices to have materials mailed directly to you or visit our web site at [www.pumpefficiency.org](http://www.pumpefficiency.org) for downloadable PDF versions.

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In addition to the four main education components discussed previously, we can present concentrated sessions on various subjects such as variable frequency drives, obtaining and interpreting a pump efficiency test, seasonal irrigation scheduling, and evaluation of irrigation system performance. Call us if you have a specific topic of interest.
Using This Book

What is the Purpose of this Book?
The main purpose of this book is to present the four-point educational component of the Program. It also contains summary presentations of what is an efficient pumping plant and how correct management of those plants can save money for pump owners and operators.

The intent of this book is not to present a technical discussion of hydraulic science or the design of pumping plants. Rather it is intended for the layperson who wants to know what questions to ask in order to obtain, maintain, and manage efficient pump systems.

The approach of this book may appear to be unconventional to some. However, the Program has chosen this approach in order to effectively communicate with managers in the field who must make important decisions every day regarding energy use.

Who is the Intended User of this Book?
All owners or users of an agricultural electric or natural gas utility account used to pump water, who are paying the Public Goods Charge, are eligible to participate in the Program. Typically, this includes customers of the major investor-owned utilities (i.e. Pacific Gas & Electric, Southern California Edison, etc.) The term “agriculture” means that account billing is governed by an agricultural rate schedule and the account is classified as primary production agriculture use. This would include farms, dairies, nurseries, turf farms, livestock, and cut flower operations. However, anyone who operates a pumping plant, regardless of where or how he or she purchases energy (or what type of energy - electricity, natural gas, or diesel), may be interested in the information presented in this book.

For the most part this book discusses electrical energy use. However, most of the concepts are directly applicable to natural gas users. Please contact the Program if you have questions specific to natural gas use.

How is the Book Organized?
The book contains chapters, with several sections within each chapter.

Chapter One - Analyzing Energy Use and Costs
Chapter One is the most technical part of this book. The sections in this chapter present how the Program analyzes energy efficiency in agriculture, and provide examples indicating why efficient hardware and proper management are important. They include:

1. How the Program Analyzes Pumping Plant Costs - Section I introduces several equations that indicate the options for lowering pumping costs. You will see that the four main options for lowering pumping costs are:
   1. Reduce unit cost of energy - the dollars paid per therm of natural gas, gallon of diesel, or kilowatt-hour of electricity.
   2. Reduce required system pressures.
   3. Increase pumping plant efficiency.
   4. Improve pumping plant management.

II. Why Pumping Efficiency is Important - Section II demonstrates the cost savings available from improving overall pumping plant efficiency.

III. Why Management of Pumping Plants is Important - Section III builds on Section II by showing what happens if an efficient pump is not operated correctly.

Chapter Two - Education

This part of the book provides individual discussions of the four parts of the Program’s education message. Each section contains an overview of the message and the full text of individual brochures written for the Program. They include:

IV. Know How to Specify an Efficient Pump - Section IV discusses the basics of pumping technology. It introduces the pump operating conditions, the pump performance curve, the components of overall pumping plant efficiency, different pump types, different power sources, and the variable frequency drive for electric-powered pumps.

V. Know How to Maintain an Efficient Pump - Section V’s emphasis is not on the “janitorial” aspects of pump maintenance. Rather it is using regular pump efficiency tests to tell you if the pump’s operating condition has deteriorated or the required pump operating conditions have changed.

VI. Know How Much Water Needs to be Pumped - water pumping for irrigation is discussed with emphasis on the individual irrigation. Every irrigation should have a purpose - to put a specific amount of water into a specific volume of soil. The Pumping Energy Calculator, which accompanies this book, is introduced. The calculator estimates required pumping hours per irrigation.

VII. Know How Much Water Has Been Pumped - you need to measure water to properly manage water. Different flow meters are introduced, along with the installation requirements that result in accurate measurements of water flow rates and total water volume pumped.

Chapter Three - Helpful Information

These sections contain information that will be helpful in understanding the book, as well as a summary of how to use the Pumping Energy Calculator.

VIII. Glossary of Terms - Section VIII contains simple definitions of commonly used terms in pumping.

IX. Engineering Data - Section IX contains common engineering constants and unit conversions used in agricultural pumping.

X. Using the Pumping Energy Calculator - Section X contains examples of how to use this valuable management tool to calculate required pumping horsepower, the actual cost of pumping, required gross water application, and required hours of pumping for three common irrigation system types.
Analyzing Energy Use and Costs

I. How the Program Analyzes Pumping Costs

This section discusses how the Program Analyzes Pumping Plant Costs - Section I introduces several equations that indicate the options for lowering pumping costs. You will see that the four main options for lowering pumping costs are:

1. Reduce unit cost of energy - the dollars paid per therm of natural gas, gallon of diesel, or kilowatt-hour of electricity.
2. Reduce required system pressures.
3. Increase pumping plant efficiency.
4. Improve pumping plant management.

This discussion is somewhat technical and includes several mathematical equations. The discussion below uses a single pump supplying an irrigation system, powered by electricity. Most of the concepts are directly applicable to natural gas users also. Please contact the Program if you have questions specific to natural gas use.

Annual energy costs for a water pump used for irrigation can be estimated using Equation I.1:

\[ \text{$/yr} = \text{$/kWh} \times \text{kWh/AF} \times \text{AF/yr} \]

Where:
- \( \text{$/yr} \) = annual cost of energy (note that this excludes demand charges)
- \( \text{$/kWh} \) = average cost per kilowatt-hour
- \( \text{kWh/AF} \) = average number of kilowatt-hours required to pump an acre-foot of water through the system
- \( \text{AF/yr} \) = number of acre-feet pumped each year

Equation I.1 indicates that to lower annual pumping costs you can lower the unit energy cost, lower the kilowatt-hours required per acre-foot, or reduce the number of acre-feet pumped per year.

Lowering \( \text{$/kWh} \)

The average cost per kilowatt-hour can be minimized several ways. It is most important for electricity users to be on the correct rate schedule. Various rate schedules are intended for different types of users. Contact your utility representative if you are not sure about the correct schedule, have changed your operations recently, or have not examined this option for some time.

One of the most common options for minimizing \( \text{$/kWh} \) is to use a Time-of-Use rate schedule (TOU) and refrain from pumping during “peak” hours. (Peak hours are usually from about noon to 6:00 PM, Monday through Friday, during summer months, the time when maximum energy use occurs throughout the state.) This assumes that your operations will allow for 18 to 20 hours of pumping per weekday or less. There are many different types of TOU schedules available.

Another option that is readily available is an interruptible service option. With this type of schedule, the average \( \text{$/kWh} \) is lower than normal because the customer promises to stop using energy when notified of critical energy-supply situations.

Because of recent attempts to deregulate electric utilities in California, rate schedules will probably be changing. Stay aware of the options available to you. Contact your account representative or visit your utility’s web site regularly. Many agricultural organizations (such as California Farm Bureau Federation or the Western Growers Association) also provide information to their members.
I. How the Program Analyzes Pumping Costs

This section discusses how the Program Analyzes Pumping Plant Costs -- Section I introduces several equations that indicate the options for lowering pumping costs. You will see that the four main options for lowering pumping costs are:

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2. Reduce required system pressures.
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Annual energy costs for a water pump used for irrigation can be estimated using Equation 1.1:

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\$/yr = \$/kWh \times kWh/AF \times AF/yr
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Where:
- \(\$/yr\) = annual cost of energy (note that this excludes demand charges)
- \(\$/kWh\) = average cost per kilowatt-hour
- \(kWh/AF\) = average number of kilowatt-hours required to pump an acre-foot of water through the system
- \(AF/yr\) = number of acre-feet pumped each year

Equation 1.1 indicates that to lower annual pumping costs you can lower the unit energy cost, lower the kilowatt-hours required per acre-foot, or reduce the number of acre-feet pumped per year.

Lowering \(\$/kWh\)

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Lowering kWh/AF

Equation I.2 is used to calculate the number of kilowatt-hours required to pump an acre-foot (kWh/AF) of water through a pumping system:

\[ \text{kWh/AF} = 1.0241 \times \frac{\text{TDH}}{\text{OPE}} \]

Where:  
- \( \text{kWh/AF} \) = the number of kilowatt-hours required to pump an acre-foot of water through a pumping system  
- 1.0241 = a constant  
- \( \text{TDH} \) = total dynamic head in the pumping system; this is the total pressure developed by the system  
- \( \text{OPE} \) = the overall pumping plant efficiency of the system as a decimal (0 - 1.0)

Equation I.2 indicates that to lower kWh/AF one would try to either lower the required system pressure (reduce TDH) or increase the pumping plant efficiency (increase OPE).

Lowering AF/year

Equation I.3 is one method of estimating the number of acre-feet required to irrigate a field annually:

\[ \text{AF/yr} = \text{CL} + \left( \text{Ac} \times \frac{\text{ETc} - \text{RAINeff}}{(1 - \text{LR}) \times \text{IE}} \right) \]

Where:  
- \( \text{AF/yr} \) = number of acre-feet required to irrigate a field annually  
- \( \text{CL} \) = annual losses to move water to the field in acre-feet  
- \( \text{Ac} \) = number of acres in the field  
- \( \text{ETc} \) = annual net crop water use in acre-feet/acre  
- \( \text{RAINeff} \) = annual rainfall that is effective in satisfying crop water use in acre-feet/acre  
- \( \text{LR} \) = required leaching ratio (0 - 1.0) to maintain a salinity balance in the crop root zone  
- \( \text{IE} \) = irrigation efficiency in the field as a decimal (0 - 1.0)

Any one of the variables in Equation I.3 can be changed in order to reduce AF/yr. The APEP is most interested in increasing the irrigation efficiency (IE), that is, improving the management of the system. The third and fourth components of the APEP’s education message address management. The best hardware in the world is of no use if it is not managed correctly.
Summary

The discussion in Section I identifies four options for reducing energy costs:

1. **Reduce the unit cost of energy.** Things to look for are:
   a. Make sure you are on the most appropriate rate schedule.
   b. If not on a time-of-use rate schedule, investigate the possibilities.
   c. Keep track of changes occurring in the energy industry that may provide opportunities, including voluntary interruptible schedules and real-time pricing meters.

2. **Reduce the system pressure.** Some options are:
   a. When installing new systems, check with the designer to make sure that required system pressures are minimized. Make sure appropriate pipe sizes are used and that use of throttling valves is avoided or minimized. Investigate the use of low-pressure sprinkler nozzles rather than standard smooth-bore nozzles for field sprinkler systems.
   b. If you are currently using a pressurized system, have a qualified engineer or technician audit the system to check for opportunities to lower required pressure.
   c. If you have a water well, check with your local well driller or pump company for potential problems with the well itself that might result in excessive drawdowns.
   d. Utilize the best engineering and construction methods you can when constructing new wells.

3. **Improve the overall pumping plant efficiency.**
   As discussed later in this book, make sure you know the factors involved in specifying an efficient pump. Have periodic pump efficiency tests performed to identify potential problems.

4. **Improve the management of the system.**
   Make sure you are using appropriate water management practices to maximize irrigation efficiency. Also, use the *Pumping Energy Calculator* supplied with this book, or some other method, to make sure you know how long to run the pump.
II. Why Pumping Efficiency is Important

Very simply, energy costs money. The less energy you use, the lower your pumping costs will be. This section presents an energy cost analysis of an irrigation system before and after improvement. The calculations were done using the equations presented in Section I.

The before situation includes:

- A drip irrigation system utilizing poor irrigation scheduling practices, pressure-regulating valves in the field set incorrectly, and excessive leakage, resulting in a sub-par 70% irrigation efficiency.
- An older water well with encrustation of the perforations, resulting in excessive drawdowns.
- A booster pump that was incorrectly matched to the irrigation system during installation. Not only is this pump producing excessive pressure, but the throttling valves used to produce the desired pressure in the field make the pump operate at a low efficiency.

The improved situation includes fixing system leaks, resetting pressure-regulating valves and improved irrigation scheduling. The well is chemically treated and swabbed to reduce encrustation and results in lowered drawdown. Finally, the impeller of the booster pump is trimmed to match the operating condition to the requirements of the irrigation system. This reduces the TDH in the pumping system, as well as improves overall pumping plant efficiency. This all results in an improved irrigation efficiency of 83%.

Note: All examples in this section use a kWh cost of $.125.

The following illustrate the before and after savings in water, energy and dollars.

### II.1 Improved Irrigation Efficiency = Reduced Pumping Requirements

The comparison below indicates how improving the pumping system management, in this case irrigation efficiency, can result in reduced pumping requirements. Remember, the less water that needs to be pumped, the less energy used.

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF/yr = CL + (Ac x ((ETc - RainEff)/(1 - LR) x IrrEff)</td>
<td>AF/yr = CL + (Ac x ((ETc - RainEff)/(1 - LR) x IrrEff)</td>
</tr>
<tr>
<td>Where:</td>
<td>Where:</td>
</tr>
<tr>
<td>CL = 10 acre-feet/yr</td>
<td>CL = 10 acre-feet/yr</td>
</tr>
<tr>
<td>AC = 100 acres</td>
<td>AC = 100 acres</td>
</tr>
<tr>
<td>ETc = 3 acre-feet/acre</td>
<td>ETc = 3 acre-feet/acre</td>
</tr>
<tr>
<td>RainEff = .8 acre-feet/acre</td>
<td>RainEff = .8 acre-feet/acre</td>
</tr>
<tr>
<td>LR = .05</td>
<td>LR = .05</td>
</tr>
<tr>
<td>IrrEff = 70% Irrigation Efficiency</td>
<td>IrrEff = 83% Irrigation Efficiency</td>
</tr>
<tr>
<td>AF/yr = 10 + (100 x ((3 - .8)/(1 - .05) x .7)</td>
<td>AF/yr = 10 + (100 x ((3 - .8)/(1 - .05) x .83)</td>
</tr>
<tr>
<td>AF/yr = 340.82 (Approximately 341)</td>
<td>AF/yr = 289</td>
</tr>
</tbody>
</table>

Improving both the efficiency of the pumping system and its management indicates a savings of 24,850 kWh per year energy and $3,106.25 in energy costs.

The comparison below indicates the overall energy use and cost reductions that occur due to the improvements in hardware and management discussed previously.

### II.3 Improved System Hardware and Management = Lower Energy Use and Costs

Where: Where:

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>kWh/yr = AF/yr x kWh/AF</td>
<td>kWh/yr = AF/yr x kWh/AF</td>
</tr>
<tr>
<td>Where:</td>
<td>Where:</td>
</tr>
<tr>
<td>kWh/yr = 340.82 x .125</td>
<td>kWh/yr = 289 x .125</td>
</tr>
<tr>
<td>kWh/yr = 43,350 kWh/yr</td>
<td>kWh/yr = 35,625 kWh/yr</td>
</tr>
<tr>
<td>$/yr = kWh/yr x $/kWh</td>
<td>$/yr = kWh/yr x $/kWh</td>
</tr>
<tr>
<td>$/yr = 5,418.75</td>
<td>$/yr = 4,453.19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF/yr = 341</td>
<td>AF/yr = 289</td>
</tr>
<tr>
<td>kWh/AF = 260</td>
<td>kWh/AF = 200</td>
</tr>
<tr>
<td>kWh/yr = 68,200 kWh/yr</td>
<td>kWh/yr = 56,600 kWh/yr</td>
</tr>
<tr>
<td>$/yr = AF/yr x $/kWh</td>
<td>$/yr = AF/yr x $/kWh</td>
</tr>
<tr>
<td>$/yr = 8,525.00</td>
<td>$/yr = 7,050.00</td>
</tr>
</tbody>
</table>

Improving both the efficiency of the pumping system and its management indicates a savings of 24,850 kWh per year energy and $3,106.25 in energy costs.
II.2 Improved Pumping Plant Efficiency = Lower Overall Energy Requirements

The comparison below shows how improving the overall pumping plant efficiency results in reduced energy use overall. The kilowatt-hours required to pump an acre-foot are reduced, so total energy use will be reduced for any amount of water pumped. Also note the increase in flow rate.

---

**Before**

\[
\text{kWh/AF} = 1.0241 \times \frac{\text{TDH}}{\text{OPE}}
\]

Where:

- \( \text{TDH} = 96 \text{ feet} \)
- \( \text{OPE} = 49\% \)
- \( \text{gpm} = 1000 \)

\[
\text{kWh/AF} = 1.0241 \times 96 / 49
\]

\[
\text{kWh/AF} = 200.64
\]

---

**After**

\[
\text{kWh/AF} = 1.0241 \times \frac{\text{TDH}}{\text{OPE}}
\]

Where:

- \( \text{TDH} = 88 \text{ feet} \)
- \( \text{OPE} = 60\% \)
- \( \text{gpm} = 1350 \)

\[
\text{kWh/AF} = 1.0241 \times 88 / 60
\]

\[
\text{kWh/AF} = 150.20
\]

---

II.3 Improved System Hardware and Management = Lower Energy Use and Costs

The comparison below indicates the overall energy use and cost reductions that occur due to the improvements in hardware and management discussed previously.

---

**Before**

\[
\text{kWh/yr} = \text{AF/yr} \times \text{kWh/AF}
\]

Where:

- \( \text{AF/yr} = 341 \)
- \( \text{kWh/AF} = 260 \)
- \( \text{kWh/yr} = 341 \times 200 \)
- \( \text{kWh/yr} = 68,200 \text{ kWh/yr} \)

and

\[
\text{$/yr} = \text{kWh/yr} \times \text{$/kWh}
\]

where

- \( \text{kWh/yr} = 68,200 \)
- \( \text{$/kWh} = .125 \)
- \( \text{$/yr} = .125 \times 68,200 \)
- \( \text{$/yr} = 8,525.00 \)

---

**After**

\[
\text{kWh/yr} = \text{AF/yr} \times \text{kWh/AF}
\]

Where:

- \( \text{AF/yr} = 289 \)
- \( \text{kWh/AF} = 150 \)
- \( \text{kWh/yr} = 289 \times 150 \)
- \( \text{kWh/yr} = 43,350 \text{ kWh/yr} \)

and

\[
\text{$/yr} = \text{kWh/yr} \times \text{$/kWh}
\]

where

- \( \text{kWh/yr} = 43,350 \)
- \( \text{$/kWh} = .125 \)
- \( \text{$/yr} = .125 \times 43,350 \)
- \( \text{$/yr} = 5,418.75 \)

---

Improving both the efficiency of the pumping system and its management indicates a savings of 24,850 kWh per year energy and $3,106.25 in energy costs.
III. Why Management of Pumping Systems is Important

This section discusses why changes to hardware may not be enough. Management of the system is all-important. Two comparisons are briefly examined:

III.1 Management does not take advantage of the changes to system hardware to reduce the amount of water pumped.

III.2 Management does not take advantage of the changes to pumping hardware and operates the pump for the same amount of hours.

III.1 Same Amount of Water is Pumped After Improvements

The comparison assumes that the same amount of water is pumped, even after the improvements to the irrigation system. That is although the potential irrigation efficiency is 83%, requiring only 289 acre-feet of water, the pump is still run to supply 341 acre-feet.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>kWh/yr = AF/yr x kWh/AF</td>
<td>kWh/yr = AF/yr x kWh/AF</td>
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<tr>
<td>Where:</td>
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<tr>
<td>AF/yr</td>
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<td>341</td>
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<tr>
<td>kWh/AF</td>
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<tr>
<td>kWh/yr</td>
<td>68,200</td>
<td>51,150</td>
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<td>and</td>
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<tr>
<td>$/yr</td>
<td>kWh/yr x $/kWh</td>
<td>kWh/yr x $/kWh</td>
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<td>kWh/yr</td>
<td>68,200</td>
<td>51,150</td>
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<tr>
<td>$/kWh</td>
<td>.125</td>
<td>.125</td>
</tr>
<tr>
<td>$/yr</td>
<td>.125 x 68,200</td>
<td>.125 x 51,150</td>
</tr>
<tr>
<td>$/yr</td>
<td>$8,525.00</td>
<td>$6,393.75</td>
</tr>
</tbody>
</table>

In this form of mismanagement, the savings are only 17,050 kWh per year (instead of the possible 24,850 kWh per year) and $2,131.25 per year (instead of the possible $3,106.25).
III.2 Pump Ran for Same Amount of Time After Improvements

In certain situations pumping plants are managed in terms of time. Due to labor constraints, or possibly the rules and regulations of a water district, pumps may be operated in blocks of 12 or 24 hours only. Assume that management repairs both the irrigation system and the pumping system, but continues to operate the pump for the same amount of hours.

Before the repair it would take 1,852 hours of pump operation at 1,000 gpm to pump 341 acre-feet. After the repair, running the pump for 1,852 hours at 1,350 gpm would supply 460 acre-feet.

### Before

<table>
<thead>
<tr>
<th>kWh/yr = AF/yr x kWh/AF</th>
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</thead>
<tbody>
<tr>
<td>Where:</td>
</tr>
<tr>
<td>AF/yr = 341</td>
</tr>
<tr>
<td>Flow = 1,000 gpm</td>
</tr>
<tr>
<td>Hours of Operation = 1,852</td>
</tr>
<tr>
<td>kWh/yr = 341 x 200</td>
</tr>
<tr>
<td>kWh/yr = 68,200 kWh/yr</td>
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</tbody>
</table>

**And**

<table>
<thead>
<tr>
<th>$/yr = kWh/yr x $/kWh</th>
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<tbody>
<tr>
<td>kWh/yr = 68,200</td>
</tr>
<tr>
<td>$/kWh = .125</td>
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<tr>
<td>$/yr = $8,525.00</td>
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### After

<table>
<thead>
<tr>
<th>kWh/yr = AF/yr x kWh/AF</th>
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<tbody>
<tr>
<td>Where:</td>
</tr>
<tr>
<td>AF/yr = 460</td>
</tr>
<tr>
<td>Flow = 1,350 gpm</td>
</tr>
<tr>
<td>Hours of Operation = 1,852</td>
</tr>
<tr>
<td>kWh/yr = 460 x 150</td>
</tr>
<tr>
<td>kWh/yr = 69,000 kWh/yr</td>
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**And**

<table>
<thead>
<tr>
<th>$/yr = kWh/yr x $/kWh</th>
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<tr>
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</tr>
<tr>
<td>$/kWh = .125</td>
</tr>
<tr>
<td>$/yr = $8,625.00</td>
</tr>
</tbody>
</table>

In this form of mismanagement, the operator actually uses more energy than before and increases the power bill. Also note that this form of mismanagement negates any improvements to the irrigation system.

**IMPORTANT!**

In some cases, a repaired pump may actually increase the power bill, even with the correct amount of pumping hours. This can occur if the pump is in a water well and the increased flow rate results in a greatly increased drawdown (increased TDH) that offsets the improvement in efficiency and flow rate. As will be discussed in Section V, it is important to have pump efficiency tests so that objective information is used to determine if a repair will be profitable.
IV. Know How to Specify an Efficient Pump

This section will introduce you to some of the basic concepts involved in specifying pumps. You will learn about:

1. The pump performance curve.
2. The operating condition.
3. Overall pumping plant efficiency and its three components: power plant efficiency, transmission efficiency, and bowl efficiency.
4. The advantages and disadvantages of being able to vary the pump rpm using either an internal combustion engine or a variable frequency motor controller.

You will see that the keys to specifying an efficient pump are to identify the required operating condition or conditions and then use published pump performance curves to match the pump to those conditions. However, the operating condition may be stable, as with a booster pump supplying a well-designed drip irrigation system, or variable, as with a water well with a widely fluctuating water table. Again however, the key is in recognizing the condition, or the required range of conditions, and choosing the best match for the required condition(s).

The purpose of this section is not to train you to be a pump designer; rather it is to introduce the basic concepts of pump specifications so you know what questions to ask a pumping plant designer.

Definition of Concepts and Terms

This section introduces some concepts and terms that help specify an efficient pump. Among these concepts are:

- **The basic horsepower equation** - this equation determines how much horsepower is needed for pumping.
- **Input horsepower** - the horsepower input to a pumping plant in the form of electricity, diesel fuel, or natural gas (propane).
- **Water horsepower** - the combination of water flow and total dynamic head developed by the pumping plant.
- **Total dynamic head (TDH)** - the total amount of head (another term for pumping pressure) developed by the pump. Note that 2.31 feet of head equals 1 pound-per-square-inch (1 psi) pressure.
- **The operating condition** - the combination of flow and pressure (total dynamic head) developed by the pump.
- **The pump performance curve** - a graph showing the different combinations of flow rate and total dynamic head available from a pump.
- **Overall pumping plant efficiency (OPE)** - a measure of how much water horsepower is produced by the pumping plant from the input horsepower. It is the combination of three efficiencies:
  - **Bowl efficiency** - the efficiency of the pump itself.
  - **Driver efficiency** - the efficiency of the electric motor or engine.
  - **Transmission efficiency** - a measure of losses that occur in transmission shafts, chains, pulleys, and v-belts.
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   Transmission efficiency - a measure of losses that occur in transmission shafts, chains, pulleys, and v-belts.
The Pumping Plant as an Energy Converter

Agricultural water pumping plants are energy converters. This conversion is a two-step process:

1. The power source of the pumping plant takes electrical energy or the energy embedded in a fossil fuel (diesel, natural gas, gasoline, propane) and converts it to mechanical energy. This is most commonly rotating (i.e. turbine water pumps) or reciprocating (i.e. fertilizer injectors) energy.

2. The pump itself takes the mechanical energy and turns it into fluid energy - moving water at a certain flow rate and pressure.

The major concern is how efficient the pumping plant is in converting the input energy to fluid energy.

The Basic Horsepower Equation

The reason for this concern is found in the equation that relates horsepower to water flow rate and total dynamic head (pumping pressure when the pump is operating).

\[ HP_{in} = \frac{\text{Flow} \times \text{TDH}}{39.60 \times \text{OPE}} \]

Where:
- \( HP_{in} \) = required input horsepower
- \( \text{Flow} \) = pump flow rate in gallons per minute
- \( \text{TDH} \) = total dynamic head in feet of water head (ft)
- \( 39.60 \) = a constant
- \( \text{OPE} \) = overall pumping plant efficiency

Example:

\[
\begin{align*}
\text{Flow} &= 1,000 \text{ gpm} \\
\text{TDH} &= 50 \text{ feet} \\
\text{OPE} &= 65\% \\
\end{align*}
\]

The required input horsepower is:

\[
\begin{align*}
HP_{in} &= \frac{\text{Flow} \times \text{TDH}}{39.60 \times \text{OPE}} \\
&= \frac{1,000 \times 50}{39.60 \times 65} \\
&= 19.4 \text{ HP}
\end{align*}
\]

Thus, if a pumping plant has an overall pumping efficiency of 65% it will require 19.4 horsepower input to the plant to pump 1,000 gallons per minute at 50 feet of head.

It stands to reason that the higher the OPE, the lower the required input horsepower. The more efficient the pumping plant, the lower your energy bill.
The Operating Condition - the Combination of Flow Rate and Total Dynamic Head

As Equation IV.1 indicates, input horsepower depends in part on the combination of flow and pressure developed (Flow x TDH). Operating condition is the special term used for the combination of flow and pressure (total dynamic head).

If you are asked, "What is the pump’s operating condition?" the engineer wants to know what combination of flow and pressure is being (or needs to be) developed.

The Pump Performance Curve

Turbine pumps can operate over a range of conditions. Pump manufacturers know this and publish pump performance curves.

The pump performance curve is a graphical depiction of the range of operating conditions in which a particular pump can deliver. Figure IV.1 is an example of such a curve.

![Total Dynamic Head/Flow Chart](image)

**FIGURE IV.1** - Simple pump performance curve showing relation between pump flow (gpm) and Total Dynamic Head (TDH) measured in feet.

Bowl Efficiency and Why it Varies

Given that pumps can operate over a wide range of operating conditions, why would one pump be chosen over another? The answer lies in the bowl efficiency. As previously noted, pumping plants are energy converters. The power plant (either an electric motor or internal combustion engine) converts electrical energy (or the energy contained in diesel, natural gas, propane, or gasoline) into rotating mechanical energy. The pump then converts this mechanical energy into moving water at a certain pressure.

Just as the power plant has a certain efficiency in converting the electric or fuel energy to mechanical energy, the pump has a certain efficiency in converting the mechanical energy to moving water. This efficiency is termed bowl efficiency.
The bowl efficiency varies over the range of operating conditions due to the physics of how water moves through the pump. As the flow rate through a pump changes, losses due to friction and turbulence also change.

Pump manufacturers supply this information on a pump performance curve. Figure IV.2 is an example of a complete pump performance curve.

**FIGURE IV.2** - Published pump performance curve with bowl efficiency, required pump input power and required net positive suction head.

The lines in Figure IV.2 are explained as follows:

- The green lines indicate the Head-Flow Rate Curve, showing the range of operating conditions the pump will operate within. Note that four curves are given depending on the diameter of the impeller (4.50” - 5.25”). The diameter of the impeller is called trim.
- The red lines indicate the bowl efficiency at any operating condition.
- The blue lines indicate the brake horsepower required at the pump for any one operating condition. The four lines correspond to the four impeller diameters.
- The brown line indicates the Net Positive Suction Head (NPSH) that is required at each pump flow.

**IMPORTANT!**

Net Positive Suction Head (NPSH) is a very important factor in the actual engineering design and installation of the pumping plant. Insufficient NPSH can result in cavitation, which occurs when a vacuum is formed in the pump bowl. Air bubbles are created that implode (collapse) violently against the impeller making a loud rumbling noise. This can cause pitting of your impeller, decreasing efficiency and can lead to pump failure.
**Keys to Specifying an Efficient Pump**

The keys to specifying an efficient pump are:

1. Knowing the required operating condition or conditions.
2. Choosing a pump that runs at the highest efficiency at those conditions.

For example, you would probably not choose the pump shown in *Figure IV.2* if you had to pump 100 gallons per minute at 32 feet of head. Note that it only runs at 60% bowl efficiency (Point A) at this condition. However, you might choose this pump if your required condition was 250 gpm at 28 feet. Then the bowl efficiency is a very good 80% (Point B).

**Specifying a Stable Operating Condition**

Required operating conditions can be stable or vary throughout a season or for longer periods of time. An example of a predictable and stable operating condition would be a booster pump, drawing from a reservoir, supplying a well-engineered sprinkler system.

The key aspect of a stable operating condition is to make sure that all pressure requirements are identified correctly. *Figure IV.3* is a schematic of a stable operating condition situation.

Note the components of the total dynamic head shown in *Figure IV.3*:

1. Suction pipe friction - loss of pressure as the water moves through the suction pipe.
2. Suction lift - the distance water has to be lifted to the pump.
3. Screen losses - there will be a drop in pressure as the water moves through the inlet strainer.
4. Discharge pipe friction - there will be a pressure loss as water moves through the pipe on the discharge side.
5. Elevation lift - water has to be lifted to a higher elevation.
6. Operating pressure - there is a certain amount of pressure required to run the irrigation system efficiently.

*FIGURE IV.3 - Schematic of a stable operating condition*
What to Do with a Variable Operating Condition

An example of a widely varying operating condition would be a water well with a pumping water level that fluctuates depending on the time of year. Usually it will be lower in the summer when it, and any surrounding wells, are pumping the most. The problem could be compounded in the situation where the well might be supplying a flood irrigation system one day, and then a booster pump for a portable sprinkler system the next.

Pumping plant designers recognize seasonal fluctuations. A common solution is to choose a pump that operates “to the right” of optimum efficiency during the early part of a season. As the water table drops (with a concurrent increase in required total dynamic head), the pump operating condition moves into the optimum efficiency. An example of this is seen in Figure IV.4.

The pump is chosen so that it operates at Point A during the early part of a season. Note that it is only producing about 45 feet of total dynamic head, but 1,700 gpm. As the water table drops, and the total dynamic head requirements increase, the operating condition will move up to Point B. Now the pump is providing the required increase in total dynamic head, 65 feet, but flow is only 1,200 gpm - enough to sufficiently water the crop during the hottest part of the growing season. Note that the pump is operating near its maximum efficiency at Point B, at the time of peak pumping.

Designers also do this to compensate for predicted pump wear. As the impeller wears, the pump will not operate along its original pump performance curve. Point C on Figure IV.4 might be the operating condition in the middle of summer after several years of use. The required 65 feet of TDH is still being supplied and it is hoped the approximate 1,000 gpm is still enough to irrigate the crop.
Basic Impeller Types

Three basic impeller designs used in agriculture turbine water pumps are:

- **Axial Flow** (open impeller)
- **Radial Flow** (closed impeller)
- **Mixed Flow** (semi-open or semi-closed impeller)

Each of these impeller types provides a certain range of operating conditions. The impeller type is chosen based on the required operating condition.

An axial flow pump (open impeller) is much like the propeller on a speed boat. Water moves generally in a straight line through the pump. Axial flow pumps provide very high flows but at relatively low pressures. In agriculture these impellers often are used in canal lift pumps.

In contrast, water flow through a closed impeller takes a 90 degree turn. This is the type of impeller used in the horizontal centrifugal pump and many deep wells. These impellers produce relatively high pressures but lower flows. Radial flow impellers are most often used for booster pumps.

The third type is called a mixed flow or semi-open impeller. In this type of pump, water travels or flows through and out the impeller at some angle less than 90 degrees. The water flow is constrained on one side by the impeller and on the other by the bowl.

**IMPORTANT!**

The mixed flow impeller is the one type of pump where pump adjustments can make large differences in efficiency. This is because as water flows through the pump, one side of the water is constrained by the bowl. The clearance between the impeller and the bowl can be adjusted to increase efficiency. This should only be attempted by an irrigation pump professional.
Power Source Options

Remember that the overall pumping efficiency is a combination of three efficiencies. Not only must we consider the bowl efficiency but also the transmission efficiency and the efficiency of the power plant itself.

The two main options for the power plant are the electric motor and the internal combustion engine. There are advantages and disadvantages to each. The main factor in the decision for many people is the cost of the energy, either electricity, diesel, or natural gas. However, one should consider the initial cost of installation, reliability, serviceability, availability, service charges, environmental regulations, required maintenance over time, and government regulations. Also note that the costs for any fuel can vary greatly over time and fluctuate quickly.

### ELECTRIC MOTOR:

**Advantages:**
- High reliability
- Low maintenance
- High efficiency (85-95%)
- Few government regulations
- Simple equipment to operate

**Disadvantages:**
- Must be repaired by professional pump company
- Not flexible or mobile
- Possible blackouts and brownouts
- Safety issues with high voltage
- Stand-by charges when not in use

### INTERNAL COMBUSTION ENGINE:

**Advantages:**
- Can be maintained by farmer
- Flexible and mobile
- Currently cheaper energy costs

**Disadvantages:**
- Less reliable than electric motor
- Requires more maintenance
- Increasing government regulations (air quality)
- Less efficient
- Price fluctuations

Submersible-type motors are a type of electric motor option with additional advantages and disadvantages. These motors are used mainly in water wells. The motor is attached to the pump and both are submerged. They do not require long transmission shafts, as with the normal vertical turbine, since the power source is at the pump. Thus, transmission efficiency is higher. They also minimize above-ground hardware, which may be an aesthetic or security concern. And, in crooked wells, they may be mandatory.

Submersible motors may have added energy losses due to long cable lengths from the ground surface to the motor. They are by nature, less efficient than normal line-shaft motor designs.

Make sure that you do a valid lifetime cost analysis when choosing between a submersible and a standard line-shaft pumping plant.
Varying Pump Speeds - Engine Versus the Variable Frequency Drive

Varying the rotational speed of a pump changes the performance curve. This may help you supply variable operating conditions with less required energy as shown in Figure IV.5.

![Figure IV.5 - Pump performance curves for a pump operating at different speeds.](image)

At Point A, operating at 1,350 rpm, the pump will supply 80 feet of head at 3,000 gpm of flow. At Point B, 900 rpm, it will only supply 30 feet of head at 3,000 gpm of flow. The efficiency of the pump at Point A is 80% and at Point B, it is at 83%. Even though one of the operating conditions (in this case head) has changed, the efficiency remains relatively high.

The above example shows how varying pump speeds can aid a grower with different field elevations from set to set. In this situation, the farmer needs constant flow, but the head (pressure) condition changes depending on different elevations of each individual set.

Let’s consider another example of what operating conditions might need to be met. Assume a vegetable grower has different acreage requirements for a pressurized system throughout the season. In May, there are 160 acres requiring 4,000 gpm at 65 feet of head (Point C). However, in July, there are only 120 acres requiring 2,500 gpm at 65 feet of head - same sprinkler system, just a different set size (Point D).

Varying the pump speed from approximately 1,350 rpm to 1,200 rpm will result in the new operating condition requirements, but pump efficiency again remains relatively constant, from 83% efficiency (Point C) to 77% efficiency (Point D). A throttling valve at the pump could be used to reduce the flow from 4,000 gpm to 2,500 gpm and maintain 65 feet of head in the field. However, this would greatly increase the head at the pump, lower the pump’s efficiency and therefore cost more money to run the system.

As noted in the section above, one of the advantages of an internal combustion engine is its ability to vary pump speeds. Using a Variable Frequency Drive (VFD or adjustable speed drive) can do the same thing for electric motors. A VFD changes the frequency of the electric current, which in turn varies the speed of the motor.
The decision to use a VFD should be based on economics. Is the cost of the VFD offset by the savings in energy? This depends on your ability to correctly identify the load profile of your pumping plant. The load profile describes the various required operating conditions and the percentage of time that the pump operates at those conditions. Table IV.1 is an example load profile.

Given a load profile and other energy and operating cost data, VFD manufacturers and suppliers can estimate energy and cost savings, thus identifying the economics of any situation.

There are limits to the amount of speed variance available with a VFD. And in either case, an electric motor or an internal combustion engine, efficiency varies with varying speed and load.

A VFD is best used where there is a consistent requirement for widely varying operating conditions. Common situations are:

- Milking systems for cows
- Municipal water systems
- Golf course systems
- Elevation changes from one set to another

Another important factor to consider when installing a VFD is power quality. VFD’s are sensitive to transient voltages, either due to the servicing utility or switching of other loads on the same supply line. Also, harmonic currents caused by the VFD can produce additional heating in electric motors.

**Always consult an expert before deciding to install a VFD.**

### In Summary

The first part of the Program’s educational message is to know how to specify an efficient pump.

There is no single “most efficient pump” for all conditions. Specifying an efficient pump depends largely on correctly identifying the required operating conditions (the required combination of flow rate and pressure). Also important is recognizing when the required operating conditions are likely to change.

However, recognize that the overall pumping plant efficiency depends on three factors:

1. **Power plant efficiency** - how efficient the electric motor or engine is in using input energy (either electricity or liquid fuel).
2. **Transmission efficiency** - losses in drive shafts or v-belts, bearings, etc.
3. **Bowl efficiency** - the efficiency of the pump itself in converting brake horsepower to water horsepower.

There are also many other aspects to consider since the prime goal is lowest (lifetime) cost, such as:

- First cost vs. operating costs
- Reliability
- Serviceability (fast response from supplier)
- Other factors (required payback, borrowing capacity, experience, etc.)

<table>
<thead>
<tr>
<th>Required Operating Condition</th>
<th>Flow Rate</th>
<th>Total Dynamic Head</th>
<th>Percent of Time Operating at This Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate</td>
<td>GPM</td>
<td>Feet</td>
<td>%</td>
</tr>
<tr>
<td>1400</td>
<td>150</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>1100</td>
<td>120</td>
<td></td>
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<tr>
<td>800</td>
<td>95</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>650</td>
<td>75</td>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

**TABLE IV.1 - Example load profile for a pumping plant.**
V. Know How to Maintain an Efficient Pump

There are at least four important aspects of maintaining an efficient pumping plant:

1. Initial specification and installation of the pumping plant.
2. Ensuring that standard ("janitorial") maintenance procedures necessary to keep machinery running are employed.
3. Knowing if the pump’s operating conditions have changed.
4. Knowing if the required operating conditions have changed.

The first and second aspects are not discussed here. It is assumed that an efficient pump was specified and installed correctly initially and the pump owner has received proper maintenance instructions and guidance from his or her pump installer. Further, it is assumed that these maintenance procedures are known and are being followed (i.e. maintaining oil levels in oil cans, correct packing installation and adjustment, periodic inspections of electrical panels).

The Program is most interested in the last two aspects listed above: knowing if the pump’s operating condition has changed and knowing whether the required operating conditions have changed. The former is concerned with the physical condition of the pump, especially wear of the impellers or bowls. The latter is concerned with whether the pumping requirements have changed. For example, has there been a change in the irrigation system that requires more or less flow or pressure? If the pump is in a water well, has there been a systematic change in the water table over time? Either of these situations may be identified through the pump efficiency test. This section discusses pump efficiency tests and how you can utilize them to help maintain an efficient plant in the field.

The APEP provides subsidized pump efficiency tests to pump owners through participating pump test companies. A listing of these companies is contained on the web site (www.pumpefficiency.org) or you can call any of the offices to locate a pump tester near you.

Pump Efficiency Tests

What is a Pump Test?

A pump test measures various aspects of the pump’s operation. The end result of a pump test is an estimate of the overall efficiency of your pump and the cost of running it under the conditions of the test. The test also may give an indication of water well performance.

Who Does the Pump Testing?

Pump tests may be available from:

• Public utilities - using either their own employees or contract testers.
• Pump dealers - using their own employees or contract testers.
• Independent pump test companies - many of these testers have a public utility background.
What Does a Pump Tester Measure?
The tester measures at least four variables:
1. Water flow rate;
2. Pumping lift (or inlet pressure);
3. Pump discharge pressure; and
4. Energy input to the pumping plant.
Calculations are performed with the flow, lift, and pressure measurements and the results are compared to the energy input. A sample pump test report and an explanation of what it measures and calculates can be found on pages 2.14 - 2.15.

Why Should I Test My Pump?
Regular pump testing can identify problems before a breakdown occurs or before energy bills climb. This allows you to perform an objective economic analysis to identify when it can be profitable to invest in a retrofit or repair. On a new pump, a test will establish a baseline of performance and verify that equipment is operating as designed. A typical analysis of pumping costs derived from a test, along with explanations of the variables used in the calculations, is shown on page 2.16 - 2.17.

How Do I Prepare for a Pump Test?
Check with your pump tester about how to prepare for a pump test. Some testers use flow measurement equipment that requires an access hole in the pump discharge pipe. Generally, the pump needs to be off in order to cut the hole and insert the device. Some measurement devices do not require this provision.
The pump must be running during the test and there must be some place for the pumped water to go. If the pump is in a water well, the tester will need to run the pump for 15-60 minutes to stabilize the pumping water level.
The pump tester also will need information regarding the pump’s management and design in order to do a complete cost analysis. Key information will include:
• annual acre-feet pumped (or hours of operation);
• average cost of energy for the year ($/kWh or $/therm);
• intended operating condition;
• required flow rate; and
• required discharge pressure of the pump.
If a water well is running when the tester arrives, the tester will want to shut it off and measure the “recovered water level” of the well. This is valuable information for you that indicates current well performance.

Can Two Pumps Be Tested Together?
Pumping plants may be designed with a well pump to lift the water to the surface and a booster pump to supply pressure to the irrigation system. Typically, the well pump is tested first and then the well/booster combination is tested. The booster pump efficiency is determined by subtracting the inlet pressure into the booster. In some cases, amperage and voltage readings for each pump are taken to determine input horsepower.
What is Needed for Accurate Measurements?

Water flow in a pipe can only be accurately determined if the location for flow measurement (known as the test section) is free from turbulence. Ideally, the test section should be a run of straight pipe with lengths 8 - 10 pipe diameters upstream and 2 - 4 pipe diameters downstream of the measurement point that are free of obstructions or turns (as shown in the diagram to the right). In addition, access via a sounding tube or a factory-made hole in the discharge head may be needed to determine standing and pumping water levels in a well.

This schematic shows an ideal test section:

- 8 - 10 pipe diameters upstream
- 2 - 4 pipe diameters downstream, clear of obstructions or turns

(For a 6” diameter pipe this would mean 48” to 60” upstream and 12” to 24” downstream clear.)

What is a Multi-Condition Pump Test?

A pump can operate with a wide variety of flow and pressure outputs. A multi-condition test consists of making the required measurements at several different flow rates. This type of test is useful in situations where the pump design is unknown or where aquifer or discharge conditions have changed substantially.

How Do I Use the Data from a Pump Test?

You should have a copy of your pump’s original pump performance curve. Record the results of each pump test and compare them to that curve and to previous tests. Consult with your pump dealer to determine if a pump adjustment or repair will be profitable.

IMPORTANT!

The pump test results are only valid for the combination (or combinations) of flow and total lift measured. You should attempt to ensure that the test conditions are as close as possible to typical running conditions.

How Often Should I Test My Pump?

A pump should be tested every 1 to 3 years depending on the annual usage and severity of operating conditions. For example, you might want to test a well that is pumping a lot of sand every year. On the other hand, a booster pump supplied by clean water might only be tested once every 2 or 3 years.

How Can I Obtain a Pump Test?

Log on to the Program’s web site or call one of the Program offices to obtain a list of participating pump test companies. You can use any of the companies on this list - just call them to arrange the time of the test. They will handle all of the paperwork and the rebate for the pump test will be paid directly to them.
How to Interpret a Pump Test Report

The results section of an electric-powered pump test report prepared by one of the Program’s participating pump test companies is shown below.

The following explanations can give you a better idea of what is measured and calculated in a pump test:

1. **Standing Water Level** - The water level in the well when a pump has not been running.
2. **Recovered Water Level** - The water level in the well 10 minutes after shutting off the pump.
3. **Draw Down** - The difference between the pumping water level (line 4) and the standing water level (line 1).
4. **Pumping Water Level** - Where the water level in the well stabilizes under constant pumping conditions.
5. **Discharge Pressure at Gauge** - The pressure on the outlet side of the pump.
6. **Total Lift** - Includes the pumping water level, discharge pressure, and any gauge corrections.
7. **Flow Velocity** - How fast the water is moving in the discharge pipe. It should be 1 foot per second or faster to ensure an accurate test.
8. **Measured Flow Rate (gpm)** - The flow rate measured in gallons per minute using the tester’s instruments.
9. **Customer Flow Rate (gpm)** - The flow rate measured with the customer’s flow meter (if one is present).
10. **Well Specific Capacity** - The measured flow rate divided by the draw down (line 8 divided by line 3). It is a measure of well performance, not pump performance.*
11. **Acre-Feet per 24 Hours** - The number of acre-feet pumped in 24 hours at the measured flow rate. One acre-foot of water is equal to 325,851 gallons of water.
12. **Cubic Feet per Second (cfs)** - The measured flow rate expressed as cubic feet of water per second.
13. **Horsepower Input to Motor** - The horsepower input to the motor read at the utility meter.
14. **Percent of Rated Motor Load** - The estimated horsepower output of the motor divided by the name plate horsepower. If this is not between 80% and 115% it is an indication that the motor is not matched to the pumping condition.
15. **Kilowatt Input to Motor** - The power input to the motor in terms of kilowatts. One horsepower is equal to 0.746 kilowatts.
16. **Kilowatt-hours per Acre-Foot** - The amount of kilowatt-hours required to pump an acre-foot of water at the operating condition measured.
17. **Cost to Pump an Acre-Foot** - Kilowatt-hours per acre-foot multiplied by the Base Cost per kWh (line 19).
18. **Energy Cost ($/hour)** - The cost per hour to run the pump at the Base Cost per kWh (line 19).

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**Run Number 1 of 1**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1. Standing Water Level (ft):</td>
<td>43</td>
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<tr>
<td>2. Recovered Water Level (ft):</td>
<td>45</td>
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<tr>
<td>3. Draw Down (ft):</td>
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<td>4. Pumping Water Level (ft):</td>
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<tr>
<td>5. Discharge Pressure at Gauge (psi):</td>
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<td>6. Total Lift (ft):</td>
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<td>7. Flow Velocity (ft/sec):</td>
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<td>8. Measured Flow Rate (gpm):</td>
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<td>9. Customer Flow Rate (gpm):</td>
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<td>10. Well Specific Capacity (gpm/ft):</td>
<td>88</td>
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<td>11. Acre-Feet per 24 Hours:</td>
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<td>12. Cubic Feet per Second (cfs):</td>
<td>0.98</td>
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<td>13. Horsepower Input to Motor:</td>
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<td>14. Percent of Rated Motor Load:</td>
<td>104%</td>
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<td>15. Kilowatt Input to Motor:</td>
<td>17.2</td>
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<td>16. Kilowatt-Hours per Acre-Foot:</td>
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<td>17. Cost to Pump an Acre-Foot:</td>
<td>$22.26</td>
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<tr>
<td>18. Energy Cost ($/Hours):</td>
<td>$1.81</td>
</tr>
<tr>
<td>19. Base Cost per kWh:</td>
<td>$0.105</td>
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<td>20. Name Plate rpm:</td>
<td>1760</td>
</tr>
<tr>
<td>21. Measured rpm:</td>
<td>1755</td>
</tr>
<tr>
<td>22. Overall Plant Efficiency (%):</td>
<td>45.7%</td>
</tr>
</tbody>
</table>

---

*Well-specific capacity is a complex relationship based on the aquifer conditions, well casing diameter, well screen, gravel pack selection, and the initial development. For example, high specific capacity wells in the San Joaquin Valley have specific capacity greater than 10 gpm/ft. Low specific capacity wells can be a problem. Well performance will generally degrade with time. Well screens can corrode or encrust with various deposits that reduce flow openings into the well. Gravel packs can also become clogged and reduce inflow. The water level in the well can rise if you are using too big a pump for the aquifer. This subject is very important to your pumping costs. Consult with your pump dealer and/or well driller if available experts before making the decision to retrofit/repair a pump.
19. **Base Cost per kWh** - The average cost of a kilowatt-hour for this account.

20. **Name Plate rpm** - The rated speed of the motor.

21. **Measured rpm** - The actual rotational speed measured.

22. **Overall Plant Efficiency** - The power output of the pump *(a function of the flow rate and total lift)* divided by the input power.**

* Well-specific capacity is a complex relationship based on the aquifer conditions, well casing diameter, well screen, gravel pack selection, and the initial development. For example, high specific capacity wells in the San Joaquin Valley have specific capacity greater than 100 gpm per foot of draw down. Good wells are between 50 to 100 gpm per foot. Low specific capacity of 5 to 20 gpm per foot may be typical for your area or may indicate a problem. Well performance will generally degrade with time. Well screens can corrode or encrust with various deposits that reduce flow openings into the well. Gravel packs can also experience plugging from fine materials such as silt. Attempting to pump too much water by using too big a pump for the aquifer also results in low well specific capacity. This subject is very important to your pumping costs. Consult with your pump dealer and/or well driller if the pump test history reveals significant reductions in well specific capacity over time.

**Overall plant efficiency can be generally characterized as follows:

- 60% and higher is excellent.
- 50% to 60% is good.
- 49% or less indicates a pump that may need a retrofit, repair, or adjustment. It also may indicate the pump is not matched to the current required operating conditions. An example of this would be where a water table has dropped substantially over time, increasing the total lift above the original specifications.

Pumps with submersible motors will usually run about 10% lower efficiency in each of the categories above. For example 50% or above would be considered excellent for a submersible pump.

**IMPORTANT!**

*These are general characterizations. Always consult with your pump service company and other available experts before making the decision to retrofit/repair a pump.*
Pumping Cost Analysis

Below is an example of the pumping cost analysis section of an electric-powered pump test report prepared by a participating pump test company of the Program.

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Expected Efficiency</th>
<th>Estimated Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall plant efficiency is improved to: 66.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor loaded at: 105%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow rate will be: 540 gpm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Head will be: 117 feet = 49 ft PWL, 29 psi discharge (PWL = pumping water level)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water requirements will be: 122.5 acre-ft/year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Existing Efficiency</th>
<th>Improved Efficiency</th>
<th>Estimated Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. kWh/AF</td>
<td>212</td>
<td>182</td>
<td>31</td>
</tr>
<tr>
<td>7. Estimated Total kWh</td>
<td>25,970</td>
<td>22,242</td>
<td>3,728</td>
</tr>
<tr>
<td>8. Average Cost per kWh</td>
<td>$0.13</td>
<td>$0.13</td>
<td></td>
</tr>
<tr>
<td>9. Average Cost per hour</td>
<td>$3.15</td>
<td>$3.00</td>
<td>$0.15</td>
</tr>
<tr>
<td>10. Average Cost per Acre-Foot</td>
<td>$28.04</td>
<td>$24.98</td>
<td>$3.06</td>
</tr>
<tr>
<td>11. Estimated Acre-Feet Per Year:</td>
<td>123</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>12. Overall Plant Efficiency:</td>
<td>45.7%</td>
<td>66.0%</td>
<td></td>
</tr>
<tr>
<td>13. Estimated Total Annual Cost:</td>
<td>$3,449</td>
<td>$3,073</td>
<td>$376</td>
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</table>

**IMPORTANT!**

The pumping cost analysis presented is only valid for the assumptions listed in lines 1 - 5 and for the conditions measured during the test. One or more of the assumed variables resulting from a pump repair could be in error and the economics presented would be misleading. Use this section only as a guide to the magnitude of potential savings. Always consult with your pump service company and other available experts before making the decision to retrofit/repair a pump.
**Lines 1 - 5:**

Lines 1-5 list the important assumptions regarding the pump performance after any retrofit or repair, including:

1. The improvement expected in Overall Plant Efficiency.
2. Motor loading (this may be greater than 100% if it is currently measured as greater than 100%).
3. Any change in Flow Rate.
4. Any change in Total Lift.
5. Annual water requirements will be assumed to be unchanged.

The software used by participating pump test companies allows for any of these assumptions to be changed as needed. You may want to discuss these assumptions with the tester so that they match your expectations (or the expectations of your pump repair company).

**Lines 6 - 13:**

Lines 6 - 13 are termed the “Before and After” section and list statistics based on the measured condition and the improved condition assumed as a result of a retrofit/repair project.

6. **kWh/AF** - The kilowatt-hours required to pump an acre-foot through the system.
7. **Estimated Total kWh** - The total kilowatt-hours used annually if the hours of operation or total acre-feet pumped per year are known.
8. **Average Cost per kWh** - The average cost per kilowatt-hour as stated by you, or estimated by the tester based on your pump size and rate schedule.
9. **Average Cost per Hour** - The average cost per hour to run the pumping plant.
10. **Average Cost per Acre-Foot** - The average cost to pump an acre-foot of water through the system.
11. **Estimated Acre-Feet per Year** - The estimated acre-feet of water per year pumped through the system.
12. **Overall Plant Efficiency** - The overall pumping plant efficiency (which may be zero in the case where the pumping water level in a well cannot be measured for some reason).
13. **Estimated Total Annual Cost of Energy** - The estimated annual cost of energy may not include demand charges or other surcharges to run the pump. This will be zero if the annual hours of operation or annual acre-feet pumped are not known.

**Important!**

If the annual hours of operation or acre-feet pumped are not known, use line 10 (the average cost per acre-foot) as an indicator of potential energy and dollar savings.

**Summary**

The second part of the Program’s education message is “Know how to maintain an efficient pump.” This goes beyond the obvious correct installation and regular janitorial maintenance aspects. We are most interested in making sure that you know if the required operating conditions have changed or the physical operating condition of the pumping plant has deteriorated. Regular pump efficiency tests can tell you the overall efficiency of your plant as well as indicate if it is a pump condition problem or the required operating condition has changed.
VI. Know How Much Water Needs to be Pumped

Although the Agricultural Pumping Efficiency Program focuses on pumping for irrigation, the message of this component of the educational program can be applied to any pumping system. That is, know how much water needs to be pumped so that pumping operation is minimized. The obvious question is "How do I know how much water needs to be pumped?"

The focus of this section is on planning an individual irrigation. Each irrigation should have a purpose to put a specific amount of water into a specific volume of soil. Section VI provides methods that you can use to estimate how much water is required for the irrigation, which then leads to an estimate of how long to run the pump. The first part of this section introduces some basic concepts of irrigation science. The second part provides simple procedures for planning individual irrigations. The Pumping Energy Calculator that accompanies this book can be used to easily solve the equations in this section.

The Center for Irrigation Technology (managers of APEP) also maintains the WATERIGHT web site (www.wateright.org). This is a web site dedicated to irrigation water management for homeowners, large turf managers, or irrigated agriculture. Included in this site is the ability to develop seasonal irrigation schedules.

Introduction to Irrigation Science

Definition of Concepts and Terms

This section introduces some concepts and terms that can help you to plan an individual irrigation so that you have a target volume of water to be pumped and a target number of hours to pump. Among these concepts will be:

Application rate (AR) - equivalent depth of water applied to a given area per hour by the system, usually measured in inches/hour.

Daily crop water use (evapotranspiration) - this is the net amount of water extracted from the soil daily by the crop and surface evaporation from the soil.

Distribution uniformity (DU) - a measure of how evenly water is applied across the field during an irrigation.

Effective root zone - the depth of soil in which you are actively managing the crop.

Field capacity - the maximum amount of water the soil will hold.

Frequency - refers to how often you irrigate: high frequency vs. low frequency.

Irrigation efficiency (IE) - a measure of how much water that is pumped and applied to the field is beneficially used.

Net water needed versus gross water applied - net water is what you need to replace in the field. Gross water is how much you have to pump in order to accomplish this goal.

Soil moisture depletions (SMD) - the net amount of water that you need to replace in the root zone of the crop.

Soil probe - this is nothing more than a long piece of 3/8” steel bar, usually tipped by a ball bearing, with a handle (see diagram). The probe is pressed into wetted soil to judge how deep water has penetrated. It can be used during an irrigation to indicate when enough water has soaked into the ground. It can also be used to judge the uniformity of an irrigation. If 2-3 days after an irrigation the probe can be pushed into the soil to a depth of 4 feet at the top of a furrow, and only to 2 feet at the bottom of the same furrow, this is an indication of poor distribution uniformity.
Effective, Efficient Irrigations

Irrigation is both an art and a science. Research has provided many concepts and methods for measuring the various processes involved in irrigation. However, your knowledge of your field and crop, along with your experience in interpreting this science, will remain of utmost importance in achieving effective, efficient irrigations.

- **Effective irrigations produce the desired crop response.**
- **Efficient irrigations make the best use of available water.**

Irrigation efficiency does no good if it is not effective in producing a profitable crop.

Effective, efficient irrigations are a result of knowing *when* to irrigate, *how much* to irrigate, and *how* to irrigate.

- **When** - to irrigate is an agronomic decision based on how you want to manipulate your crop.
- **How much** - to irrigate is the *soil moisture depletion* in the effective root zone. This is the amount of water needed to take the soil moisture reservoir back to field capacity or other desired level.
- **How** - to irrigate is not just knowing how to set a siphon, or connect a sprinkler pump. It is also knowing how to apply water evenly to a field while controlling the total amount applied.

Effective, efficient irrigations produce a profitable crop while making the best use of available water supplies and creating a minimal impact on water quality. In doing so they also minimize energy use and save you money.

Distribution Uniformity versus Irrigation Efficiency

There are two measures of irrigation performance - distribution uniformity (DU) and irrigation efficiency (IE).

**Distribution uniformity** is a measure of how evenly water soaks into the ground across a field during the irrigation. If eight inches of water soaks into the ground in one part of the field and only four inches into another part of the field, that is poor distribution uniformity. Distribution uniformity is expressed as a percentage between 0 and 100%. Although 100% DU (*the same amount of water soaking in throughout the field*) is theoretically possible, it is virtually impossible to attain in actual practice.

**Irrigation efficiency** was defined by the American Society of Civil Engineers On-Farm Irrigation Committee in 1978. IE is the ratio of the volume of irrigation water which is beneficially used to the volume of irrigation water applied. Beneficial uses may include crop evapotranspiration, deep percolation needed for leaching for salt control, crop cooling, and as an aid in certain cultural operations. Differences in specific mathematical definitions of IE are due primarily to the physical boundaries of the measurement (*a farm, an irrigation district, an irrigation project, or a watershed*) and whether it is for an individual irrigation or an entire season.

Irrigation efficiency is also expressed as a percentage between 0 and 100%. An IE of 100% is not theoretically attainable due to immediate evaporation losses during irrigations. However, it could easily be close to 95% IE if a crop is under-watered. In this case, assuming no deep percolation, all water applied and not immediately evaporated would be used by the crop.

The term irrigation efficiency should not be confused with the term water use efficiency (WUE). WUE is generally a measure of yield per unit water applied.
Relationships Between DU and IE - There are two important relationships between DU and IE, described with the help of Figures VI.1 - VI.4.

The figures are a profile view of two adjacent sprinklers in a field and the root zone under them. The horizontal, dashed line in the figures depicts the depth of the actual soil water depletion at irrigation. This is the amount of water that the grower would be trying to soak into the soil to satisfy crop water use requirements. The blue shading depicts the actual depth of water infiltrated during the irrigation.

Deep percolation is indicated whenever the actual depth of irrigation (blue water level) is below the soil water depletion line (the horizontal, dashed line). Conversely, under-irrigation is indicated whenever the actual depth of irrigation is above the soil water deficit line.

Figures VI.1 and VI.2 demonstrate the first relationship:

There must be good distribution uniformity before there can be good irrigation efficiency if the crop is to be sufficiently watered.

In Figure VI.1, the farmer has irrigated to sufficiently water the entire field. The poor DU, indicated by the uneven blue water level, has resulted in excessive deep percolation. (Much more water infiltrated between the sprinklers than next to the sprinklers.)

IMPORTANT!

Leaching must be uniform across the field over a number of years to prevent areas of excessive salt accumulation.

FIGURE VI.1 - Depiction of irrigation resulting in poor distribution uniformity and excessive deep percolation.
In Figure VI.2, the farmer has acted to prevent excessive deep percolation by shortening set times. Now part of the field remains under-irrigated. Under-irrigation usually results in high irrigation efficiency because most water applied is stored in the root zone, available for plant use. However, under-irrigation is usually not an effective way of growing since the resulting water stress on the crop in some parts of the field will usually decrease yields. Also, there is a need for some deep percolation for leaching to maintain a salt balance.

Figures VI.3 and VI.4 demonstrate the second relationship:

**Good distribution uniformity is no guarantee of good irrigation efficiency.**

Figure VI.3 depicts a good irrigation. There was a high DU as indicated by the flatter blue water level. Approximately the right amount of water was applied. There is little deep percolation (enough for salt control) and the entire field is wetted sufficiently. It is assumed that surface runoff was minimal or collected for reuse.
To summarize: Improved irrigation system hardware or management may result in higher distribution uniformity and improve the potential for higher irrigation efficiency. It then follows that distribution uniformity is the first concern when improving irrigation system performance. However, actually achieving high irrigation efficiency ultimately depends on two factors - knowing how much water is needed and controlling the amount of water applied to match that need.

**Know (and Improve) the Distribution Uniformity of the Irrigation System**

Remember that the first consideration for effective, efficient irrigations is distribution uniformity. DU can be improved by understanding the different aspects of DU for each system type, then working to improve these parts.

**Furrow and border strip systems**

You need to be concerned about:

1. **Down-row uniformity** - how evenly water infiltrates at the top and at the bottom of a furrow.

2. **Cross-row uniformity** - how evenly water infiltrates from row to row. Be especially aware of the different infiltration rates in rows compacted by tractor tires.

3. **Soil variability** - although there is usually very little that can be done to alleviate the effects of soil variability, be aware of different soil types within a field. Modify your irrigation management whenever possible to compensate for the different infiltration rates.

Generally, with border systems you would only be concerned with the down-row uniformity and soil variability issues.

**Figure VI.4** depicts an irrigation with the same high DU as **Figure VI.3**. However, twice as much water as needed was applied, resulting in low irrigation efficiency. A practical example of this situation is the farmer who is using a well-designed and maintained micro-irrigation system. The hardware provides good DU and the potential for high IE. However, if the farmer runs the system twice as long as necessary, that potential is not realized.
Sprinkler systems
There are three main factors in uniformity:

1. **Pressure uniformity** - Check the pressure throughout the irrigation system. It should not vary more than 10-15% at the nozzles throughout the field. Also make sure the system is operating within the correct base pressure range (minimum to maximum.)

2. **Device uniformity** - Device uniformity means that each sprinkler is emitting the same amount of water. Assuming that the pressure uniformity is okay, check for worn or plugged nozzles and systems with more than one size nozzle or sprinkler head.

3. **Overlap uniformity** - Overlap uniformity is important with field sprinkler systems and depends on the correct choice of sprinkler spacing, pressure, and head/nozzle size. In many areas, wind is the major factor affecting overlap uniformities. Using alternate sets is always a good idea with field sprinkler systems. Also make sure that the risers are high enough so that the crop doesn’t interfere with the stream. Overlap uniformity is not as important with undertree systems since the widespread rooting system of the orchards will compensate.

Micro-irrigation systems
You need to be concerned with pressure uniformity and device uniformity with micro-irrigation systems. Also with trickle systems make sure the filters are kept clean. Use chemical amendments on a regular basis to prevent algae and slime buildup. Keep the system flushed clean.

There should not be excessive surface runoff with sprinkle/trickle/spitter systems. If there is, either the set times are too long or the system was not designed properly. The soil/water chemistry interactions may also have changed. Check for required amendments.

Mobile Irrigation Laboratories
There may be a Mobile Irrigation Laboratory in your area. They can perform irrigation system evaluations. They will measure the distribution uniformity of your system and offer suggestions for improvement. A list of Labs in California and how to contact them is provided in the "Other Tools" section on page 2.30. Another important resource is your local University of California Cooperative Extension office.

Control the Total Irrigation Water Application
Remember, good hardware is only as good as its management. The most uniform drip irrigation system in the world is only 50% efficient if it is run twice as long as needed. Plan your irrigations and know how much water you are trying to apply. Measure water flows to know how much water has been applied and turn off the irrigation system when enough water has been applied.

Be aware of how much flexibility you have in the frequency, flow rate, and duration of your water supplies. Some irrigation districts deliver water in 24-hour increments. In some situations, investing in an on-farm reservoir may be profitable.
High Frequency versus Low Frequency Irrigation Systems

Frequency refers to how often you irrigate. High frequency irrigation systems are utilized every 1 to 3 or 4 days and are typically micro-irrigation systems. The intent is to maintain an optimum soil moisture condition, usually with a high uniformity and efficiency.

On the other hand, low frequency irrigation systems are utilized every 8 to as much as 20-30 days depending on the climate, crop, and soil. These are typically furrow, border strip, or field sprinkler systems.

Another important aspect of high versus low frequency systems is the amount of soil that is wetted. Flood irrigation systems and field sprinkler systems will wet the entire field. High frequency, micro-irrigation systems only wet part of the field.

The frequency of irrigation is important since the method of estimating how much water to apply at each irrigation is different for low versus high frequency systems.

With low frequency irrigation systems usually some method is used to estimate the soil moisture depletion (SMD) in the effective root zone. This is because the SMD is substantial due to the long interval between irrigations. Also, since the entire field is being wetted there is no question as to the extent of the wetted root zone.

However, with a high frequency system, it can be hard to judge the SMD when crop water use is on the order of at most .3 to .35 inches per day. A further complication is that not all of the field is being wetted so there is a question as to the extent of the actual root zone. Thus, with high frequency irrigation systems it is advisable to use estimates of the daily crop water use to plan irrigation system run times and some form of soil moisture monitoring system that tracks changes or trends over time.

Planning The Individual Irrigation

Planning a Furrow or Border Strip Irrigation

The following is a suggested way of planning a furrow, border strip, or any type of low frequency irrigation. Four important steps are:

1. Estimate the soil moisture depletion (SMD)(and required leaching if any) - this is the amount of water you want to put into the soil.

2. Pre-plan the irrigation - a simple equation can indicate how long you need to apply water at a given flow rate. This includes considering irrigation efficiency (the combination of distribution uniformity and losses).

3. React to the first irrigation set - it is often difficult to predict exactly what will happen during a furrow irrigation due to changes in climate, soil surface conditions, and soil moisture conditions.

4. React to the irrigation - check the field after the irrigation to see the actual depth and uniformity of water penetration. Compare the total amount of water pumped to your estimate of what was needed. Learn from any mistakes.

The following is a detailed discussion of these steps.

STEP 1: Estimate the SMD in the Effective Root Zone - Using a soil sampler and the moisture chart (Table VI.1 on page 2.25) is fast, flexible, and inexpensive. Using something like a neutron probe is expensive, less flexible (constrained to the sampling site), but more accurate (at the site - a question is whether the site is representative of the field). You also may want to compare your estimates to estimates of the total crop evapotranspiration (water use) since the last irrigation.
2.24 Agricultural Pumping Efficiency Program

The following is a suggested way of planning a furrow, border strip, or any type of low frequency irrigation system.

**Planning a Furrow or Border Strip Irrigation**

High frequency irrigation systems are expensive, less flexible (compared to low frequency systems), and wet only part of the field.

**High Frequency versus Low Frequency Irrigation Systems**

- **High Frequency**:
  - Only wet part of the field.
  - Frequency refers to how often the irrigation takes place.

- **Low Frequency**:
  - Use for low versus high frequency systems.
  - Frequency is the amount of water you want to put into the soil.

**Frequency**

- **Step 1**: Estimate the soil moisture depletion (SMD) and re-estimate.
- **Step 2**: Pre-plan the irrigation.
- **Step 3**: React to the first irrigation set.
- **Step 4**: React to the irrigation.

**Learn from any mistakes.**

**Estimating soil moisture depletion from the look and feel of a soil sample**

<table>
<thead>
<tr>
<th>Dominant Texture</th>
<th>Available Water Capacity (in/foot)</th>
<th>Available Soil Moisture</th>
<th>Soil Moisture Deficit in inches per foot when the feel and appearance of the soil is as described.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fine Sand and Loamy Fine Sand</strong></td>
<td>0.6 - 1.2</td>
<td>0% to 25%</td>
<td>Dry, will hold together if not disturbed. Loose sand grains on fingers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25% to 50%</td>
<td>Slightly moist, forms weak ball with well-defined finger marks. Light coating of loose and aggregated sand grains on fingers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50% to 75%</td>
<td>Moist, forms a weak ball. Very few aggregated soil grains breaking away. Light water staining.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75% to 100%</td>
<td>Wet, forms a weak ball, loose and aggregated sand grains form uneven coating on finger.</td>
</tr>
<tr>
<td><strong>Sandy Loam and Fine Loamy Sand</strong></td>
<td>1.3 - 1.7</td>
<td>0% to 25%</td>
<td>Dry, forms a very weak ball. Aggregated soil grains break from ball.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25% to 50%</td>
<td>Slightly moist, forms a weak ball with defined finger marks, few aggregated soil grains break away. Darkened color, very light water staining.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50% to 75%</td>
<td>Moist, forms a ball with very few aggregated soil grains breaking away. Light water staining, darkened color.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75% to 100%</td>
<td>Wet, forms a ball, free water appears on soil surface when squeezed or shaken. Irregular soil/water coating on fingers.</td>
</tr>
<tr>
<td><strong>Sandy Clay Loam and Clay</strong></td>
<td>1.5 - 2.1</td>
<td>0% to 25%</td>
<td>Dry, soil aggregations break away easily, no moisture staining on fingers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25% to 50%</td>
<td>Slightly moist, forms a weak ball with rough surfaces, darkened color, and moisture staining on fingers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50% to 75%</td>
<td>Moist, forms firm ball with well defined finger marks, irregular soil/water coating on fingers. Darkened color and pliable.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75% to 100%</td>
<td>Wet, forms soft ball, soil may glisten after squeezing or shaking. Light to heavy soil/water coating on fingers.</td>
</tr>
<tr>
<td><strong>Clay, Clay Loam or Silty Clay Loam</strong></td>
<td>1.6 - 2.4</td>
<td>0% to 25%</td>
<td>Dry, soil aggregations separate easily, hard clods crumble under pressure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25% to 50%</td>
<td>Slightly moist to moist, forms a weak ball. Very few soil aggregations break away, no water stains. Clods flatten under pressure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50% to 75%</td>
<td>Moist, forms smooth ball with defined finger marks, little or no granules remain on fingers. Pliable, ribbons between thumb and forefinger.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75% to 100%</td>
<td>Wet, forms soft ball, soil may glisten following squeezing or shaking. Light to heavy soil/water coating on fingers, easily ribbons.</td>
</tr>
</tbody>
</table>

**TABLE VI.1** - Estimating soil moisture depletion from the look and feel of a soil sample (from USDA, NRCS Booklet “Estimating Soil Moisture by Feel and Appearance”).
STEP 2: Pre-plan the Irrigation - Use Equation VI.1 to estimate how long the pump should run:

\[
\text{Hours} = \frac{\text{SMD} \times \text{Acres} \times 452.2}{\text{Pump Flow} \times \text{IrrEff}}
\]

Where:
- SMD = soil moisture depletion in inches
- Acres = area of field in acres
- 452.2 = a constant
- Pump Flow = pump flow rate in gallons per minute
- IrrEff = irrigation efficiency as a decimal (0 to 1.0)

It’s important to understand that 0 to 1.0 IrrEff is equal to 0% to 100%. For example,.50 is equal to 50% and .75 is equal to 75%.

Example A:

Pump Flow = 1350 gpm  
SMD = 4.0 inches  
Acres = 147 acres  
IrrEff = 75% (.75 as a decimal)

\[
\text{Hours} = \frac{\text{SMD} \times \text{Acres} \times 452.2}{\text{Pump Flow} \times \text{IrrEff}}
\]

\[
= \frac{4 \times 147 \times 452.2}{1350 \times .75}
\]

\[
= 263 \text{ hours} = 10.9 \text{ days}
\]

This example demonstrates that if you are trying to apply 4 inches of water into the root zone at 75% irrigation efficiency with a pump flow of 1,350 gpm, you need to run the pump for about 11 days.

Use Equation VI.2 to estimate the volume of water to pump:

\[
\text{Acre Feet} = \frac{\text{Hours} \times \text{Pump Flow}}{5432}
\]

Where:
- Acre-Feet = acre-feet needed for irrigation
- Hours = hours of pumping
- Pump Flow = pump flow rate in gpm
- 5432 = a constant
STEP 3: React to the First Irrigation Set - Assuming you estimated the SMD correctly and you know your pump’s flow rate, the equation and the answer of 11 days from the previous example is only good if the irrigation efficiency is actually 75%. Use a soil probe to judge how fast water is soaking into the ground. Keep track of how long it is taking for water to reach the end of the furrow. Change the operating parameters (set time, flow per furrow) as needed. Using night irrigators can cost more money but this should be compared to potential water and energy savings.

STEP 4: React to the Irrigation - Use the soil probe 2 or 3 days after the irrigation to judge how far water penetrated at the top and bottom of the furrow. Judge crop response and water penetration to see how close your initial estimate of SMD was to actual. Compare the total amount of water delivered to the field (use a flow meter!) to your estimates of SMD and the pre-planning calculations.

Work Backwards as a Check on Performance - You can use Equation VI.1A to check on your actual irrigation efficiency, assuming that your estimate of SMD was correct. For example, assume the same situation as in Example A but without knowing the irrigation efficiency, and knowing that it took 15 days to complete the irrigation.

**Equation VI.1A**

\[
\text{IrEff} = \frac{\text{SMD} \times \text{Acres} \times 452.2}{\text{Pump Flow} \times \text{Hours}}
\]

**Where:**
- SMD = soil moisture depletion in inches
- Acres = area of field in acres
- 452.2 = a constant
- Pump Flow = pump flow rate in gallons per minute
- IrEff = irrigation efficiency as a decimal (0 to 1.0)

**Example B:**
- Pump Flow = 1350 gpm
- SMD = 4.0 inches
- Acres = 147 acres
- Hours = 360 (24 hrs/day x 15 days)

\[
\text{IrEff} = \frac{\text{SMD} \times \text{Acres} \times 452.2}{\text{Pump Flow} \times \text{Hours}}
\]
\[
= \frac{4 \times 147 \times 452.2}{1350 \times 360}
\]
\[
= 0.55 = 55\%
\]

The question with this example is whether or not 55% is an acceptable irrigation efficiency.
Planning a Sprinkler Irrigation

The same process as outlined in the previous section can be used for sprinkler systems. However, there is an alternative equation to use if you know the application rate of the system.

**Application Rate (AR)** - equivalent depth of water applied to a given area per hour by the system, usually measured in inches/hour. Thus, if an application rate is .2 inches/hour that means that every hour that the system is run is equivalent to a .2 inch rainfall.

Five basic steps (with a little different mathematics) are used to pre-plan a sprinkler or drip irrigation.

1. Estimate the soil moisture depletion in the effective root zone.
2. Know the application rate of the irrigation system.
3. Pre-plan the irrigation.
4. React to the first set.
5. React to the irrigation.

**STEP 1: Estimate the SMD in the Effective Root Zone** - Estimate the soil moisture depletion in the same manner as for furrows (refer to the discussion on page 2.24).

**STEP 2: Know the Application Rate of the Irrigation System** - Refer to Table VI.2. Each combination of nozzle size, sprinkler spacing, and system pressure produces a distinct application rate. For example, a 7/64” nozzle running at 55 psi on a 30 x 40 spacing has an application rate of about .2 inches/hour. This means that every hour you run the system is just like a .2 inch rainfall on the field.

If your system combination is not in Table VI.2 or you wish to determine your system’s AR exactly, use the following equation.

\[ \text{AppRate} = \frac{\text{GPMn} \times 96.3}{\text{Area}} \]

Where:
- \( \text{AppRate} \) = the application rate of the system in inches/hour
- \( \text{GPMn} \) = the flow through the sprinkler nozzle in gallons per minute
- 96.3 = a constant
- \( \text{Area} \) = the system spacing, lateral move times length of each lateral (feet)

For example, if you had a 30-foot sprinkler lateral with a lateral move of 45 feet, and the flow through each nozzle was measured at 2.8 gpm, then:

\[ \text{AppRate} = \frac{2.8 \times 96.3}{30 \times 45} = .20 \text{ inches/hour} \]

**Example C:**

Table VI.2

<table>
<thead>
<tr>
<th>Sprinkler Spacing (ft)</th>
<th>3/32”</th>
<th>7/64”</th>
<th>1/8”</th>
<th>9/64”</th>
<th>5/32”</th>
<th>11/64”</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 x 30</td>
<td>.19</td>
<td>.27</td>
<td>.34</td>
<td>.44</td>
<td>.54</td>
<td>.65</td>
</tr>
<tr>
<td>30 x 40</td>
<td>.14</td>
<td>.20</td>
<td>.26</td>
<td>.33</td>
<td>.41</td>
<td>.49</td>
</tr>
<tr>
<td>30 x 45</td>
<td>.13</td>
<td>.18</td>
<td>.23</td>
<td>.29</td>
<td>.36</td>
<td>.43</td>
</tr>
<tr>
<td>35 x 40</td>
<td>.12</td>
<td>.17</td>
<td>.22</td>
<td>.28</td>
<td>.35</td>
<td>.42</td>
</tr>
<tr>
<td>35 x 45</td>
<td>.11</td>
<td>.15</td>
<td>.20</td>
<td>.25</td>
<td>.31</td>
<td>.37</td>
</tr>
<tr>
<td>40 x 40</td>
<td>.11</td>
<td>.15</td>
<td>.19</td>
<td>.25</td>
<td>.31</td>
<td>.37</td>
</tr>
<tr>
<td>40 x 45</td>
<td>.10</td>
<td>.13</td>
<td>.17</td>
<td>.22</td>
<td>.27</td>
<td>.32</td>
</tr>
</tbody>
</table>

*Assumes standard smooth-bore nozzle in good condition at normal operating pressures.

**TABLE VI.2 - Approximate water application rates in inches/hour for varying nozzle diameters and sprinkler spacings.**
STEP 3: Pre-Plan the Irrigation - Use the following equation to estimate how long the pump should run:

\[
\text{Hours} = \frac{\text{Sets} \times \text{SMD}}{\text{AppRate} \times \text{IrrEff}}
\]

Where:
- Hours = required hours of pumping
- Sets = number of lateral moves
- SMD = soil moisture depletion
- AppRate = application rate of system in hours
- IrrEff = irrigation efficiency as a decimal (0 to 1.0)

STEP 4: React to the First Set - There should be no runoff with a sprinkler irrigation system if it is properly designed and operated. Also note excessive wind conditions or poor pressure uniformity that may decrease the estimated irrigation efficiency.

STEP 5: React to the Irrigation - Finally, react to the irrigation as a whole. Use the soil probe 2 or 3 days after the irrigation to judge how far water penetrated in different areas within the sprinkler patterns, and in different parts of the field. Judge crop response and water penetration to see how close your initial estimate of SMD was to actual. Compare the total amount of water delivered to the field (use a flow meter) to your estimates of SMD and the pre-planning calculations.

Planning a Micro-Irrigation

As previously noted, a micro-irrigation system is generally a high frequency irrigation system. Further, they generally do not wet all of the soil. For high frequency irrigations such as with drip, spray, fogger, or mini-sprinkler systems, it is best to base irrigations on daily crop water use in combination with a soil- or plant-moisture monitoring system that tracks changes or trends over time.

One method of planning micro-irrigations involves the following three steps:

1. Develop a seasonal (or possibly only monthly or weekly) first-cut irrigation schedule based on normal crop water use.
2. Maintain a reliable and regular system of monitoring soil and/or plant moisture conditions.
3. React to changes in the trends of these conditions.

STEP 1: Develop a First-Cut Schedule of Operating Hours - To develop the first-cut schedule of operating hours use this equation:

\[
\text{Hours} = \frac{\text{Sets} \times \text{ETc} \times \text{Area}}{\text{GPH} \times \text{IrrEff} \times 1.605}
\]

Where:
- Hours = required hours of pumping
- Sets = number of irrigation sets (blocks) in the drip system
- ETc = crop water use between irrigation (inches)
- Area = planted area per tree or vine (sq. ft.)
- GPH = gallons per hour per tree or vine
- IrrEff = overall irrigation efficiency (0 to 1.0)
- 1.605 = a constant
STEP 2: Maintain a Reliable, Regular System of Monitoring Soil and/or Plant Moisture Conditions - Micro-irrigation systems are sometimes referred to as subtle systems (meaning that by the time problems appear visually, much damage may have already been done). It is imperative that some type of soil and/or plant moisture monitoring be done. Commonly used methods include granular-matrix blocks, gypsum blocks, pressure chambers, TDR or FDR electronic sensors, and tensiometers.

STEP 3: Graph the Measurements and Note Any Trends - For example, if you see that the trend in soil moisture is up or down, instead of relatively steady (and at the moisture content you want) then possibly your estimate of crop water use is wrong, or there is a problem with the irrigation system.

Row Crop Drip Systems - Because of the terminology used to describe drip tape systems you would use the following Equation VI.6 instead of Equation VI.5.

\[
\text{Hours} = \frac{\text{Sets} \times \text{ETc} \times \text{Spacing}}{\text{GPM100} \times \text{IrrEff} \times 11.55}
\]

Where:
- Hours = required hours of pumping
- Sets = number of irrigation sets
- ETc = net crop water use between irrigations (inches)
- GPM100 = gallons per minute per 100' of tape
- IrrEff = overall irrigation efficiency (0 to 1.0)
- 11.55 = a constant

Other Tools

The Pumping Energy Calculator

The Pumping Energy Calculator (Figure VI.5) is available from the Program and accompanies this book. This simple-to-use device can calculate the gross depth of water required, dollars per hour or dollars per acre-foot pumping costs, and the number of required pumping hours per irrigation for the major types of irrigation systems. Contact one of the Program offices to obtain one. This calculator will help solve Equations VI.1-VI.6 presented in this book.

Figure VI.5 - The Pumping Energy Calculator.
**WATERIGHT for Seasonal Irrigation Scheduling**

The Pumping Energy Calculator can be used to estimate the number of pumping hours required for individual irrigations. An important piece of required information is the gross depth of water to apply. It is always best to use one of many available methods for checking soil moisture depletions to directly measure this at the time of irrigation. However, seasonal irrigation scheduling can help you anticipate irrigations and provide a check on the estimates for net water required.

The WATERIGHT web site (www.wateright.org) will help you to develop a normal, seasonal irrigation schedule for either low frequency or high frequency systems. This site is dedicated to improved water management. There is a link to the WATERIGHT site from the Agricultural Pumping Efficiency Program’s web site, www.pumpefficiency.org.

WATERIGHT also contains information on how you might be able to improve your irrigation system’s performance.

**Mobile Labs**

Mobile Irrigation Laboratories evaluate irrigation system performance. They measure such things as water application rates and system distribution uniformity. If necessary, they give recommendations for system improvement. Mobile labs can be an important part of managing water resources.

**Mobile Labs:**

- Santa Barbara County - (805) 928-9269, ext.5
- Riverside County
  – East County/High Desert - (760) 347-7658
  – West County - (909) 683-7691 www.rcrcd.com
  – South East County - (909) 654-7733
- North San Diego County - (760) 728-1332
  www.tfb.com/~mssnrcd/
- Fresno/Tulare County - (559) 237-5567 www.krccd.org
- Kern County - (661) 861-4129 www.pswrcd.ca.nacdnet.org
- Santa Clara Valley Water District - (408) 265-2607
- Tehama County RCD - (530) 527-3013, ext. 119
- Lava Beds-Butte Valley RCD - (530) 667-3473
- Yolo/Colusa County - (530) 662-2037, ext 5
  www.yolorcd.org

Additional Mobile Lab information can be found at: www.pumpefficiency.org/mobilelabs
VII. Know How Much Water Has Been Pumped

Section VII covers the importance of measuring water flow. You cannot manage water if you do not measure it. Even if you use the methods presented in Section VI to determine how much water to pump, if you do not have a way of measuring actual water flow how will you know if you managed the system correctly?

This section discusses flow meters and the requirements for installation. Ag pumpers should realize that water flow can be measured in ditches as well as pipelines.

Flow Meters

What Does a Flow Meter Measure?

Water flow meters (flow meters or meters) can measure the flow rate of water or the total water that has passed by the measuring point. Many meters will do both.

Instantaneous reading is a term used for meters that measure flow rate.

Totalizer is a term used for meters that measure the total volume of water.

Flow rate is the volume of water per unit of time moving past the measuring point. Typically flow rates are measured in either gallons per minute (gpm) or cubic feet per second (cfs).

Total volume readings may be in either gallons or acre-feet of water (one acre-foot of water equals 325,851 gallons).

Measure Flow Rate or Total Volume of Water?

Each measurement is important for managing an irrigation system. Flow rate is the type of information often used to help verify that pressurized irrigation systems (i.e. sprinkler or micro-irrigation systems) are operating correctly. Flow rate also is important in judging pumping plant efficiency.

Total volume readings are used in irrigation scheduling methods that use a water balance approach. They serve as a check on how much water was actually pumped to a field versus what you thought you needed. They also are used by water supply or drainage agencies to measure total water volume moving onto or off farms.
Why is Flow Rate Important to Energy Savings?

It requires energy to power a water pump and energy is costly. A flow meter can help identify pump, well, and irrigation system problems before a failure occurs. In drip and micro-irrigation systems, catastrophic problems due to plugging or pipeline/hose breaks can be detected and corrected before crop loss or flooding occurs. Keeping records of flow meter readings can indicate when a pumping system is deteriorating. Thus, meters can help you maintain highly efficient hardware in the field.

However, energy-efficient hardware is of little help in reducing energy costs if it is run longer than needed. Flow measurement will help you judge how long you need to run the pump.

Why is Flow Measurement Important to Water Savings?

You need to measure water to manage water. Efficient and effective irrigations deliver the right amount of water at the right time, spread evenly across the field. Thus, it is important to know how much water is required for each irrigation. However, if you do not know how much water is actually applied during an irrigation you will not know how efficient it was or whether you need to improve.

If you are using a pressurized system such as a sprinkler or drip system, there is a design flow rate for that system. A flow meter can identify if the right amount of water is moving through the system. A meter with a totalizer will indicate how much water was applied per irrigation and can help judge how closely the irrigations met water management objectives.

Doesn't a Pump Test Give Me the Flow Rate?

A pump test does measure flow rate but only gives a snapshot of pump flow at one point in time. A flow meter will provide a measurement at any given point in time. Periodic measurements should be recorded to track your pump performance history. This is especially important with water wells where wear from sand or declining water tables can substantially impact pump performance over time.

How Much Does a Flow Meter Cost?

Flow meters range in cost from $150 each for simple models to highly-sophisticated electronic meters of several thousand dollars each. Typical propeller saddle meters range in cost from $600 to $1,000. However, the cost of flow meter installations may be increased significantly if major modifications have to be made to allow for accurate measurements.

IMPORTANT!

Although sometimes a substantial investment, the cost of a flow meter should be compared to the total cost of the pumping system and the annual cost of operating that system. Accurate flow measurements can pay for themselves many times over with decreased water and energy costs and potentially higher yields due to improved irrigation management.
What is Used to Measure Flow Rate?

There are many different ways to measure water flow in pipelines. The most commonly used flow meter in agriculture is the propeller type *(Figures VII.1 and VII.2)*, mounted as a saddle on a pipeline or inserted as a section of the pipe.

Other common types of meters used in pipelines are the Venturi type *(Figure VII.3)* and the paddle wheel type *(Figure VII.4)*. Pump efficiency testers will often use a manometer *(Figure VII.5)*.

Each of these methods has advantages and disadvantages. Consult with knowledgeable people in your area for the best device for your situation. You may want to talk to your local pump dealer, water district, irrigation system designer/installer, or UC Cooperative Extension agent.

Can I Measure Water in Ditches?

Yes. Most people think of flow meters in terms of the common propeller type installed in pipelines. However, measuring water flow in ditches and canals is quite common. It is even possible to measure flow in a single furrow. Some common ways of measuring water are the overflow weir *(Figure VII.6)*, the meter gate *(Figure VII.7)*, orifice plates, and various types of flumes.

Are Flow Meters Portable?

Yes. Many types of flow meters can be made portable, for both pipelines and canals and ditches. This allows the use of one flow meter on different pumping systems, thus, saving money. You should maintain written records of meter readings for each system.

**IMPORTANT!**

Whenever using a portable water meter, make sure that it is calibrated to the particular installation. For example, do not use a flow meter calibrated for a 6-inch pipeline in an 8-inch pipeline.
Correct Installation in Pipelines

Traditionally it is recommended there be at least 8-10 diameters of straight pipe upstream of a meter and 2-4 diameters downstream of any obstruction in a pipe (elbow, valve, pump discharge head, etc.). Obstructions create turbulent water conditions which make measurement difficult or impossible. For example, a 6” discharge pipe would require 6 times 8 which equals 48” or 4’ of straight pipe before the measurement point. Sometimes straightening vanes can be added that will allow reasonably accurate measurement within less than 8-10 pipe diameters of an obstruction. **Always check the manufacturer’s recommended specifications for an accurate installation.**

Correct Installation in Canals and Ditches

Flow measurement in open channels requires a certain amount of head loss (reduction in the overall elevation of the water flow). Thus, there must be enough freeboard (distance from the top of the flowing water to the top of the channel banks) to accommodate this loss. Care must be taken in choosing the method and designing the installation of a flow measuring device in an open channel. However, some types of flumes, especially the trapezoidal flume, require very little head loss. Also, as with pipelines, water flow into the measurement section should be straight and smooth.

**IMPORTANT!**

Whenever installing a flow meter, either in pipelines or an open channel, consult with a qualified pumping specialist or engineer to ensure that the installation will result in accurate measurements.

Flow Meter Maintenance

As with other mechanical devices, flow meters require routine maintenance and inspection. When your flow meter is installed, always ask about normal maintenance and inspection procedures and make sure to get a copy of any owner’s manual that is available for your particular meter. Follow the manufacturer’s recommended maintenance routine to make sure your flow meter is operating at its optimum level of performance.

Some things to watch for:

- Most flow meters operate very quietly. Noise is often the first sign that a failure may be near - listen for any sounds that would indicate binding or worn gears.
- Visual clues of poor flow meter operation include an unsteady flow rate indicator (indicating binding or worn gears or possibly a pipe that is not running full) or fogging of the lens (leak in the bearing assembly or external seal).
- Open channel flow measuring devices also should be properly maintained. Weirs and flumes should be level, permanent measuring staffs should be set at the correct levels, and trash should not be allowed to collect upstream of an overflow weir.

In Summary

Water flow measurement is essential to water and energy management. A flow measurement can indicate whether a pumping system or an irrigation system is operating correctly. Thus, they help you to maintain highly efficient equipment in the field. They also help you manage that equipment to minimize energy and water use. Contact the Program for more information on flow measurement.
VIII. Glossary of Terms

Acidification
Injecting an acid chemical (usually hydrochloric acid or sulfuric acid) into a well to dissolve encrusted material on the casing perforations (slots).

Acre-Foot
The quantity of water required to cover one acre of land (surface) with water one foot deep (325,851 gallons). The acre-foot is the most common measure of volume in irrigated agriculture.

Adjustable Speed Drive
Refer to Variable Frequency Drive.

Air-line
A method of sounding a well. Small diameter tubing is installed to a known point below any expected pumping water level. The air pressure required to expel air from this tube indicates the water level in the well, either during pumping or at static conditions.

Application Rate (AR)
Equivalent depth of water applied to a given area per hour by the system, usually measured in inches per hour.

Aquifer
A water-bearing soil formation or group of formations having sufficient permeability to yield useable amounts of water to wells.

Axial Flow Pump
Pump design used for low-head, high flow conditions, also called a propeller pump. This design does not use centrifugal action (see Centrifugal Pump) to move water. Rather it uses the principle of a wedge. Water is physically forced through the pump by the rotating propeller.

Booster Pump
A pump used for providing a medium to high discharge pressure. Usually used for pumps supplying sprinkler or micro-irrigation systems.

Bowl (Pump)
The pump case of a turbine pump. This is called the “volute” if referring to a centrifugal pump. It contains the rotating impeller and directs water flow into and out of the impeller.

Bowl Efficiency
Efficiency of the pump by itself (as opposed to combination of the pump driver and transmission system). It is difficult to determine bowl efficiency in the field. An estimation can be made by subtracting out other losses associated with the pumping plant such as the power plant and transmission efficiencies.

Brake Horsepower (BHP)
Usually the output horsepower of a driver. It may also be used to refer to the required input horsepower to the pump itself.

Capacity (Pump)
The flow rate of a pump. It is generally used when referring to the normal (or required design) flow rate of the pumping plant.

Cascading Water
Water entering the well at a point above the pumping water level. This can entrain air in the water and cause a significant loss of pumping efficiency. Cascading water is an indication of an inefficient well.
VIII. Glossary of Terms

Acidification
Injecting an acid chemical (usually hydrochloric acid or sulfuric acid) into a well to dissolve encrusted material on the casing perforations (slots).

Acre-Foot
The quantity of water required to cover one acre of land (surface) with water one foot deep (325,851 gallons). The acre-foot is the most common measure of volume in irrigated agriculture.

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Capacity (Pump)
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Cascading Water
Water entering the well at a point above the pumping water level. This can entrain air in the water and cause a significant loss of pumping efficiency. Cascading water is an indication of an inefficient well.
Cavitation
The rapid formation and collapse of air bubbles in water as it moves through a pump. This results from too high a vacuum in the pump itself due to insufficient “net positive suction head.” Cavitation causes pitting of the impeller and pump housing and can greatly degrade pump performance.

Centrifugal Pump
A pump in which water enters the center of a rotating impeller and is flung out radially, gaining energy in the process. This is also a term commonly used for a specific type of pump where the impeller is enclosed in a volute casing. A volute casing is a type of casing where the area of water flow increases uniformly towards the pump discharge. The increase in flow area converts the velocity achieved through centrifugal action into pressure.

Check Valve
A valve installed in a pipeline that automatically closes and stops water from flowing backwards when a pump is shut off.

Chlorination
Periodic injection of chlorine compounds into wells to prevent the growth of bacteria and slimes. Also used when referring to injection into irrigation systems, most often micro-irrigation systems.

Corrosion
Deterioration and destruction of metal by chemical and/or galvanic reactions. Chemical corrosion dissolves the metal, which is then carried away by the water. Chemical corrosion can allow sand to enter the well. Galvanic corrosion is caused by electrolytic cells forming between dissimilar metals or surfaces.

Daily Crop Water Use (Evapotranspiration)
This is the net amount of water extracted from the soil daily by the crop and surface evaporation from the soil.

Deep-Well Turbine Pump
A turbine pump installed inside a well casing below the pumping water level in the well.

Development of Well
The process of removing the finer material from the aquifer or gravel pack surrounding a well, which may include drilling mud forced into the formation during well construction. If performed after the well has been in service for some time it is referred to as “re-developing” a well.

Discharge Head (Pressure)
Pressure at the discharge flange of a pump.

Distribution Uniformity (DU)
A measure of how evenly water soaks into a field during an irrigation. It is usually a percentage between 0 and 100; the higher the number the better. A DU of 100% is theoretically possible but practically impossible to achieve. It is the upper limit of irrigation efficiency if the whole field is sufficiently irrigated.
Drawdown
The difference in elevation between static and pumping water levels in a well, usually following a specified operating time.

Driver
The energy source that powers a pump, generally either a windmill, an electric motor, or an internal combustion engine.

Effective Root Zone
The depth of soil in which you are actively managing the crop (fertilizer levels, tillth, soil moisture, etc.).

Encrustation
The accumulation of material in the perforations of the well casing, in well screen openings, and in the voids of the gravel pack and water-bearing soil. Encrustation decreases open area in the well casing, impedes water flow into the well, and decreases well efficiency.

Entrained Air
A mixture of small air bubbles within water. It can develop due to vortexing (whirlpools that form at a pump intake) or cascading water in a well. Entrained air in a pumping system displaces water from the impeller and reduces pump capacity and efficiency.

Evapotranspiration
See “Daily Crop Water Use”

Field Capacity
The amount of water the soil will hold.

Flow Meter
Any measuring device used to measure fluid flow rates in a pipe or open channel. The flow meter may measure instantaneous flow rates or total fluid volumes over a period of time.

Freeboard
Distance from the top of the flowing water to the top of the channel banks.

Friction Loss
Water pressure lost as a result of contact between moving water and the enclosure that it is moving in (either a pipeline or open channel).

Gear Drive
A mechanical device using gears to connect a driver to a pump. Commonly they are used either to provide different pump speeds or to connect an internal combustion engine to a well pump.

Gravel Pack
A thin layer of various sizes of gravel placed between the well casing and the well itself. Gravel packs are designed to prevent soil particles from entering the well casing.

Head (Water Head)
An alternative term for pressure. One pound per square inch pressure (1 psi) equals 2.31 feet of water head. That is, a column of water 2.31 feet high will exert 1 psi at the bottom of the column.

Horsepower
Horsepower is a rate of doing work - how far can a mass be moved in a period of time. One horsepower equals 33,000 foot pounds per minute, that is, one horsepower can raise 33,000 pounds one foot over the period of one minute.
Impeller
The impeller is the rotating component of the pump and is contained within the pump bowl (or pump volute). Impellers may be configured as open, closed, or semi-open. They are usually made of bronze, cast iron, plastic, or cast iron coated with porcelain enamel. The impeller transfers energy developed by the pump driver to the water as water flows through the pump bowl.

Impeller Trim
The specific diameter of the impeller used in a pump. Impellers are cast at the maximum diameter but may be “trimmed” to better match the required operating condition(s).

Input Horsepower
The horsepower input to a pumping plant in the form of electricity, diesel fuel, or natural gas (propane).

Irrigation Efficiency (IE)
A measure of how much water that is pumped and applied to a field is beneficially used. (Beneficial uses include crop water use and leaching for salt control.) One must know the physical and time boundaries of the measurement for it to be meaningful. The IE for a single irrigation on a field may be different than the average IE for all irrigations on that field for a season. It may be different than the IE for the entire farm for the season. It is usually expressed as a percentage between 0 and 100. An IE of 100% is not theoretically possible due to immediate evaporation of water during irrigation.

Manometer
A portable device using what is known as velocity head (the energy of the moving water) to measure water flow rates in pipelines. These are commonly used during pump efficiency tests due to the ease of installation and removal. However, they are large and require careful handling and are not generally recommended for use by pump owners.

Motor Load
The output horsepower of an electric motor divided by the rated horsepower of the motor as a percent. This should generally be between 80 and 115 percent.

Multi-Condition Pump Test
A pump efficiency test where pump performance is measured at two or more flow rates during the same test session.

Multi-Stage Pump
A pump having more than one impeller/bowl assembly. Commonly used when referring to turbine pumps.

Net Positive Suction Head (NPSH)
A design requirement dependent on the individual pump. The required NPSH must be available at the pump inlet to prevent cavitation.

Net Water Needed Versus Gross Water Applied
Net water is what you need to replace in the field. Gross water is how much you have to pump in order to accomplish this goal.

Operating Condition
The combination of flow and pressure (total dynamic head) developed by the pump. A pump can operate at a number of operating conditions defined by its pump performance curve.
Overall Pumping Plant Efficiency (OPE)
A measure of how much water horsepower is produced by the pumping plant from the input horsepower. It is the combination of three efficiencies:

- **Bowl efficiency** - the efficiency of the pump itself.
- **Driver efficiency** - the efficiency of the electric motor or engine.
- **Transmission efficiency** - a measure of losses that occur in transmission shafts, chains, pulleys and v-belts.

Parallel Pumps
Two or more pumps (many times of different sizes for flexibility) discharging into a common pipeline to increase the flow rate at a given pressure in the pipeline.

Participating Pump Test Company
This is a company or individual approved by the Agricultural Pumping Efficiency Program to perform pump efficiency tests that are subsidized by the program.

Pump
A mechanical device that converts mechanical energy (usually a rotating shaft or reciprocating rod) into hydraulic energy (flowing water for example).

Pump Capacity
The flow rate through a pump in gallons per minute.

Pump Efficiency Test
A series of measurements and calculations providing information concerning performance of the pump (and of the well if applicable). The test will indicate the overall pumping plant efficiency, pump flow rate, required pump input horsepower, and discharge pressure among other things.

Pump Performance Curve
A set of measurements, usually in graphical form, available from the pump manufacturer showing the relationship between total head, horsepower requirements, and net positive suction head requirements at any given flow rate for a pump.

Pumping Lift
The distance from the center line of the discharge pipe at the pump head to the water level in the pumping well.

Pumping Water Level
The water level in a well after the pump while pumping is in progress. Typically a pump tester will measure this level after 10 - 60 minutes of pumping. This may or may not represent pumping water levels hours or days later.

Recovered Water Level
The water level in a well ten minutes after the well pump has shut off.

Revolutions Per Minute (RPM)
The rotating speed of the shaft of a pump or the driver (motor).

Sand Separator
A device installed on the pump intake pipe in deep-well turbine pumps to remove sand from the water before it can enter the pump. They may also be installed on the pump outlet works and be used to remove sand in water before it enters water distribution systems (municipal, industrial, or irrigation).

Semi-Open (Semi-Closed, Mixed Flow) Impeller
An impeller design whereby water enters the eye of the impeller and exits at less than a 90 degree angle. Another defining characteristic is that the impeller is closed on only one side of the vanes. The pump bowl constrains the water flow on the other side.
Series Pumps
Two or more pumps installed so that one pump discharges into the intake of another pump, increasing pressure at a given flow rate. The total head developed by the second pump is added to the total head of the first pump. The most common configuration is a well pump discharging into a booster pump. Note also that a “multi-stage” turbine pump is actually a pump connected in series.

Shaft (Pump)
The round bar to which the impeller of the pump is fastened. It transmits the rotational energy of the driver to the impeller.

Soil Moisture Depletion (SMD)
The net amount of water that you need to replace in the root zone of the crop.

Soil Probe
A long piece of 3/8” steel bar, usually tipped by a ball bearing, with a handle. The probe is pressed into wetted soil to judge how deep water has penetrated. It can be used during an irrigation to indicate when enough water has soaked into the ground. It can also be used to judge the uniformity of an irrigation. If 2-3 days after an irrigation the probe can be pushed into the soil to a depth of 4 feet at the top of a furrow, and only to 2 feet at the bottom of the same furrow, this is an indication of poor distribution uniformity.

Sounding a Well
The process of determining where the water level is in a well. This might be the static water level (no pumping) or the pumping water level.

Sounding Tube
A small pipe extending from above the foundation or grout seal into the well casing to allow access for sounding the well.

Stage (Pump)
One impeller/bowl assembly of a turbine pump. Pumps can be termed as “single-stage” or “multi-stage” pumps.

Static Water Level
The elevation of the water level in a well when unaffected by pumping of that well.

Straightening Vanes
Metal strips attached to the inside of a pipe parallel to water flow, usually just upstream of a flow meter. They are intended to reduce turbulence and provide for a more accurate flow measurement.

Suction Lift (Suction Head)
Distance from the water surface to the pump intake when the pump is located above the water surface.

Submersible Pump
A type of deep-well turbine pump which utilizes a waterproof electric motor that is connected directly to a turbine pump, both being installed in the well below the pumping water level.

Surging
Fluctuating flow of water from a pump that is created as the pump attempts to pump more water than is flowing into the pump. As applied to a well it occurs when the pump is moving more water than is flowing into the well. This causes the pumping level to drop to the pump intake, breaking the intake suction and allowing a slug of air to enter the pump. The pump capacity falls and the well water level begins to rise. Water then re-enters the pump and the pump flow increases, causing the cycle to repeat, creating a surging action.
Test Section
The section of pipe or open channel where flow measurements are taken.

Time-of-Use Rates (TOU)
Electric power rate schedules whereby lower costs are offered for power used in the “off-peak” (and sometimes during the “shoulder” or “mid-peak”) period and higher rates are charged for power used during “on-peak” periods. The term “on-peak” refers to times when power use is the highest for a utility. Conversely, off-peak refers to that time when power use is lowest.

Totalizer
A type of flow meter, or a part of a flow meter, that provides a measure of total water volume flowing past a point over time.

Total Dynamic Head (TDH)
The pressure in a pump at the impeller outlet (last impeller if there are pumps in a series). This pressure is available to lift water to the soil surface (if in a well), to overcome pressure losses caused by friction and elevation differences, and to provide the required operating pressure in the system. Note that 2.31 feet of head equals one-pound-per-square-inch (psi) of pressure.

Turbine Pump
This pump operates on the principle of centrifugal action. As water enters the impeller it is flung outward, gaining energy, through the rotation of the impeller. Many times, multiple pump assemblies (pump bowl and impeller) are stacked on top of each other and the water is directed by the pump bowl upwards to the next impeller/bowl assembly.

Variable Frequency (Speed) Drive (VFD)
A solid-state electrical device used to change the frequency of AC electric energy supplied to an electric motor. Varying the frequency of the AC current will vary the speed of the motor, allowing the electric motor to be throttled like an internal combustion engine. VFDs are used in situations requiring many different operating conditions on a regular basis.

Vortex
A whirlpool leading into the pump inlet. These are undesirable as they generally entrain air. They are caused by insufficient submergence of the pump intake or poor design of the pump intake works.

Water Horsepower (WHP)
The output horsepower of a water pump. It is the combination of flow rate and pressure. And,

\[ WHP = \text{Flow} \times \frac{\text{TDH}}{3960} \]

Where: Flow is the pump flow rate in gallons per minute
\[ \text{TDH} \] is total dynamic head in feet of water head at that flow rate

Well Casing
Pipe (usually some type of metal but may also be plastic) used as the lining for a well. A layer of rock (termed the “gravel pack”) is usually placed between the well casing and the aquifer to help prevent soil particles from entering the well. The casing will have small openings (called perforations or slots) at levels where water-bearing soil formations are thought to be.

Well Efficiency
The drawdown outside the well casing divided by the drawdown inside the well (the higher the number the better).

Well-Specific Capacity
The well flow rate divided by the drawdown for that flow rate.
IX. Engineering Data

Conversions

Pressure
1 Atmosphere = 14.70 pounds per square inch
1 Pound per square inch = 2.31 feet of water head
1 Pound per square inch = 6.9 kilopascals
1 Pound per square inch = 2.04 inch of mercury
1 Foot of water head = .433 pounds per square inch
1 Meter of water head = 3.28 feet of water head

Length
1 Centimeter = 0.3937 inch
1 Inch = 2.54 centimeters
1 Meter = 3.281 feet
1 Meter = 39.37 inches
1 Foot = 0.3048 meter
1 Foot = 30.48 centimeters
1 Mile = 5,280 feet
1 Mile = 1,609 meters
1 Mile = 1.609 kilometers

Area
1 Acre = 43,560 square feet
1 Hectare = 2.471 acres

Volume
1 Cubic Centimeter = 0.06102 cubic inch
1 Cubic Inch = 16.39 cubic centimeters
1 Acre-foot = 43,560 cubic feet
1 Acre-foot = 325,851 gallons (US)
1 Acre-inch = 3,630 cubic-feet
1 Acre-inch = 27,154 gallons (US)
1 Cubic Foot = 7.4805 gallons (US)
1 Liter = 0.2642 gallons (US)
1 Gallon (US) = 3.785 liters

Mass
1 Pound = 0.4536 kilogram
1 Long Ton = 2,240 pounds
1 Short Ton = 2,000 pounds

Flow Rate
1 Cubic foot per second = 448.8 gallons per minute
1 Liter per second = 15.85 gallons per minute

Power
1 Horsepower = .746 kilowatts
1 Kilowatt = 1.341 horsepower
1 Kilowatt-hour = 3,413 British thermal units (btu) per hour
**Equations**

1) Efficiency = \(100 \times \frac{\text{Power Output}}{\text{Power Input}}\)

2) Water Horsepower = \(\text{Flow} \times \text{TDH} / 3960\)
   
   where:
   
   - Flow is in gallons per minute
   - Total Dynamic Head (TDH) is in feet of water head

3) Required input horsepower to a pumping plant = \(\frac{\text{Water Horsepower}}{\text{OPE}}\)
   
   where:
   
   - Overall Pumping Plant Efficiency (OPE) is expressed as a decimal from 0 to 1.00

4) Cost of pumping per hour = \(\text{HPin} \times 0.746 \times \$\text{kWh}^{-1}\)
   
   where:
   
   - HPin = input horsepower to the pumping plant
   - $\$/kWh = average dollars per kilowatt-hour (range of 0 to .40)

5) Cost to pump an acre-foot of water = \(\frac{\$\text{kWh}^{-1} \times \text{HPin} \times 4051}{\text{Flow}}\)
   
   where:
   
   - $\$/kWh = average dollar cost per kilowatt-hour
   - HPin = input horsepower to pumping plant
   - Flow = pump flow rate in gallons per minute

6) Required Hours Pumping per Irrigation = \(\frac{\text{Inches} \times \text{Acres} \times 452.5}{\text{Flow}}\)
   
   where:
   
   - Inches = gross depth of water to apply
   - Acres = acres in field
   - Flow = pump flow in gpm

7) Required Hours of Pumping per Drip Irrigation Set = \(\frac{\text{Depth} \times \text{Area}}{\text{GPH} \times 1.605}\)
   
   where:
   
   - Depth = gross depth of water to apply per set in inches
   - Area = square feet of area per tree or vine
   - GPH = total gallons per hour per tree or vine

8) Required Hours of Pumping per Drip Tape Set = \(\frac{\text{Depth} \times \text{Spacing}}{\text{GPM100} \times 96.3}\)
   
   where:
   
   - Depth = gross depth of water to apply per set in inches
   - Spacing = spacing of drip tape rows in inches
   - GPM100 = gallons per minute flow per 100 feet of tape

**Mobile Labs**

Mobile Labs:

- Santa Barbara County - (805) 928-9269, ext.5
- Riverside County
  - East County/High Desert - (760) 347-7658
  - West County - (909) 683-7691 www.rcrcd.com
  - South East County - (909) 654-7733
- North San Diego County - (760) 728-1332 www.tfb.com/~missnrcd/
- Fresno/Tulare County - (559) 237-5567 www.krcd.org
- Kern County - (661) 861-4129 www.pswrcd.ca.nacdnet.org
- Santa Clara Valley Water District - (408) 265-2607
- Tehama County RCD - (530) 527-3013, ext. 119
- Lava Beds-Butte Valley RCD - (530) 667-3473
- Yolo/Colusa County - (530) 662-2037 ext.5 www.yolorcd.org

Additional Mobile Lab information can be found at:
www.pumpefficiency.org/mobilelabs

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**Mobile Irrigation Laboratories**

Mobile labs evaluate irrigation system performance for distribution uniformity and general irrigation system management. They measure such things as water application rates and system distribution uniformity. If necessary, they give recommendations for system improvement. Mobile labs can be an important part of managing water resources.
X. Using the Pumping Energy Calculator

This section provides examples of how to use the Pumping Energy Calculator. There are six sections on the Calculator and the examples correspond with these sections.

1. Calculating Required Input Horsepower

This section solves the following equation:

\[ HPin = \frac{\text{Flow} \times \text{TDH}}{(39.60 \times \text{OPE})} \]

Where:
- \( HPin \) = required input horsepower
- \( \text{Flow} \) = pump flow rate in gallons per minute
- \( \text{TDH} \) = total dynamic head in feet of water head (ft)
- 39.60 = a constant
- \( \text{OPE} \) = overall pumping plant efficiency

Example:
- Flow = 1,000 gpm
- TDH = 100 feet
- OPE = 50%

Follow these steps:
1. Set the Pump Flow Rate at the Overall Pumping Plant Efficiency - slide the scale so that 1,000 gpm is under 50% OPE.
2. Read the Required Input Horsepower at the Total Dynamic Head - read 50 HP at 100 feet.

IMPORTANT!
Make sure you use the appropriate TDH scale, either Feet of Water Head (the upper scale, see ft) or Pounds per Square Inch (the lower scale, see psi).

2. Calculating Energy Costs for Pumping

This section calculates the energy cost per acre-foot pumped. Note that this is the cost of energy only.

IMPORTANT!
This section calculates the cost of energy only. Demand charges and any other service costs are not included.

Example:
- Flow = 1,000 gpm
- Input Horsepower = 50
- Cost/kWh = $0.15

Follow these steps:
1. Set the Input Horsepower under the Cost/kWh - slide the scale so that 50 hp is under $0.15/kWh.
2. Read approximately $5.50 Energy Cost Per Hour Pumping at the arrow.
3. Read approximately $30 Energy Cost Per Acre-Foot Pumped above 1,000 gpm Pump Flow Rate.

WATERIGHT for Seasonal Irrigation Scheduling

The Pumping Energy Calculator can be used to estimate the number of pumping hours required for individual irrigations. An important piece of required information is the gross depth of water to apply. It is always best to use one of many available methods for checking soil moisture depletions to directly measure this at the time of irrigation.

However, seasonal irrigation scheduling can help you anticipate irrigations and provide a check on the estimates for net water required. The WATERIGHT site will help you to develop a normal, seasonal irrigation schedule for either low frequency or high frequency systems. This site is dedicated to improved water management. There is a link to the WATERIGHT site from the Agricultural Pumping Efficiency Program’s web site, www.pumpefficiency.org.

WATERIGHT also contains information on how you might be able to improve your irrigation system’s performance.
3. Calculating the Gross Depth of Water to Apply

This section calculates the gross depth of water required for an irrigation given the net requirement and an irrigation efficiency. It solves the equation:

\[
\text{Gross} = \frac{\text{NET}}{\text{IrrEff}}
\]

**Where:**
- Gross = gross water application required
- Net = water required by the irrigation
- IrrEff = irrigation efficiency as a decimal (0 - 1.0)

**IMPORTANT!**

You need to use the individual field irrigation efficiency. It may well be that some of the gross water applied ends up as surface runoff (or even deep percolation) that is used on another field. However, for the purpose of determining how much water has to be applied to a particular field, you must use its irrigation efficiency.

**Example:**

- Net Depth Required = 2.1 inches
- Irrigation Efficiency = 70%

Follow these steps:
1. Set the Net Depth Required under the Irrigation Efficiency - slide the scale so that 2.1 inches is under 70%.
2. Read 3.0 inches as the Gross Depth of Water to Apply at the arrow.

Note that you can also work backwards to check on your apparent irrigation efficiency. For example, if you knew how much water was actually applied, and how much you needed, you could calculate your apparent irrigation efficiency.

**Example:**

- Net Depth Required = 2.1 inches
- Gross Depth Applied = 4.4 inches

Follow these steps to estimate your apparent irrigation efficiency:
1. Set the 4.5 inches (the gross depth applied) at the arrow.
2. Read 47% Irrigation Efficiency above 2.1 inches Net Depth required.

(When using the calculator in this manner you can ask yourself whether 47% irrigation efficiency is acceptable.)
4. Calculating Required Hours of Pump Operation

These three sections provide you with estimates of required pumping hours given a gross depth of water to apply, an irrigated area, and a pump flow rate. As with the previous example, you can work backwards with any of these scales to calculate the GROSS DEPTH APPLIED if you know the hours of pumping and the various measures of field area.

A  Row Crop Drip Irrigation

This section solves the equation:

\[ \text{Hours} = \text{Gross} \times \text{Spacing} \times 0.0866 / \text{GPM100} \]

Where:
- Hours = required hours of pumping for a set
- Gross = gross depth of water to apply
- Spacing = spacing of drip tape in the field in inches
- 0.0866 = a constant
- GPM100 = flow rate of the drip tape in gallons per minute per 100 feet of tape

Example:
- GPM per 100’ of tape = 0.33
- Gross Depth = 0.5 inches
- Drip Tape Spacing = 40 inches

Follow these steps:
1. Set the Gross Depth of Water to Apply under the Gallons Per Minute Per 100’ of Tape - slide the scale so that .5 inches is under .33 gpm/100’.
2. Read the Required Hours of Pumping Operation Per Set above the Drip Tape Spacing - read approximately 5.25 hours per set above 40 inches Drip Tape Spacing.

B  Standard Micro-Irrigation

Note that square feet per tree/vine refers to the square foot of field per tree or vine. For example, almonds on a 24 x 24 spacing have 576 square feet per tree.

This section solves the equation:

\[ \text{Hours} = \text{Gross} \times \text{Area} \times 0.623 / \text{GPH} \]

Where:
- Hours = required hours of pumping for a set
- Gross = gross depth of water to apply
- Area = square foot of field per tree or vine
- 0.623 = a constant
- GPH = total gallons per hour supplied to each tree or vine

Example:
- Gross = .5 inches
- Area = 360 square feet per tree
- GPH = 8 gph per tree

Follow these steps:
1. Set the Gross Depth of Water to Apply under the Gallons Per Minute Per Tree/Vine - slide the scale so that .5 inches is under 8 gph.
2. Read the Required Hours of Pumping Operation Per Set above the Area Per Tree/Vine - read approximately 14 hours per set above 360 square feet.
### Furrow, Flood and Low Frequency Field Sprinklers

This section solves the equation:

\[
\text{Hours} = \text{Gross} \times \text{Acres} \times \frac{452.5}{\text{Pump Flow}}
\]

**Where:**
- \(\text{Hours}\) = required hours of pumping for the irrigation
- \(\text{Gross}\) = gross depth of water to apply
- 452.5 = a constant
- \(\text{Pump Flow}\) = pump flow in gallons per minute

**Example:**
- GPM Depth to Apply = 4 inches
- Acres in Field = 50 acres
- Pump Flow = 1,000 gpm

Follow these steps:
1. Set the Gross Depth of Water to Apply under the Pump Flow Rate - slide the scale so that 4 inches is under 1,000 gpm.
2. Read the Required Hours of Pumping Operation for the entire irrigation above the Acres in the Field - read approximately 90 hours for the total irrigation above 50 acres.